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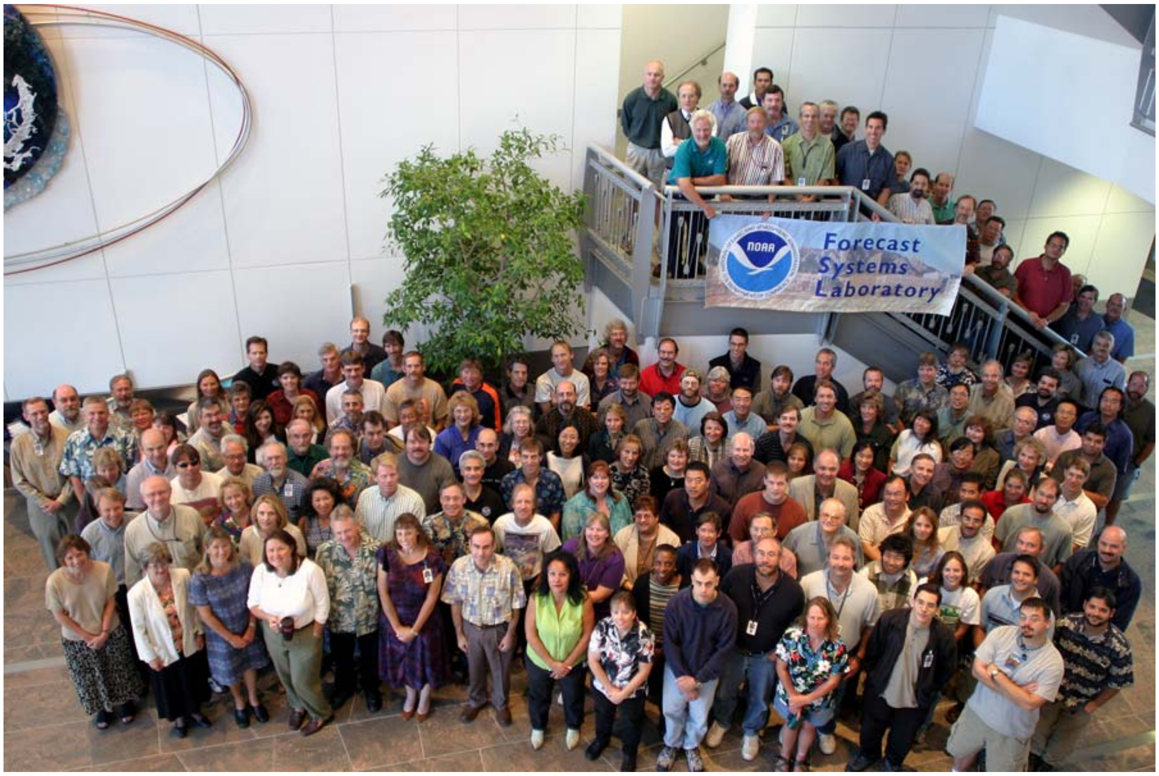

Figure 1. FSL staff in the lobby of the David Skaggs Research Center.

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Message from the Director

Fiscal Year 2005 has been a year of big changes at Forecast Systems Laboratory (FSL). We worked with other laboratories in the David Skaggs Research Center to create the new Earth System Research Laboratory (ESRL). FSL will transition on October 1, 2005 to be the Global Systems Division (GSD) of ESRL, taking its place along with three other divisions: the Physical Science Division, the Chemical Science Division, and the Global Monitoring Division. We believe that this large laboratory (approximately 600 people) will be well positioned to address the crucial weather and climate issues faced by NOAA. As before, our middle name is "systems". This recognizes that the NOAA mission requires substantial systems expertise to address crucial scientific and technological disciplines such as geophysical observing systems, advanced assimilation and modeling, advanced computing, and information systems. FSL's accomplishments presented in this report are a solid base to build toward the global weather and climate capabilities that comprise our new mission in ESRL. Some of the highlights of the past year are briefly discussed below.

Success for FSL is in working with operational agencies, particularly the National Weather Service, to transfer advances in science and technology to operations. This year saw great progress toward an operational wind profiler network. NWS will be taking over the NOAA Profiler Network, and has plans to work toward a national network of upper air observing. Much of the basis for these plans was the demonstration of a highly reliable network over the last ten years, and the observing system simulations done by FSL on the profiler network. We were able to demonstrate that wind profilers improve the tropospheric initial state by up to 30% in the domain of the network. Case studies show that this improved initial data almost always results in improved prediction of severe weather out to about 12 hours.

FSL made exciting progress in demonstrating the impact of GPS surface stations on the Rapid Update Cycle (RUC) model prediction skill. As discussed in this report, with about 275 sites, a significant improvement in relative humidity has been demonstrated through a deep layer in the troposphere, with a maximum of about 10% at 700 mb. These improvements were implemented in the operational RUC model in June of 2005. Other new observing technologies being investigated by FSL include Unmanned Aircraft Systems (UASs). A successful test of a UAS built by General Atomics, called the Altair, was conducted in cooperation with NASA in the spring. The three projects discussed above include early stage observing systems (the UASs), middle stage systems (GPS surface stations), and mature technologies (the wind profiler network). Our goal is always to bring the best science and technology to the nation's weather services as rapidly as is feasible.

FSL played a major role in a community test of the new Weather Research and Forecast model. As part of the Developmental Test Center (DTC), which is jointly staffed by NCAR and FSL, an experiment was carried out to test the model running over a large domain (the 48 states) at high resolution (5 km). It was called the DTC Winter Forecast Exercise (DWFE), with its initial period running from January 15 to March 31, 2005. This look into the future of mesoscale weather models was fascinating to the forecasters. It showed that these high resolution models can generate realistic weather, such as thunderstorm complexes, squall lines, sea breezes, cloud streets, and other phenomena. Although the models did not always have the storms in exactly the right place, they consistently portrayed the sequence of weather correctly (e.g. a line of convection starting in early afternoon near the Kansas border, becoming more severe with time.)

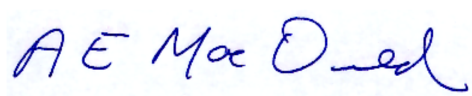
FSL also implemented its 13-km resolution RUC model at NCEP in June. This model showed improvements in precipitation and turbulence prediction.

FSL has joined with the National Center for Environmental Prediction (NCEP) and the Geophysical Fluid Dynamics

Laboratory (GFDL) to combine NOAA's research and development computing. This effort, lead by the NOAA Chief Information Officer, culminated in a combined procurement action which will serve all of NOAA's research and development.

FSL's Meteorological Assimilation Data Ingest System (MADIS) made great progress this year in a number of different areas. Its surface station reporting has reached almost 15,000 stations, providing a national mesonet that is very valuable for weather diagnosis and prediction. FSL has been working with NWS to implement an operational version of MADIS during the next couple of years. FSL also demonstrated an early version of its Advanced Linux Prototype System (ALPS), which is AWIPS based, but uses advanced components, and a new distributed data paradigm.

We end this fiscal year with preparations to become part of the Earth System Research Laboratory. Much of the FSL experience has been with high resolution capabilities over the United States: high resolution weather observing, high resolution mesoscale models, and high resolution display systems such as AWIPS. The growth of computing and communications technology will allow much of what has been learned about high resolution systems over the U.S. to be applied worldwide. For example, the Global Earth Observing System of Systems could use many of the advanced capabilities developed by FSL. Our plans are to increase the geographic scope of our observing, modeling, computing, and information systems from continental scale to global. Earth System Research Laboratory is committed to research that will advance NOAA's environmental information and service on global-to-local scales. We believe that Global Systems Division will be a great asset to NOAA and the nation as we deal with the critical issues of weather and climate as they play out in the 21st century.



Alexander E. MacDonald
Director

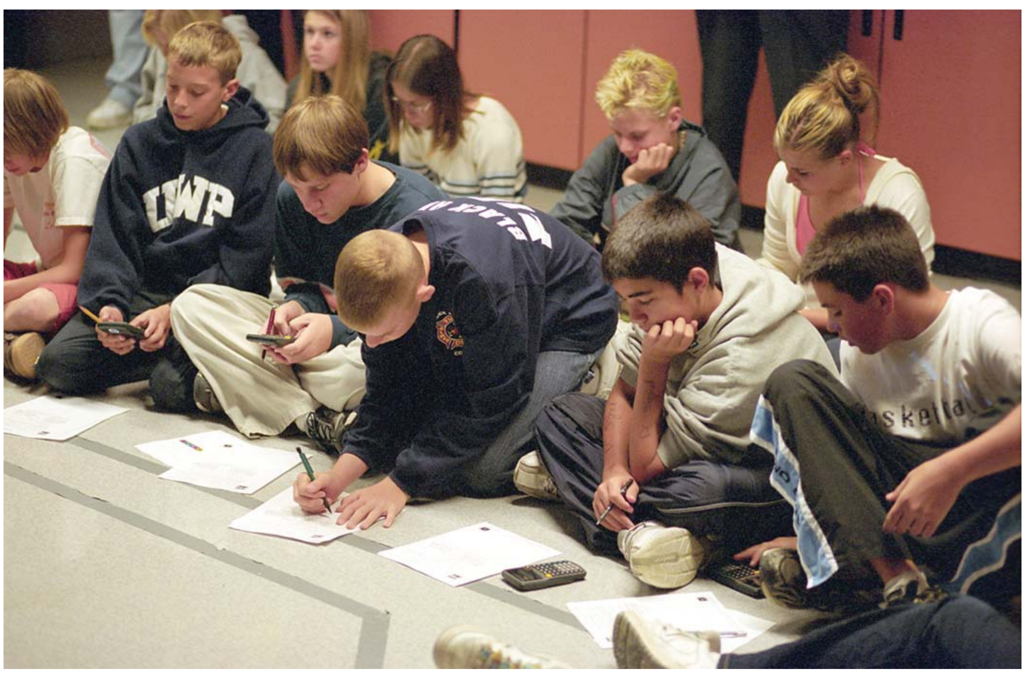


Figure 2. (top) Sandy MacDonald (left) and Richard Conti, executive director of The National Maritime Center in Norfolk, VA, at the unveiling of NOAA's Science On a Sphere™ last June. (bottom) Students from the Boulder Valley School District completing a lesson related to a demonstration of this educational tool.

(NOAA Photos by Rhonda Lange (top) and Will von Dauster, FSL)

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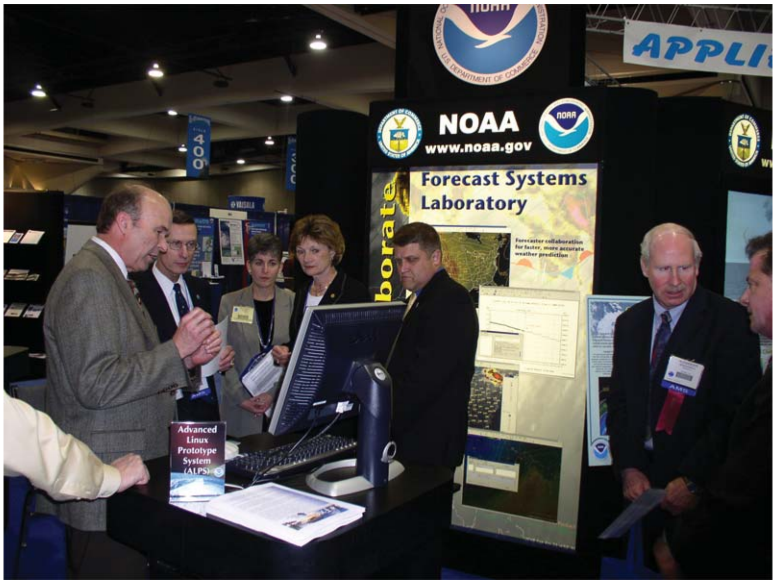

Figure 3. FSL and NOAA representatives at the 2005 Annual Meeting of the American Meteorological Society .

Background

FSL, established in October 1988, is one of 12 laboratories in NOAA Research under the National Oceanic and Atmospheric Administration (NOAA), within the Department of Commerce. The mission of FSL is to transfer new research findings in atmospheric, oceanic, and hydrologic sciences to the operational elements of NOAA and other domestic and foreign organizations. It conducts programs (involving the following activities) to integrate, evaluate, and apply developments to information and forecast systems:

- Bringing new atmospheric observing systems to maturity
- Assimilation and modeling to improve short-range weather predictions
- Investigating computer architectures as a vehicle for handling the huge computational demands of environmental models
- Developing environmental information systems for a variety of customers within and outside NOAA.

Organization

The **Office of the Director** manages FSL, in addition to special research programs conducted within the laboratory. The **Office of Administration and Research**, under the Office of the Director, provides management support, administrative support led by an Administrative Officer, IT support, contract administration, and visitor and information services. Figure 3 is a photo of the Director of the Office of Administration and Research.

The **Information and Technology Services** (ITS) is also under the Office of the Director. The FSL Chief Information Officer manages the ITS, which is responsible for the computers, communications and data networks, and associated peripherals that FSL staff use to accomplish their research and systems development mission. The FSL Central Facility comprises dozens of computers ranging from workstations and servers to a High Performance Technologies, Inc. (HPTi) supercomputer. The facility contains a wide variety of meteorological data-ingest interfaces, storage devices, local- and wide-area networks, communications links to external networks, and display devices. Over 700 Internet Protocol-capable hosts and network devices include Unix/Linux hosts, PCs and Macintoshes, and network routers, hubs, and switches. These hardware and associated software enable FSL staff to design, develop, test, evaluate, and transfer to operations advanced weather information systems and new forecasting techniques. Data and products are also provided for research activities at other NOAA Research Laboratories, the National Center for Atmospheric Research (NCAR), and university laboratories. Also, in compliance with DOC and NOAA IT security policies and directives, ITS develops and implements the appropriate IT security measures for the FSL network and computers.

Six divisions carry out the research and development activities, as follows:

> The **Forecast Research Division** (FRD) is home to most of the research in FSL on short-range forecasting and small-scale weather phenomena. High-resolution numerical models are developed by scientists in FRD to support the NWS and the aviation community with accurate short-range forecasts based on the latest observations. The Rapid Update Cycle (RUC), an operational system within the National Weather Service (NWS), provides hourly updated national-scale numerical analyses and forecasts. The portable Local Analysis and Prediction System (LAPS) can integrate data from virtually every meteorological observation system into a very high-resolution gridded framework centered on any operational forecast office's domain of responsibility. FRD scientists

participate in the development of the Weather Research and Forecast (WRF) model, a next-generation mesoscale forecast model and assimilation system that will advance both the understanding and prediction of important mesoscale weather. The forecast component of the Rapid Refresh (RR) will be used for one of the nonhydrostatic model dynamical cores already configured within the WRF code infrastructure. FRD is leading the development of a next-generation coupled weather/air quality numerical prediction system based upon the WRF model. The chemical kinetic mechanism in this numerical model system is embedded within the meteorological model structure, thus the integration of the chemistry is performed as part of WRF (WRF-Chem). Dynamical studies of mesoscale processes are conducted to improve understanding of the atmosphere. These studies include analysis of turbulence measurements from special field observations, and the analysis of data from the International H_2O Project (IHOP-2002) to improve understanding of the mesoscale variability of water vapor and apply this knowledge to improving the prediction of warm-season precipitation events. Research-quality datasets are also developed to improve mesoscale analysis, data assimilation methods, and numerical weather prediction systems.

The **Demonstration Division** evaluates promising atmospheric observing technologies developed by NOAA and other federal agencies and organizations and determines their value in the operational domain. Activities range from the demonstration of scientific and engineering innovations to the management of new systems and technologies. Current activities include the operation, maintenance, and improvement of the NOAA Profiler Network (including three Alaska sites), which provides reliable hourly observations of winds from the surface to the lower stratosphere. The Radio Acoustic Sounding System (RASS) technique has been demonstrated and proved beneficial for remote sensing of temperatures at profiler sites. The GPS-Met Demonstration Project has shown that the addition of ground-based GPS water vapor observations to a numerical weather prediction model improves forecast accuracy, especially under conditions of active weather. Wind and temperature data from Cooperative Agency Profilers (CAPs) operated by other organizations are also collected and distributed for research and operational use.

The **Systems Development Division** works closely with other FSL groups in providing technical expertise on functional specifications for new workstation and interactive display systems. FSL's continuing support to AWIPS includes an exploratory development project called FX-Collaborate (FXC), which provides interactive features such as drawing and annotation tools, a chatroom, and a capability for sharing local datasets between sites. FXC applications include weather forecast coordination between offices, classroom training, briefings from NWS to other government agencies, field experiment support, and research coordination. Other systems include the Quality Control and Monitoring System (QCMS) which provides users and suppliers of hydrometeorological observations with readily available quality control statistics. Two surface assimilation systems, the MAPS Surface Analysis System (MSAS) and the Rapid Update Cycle Surface Assimilation System (RSAS), provide direct measurements of surface conditions and give crucial indicators of potential for severe weather. In addition, the Meteorological Assimilation Data Ingest System (MADIS) provides quality-controlled observations and data access software to university and government data assimilation researchers. FSL initiated the MADIS project to expand availability of value-added observations such as radiosonde, automated aircraft, wind profiler, and surface datasets. The MADIS API also provides access to all observation and QC information in the FSL database and other supported meteorological databases. Another task is development of the Advanced Linux Prototype System (ALPS) to help the National Weather Service (NWS) accelerate the transition to an all-Linux AWIPS system architecture, and address the anticipated near-term AWIPS system challenges. The Systems Development Division is also working on a project to determine how targeted hazardous weather warnings and Reverse 911 technology can be used in future AWIPS software. A similar development is the City Escape prototype system for notifying a designated population of evacuation in the case of toxic release.

The **Aviation Division** promotes safer skies through improved aviation weather products. In collaboration with the NWS and the Federal Aviation Administration (FAA), it provides improved weather forecasting, product visualization, and verification capabilities to civilian and military forecasters, pilots, air traffic controllers, and airline dispatchers. Through research and development of high-performance computing techniques, including distributed computing on geographically and organizationally dispersed computational grids, the Aviation Division also ensures continued improvement of high-resolution numerical weather analysis and prediction systems, and greater efficiency in the use of NOAA's information technology resources.

The **Modernization Division** specifies requirements for advanced meteorological workstations, product and technique development, and new forecast preparation concepts and techniques. It manages the development and fielding of advanced prototype meteorological systems into operational NWS forecast offices, and performs objective evaluations of these operational systems. The Modernization Division plays a major role in development and operational use of AWIPS at over 100 NWS forecast offices. It provides management and direction for research in the latest scientific and technical advances, with special emphasis on their potential application to operational meteorology.

The **Technology Outreach Division** develops new project opportunities and promotes emerging FSL technologies to NOAA and other government agencies, organizations, and the private sector. In addition, this group is responsible for two specific technologies: Science On a Sphere™ and FX-Net. Science On a Sphere™ is a new concept for displaying specific data on a global platform. This system provides an ideal way to educate the public on many important issues, both environmental and economic, that face NOAA, the United States, and the entire world. FX-Net is a PC-based real-time meteorological workstation that makes AWIPS products accessible over the Internet via high- and low-bandwidth communication lines. Integral to the FX-Net technology is a wavelet compression technique that can reduce and transmit product file sizes with a minimal loss of resolution and also compress model grids with a prescribed maximum allowable error for each model parameter at all grid points. The Technology Outreach Division continues to be involved in several international cooperative technology transfer agreements, such as implementation of a totally updated forecast center at the Central Weather Bureau (CWB) of Taiwan and development of a Forecaster’s Analysis System for the Korea Meteorological Administration (KMA).

Staffing

FSL is staffed by a combination of Civil Service employees, Joint Institute staff, Commercial Affiliates, and Guest Workers/Visiting Scientists. The two Joint Institutes that support FSL are the Cooperative Institute for Research in the Atmosphere (CIRA), Fort Collins, CO; and the Cooperative Institute for Research in Environmental Sciences (CIRES), Boulder, CO. We are also supported by one Commercial Service Affiliate, the Systems Research Group, Inc., Colorado Springs, CO. As of October 2004, FSL employees totaled 197 in the following categories: 87 Federal Government/Civil Service (including 4 NWS employees and 1 EPA employee), 54 Joint Institutes (38 from CIRA and 16 from CIRES), 53 Contrators/Commercial Affiliates, and 3 Guest Workers/Visiting Scientists (Figure 4).

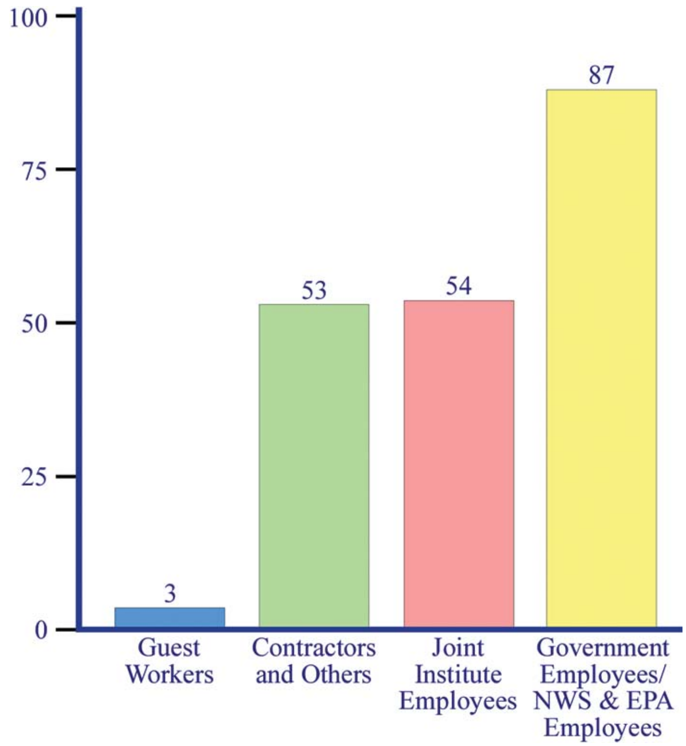

Figure 4. Categories of FSL's 197 employees as of October 2004.

Funding

Funding for FSL is received from a variety of sources. For Fiscal Year 2004, FSL received $29.1M from the following sources: $16.5M – Other NOAA funds, $5.8M – NOAA's Office of Atmospheric Research (OAR) base funds, $4.6M – Other Federal Government Outside NOAA funds, and $2.2M – Non-Federal funds (Figure 5). Other U.S. Government sources of funding included the Federal Aviation Administration (FAA) and Federal Highway Administration (FHWA) from the Department of Transportation (DOT), the Air Force and Army from the Department of Defense (DOD), the U.S. Forest Service (USFS) from the Department of Agriculture (DOA), the Bureau of Land Management (BLM) from the Department of the Interior (DOI), the Department of Energy (DOE), and the National Aeronautics and Space Administration (NASA). Funding was also received from the Taiwan Central Weather Bureau (CWB), the Harris Corporation, Lockheed Martin, and Colorado State University.

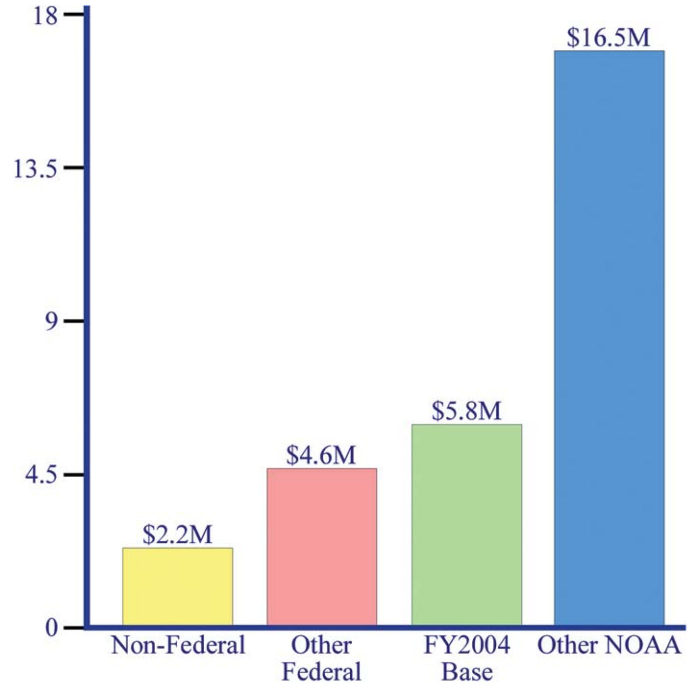

Figure 5. Funding sources totalling $29.1M for Fiscal Year 2004.

Visitors

The Visitor and Information Services program supports NOAA's educational and outreach goals. Tours and visits are scheduled with appropriate FSL staff to match special interests of the visitors. In 2004, the Office of Administration and Research accommodated at least 4,020 visitors (Figure 6), not including visits arranged directly with FSL staff outside this office. This significant increase from the previous year related to several special events: the Department of Commerce 50th Anniversary celebration; the formal arrangement between NOAA and the Boulder Valley School District to give 8th graders the opportunity to visit the NOAA Boulder campus for educational presentations, demonstrations, and hands-on learning experiences; the Annual Workshop for Local Weather Observers; and special requests to see NOAA's new educational and outreach tool, Science On a Sphere™. The largest category, 2,706 visitors, came from academia (educators and students). Other visitors included 448 from government, 239 from the private sector, 577 from the general public, and 50 from foreign countries, including China, Australia, Africa, Korea, and Taiwan. Anyone interested in visiting FSL may contact Rhonda Lange at 303-497-6045 or by e-mail at *Rhonda.K.Lange@ noaa.gov*.

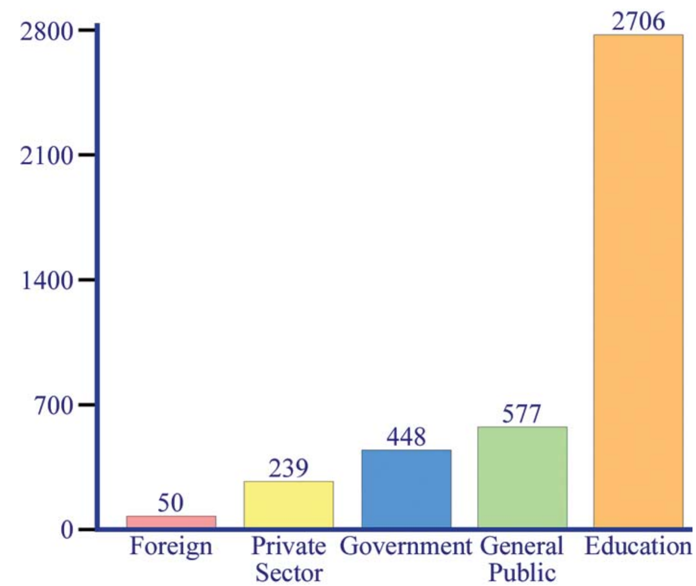

Figure 6. Categories of the 4,020 recorded visitors during Fiscal Year 2004.

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Objectives

The Information and Technology Services (ITS) manages the computers, communications and data networks, and associated peripherals that FSL staff use to accomplish their research and systems-development mission. The FSL Central Facility comprises over 100 Dell, Sun Microsystems, Inc., Silicon Graphics, Inc. (SGI) computers ranging from workstations and servers to a High Performance Technologies, Inc. (HPTi) supercomputer. The facility also contains a variety of meteorological data-ingest interfaces, storage devices, including the FSL Mass Store System (MSS), local- and wide-area networks, communications links to external networks, and display devices. Over 600 Internet Protocol (IP)-capable hosts and network devices are connected to the FSL network. They include Unix/Linux hosts, PCs and Macintoshes, and network routers, hubs, and switches. This hardware and associated software enable FSL staff to design, develop, test, evaluate, and transfer to operations advanced weather information systems and new forecasting techniques.

The group designs, develops, upgrades, administers, operates, and maintains the FSL Central Computer Facility. For the past 24 years, the facility has undergone continual enhancements and upgrades in response to changing and expanding project requirements in FSL, and new advances in computer and communications technology. In addition, ITS lends technical support and expertise to other federal agencies and research laboratories in meteorological data acquisition, processing, storage, distribution, and telecommunications.

The Central Facility acquires and stores a large variety of conventional (operational) and advanced (experimental) meteorological observations in real time. The ingested data encompass almost all available meteorological observations in the Front Range of Colorado and much of the available data in the entire United States. Observations are also received from Canada, Mexico, and other locales around the world. The richness of this meteorological database is illustrated by such diverse datasets as advanced automated aircraft, wind and temperature profiler, satellite imagery and soundings, Global Positioning System (GPS) moisture, high-resolution Doppler radar measurements, and hourly surface observations. The Central Facility computer systems are used to analyze and process these data into meteorological products in real time, store the results, and make the data and products available to researchers, systems developers, and forecasters. The resultant meteorological products cover a broad range of complexity, from simple plots of surface observations to meteorological analyses and model prognoses generated by sophisticated mesoscale computer models.

Accomplishments

Central Computer Facility

FSL High-Performance Computing System and Mass Store System – During 2004, the contract for the High-Performance Computing System (HPCS) was extended for two years. Work in this area involved decommissioning the Alpha-processor-based portion of the HPCS in September 2004 and implementing a major upgrade. The upgraded HPCS, based on the Intel EM64T (64-bit Xeon) system comprising 608 3.2 GHz CPUs, was accepted in December 2004 and entered into production January 2005.

The RAID (Redundant Array of Independent Disks) system, acquired from the Census Bureau, has been decommissioned. The DataDirect Networks (DDN) RAID system, acquired under the current contract, has been further expanded to meet the users' growing need for online storage. This contract includes implementation (in January 2005) of a third DDN RAID based on SATA (Serial Advanced Technology Attachment) disks that provide very dense storage (approximately 50 Terabytes, or 50,000 Gigabytes).

The High-Performance Computing System (HPCS) provides computational capability for numerous FSL modeling efforts related to the atmosphere, ocean, climate, and air quality. In addition, other NOAA organizations take advantage of FSL's HPCS for activities such as Weather Research and Forecasting (WRF) model development and testing, North American Observing Systems (NAOS) testing, and high-performance computing software development. The research is carried out by some of the OAR (Office of Oceanic and Atmospheric Research) laboratories, the National Weather Service (NWS), National Centers for Environmental Prediction (NCEP), and several Joint Institutes. The HPCS management team continued to improve the reliability of the system over the year. For example, the improved backup performance for the NCEP Rapid Update Cycle (RUC) model is illustrated in Figure 7, with above 99% reliability in most cases. (See *http://hpcs.fsl.noaa.gov/* for more information on the FSL HPCS.)

FSL's supercomputer provided computational capability for modeling efforts and high-performance computing software development within FSL and support for numerous other NOAA organizations. More than half of NOAA's 12 Research Laboratories currently use HPCS resources: the Aeronomy Laboratory (AL), Atlantic Oceanographic and Meteorological Laboratory (AOML), Air Resources Laboratory (ARL), Climate Diagnostics Center (CDC), Environmental Technology Laboratory (ETL), Geophysical Fluid Dynamics Laboratory (GFDL), and Pacific Marine Environmental Laboratory (PMEL), Fisheries, National Ocean Service (NOS), and the National Environmental Satellite, Data, and Information Service (NESDIS) National Geophysical Data Center. All HPCS projects are reviewed on the basis of scientific merit and appropriateness for a commodity, distributed-memory machine.

Over the past year, the reliability and performance of the Mass Store System (MSS) has continued at the previous year's much improved level. The older portion of the MSS, based on ADIC's (Advanced Digital Information Corporation) FileServ/VolServ and Sony's AIT technology, has been decommissioned, and most of the data from that system was migrated to the newer StoreNext and Linear Tape-Open (LTO) systems. The additional LTO media increased the capacity of MSS.

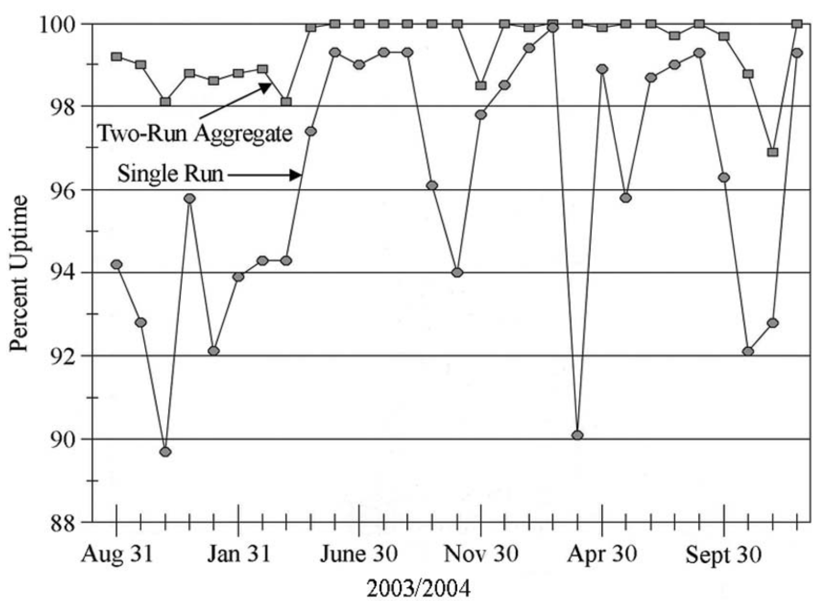


Figure 7. FSL High-Performance Computing System backup performance for the NCEP Rapid Update Cycle (RUC) model from August 31, 2003–September 30, 2004.

Central Facility Systems, Enhancements, and Upgrades – The ITS Systems Administration group consists of five Linux/Unix administrators and one PC administrator. The team maintains a high level of experience in AMD, HP, Intel, SGI, and Sun computer systems. They are charged with day-to-day operation of the Central Facility computer systems as well as assisting with tasks within each of FSL's divisions. Their primary managed services include DNS (Domain Name Service), e-mail, central FSL systems backup administration, and all PC services. The number of FSL systems administrators (currently 13) has risen and declined commensurate to the number of FSL staff. The number of systems administrators per division has typically been based on several factors. First, the trend has been at least one systems administrator for every 20 staff members; this ratio of 20:1 helps keep costs down while maintaining enough resources to complete all related tasks. The Forecast Research Division had two systems administrators for most of the year, but now has only one with no plans to backfill the vacant position. ITS has a PC administrator, supercomputer administrator, and lead administrator, all of whom provide services to the entire laboratory.

The required number of systems administrators is also determined by the number of network devices managed and the number of systems administrators per division. The ratio of devices to systems administrators is 125:1, which represents the number of networked systems that a single systems administrator can effectively administer. The main issue in managing these devices is IT security. Numerous software and operating system patches must be installed according to the severity of the problem. With the rapidly increasing number of required security actions over the past few years, this has become a daunting task.

Other factors in managing systems administration staff involve the number of systems components and software that must be installed and maintained in each FSL division (Figure 8). Typically about 1,000 components (disk drives, memory sticks, monitors, printers, etc.) and 500 pieces of software (operating systems, word processors, spreadsheets, etc.) are managed by each systems administrator. This software must be updated regularly in adherence with IT security, and when components fail, whole systems may need to be rebuilt, depending on the severity of the problem.

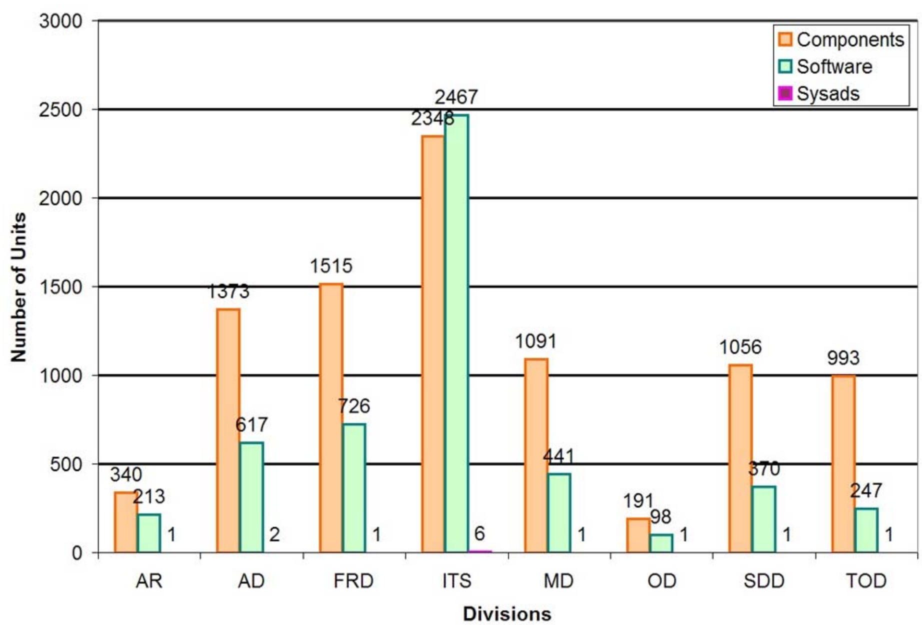


Figure 8. Current number of system components, software, and systems administrators for each FSL division.

Tracking studies also show a trend of hardware replacement every three years. However, this does not represent complete replacement of all hardware, but only the oldest systems, allowing systems to remain operational for about five years.

During the years that FSL invests in its network infrastructure, spending escalates in ITS (the infrastructure) and dips in the divisions. Conversely, during the years that internal spending in each division increases, ITS spending is down. This pattern oscillates every other year, which has proven to work quite well, because both the divisions and the FSL infrastructure are maintained with new equipment as old equipment fails or is too expensive to maintain. In 2000, the total number of networked devices peaked, and at this point management decided to switch from "Big Iron" systems such as HP, IBM, SGI, and Sun to commodity (Dell) PC systems running Linux. The total number of systems after 2000 dipped as a result of the decision to get rid of these systems, while the number of systems increased with the purchase of the new Dell systems running Linux.

The number of systems administrators also increases and decreases with the addition or deletion of hardware equipment, which justifies the number of systems administrators needed to administer networked devices. The total dollar value of equipment in each division over the last13 years (Figure 9) illustrates the peaks in 2000 when FSL still maintained the "Big Iron" equipment. In subsequent years, however, the total dollar value by division drops significantly, a direct effect of decommissioning the expensive equipment and replacing it with less expensive Dell workstations and servers running Linux. This decision has also saved FSL significant maintenance costs for its computer systems. Typically, FSL receives a three-year warranty with Dell systems in contrast to one- or two-year maintenance contracts with Unix system vendors. Linux has proven to be a very cost-effective way to achieve the compute power needed to receive, process, and analyze large volumes of data, which, of course, plays a key role in FSL's success.

FSL contracted with Global Technologies/Inflow Data Outsourcing to host the Meteorological Assimilation Data Ingest System (MADIS) data for access by external users. This has proven to be a valuable resource, because as requirements increase, FSL's bandwidth quota is no longer overburdened when accommodating ever-increasing demands for data. For example, the MADIS input and output network bandwidth usage at Inflow for 2004 illustrates (in Figure 10) the popularity of MADIS data – network bandwidth usage tripled in just one year.

ITS systems administrators, network administrators, IT security officer, and other staff have worked together to implement a secure method to access FSL's Websites. Watchfire AppShield software was purchased and configured to meet the NOAA security and Web server mandates and ensure system and information security for FSL Web servers. AppShield software minimizes the effort needed by the Web developers in each FSL division and minimizes the associated software development costs. It also keeps FSL's Web presence as transparent as possible to customers, and enables the seamless addition of Web servers and Websites for new projects.

FSL's main Windows domain controllers were replaced with new servers, and the operating system was upgraded to Windows Server 2003. This upgrade takes advantage of new features in the new operating system, which allows for remote installation and management of software. This greatly increased the productivity of the PC administrator and alleviated the need to hire a second person to perform these duties.

ITS has set up and configured the SystemImager software, which allows ITS systems administrators to create a so-called "Golden Image" from a specific machine that is optimally configured. This image can be placed on any number of additional systems which then become identical copies of the primary system, except for changes to host-specific information such as hostname and IP address. Imaging of new systems in this manner usually takes only about 30–60 minutes compared to hours using previous technology. ITS systems administrators worked with colleagues in other FSL divisions to help them set up similar SystemImager servers. This implementation boosted productivity, ensured that systems remain similarly configured, and reduced the amount of time developers spend verifying each new system.

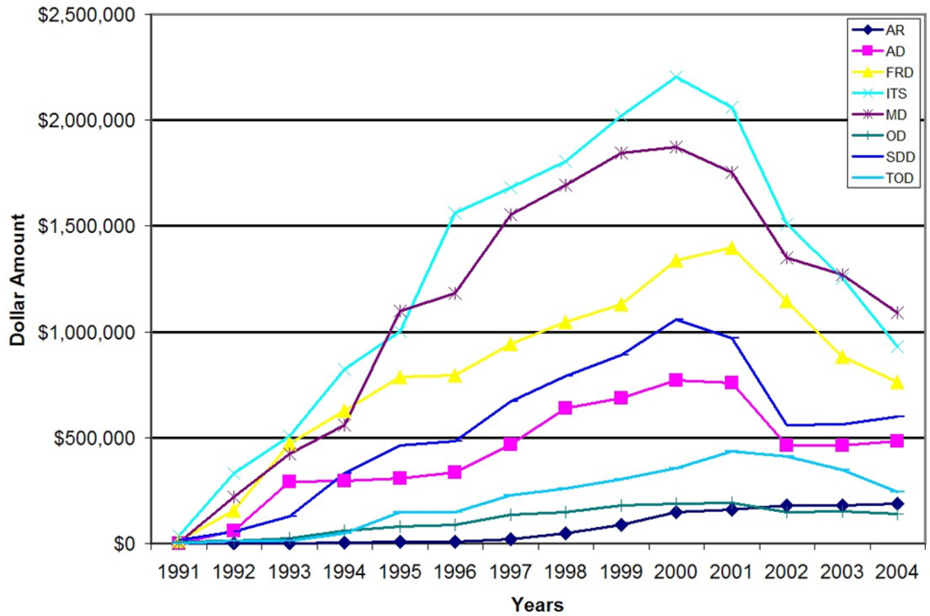


Figure 9. Chart showing the value of computer equipment in each FSL division over the last 13 years.

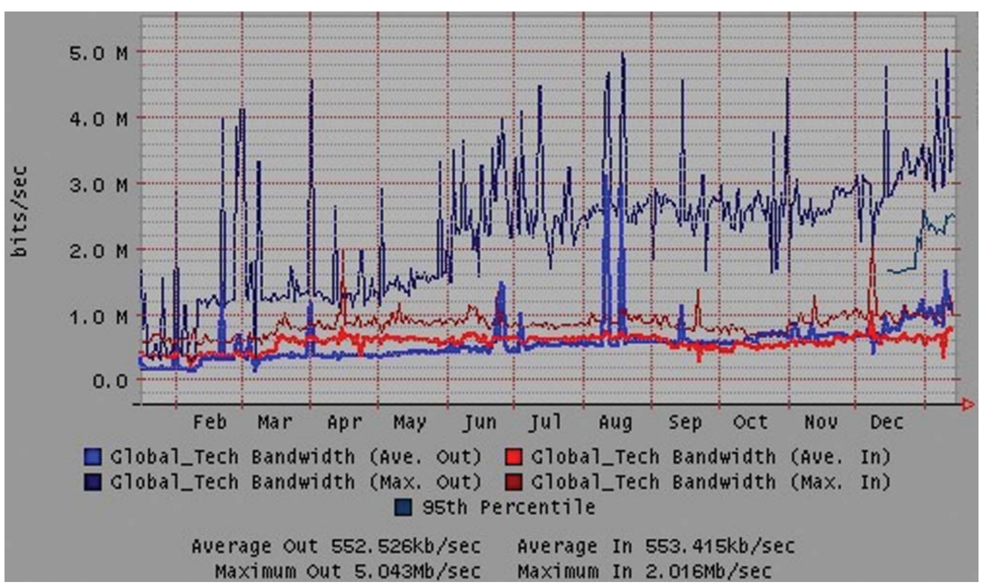


Figure10. Graph showing tripling of MADIS input and output network bandwidth usage at Global Technologies/ Inflow Data Outsourcing Company for 2004.

Systems Support and Computer Operations – The Systems Support Group (SSG) log provides an important mechanism for intercommunication among the SSG operators, Data Systems Group (DSG), system and network administrators, and other technical staff. This, in turn, results in a higher level of service in dealing with numerous and varied issues within the FSL Central Facility that require SSG's daily attention. The SSG log also provides a history of events and tracking procedures used to correct problems. Last year SSG initiated and resolved about 2200 SSG log tickets and serviced about 140 customer FSLHelp requests for data compilations, file restoration, account management, video conferencing, and other requests requiring SSG operator assistance.

The Web database that documents the procedures for maintaining the FSL Central Facility totaled 150 documents in 2004. This documentation provided SSG operators the means to efficiently and consistently troubleshoot and resolve issues involving real-time data, Central Facility equipment, and other critical systems. These new procedures and system changes simplified regular updating and refining of these documents. The transfer of SSG documentation to the new FSL Intranet Web server required that all documents be checked and sometimes modified to ensure proper link functioning.

SSG staff provided assistance to systems administrators in maintaining user accounts (i.e., adding/removing accounts); updating basic files; performing system reboots, failovers, and file restorations; adding/removing clients from the FSL backup system; and other special projects on an as-needed basis. As a result of ITS budget reduction, the SSG hours of coverage were reduced to 12 hours Monday through Friday and 8 hours on weekends and holidays. Although this also necessitated staff reduction and schedule adjustments, SSG continued to provide 100% coverage for the reduced hours throughout the year while keeping overtime to a minimum. SSG operations provided extended coverage when necessary for emergency situations, or when FSL was in active NCEP RUC backup mode. A new operator was recruited and trained to replace an operator who transferred to the Data Systems Group.

SSG oversaw the daily FSL computer system backups, with about 365 GB of information written each night for about 200 system clients throughout the laboratory, and quarterly offsite backups were completed on time for 144 critical clients. To reduce the number of missed system backups, a priority was placed on identifying regularly failing backup clients, investigating the reasons for the failure(s), and implementing proper corrective measures. SSG continued to track and record the daily volume of backups and daily tape usage, and provided this information to management via Web-based graphs and spreadsheets. Clients who were backing up too much data (often real-time) were identified and reported to appropriate systems administrators for correction. This resulted in more effective use of system/network resources and a higher level of service for all FSL users. Staff promptly handled, and called for service when necessary, any problems that arose with the main backup server and FSL's four backup tape robots. In coordination with DSG staff, we added new data, products, and systems to the Facility Information and Control System (FICS) monitor. To support these additions, we updated the FICS code and configuration files, critical support documents, and SSG Help documentation. This improved monitoring, troubleshooting, and resolution of real-time data issues.

All SSG employees received refresher training on the Central Facility computer room Vesda Smoke Detection System and FM200 Fire Suppression System.

The SCADA 3000 Temperature Monitor and Control System in the FSL computer rooms was monitored, and corrective action was taken when the system generated an alarm. The system's temperature set points were updated, as required. Its documentation was updated, as well as the PC that runs the SCADA monitoring software. Appropriate Microsoft Windows patches were applied, and an additional monitor was installed to enhance visual monitoring capabilities.

A Stage 3 level alarm was added for the two main FSL computer rooms to provide an automatic emergency power off (EPO) function if a certain temperature setting is reached within the rooms. An outside contractor programmed this EPO feature, but SSG reconfigured the FSL SCADA system software to accommodate this new capability.

FSL continued to provide backup service for the Rapid Update Cycle model and RSAS for the NWS National Centers for Environmental Prediction. On several occasions, SSG provided responsive monitoring and communication about FSL's RUC and RSAS production and delivery to NCEP during active backups or periods of backup unavailability, for example, during maintenance of the FSL High-Performance Computing System.

In support of maintaining appropriate computer security, staff took the NOAA online IT Security Awareness training, completed the in-depth SANS (Sys Admin, Audit, Network, Security) Institute security training, and participated in other in-house security training. The operators performed all required security tasks, such as the quarterly password changes.

Facility Infrastructure Upgrades – Two significant upgrades were accomplished within the Central Computer Facility to address power requirements related to upgrading the High-Performance Computer System. Numerous other projects were completed to enhance laboratory operations. The first major upgrade involved the replacement of a General Power 75 kVA Uninterruptible Power Supply (UPS), which had experienced a catastrophic failure. Since this UPS provider could no longer provide the reliability required of UPS equipment servicing the Central Facility, a 100 kVA Chloride UPS was procured and installed (Figure 11). This new machine is from the same manufacturer as all other UPS systems in the Central Facility. The upgrade also included replacement of the external transformer.

The second infrastructure upgrade entailed extensive reconfiguration of electrical distribution in the main Central Facility computer room in anticipation of the HPCS upgrade. New system racks were designed to receive power from

Figure 11. The new 100 kVA Chloride Uninterruptible Power Supply in FSL Central Facility.

NEMA locking 120V/30 A circuits. Each of 15 new racks required three circuits, necessitating modification of 45 circuits to accommodate the new system. Proper load balancing and breaker panel distribution were performed to keep the Central Facility three-phase power system balanced. This work allowed the new HPCS racks to be installed and powered up in a timely manner. Also, to accommodate installation of the HPCS upgrade, outdated equipment had to be removed. As mentioned earlier, the previous Alpha processor-based system was decommissioned, as well as the RAID storage system to provide the necessary space and power required to support the new computer system upgrade.

Data Acquisition, Processing, and Distribution

In support of NOAA's goal to "serve society's needs for weather and water information," researchers in the Data Systems Group (DSG) collaborated with FSL, CIRES (Cooperative Institute for Research in Environmental Sciences), and SRG (Systems Research Group) scientists, researchers, and developers regarding how to implement and maintain a state-of-the-art meteorological data center. This activity allows fellow scientists to perform advanced research in the areas of modeling, application development, and meteorological analysis and forecasting. Multiple computers operate in the FSL Central Facility in a distributed, event-driven environment known as the Object Data System (ODS) to acquire, process, store, and distribute conventional and advanced meteorological data. The Central Facility services provided by DSG are shown in Figure 12; refer to *http://www-its.fsl.noaa.gov/dsg/* for additional information.

The following data are received from a variety of operational and experimental sources:

- National Weather Service (NOAAPORT and NCEP)
- WSR-88D Doppler radar
- Aeronautical Radio Inc. (ARINC)
- Weather Services International Corporation (WSI)
- FSL Demonstration Division
- Geostationary Operational Environmental Satellite (GOES)-10 and GOES-12
- National Center for Atmospheric Research (NCAR)

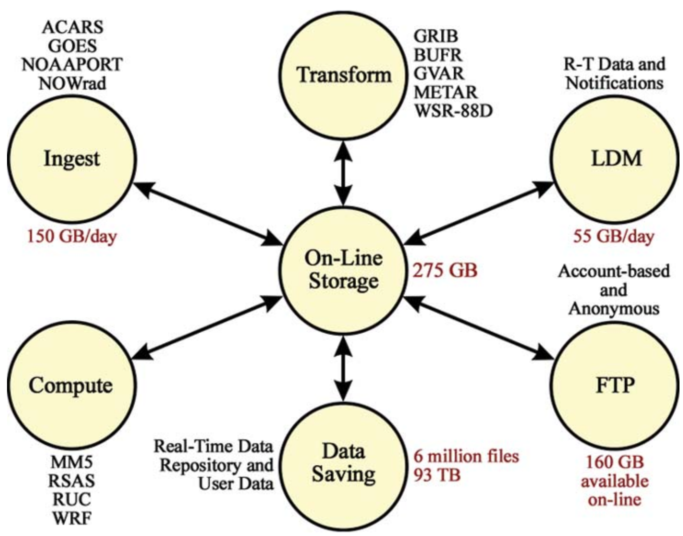


Figure 12. Central Facility services provided by the Data Systems Group.

- Meteorological Assimilation Data Ingest System (MADIS) data providers
- U.S. Navy's Fleet Numerical Meteorology and Oceanography Center (FNMOC).

Using the Unidata Local Data Manager (LDM) protocol, real-time data are distributed to numerous external organizations, as follows:

- GOES imagery data to the NOAA Environmental Technology Laboratory (ETL)
- Wind profiler data to UCAR Unidata program
- Quality controlled Aircraft Communications Addressing and Reporting System (ACARS) data to NCAR, government agencies, and universities
- WSR-88D Level-II data to the Collaborative Radar Acquisition Field Test (CRAFT)
- MADIS data to a large number of government agencies and universities.

Ingest and processing capability was added for acquiring NCAR/Research Applications Laboratory Oceanic Weather Product Development Team products, including Integrated Icing Diagnosis Algorithm (IIDA), Integrated Icing Forecast Algorithm (IIFA), and Cloud-Top Height products. Also implemented was retrieval of the University of Wisconsin Space Science and Engineering Center (SSEC) Cloud-Top Pressure and Total Water Vapor products, Ice Mapping System (IMS) snow product from NCEP, Operational Mesoscale Model (MM5) data from the Air Force Weather Agency (AFWA), and WSR-88D 3-D Mosaic files from the National Severe Storms Laboratory (NSSL).

The WSI ingest hardware and software were upgraded to replace the Solaris X86, previously ingesting these data. An Ethernet connection used to transport the data to the processing node has been replaced with a WSI processing node that now ingests the data directly.

To increase system reliability, several FTP ingest machine pairs were set up using high-availability software to allow for an automated failover from one node to another in case of a system or hardware failure.

For MADIS, the following data sources were added: Oklahoma Mesonet, Colorado E-470 Public Highway Authority Mesonet (CO_ E-470), West Texas Mesonet (WT-Meso), Wisconsin Department of Transportation (WIDOT) Mesonet, and the LSU-JSU Mesonet.

An LDM client was created to handle NEXRAD data ingest for the entire national radar network (128 radars). Compressed volume scan files for each radar ingested are available to FSL users on a shared NFS server. In response to FSL user requests, netCDF files are generated for 13 sites.

Software was designed and developed to streamline the acquisition and processing of BUFR formatted data. GRIB-handling software was extended to create AWIPS-compatible netCDF files. This new software was created using Object Oriented (OO) methods to reduce maintenance and to allow for the generic handling of data types.

The DSG team continued research and development of an OPeNDAP (open-source project for a Network Data Access Protocol) server and a THREDDS (Thematic Real-time Environmental Distributed Data Services) catalog for use with MADIS and RUC.

OPeNDAP provides a discipline-neutral means of requesting and providing data across the World Wide Web. The goal is to allow end users, whoever they may be, immediate access to whatever data they require in a form they can use, employing widely available applications.

The Data Systems Group continued to develop CVS (Concurrent Versions System) methods to ensure efficient maintenance of real-time software configurations for over 40 Central Facility data-acquisition and processing servers.

We completed research into supporting the new NOAAPORT Digital Video Broadcast System (DVBS), and the NWS scheduled this system for transfer to operations late February 2005.

New hardware was configured for MADIS in a high-availability arrangement to increase system uptime. MADIS data processing was redesigned to improve throughput by recasting the data distribution scheme, thus eliminating a problem that previously resulted in data dropouts. The MADIS processing and distribution system is shown in Figure 13.

Several additional Central Facility data-processing machines were converted into high-availability configurations to increase reliability and provide for automated failover.

Work to ingest and process Tropospheric Airborne Meteorological Data Reporting (TAMDAR) data was completed. These data are acquired from new sensor packages mounted on aircraft flying below 25,000 feet. The TAMDAR sensors will be installed on 64 Mesaba airplanes operating in the Great Lakes Region. The sensors measure temperature, pressure altitude, relative humidity, wind speed and direction, turbulence, and ice accretion. Additional data processing was developed to handle a new Delta Airlines ice format.

New hardware was configured to disseminate operational NOAAPORT data to the Taiwan Central Weather Bureau (CWB). This was accomplished using dedicated frame relay technology with the Internet serving as a backup.

The Facility Information and Control System (FICS) was upgraded and modified, as needed, to handle a variety of new datasets. FICS was ported to a high-availability server pair to increase the reliability of this critical monitoring tool by providing automated failover for the FICS servers.

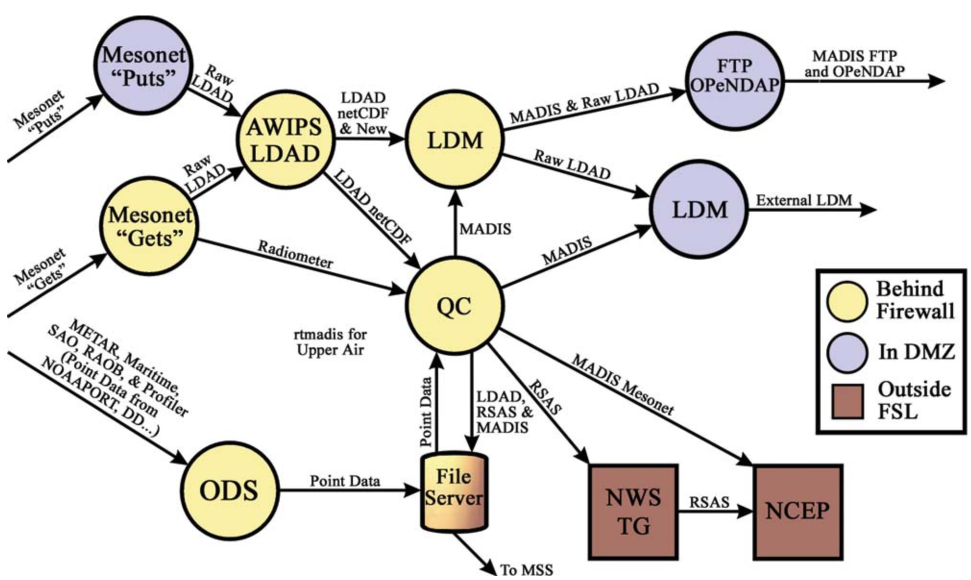


Figure 13. The MADIS processing and distribution system.

The AWIPS real-time data processing system provides data used by several FSL projects including FX-Net, Real-Time Verification System (RTVS), Local Analysis and Prediction System (LAPS), the National Interagency Fire Center (NIFC), and MADIS. The Central Facility AWIPS data servers were transferred from an HP-UX system to Linux, and the AWIPS processing software was upgraded to Operational Build 2. DSG also completed configuration of a high-availability setup for increased reliability and automated failover for these servers.

The MADIS data distribution was moved to an application hosting service, and its contact and account information was moved to an Open Lightweight Directory Access Protocol (OpenLDAP) directory to better maintain information. The directory is a database optimized for reading, browsing, and searching.

We began decommissioning the legacy FileServ/VolServ-based Mass Store System (MSS) and UniTree MSS, and continued the design and development of utility scripts for improved access to the current FSL MSS. These scripts provide simplified access for storing and retrieving data from the MSS.

DSG staff participated in NOAA's Web usability, collective resources, and best practices Web content management groups. In coordination with the ITS systems administrators, we began working on the AppShield transition. An "FSL Secure Web Programming Guidelines" document was created and made available on FSL's Intranet Website.

We completed the graphical redesign and structural reorganization of the FSL Website, which is more intuitive and thus simplifies and reduces the number of clicks needed to access information. The new graphical design allows for dynamic model graphics to be displayed on the FSL homepage and reflects modern Web practices. An FSL icon was created that displays in bookmarks and browsers. Additionally, internal and external content was separated for FSL, ITS, and other FSL division/group Websites to improve security of internal content. The recently redesigned FSL Homepage is shown in Figure 14.

Websites were established, updated, and/or maintained for the High-Resolution Temperature project (*http://highrestemp.noaa.gov/*) and for utilization of UAVs for the Global Climate Change Research Conference (*http://www.fsl.noaa.gov/uav_workshop*). Public and internal Websites were created for the NOAA High-Performance Computing System (research and development procurement), and two database-driven surveys for the NOAA High Performance Computing Study. Other Website changes were made for the main FSL Website, FSL Intranet, and the Office of the FSL Director, Administration and Research, Forecast Research Division, Technology Outreach Division, and Information and Technology Services. Additional work included the creation of feedback forms for the FSL Website and ITS services page and compilation of a list of all Web servers in the laboratory (updated throughout the year) for the DOC annual certification. Web technology information was shared with the laboratory by participating in the FSL World Wide Web Working Group (W4G), giving presentations, writing a Web column in the weekly *FSL Notes*, and participating in the NOAA Web Shop.

Technology transfer was facilitated in many different ways. For example, the Data Systems Group collaborated with the Aviation Division and NCEP's Computer Development Branch to create General Aviation Meteorological Information (GAMET) text messages from Graphical Area Forecasts to replace the existing text-based Area Forecasts. This project involved creating a National Center Advanced Weather Interactive Processing System (N-AWIPS) Meteorological Analysis Package (NMAP) library to automatically create the GAMET text product. Another technology transfer involved the design and development of a reference implementation METAR decoder. This software was delivered to the FAA and Honeywell.

FSL Network

Network Administration provided several key enhancements to the FSL IT environment in 2004. These included infrastructure upgrades and new services to improve user access and security, and to create a better understanding of networking as an enabler of the FSL mission.

The final phase of a three-year project to convert the FSL network from Asynchronous Transfer Mode (ATM) to Gigabit Ethernet (GigE) was completed. A one-time funding opportunity allowed FSL to take advantage of matching funds from the NOAA Boulder Network Operations Center (NOC) to obtain an array of six GigE network switches. These switches provided the redundancy needed in the GigE core network as well as high-speed access for office connections to match the GigE network service previously implemented in FSL computer rooms and at our security perimeter. Standardizing the network on Ethernet technology 1) greatly simplifies configuration, troubleshooting, and management, making network support more efficient; 2) allows a new level of visibility into monitoring traffic and data flows for enhanced security and resource management; 3) improves network performance with TCP (Transmission Control Protocol) tuning and the implementation of jumbo frames; and 4) positions FSL to more readily integrate new technologies as needed, such as Voice over IP (VoIP).

Figure 14. The redesigned FSL Website.

Discontinuing vendor maintenance on the replaced ATM equipment saved FSL $16K in Fiscal Year 2004. Figure 15 shows the new FSL GigE network topology. In direct response to FSL's network security needs, a token-based authentication system was designed and implemented for remote access. This solution replaced user passwords for dial-in and Virtual Private Networking (VPN) with a two-factor system that requires a user PIN and a randomly generated one-time-use password. Several vendors were evaluated, and the SafeWord Premier Access solution was chosen for compatibility with the FSL environment, scalability, and integration with SmartCard technology and Public Key Infrastructure (PKI). The implementation of tokens for Secure Shell (SSH) access to FSL is underway, and integration with other applications, such as desktop, Web, and scripted applications, are also being studied. The token solution simplifies user password management by eliminating the need for users to remember (and change), remote access passwords. This ensures that remote access passwords are perpetually unique from any other user password. The SafeWord Premier Access solution provides a comprehensive remote access user profile database, whereas before, each user needed multiple accounts for each type of access desired. More important, the token-based authentication system at FSL mitigates the threat of stolen user credentials, which is a known and proven IT security threat vector. We implemented the tokens at FSL and received extraordinary user support as a result of the close involvement of the users in the testing and evaluation stages, and the many presentations and training sessions held by the Network Administration staff on this new technology.

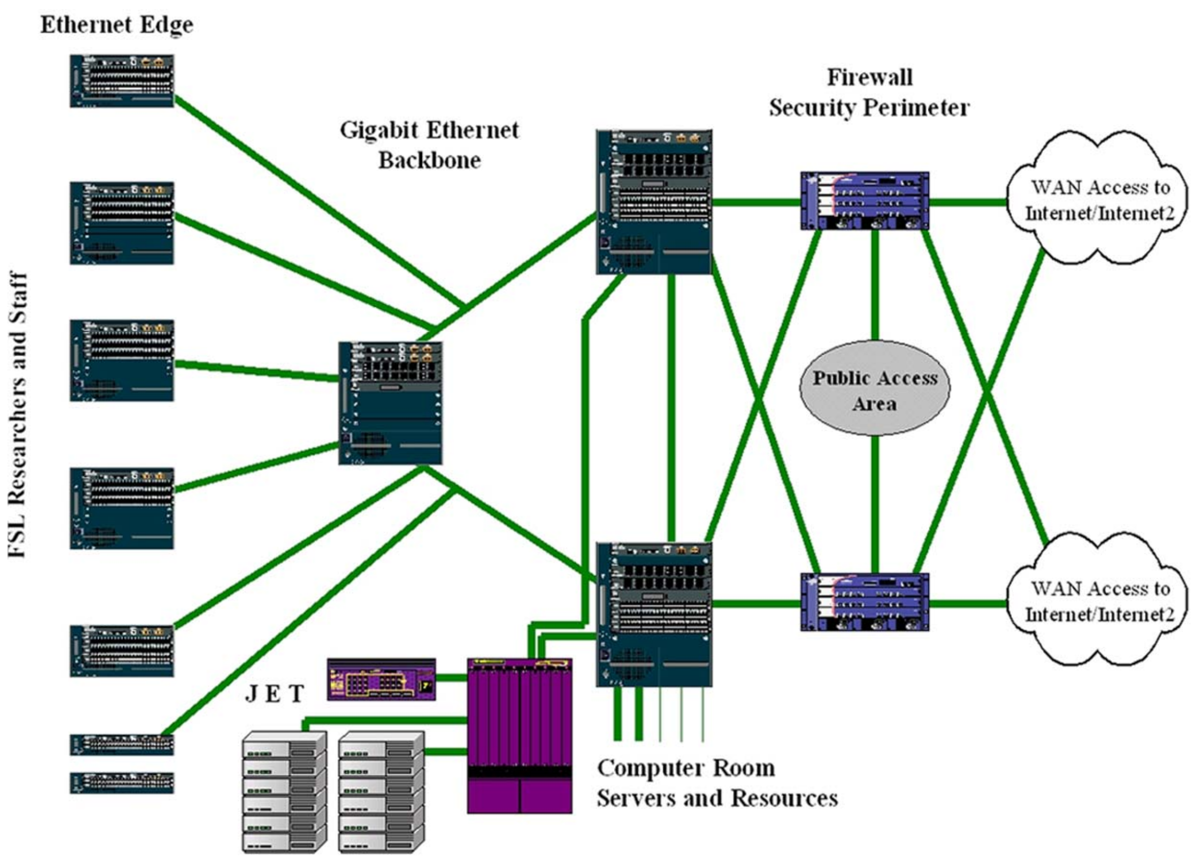


Figure 15. The new FSL GigE network topology.

The FSL wireless network was expanded and improved in 2004. FSL provided the first laboratory-wide wireless network for users at NOAA Boulder in 2003. This initial system utilized shared access points at 11 megabits per second (Mbps) bandwidth; provided access to the Internet, E-mail, VPN, and SSH; and was authenticated via a hardware-based system. A fully operational wireless network has allowed FSL to easily integrate into the expanded wireless network funded by the NOAA Boulder NOC. Wireless access is now provided for FSL users with complete coverage throughout the David Skaggs Research Center, utilizing shared access points at 54 Mbps. Access to the Internet and applications have not changed, but authentication is now based on the simpler NOAA Enterprise Messaging System (NEMS) database. The wireless NEMS authentication also allows NOAA users to create temporary guest accounts for visitors who need Internet access onsite. One additional benefit of merging into the building-wide wireless network is that all maintenance is provided and funded by the NOAA Boulder NOC, and local wireless client support for FSL users is still maintained by the Network Administration staff.

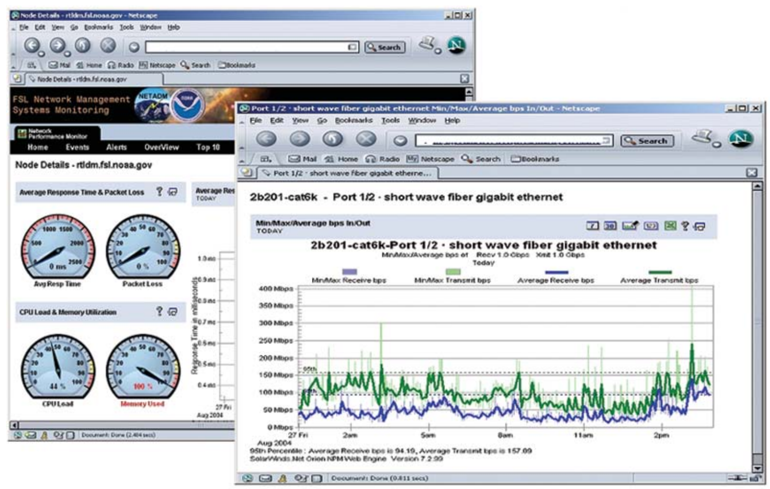
Two high-performance network load balancers were implemented to upgrade the FSL Demilitarized Zone (DMZ), or public access area, for Web and public data service. Two Foundry Networks ServerIron load balancers now ensure optimal use of resources and availability of access to the AppShield and Web/Proxy servers, and to the other general public servers located in the DMZ. This architecture upgrade provides switch, server, link and session level redundancy, as well as the most efficient use of bandwidth and IT resources available on our Web servers at any given time. For example, in the event of a server or application outage, the load balancer provides detection and subsecond fail-over to the next server in the logical group. Security features, also a valuable part of this enhanced solution, strengthen our IT security posture. TCP and User Datagram Protocol (UDP) connection rate limiting, server transaction rate limiting, SYN-Guard (denial of service attack protection), and access control lists all work together to provide a flexible means for securing our DMZ, which now has 39 physical and/or logical servers.

Advances in network monitoring at FSL provided benefits to the Network Administration staff and computer users. For the last few years, network monitoring was accomplished via public domain/shareware packages that provided some information; however, their configuration and management were too time-intensive. The comprehensive solution implemented this year leveraged our now standardized GigE architecture allowing benefits such as 1) nonintrusive detailed network monitoring at all levels of the FSL network (previous monitoring aggregated this data for over 300 computer systems); 2) improved network management, including data flow optimization, trend analyses, and better resource planning due to a more accurate measure of network activity; and 3) faster isolation of trouble points in the network in support of network uptime and security. Network monitoring is vital to FSL because the generated statistics improve our understanding of FSL IT systems and their effectiveness in supporting our research and customers.

FSL's network monitoring solution comprises a suite of applications, but it is primarily serviced by two software packages that provide two distinct sets of network information. The first, Crannog software, utilizes NetFlow data that are generated from our Cisco GigE network switches. The software provides data flow visibility to every port on every switch without requiring client software on host nodes. It provides a dynamic "drill-down" capability to examine traffic volume, utilization and data rates, as well as the top applications, source and destination addresses, and top conversations on any given link broken down by protocol and percent of bandwidth used. This tool is most useful to the Network Administration staff for generating network baselines, deviations, and problem identification and correction at all levels in the network. The second package, SolarWinds software, uses the Simple Network Management Protocol (SNMP) which polls software clients on network devices and hosts for information. This tool provides excellent visibility for end users via Web links to vital data on all nodes. Data such as average response time, CPU load, memory usage, packet loss, alerts, and event summaries are readily available. The FSL HPCS team utilizes this tool to view the status and activity of the HPCS-Sun host. The data most valuable to them include the total bytes transferred to/from the node every 30 minutes, the minimum/maximum bytes and packets per second, and percent of network utilization. All of this information is automatically plotted for one, seven, and thirty days worth of data in user-friendly easy-to-read plots, charts and dials, and can be easily integrated into reports or presentations.

The SolarWinds monitoring package provides host and network information, and complementary Crannog software provides network link and data flow information. Though either package can be used independently, both software packages together (Figure 16) provide a substantial suite of network data not previously available to FSL.

The three network administrators serviced 454 FSLHelp requests for 194 FSL staff in 2004. A new Network Event Database was also instituted to track planned and unplanned network outages, the scope of affected users, and causes and resolutions. The FSL network maintained a 99.654% uptime last year, including planned lengthy maintenance tests for the GigE upgrade, but about half of all outages were kept to under five minutes.



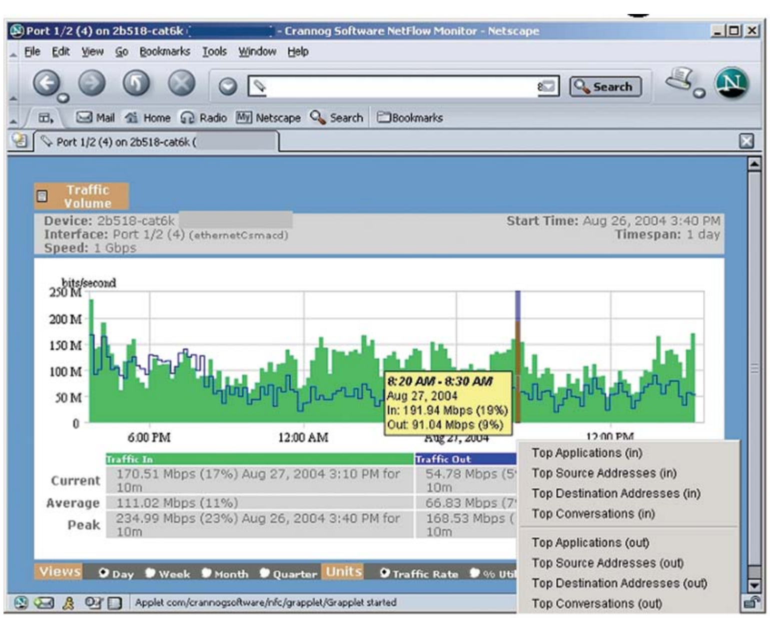


Figure 16. Screens showing FSL network SolarWinds monitoring software (above right) and Crannog network link and data flow software (below left).

FSL network CPU loads, active port capacities, bandwidth utilization, and data usage comparisons are shown in the following tables. Table 1 shows that CPU utilization of FSL network devices is quite low, meaning that our Cisco solution is handling the load efficiently with ample room for bursts of high activity and growth. In-use or active port capacity, also more than ample, is balanced based on planned system needs for FSL divisions. Note that most growth occurred in computer rooms 2B201 and 2B518. Plans are underway to address the 88% 10/100BT utilization amount in 2B518 with a rack aggregation solution for clustering large numbers of computer systems. The 100% GigE utilization in the network backbone shows full use of resources, with no anticipated requirement for expanding FSL office space. GigE access was also provided in the wiring closets located near each FSL division for the first time in 2004 (two ports each), with one used as the uplink and one available for a GigE downlink to a server or other device.

Table 1. Network Device CPU Utilization and Port Capacity (in-use).

Device	Service To	CPU Utilization	2004 Port Capacity 10/100BT	2004 Port Capacity GigE	Change During 2004 10/100BT	Change During 2004 GigE
2B201-Cat6k	Computer Rm	5%	56%	56%	+16 ports	+9 ports
2B518-Cat6k	Computer Rm	4%	88%	62%	+57	+10
2B601-Cat4k	GigE Backbone	9%	0	100%	0	+8
2A402-Cat6k	ITS/AD	3%	52%	100%	-8	+2
2B701-Cat6k	FRD/AD	3%	53%	50%	-3	+2
2C202-Cat6k	TOD/ITS	1%	60%	50%	+6	+2
3B905-Cat4k	OD/A&R	8%	40%	50%	+6	+2
3C201-Cat6k	SDD/MD	4%	48%	50%	+2	+2

Table 2 shows a sizeable increase in network utilization on FSL's Wide Area Networks (WANs) for accessing and providing access to Internet and Internet2 customers. The most significant increase, 47% peak usage, is shown on the GigE Backbone between the computer rooms. The 2% decrease in average utilization at the network edge (access to divisions) reflects a move of servers from division auxiliary computer rooms to the FSL computer rooms. Currently, there is very little demand or justification for GigE in offices (at the network "edge"), as shown in the table where GigE Edge links only utilize an average of 3% of the bandwidth available to an entire division. As bandwidth requirements increase beyond 1000 Mbps, this will be addressed by implementing link aggregation (the logical binding together of multiple GigE links) to scale the capacity of our links as much as eight fold. FSL's network also can support 10-gigabit Ethernet capability when needed. FSL continues to rank highest in NOAA Boulder network users (Table 2).

Table 2. Network Link Utilization.

Link	Maximum (Mbps)		Average (Mbps)		Change During 2004 Maximum	
FSL WAN Uplinks	310	31%	90	9%	+23%	+7%
DMZ Traffic	104	10%	61	6%	+4%	+4%
GigE Backbone	577	58%	216	22%	+47%	+17%
GigE Edge	240	24%	30	3%	+7%	-2%
All NOAA Boulder (WAN)	152	15%	33	3%	+7%	0%

Table 3. Top NOAA Boulder Wide-Area Network Users.

Top Laboratories	To Internet	To Internet2
FSL	31%	55%
Climate Diagnostic Center	17%	16%
NOAA Boulder Network Operations Center (NOC)	22%	6%
National Geophysical Data Center	15%	7%
Aeronomy Laboratory	1.2%	8%

An interesting statistic collected for the first time in 2004 at FSL concerns the total bytes transferred over key segments of the network. With the advent of new monitoring tools, our measured data only extends for four months; however, as shown in Table 4, we can extrapolate to show what the anticipated data will be for one year (Table 4). These data represent the amount of all traffic on the network segment, but do not reflect the amount of data transferred to or from servers or customers. Units are in terabytes (TB) and gigabytes (GB). The total amount of measured traffic on all network segments at FSL averages 6.33 TB per day.

Table 4. Total Bytes Transferred over Key Network Segments
September–December 2004.

Network Segment	Over 4 Months (Measured)	Daily Average	Maximum	1 Year Total (Extrapolated)
FSL GigE Backbone	159.42 TB	1.31 TB	1.64 TB on 9/15/04	478.26 TB
FSL WAN Uplinks				
Transmitted Outbound	39.1 TB	320.0 GB	457.0 GB on 9/24/04	117.3 TB
Received Inbound	26.2 TB	215.0 GB	317.0 GB on 9/01/04	78.5 TB

Information Technology (IT) Security

The Network Administration implemented the hardware token-based authentication infrastructure for use with all remote access methods, which significantly enhanced FSL's resistance to "stolen-credential" attacks. In addition, ITS systems administrators and Webmasters implemented a secure (inbound) Web proxy in FSL's public network segment. The secure proxy acts as an application-layer firewall in protecting internal Web servers against various forms of malicious activity from Internet clients. The transition of internal websites to the new proxy is ongoing; each site transition requires a great deal of planning, testing, and coordination with Web developers. Once complete, FSL will have a single, secure point-of-entry for all public Web traffic. ITS has also hired an assistant IT Security specialist to help with the ever-increasing IT Security workload.

Projections

Central Computer Facility

FSL High-Performance Computing System and Mass Store System – Plans for 2005 include commissioning the

EM64T-based portion of the HPCS, acceptance and deployment of the Serial Advanced Technology Attachment (SATA)-based DDN RAID, testing, and potential deployment of the Lustre file system using the new DDN RAID on the HPCS. In collaboration with the Aviation Division, cross-platform model optimization and model portal development will proceed. As NCEP's operational backup facility becomes available, FSL may no longer be a "hot" backup for the RUC and RSAS products. This could free some computational and staff resources for other purposes.

As a result of NOAA's corporate study of High-Performance Computing and Communications (HPCC) resources, FSL is participating in a NOAA-wide HPCS procurement for Research and Development (known as the RDHPCS). The request for proposals will be available to potential bidders in January 2005. The current schedule requires proposals in May, final proposals in late spring, and contract signing by the end of Fiscal Year 2005. The first delivery of hardware is intended to supplement and eventually replace the HPCS currently managed by FSL. As part of the new Earth System Research Laboratory (ESRL), GSD HPCS staff will continue to manage a portion of NOAA's HPCC resources.

Central Facility Systems, Enhancements and Upgrades – The new FSL backup systems (Figure 17) to be implemented in 2005 will allow FSL to complete nightly backups more quickly, since they are written to RAID arrays of disk drives instead of tape drives. This will decrease the nightly backup window, and reduce the impact that backups have on daily work. The systems also allow us to locate the tape robot offsite for final archiving.

All desktop PC systems are being upgraded to Microsoft Windows XP, since standardized configurations reduce the need for special or extra support.

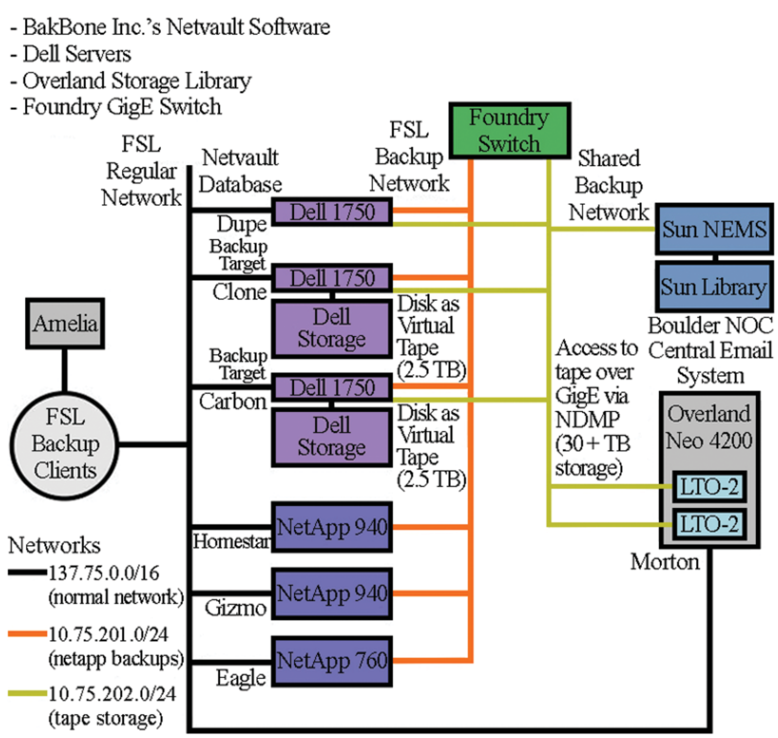


Figure 17. Schematic of new FSL backup system.

Updating the Hardware Assets Management System (HAMS) will be a major task for ITS in 2005. New hardware, new Oracle software, and new users will all eventually be part of HAMS. The current eight-year-old hardware must be replaced before a major failure occurs, thus a careful study has been commissioned to investigate the design of next-generation HAMS hardware and software.

Data storage will also be a major concern in 2005. A large amount of data storage is distributed throughout the laboratory, and it needs to be managed to free up space for new or more frequently used data. ITS will research new technologies to help FSL better manage data and storage resources.

Systems Support and Computer Operations – The Systems Support Group will continue to work on improving the handling and communication of issues and problems associated with the FSL Central Facility. A new, more capable laboratory-wide trouble/help ticket system will be investigated and possibly implemented, once we learn how to best utilize it. The new system will be incorporated into the existing automated systems to handle the increasing number of FSLHelp requests.

SSG documentation will be updated and expanded, as needed, and new formats for the SSG Documentation scheme will be researched and tested.

The vacancy of the lead computer operator will necessitate recruitment, selection, and training of a replacement.

ITS systems administrators will set up and deploy the new FSL backup system (Figure 19). SSG Operators will be responsible for monitoring the new system, setting up reporting, and continuing to track down issues and problems with the nightly backups.

Staff will receive refresher training on the Vesda/FM200 fire-detection and extinguisher systems. Additional training in normalizing the Vesda system is also planned. The SCADA Temperature Monitor and Control System documentation and monitoring tools will be updated when necessary.

We will continue to provide high level RUC/RSAS backup monitoring and notification service, and relevant documentation will be updated to accommodate any changes that affect the RUC/RSAS backup system.

FSL staff will receive training on the updated version of the NOAA Security Awareness, and will complete in-depth NOAA SANS Security online training. ITS employees will also attend other security training that is required.

Facility Infrastructure Upgrades – FSL is scheduled to complete a new computer room at the David Skaggs Research Center to house a portion of the new NOAA Research and Development High-Performance Computer System. This system will have 2600 sq. ft. of raised floor space to accommodate the high-performance computer industry's most advanced state-of-the-art equipment.

Another infrastructure improvement involves the construction of FSL's new Planet Theater™ that will house the Science-on-a-Sphere™ development project, as well as a show room for audiences to view improved displays of this new educational tool.

The Central Facility annex computer room housing a large portion of FSL's computer equipment is protected with only a fire sprinkler system in accordance with GSA regulations. To better protect the valuable equipment in this room, a clean-agent fire suppression system will be installed. This new system, similar to that already installed in the main computer room, will help detect and extinguish a potential fire before the sprinkler system releases, thus reducing downtime, equipment damage, and recovery.

Data Acquisition, Processing, and Distribution

ITS will continue the ongoing design and development of new and modified datasets. As legacy translators and product-generation methods are replaced by new, more flexible techniques, utilization of Object Data System applications and methods will expand. Work will also continue on development of Object Oriented software for point data types.

The Data Systems Group will continue work on the design and development of an automated archive and search system, which will make it easier to retrieve datasets for use by researchers studying interesting weather events.

We will continue development of new metadata handling techniques that will facilitate the use of real-time and retrospective datasets. This plan includes an automated system for acquiring and incorporating metadata. Further research will be conducted on the interactive interface that allows for easy query and management of metadata content. Program interfaces will be added to allow for secure, controlled data access, along with the incorporation of retrospective data processing and metadata management.

Techniques for incorporating AWIPS configurations into CVS will be completed for improved AWIPS configuration management.

ITS will continue the transition of the rest of MADIS to high-availability configuration, which will increase MADIS reliability.

We will continue research into other clustering technologies such as Single System Image Clusters for Linux (OpenSSI) (see *http://openssi.org*).

FSL Network

The Network Administration staff will continue to enhance the level of service provided to the laboratory. Plans are to upgrade systems to improve network efficiency in meeting the needs of FSL scientists and researchers, additional analyses of the abundant network monitoring data now available, and to investigate and integrate new technologies into the network. The most significant upcoming project is participation in the planning, development, and consolidation of IT and network support services of the current Boulder laboratories into the proposed Earth System Research Laboratory (ESRL).

FSL will play a key role in determining the IT needs of the planned ESRL and how they can best be met by a combination of centralized and distributed services. Emphasis will be placed on IT performance measures throughout the consolidation process. It is critical that IT support and procurements are aligned with NOAA and OAR missions and strategic plans. IT performance measures can be used to help accomplish this. ESRL stands to benefit in this consolidation, utilizing the many standards of IT excellence at FSL that can be expanded to serve the new laboratory. One example is the token-based authentication developed for secure remote access. FSL's token solution will easily scale to support all of ESRL, and work is underway to integrate tokens with additional security applications such as SSH, Windows desktop logons, and the Grid computing utility Globus.

Computer room network upgrades will include more robustness in the Cisco Catalyst 6500 backbone switches through installation of redundant supervisor modules in these key devices. These will minimize network failures for the main and auxiliary computer rooms in case of a hardware failure. This upgrade will also increase backplane network capacity from 32 gigabits per second (Gbps) to 720 Gbps in the main computer room that serves NOAA's High-Performance Computing System located there. It will ensure that new technologies such as 10 GigE and Dense Wavelength Division Multiplexing (DWDM) will have ample capacity when needed, in conjunction with the 95 other server connections.

An additional enhancement planned for computer room network topology is a more cost-efficient deployment of network ports for high-density system clusters. Smaller GigE and 100BT Ethernet switches will be implemented in system racks to aggregate network connections. This will support a standardized configuration for system racks, greatly decrease the number of network cables and patch connections needed between rack systems and the core switch, and free up port capacity in the core switch for truly needed high-performance requirements. A ten-fold cost savings on cable expenses will be realized, and the cost per port will decrease eight-fold by using rack aggregation switches instead of ports on the core switch.

New network technologies will be planned for further evaluation such as Voice over IP (VoIP) and DWDM. The FSL network is fully compatible with VoIP, and is ready for testing. A small number of IP phones in the FSL environment will be tested to learn how best to integrate this technology with similar plans proposed by NOAA Boulder and NIST. Another new technology is pending approval of a 2005 NOAA High-Performance Computing and Communications (HPCC) proposal. Network Administration staff proposes to build a DWDM network test bed using the Boulder Research and Administrative Network (BRAN) between FSL and NCAR. Co-investigators include the NOAA Boulder NOC, the NOAA Silver Springs NOC, and NCAR. The plan is to obtain experience with DWDM equipment and the process of dividing wavelengths into physically separate networks for 10-GigE and multiple 1-GigE connections. Additional research will be applied toward the optimization of 10-GigE data flows between FSL and NCAR, and methods will be explored on how to secure high-speed data flows. This technology has very direct application for NOAA's plans to utilize the National Lambda Rail (NLR) network for high-performance computing and sharing of IT resources over WANs.

Information Technology (IT) Security

Securing very high-speed (10-Gigabit Ethernet) WAN connections will be the grand IT security challenge for 2005. With the advent of the NLR, the infrastructure will soon be in place to allow supercomputing centers across the country to interconnect at multigigabit speeds. There is currently no firewall technology that can sustain 10-GigE throughput and even a reactive Intrusion Detection System (IDS) or Intrusion Prevention System (IPS) would only be able to stop the most unsophisticated attacks. The recent TeraGrid mass-compromise revealed how vulnerable supercomputing sites can be when a presumably secure grid network is subverted. This has ramifications for incorporation of the NLR into future grid computing architectures. No single entity controls all access to the NLR, and as such, it cannot be considered secure. Using this infrastructure securely will require a great deal of planning and hardening. One of the largest remaining local security obstacles is the problem of physical access to FSL's network. We plan to begin implementation of port-level security at each site to better react to unauthorized or misconfigured network devices in the future.

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Objectives

The Forecast Research Division (FRD) is home to most of the research in FSL on short-range numerical weather prediction (NWP), development of advanced modeling and data assimilation techniques, diagnostic studies of mesoscale weather phenomena, and applications of NWP to nonmeteorological uses. A major emphasis involves the assimilation of operational, research, and future meteorological observations for analyzing current atmospheric conditions and the subsequent generation of short-range numerical forecasts. Produced in real time at frequent intervals on national and local scales, these analyses and forecasts are valuable to commercial aviation, civilian and military weather forecasting, the energy industry, regional air pollution prediction, and emergency preparedness. FRD also has supported several large meteorological field experiments and continues to perform this service to the community.

The Forecast Research Division is comprised of the following organizational structure:
Regional Analysis and Prediction Branch (RAPB)
Local Analysis and Prediction Branch (LAPB)
Special Projects Office (SPO)

The Regional Analysis and Prediction Branch supports the following research programs:

Rapid Update Cycle (RUC) – A complete analysis/forecast system for hourly assimilation of meteorological observations over the United States into a numerical prediction model, the RUC has been implemented as an operational forecast system at the National Centers for Environmental Prediction (NCEP). The branch develops and tests improvements to the RUC and its planned 2007–2008 successor, the WRF-based Rapid Refresh, in the following areas:

• *Data Assimilation* – Improved techniques for estimating meteorological parameters on a regular grid, combining information from in situ and remote observations with that from a forecast model, and investigation of uses for new data sources, such as rapid updating using Geostationary Operational Environmental Satellite (GOES) raw radiances and derived products. The latter task is being performed partly in collaboration with other members of the Joint Center for Satellite Data Assimilation, National Envirionmental Satellite, Data, and Information Service (NESDIS); National Aeronautics and Space Administration (NASA); and National Centers for Environmental Protection (NCEP).

• *Numerical Prediction* – Design, testing, and implementation of improvements to the RUC and WRF numerical prediction model, with a major emphasis on improving representation of processes near the surface and in clouds, which exert a strong control on mesoscale forecasts.

• *Analysis and Model Verification* – Statistical and subjective evaluations of RUC and WRF analysis and forecast products for standard atmospheric variables, surface conditions, aviation-impact variables, clouds, and precipitation.

• *Data Sensitivity Studies* – Using the RUC, conducted studies to determine the effects of different types of observations on short-range numerical forecasts, including wind profilers, GPS, and space wind lidar systems of the future.

RUC Applications – Development of coupled atmospheric/land surface model capability in support of NCEP implementations of the RUC, forecasting of aviation impact variables (icing, turbulence, ceiling, and visibility) in support of the Federal Aviation Administration (FAA), wind forecasting applied to wind energy utilization, and real-time support for field projects in which NOAA is engaged.

Collaborative Modeling Projects – Lead role in the development and evaluation of the coupled WRF/Air Chemistry model, continued collaboration with NCAR in the advancement of the science of modeling precipitation physics, and participation in the development and application of the Weather Research and Forecasting (WRF) model system.

The Local Analysis and Prediction Branch is engaged in the following efforts:

Local Analysis and Prediction System (LAPS) – Incorporation of local datasets into numerical models (e.g., WRF, MM5, RAMS) for the production of very detailed analyses of local weather conditions and short-range forecasts. The model is updated using variational methods and Kalman filtering techniques with new observations at least hourly. A diabatic initialization procedure known as the “Hot Start” has been developed for reducing the problem of cloud and precipitation “spinup” in the early hours of model integration. LAPS supports a broad clientele of mostly government and military entities, including the National Weather Service (NWS), Federal Aviation Administration (FAA), Federal Highway Administration (FHWA), U.S. Air Force Weather Agency (AFWA), Department of Defense (DOD/Army, Lockheed Martin, the Central Weather Bureau of Taiwan, and the Korean Meteorological Administration.

LAPS Observation Simulation System (OSS) – Evaluation of new observation technology or siting of existing observational systems. This system has been employed to assess the potential of new satellite systems for instrument placement around eastern and western space centers of the U.S. Air Force and spaceborne wind lidar systems for NOAA.

Satellite Products – Utilization and evaluation of raw radiances and products derived from GOES atmospheric soundings, for the purpose of developing a complete national-scale moisture analysis useful for high-resolution model initialization. The branch also participates in the Joint Center for Satellite Data Assimilation.

Weather Research and Forecasting (WRF) Model Support – Development of a Standard Initialization procedure for community use in initializing the WRF model with background fields obtained from other models and static data defining the surface properties. High-resolution local applications of WRF are being developed and tested, including evaluation during the International H_2O (IHOP-2002) field experiment in the Southern Plains and application for the Coastal Storms Initiative (CSI), and participation during the DTC Winter Forecast Experiment (DWFE).

WFO-Advanced Support – Full support of an operational version of LAPS on the WFO-Advanced workstation, including both analysis and prediction. The WFO-Advanced forecaster workstation is used to demonstrate Advanced Weather Interactive Processing System (AWIPS) functions in support of future Weather Forecast Office (WFO) operations.

Local Model Implementations and Demonstrations – Configuring and installing modeling systems that take advantage of local datasets, advancements in affordable parallel computing, and the results of weather modeling research and developments from FSL and elsewhere. Current and upcoming applications of various models on different computing platforms all take advantage of LAPS initialization. Ensembles of local models will be an increasingly useful approach to numerical weather forecasting problems and applications to a broad spectrum of uses ranging from hydrometeorology to ground transportation needs.

Research efforts in the Special Projects Office consist of the following:

Diagnostic Turbulence Forecasting – Development, testing, and verification of diagnostic tools using the RUC model for forecasting turbulence in support of the Aviation Weather Research Program.

Mesoscale Diagnostic Studies – Research performed to increase the understanding of weather systems, improve conceptual and diagnostic models of the atmosphere using data from conventional instruments and new state-of-the-art sensors, and investigate mesoscale dynamical processes. Current studies include potential vorticity streamers, the structure and dynamics of the low-level jet and its role in moisture transport, the role of gravity waves in turbulence generation and convection initiation, and the dynamics and structure of bores and solitons.

Research Quality Datasets – Production of quality-controlled hourly precipitation data, meteorological data from commercial aircraft (ACARS and AMDAR), and North American radiosonde data for access on CD-ROMs and the Web. Assessments of and improvements to the set of hourly precipitation measurements are utilized for verification purposes by the Real-Time Verification System (RTVS).

Websites for FSL Data – Development of Websites for the NOAA Chemical Weather Research and Development program, national precipitation data, aircraft data, interactive soundings, national mesonetwork data, and FSL publications.

Regional Analysis and Prediction Branch

Stanley G. Benjamin, Chief

Objectives

The focus of the Regional Analysis and Prediction (RAP) Branch is research for and development of future operational regional numerical weather prediction (NWP) systems, primarily current and future versions of the Rapid Update Cycle (RUC). Through the RUC, NOAA provides high frequency, hourly analyses of conventional and new data sources over the contiguous United States, and short-range numerical forecasts in support of aviation and severe storm forecasting and other mesoscale forecast users. The RUC runs operationally at the National Centers for Environmental Prediction (NCEP) at the highest frequency among its suite of operational models. The branch works closely with NCEP in developing, implementing, and testing RUC improvements at FSL, and transferring them to NCEP. A variety of model and assimilation development, verification, and observational data investigation activities are carried out under the RUC focus. Applications of the RUC include contributions to development of improved convection and ceiling/visibility forecasts for aviation, the NOAA energy projects such as the New England High-Resolution Temperature (NEHRT) project, and forecasting detailed wind fields in collaboration with the National Renewable Energy Laboratory. The RUC has a unique role within the NWS in that it is the only operational system that provides updated national scale numerical analyses and forecasts more often than once every 6 hours. It was developed in response to the needs of the aviation community and other forecast users for high frequency mesoscale analyses and short range forecasts covering the conterminous United States. RUC is widely used in NWS Forecast Offices, NWS centers for aviation weather, storm prediction and marine prediction, the FAA, and other facilities. Evaluations of the RUC have continued to demonstrate its advantage in providing high frequency, recently initialized forecasts based on the latest observations. The RUC is a key part of the FAA Aviation Weather Research Program (AWRP), since commercial and general aviation are both critically dependent on accurate short range forecasts. With the implementation of the 13-km RUC at NCEP in June 2005, the successful collaboration between FSL and NCEP now shifts its primary focus toward development of a rapid update component using the WRF model by 2007–2008.

In collaboration with other government agencies (e.g., NCAR, NCEP, NESDIS) and universities, RAP branch scientists develop improved data assimilation and modeling methods for use in the RUC and the WRF models. Techniques for assimilating new observational datasets are developed toward the goal of the best possible estimate of current atmospheric and surface conditions, as well as the best possible short-range forecast. The branch also interacts with other FSL staff in implementing optimal computing methods with RUC and WRF software, making the model as efficient as possible on modern computing platforms.

A second primary focus of the branch, part of its efforts toward future operational NWP systems, is the development, real-time implementation, and evaluation of a fully coupled atmospheric/air chemistry mesoscale model prediction system. A fully coupled atmospheric-chemistry version of the WRF model has been in continuing development at FSL, where it has also been run experimentally in real- time in support of NOAA air quality activities in 2003–2005. An increasingly important focus of research involves regional air pollution studies.

Accomplishments

Implementation of 13-km RUC with Assimilation of GPS Precipitable Water, Mesonet, and METAR Cloud Observations – A new major revision of the Rapid Update Cycle was implemented into operations at NCEP. The 13-km RUC replaced the previous 20-km RUC, including increased horizontal resolution but also major improvements to its data assimilation and numerical prediction model components. New observation types were added to the hourly assimilation in the RUC cycle – GPS precipitable water, mesonet, and METAR cloud observations – the first time any of these observation types have been used in any NCEP operational model. The goals of the 13-km RUC implementation include:

- Improved near-surface forecasts
- Improved precipitation forecasts
- Improved cloud, ceiling, visibility, and icing forecasts
- Improved moisture forecasts in the lower troposphere and near surface
- Improved frontal/turbulence forecasts.

The 13-km RUC implementation is probably the most significant change in the RUC model for its combined analysis/model effects on moisture/cloud forecasts since 1998. The 13-km spatial resolution allows more accurate depiction of the actual terrain, and more faithful representation of coastlines and lakes compared to the current 20-km RUC. In addition to improved depiction of terrain-related flows and sea/lake breeze flows, the enhanced horizontal resolution produces improvements in forecasts of aviation related fields, including convection, icing, ceiling, visibility, and turbulence. The RUC13 continues to use 50 vertical levels and retains the same isentropic-sigma hybrid coordinate found advantageous in previous RUC versions. The horizontal resolution increase from 20-km to 13-km is complemented by enhancements to the model physics and 3DVAR analysis procedure. Development and testing for these enhancements are either completed or ongoing at FSL. Specific components of the upgrade package include:

- Use new higher resolution (also 13 km) fixed files for terrain elevation, land use (with land-sea mask), soil type, and roughness length.
- Modify Grell-Devenyi convective parameterization to use optimized weighting for multiple closures and ensemble treatment of inversion cap strength.
- Implement updated version of RUC/NCAR bulk mixed-phase cloud microphysics resulting in more accurate precipitation, a treatment for drizzle, and more accurate depiction of supercooled liquid water needed for icing forecasts.
- Modify moisture analysis variable from log of water vapor mixing ratio (ln q) to pseudo-relative humidity.
- Modify RUC model digital filter initialization to improve initial moisture fields.
- Add soil temperature and moisture nudging in analysis, only included under certain conservative conditions, based on near-surface analysis increments of temperature and moisture.
- Assimilate new observations from GPS precipitable water (GPS-PW), mesonet surface stations, and METAR cloud, visibility, and current weather data.
- Assimilate METAR observations of cloud levels and visibility to improve initial conditions for RUC 3D hydrometeor fields.

A more complete list of RUC13 changes is provided in *http://ruc.fsl.noaa.gov/ruc13_docs/RUC13-summary.html*.

Assimilation of METAR cloud observations in the RUC-13 cloud analysis was added to the previous assimilation of GOES cloud-top data with background 1-hour RUC forecasts of 3-D hydrometeor mixing ratio fields. METAR cloud assimilation provides a much improved definition of the ceiling or cloud base. A cross section of the modification of cloud water mixing ratio is shown in Figure 18, depicting additional low stratus clouds west of the Appalachian Mountains in this case. Improved ceiling nowcasts and forecasts are critical for aviation operations, with specific limitations for required flight ratings based on ceiling and visibility conditions. The assimilation of METAR ceiling/visibility observations is one of the most important steps yet taken to improve RUC ceiling/visibility forecasts. A horizontal view of a different case for the effect of METAR cloud assimilation is presented in Figure 19, with a much improved depiction of low ceiling IFR/LIFR (Instrument Flight Rules/Limited Instrument Flight Rules) conditions diagnosed from RUC 3-D hydrometeor fields. (Ceiling is calculated as the first level upward from the surface where cloud water mixing ratio exceeds 10^{-5} g/g.)

GPS precipitable water observations also were added to 13-km RUC initial conditions, after a multiyear period of RUC assimilation testing by FRD, and development of the GPS-PW network itself by FSL Demonstration Division. Figure 20 shows a consistent improvement in 3-hour forecasts of precipitable water from the RUC-13 (assimilating GPS-PW) compared to the previous RUC-20 without GPS-PW.

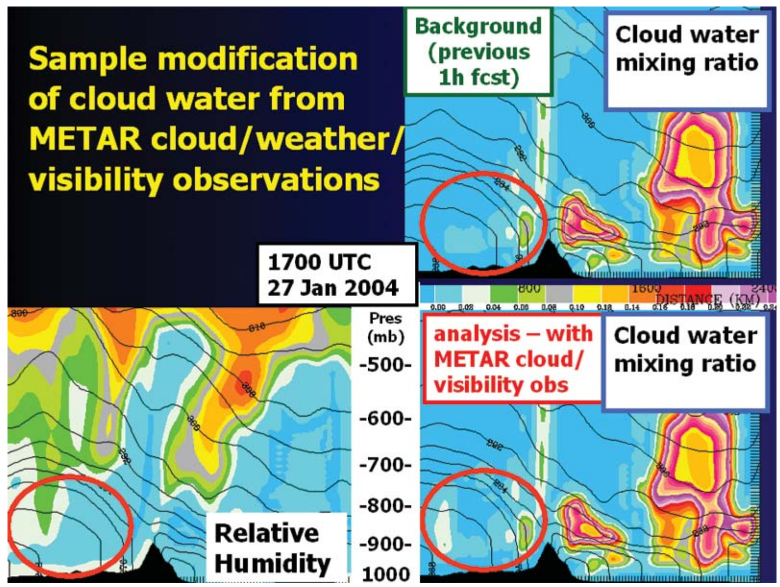


Figure 18. Vertical cross section of cloud-water mixing ratio for 27 January 2004 showing a sample modification of cloud water in 3-D RUC analysis fields from METAR cloud/visibility/current weather observations. Note the stratus clouds depicted in the analysis using METAR data in the red circled area.

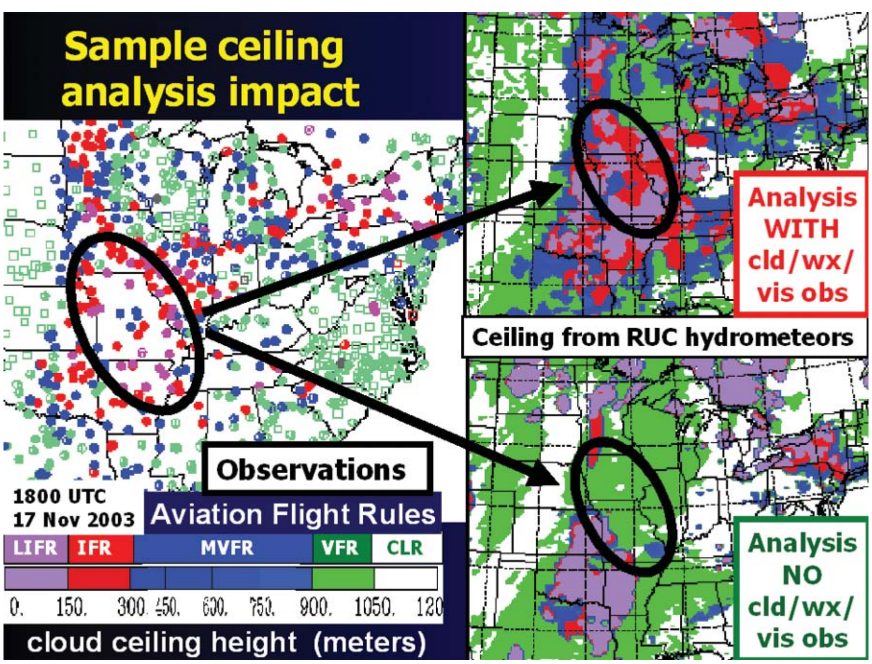
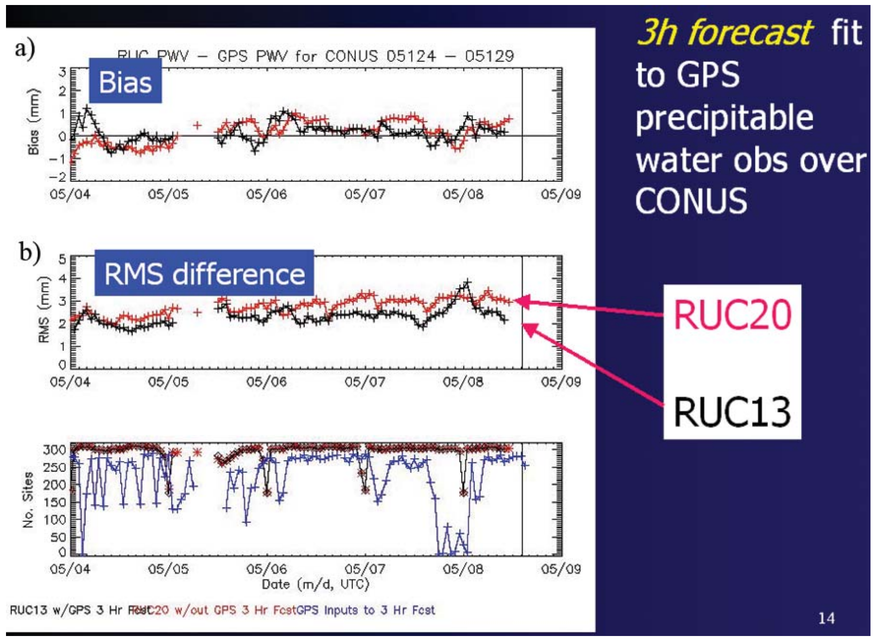


Figure 19. Depiction of aviation flight rules based on ceiling and visibility for 1800 UTC 17 November 2003.a) from METAR observations, b) from RUC analysis 3D hydro-meteor fields without METAR cloud assimilation, and c) same as b) but for RUC analysis including METAR cloud assimilation. Aviation flight rules are defined by thresholds for ceiling and visibility, with IFR (Instrument Flight Rules) ceiling corresponding to ceiling < 1000 ft, and LIFR (Limited Instrument Flight Rules) ceiling corresponding to < 500 ft.

Use of GPS-PW assimilation was combined with a novel approach to *utilize boundary-layer depth for improved assimilation of surface observations* (also developed at FSL over the last year), both improving near-surface and lower-tropospheric forecasts. Figure 21 shows the improved forecast of convective available potential energy (CAPE) from using GPS-PW and PBL-based assimilation (both now operational in the RUC13) for the Illinois tornado outbreak on 20–21 April 2004.

Figure 20. Accuracy of 3-hour RUC forecasts of precipitable water from RUC-13 (assimilating GPS-PW) and RUC-20 (no assimilation of GPS-PW). a) bias between GPS-PW observations and RUC forecasts, b) RMS difference between GPS-PW and RUC forecasts.



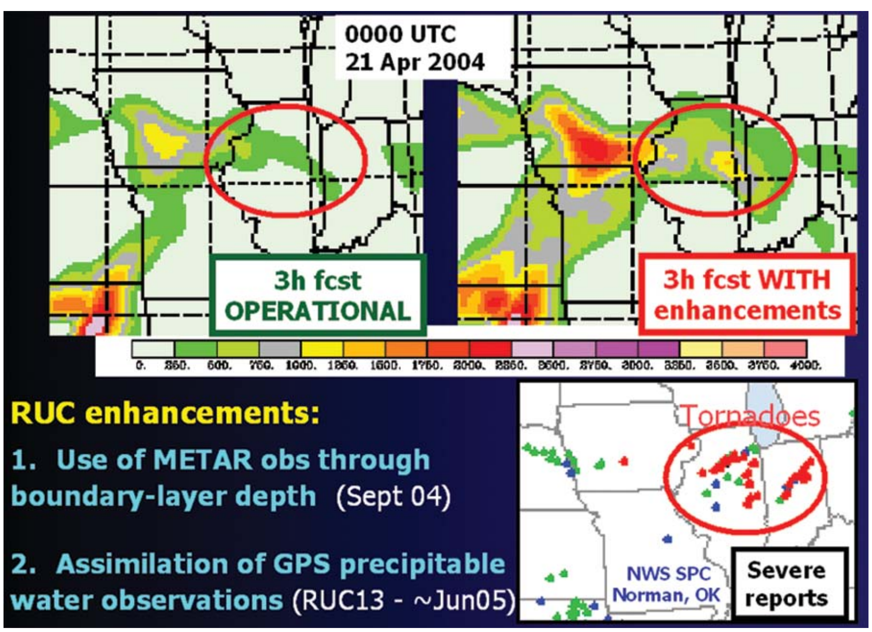


Figure 21. Three-hour CAPE forecasts valid at 0000 UTC 21 April 2004 for operational RUC and experimental RUC with enhancements now operational in 13-km RUC. Enhancements are adding assimilation of GPS precipitable water observations, and use of boundary-layer depth in assimilation of surface observations in the RUC analysis.

Finally, the improvements in parameterizations of convective precipitation (Grell-Devenyi), accuracy of detailed RUC analysis, and higher horizontal resolution in the 13-km RUC have all added to improved accuracy in its precipitation forecasts. The 3-hour accumulated precipitation forecast from 12-h RUC forecasts for 12 May 2005 (Figure 22) show a much improved depiction of the extensive east-west convective zone in the 13-km RUC forecast.

Transition to Rapid Refresh (RR)

The current 13-km horizontal resolution of the operational RUC is close to the limit of applicability of the hydrostatic approximation, used in the current RUC hybrid-isentropic model. FSL has been involved in development of the Weather Research and Forecast (WRF) model from its beginning, in collaboration with NCAR, NCEP/EMC, CAPS and university researchers, and can capitialize on model development activity (particularly parameterization of physical processes) in this wider community. Thus we have decided to use the forecast component of the Rapid Refresh (RR) for one of the nonhydrostatic model dynamical cores already configured within the WRF code infrastructure. (A nonhydrostatic hybrid isentropic-sigma dynamical core does not exist yet within the WRF code infrastructure.) In response to requests from users of the RUC, we tentatively plan to expand the present CONUS RUC domain by a factor of about 2.5 in area to cover most of North America and the Caribbean Sea (Figure 23). This will necessitate extensive use of satellite radiances in the assimilation cycle, since much of the domain is over water. Principally because of this, we have chosen the Gridpoint Statistical Interpolation (GSI) 3DVAR scheme, now under development at NCEP, to replace the present RUC 3DVAR. GSI is a new generation of 3DVAR to replace the successful Spectral Statistical Interpolation (SSI) analysis scheme, developed at NCEP during the early 1990s. (The GSI will also be used with the WRF-NAM, to replace the Eta-NAM at NCEP in 2006.) With a new, larger domain, a new analysis scheme, and a new model, the Rapid Update Cycle will be given a new name, the Rapid Refresh (RR). Our current plan calls for operational implementation of the RR at NCEP in 2007–2008.

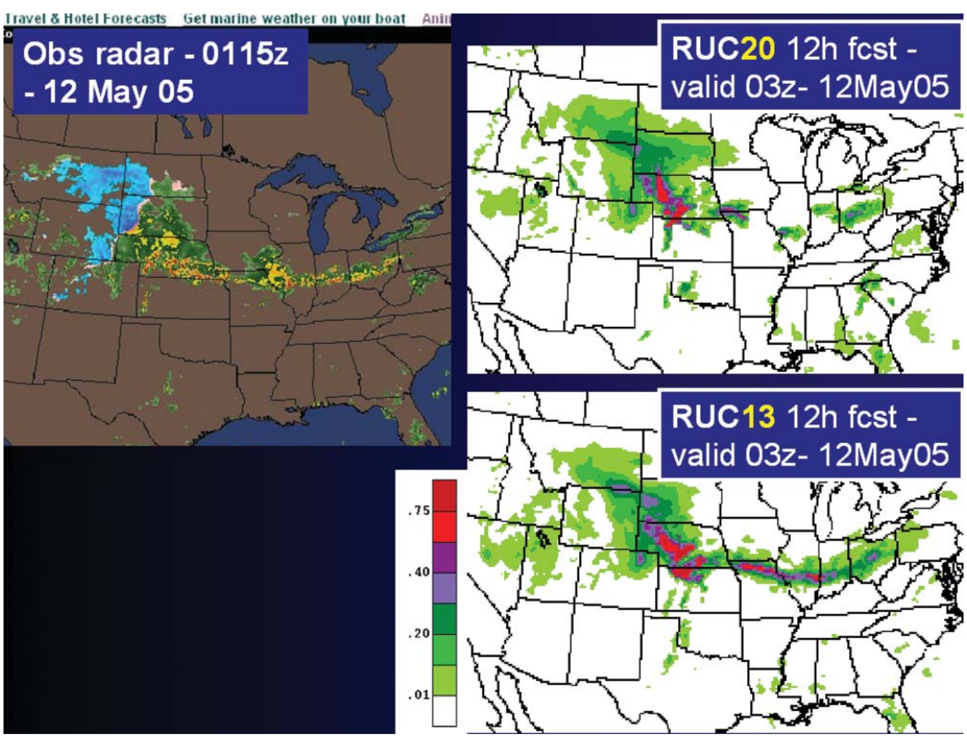


Figure 22. Twelve-hour RUC forecasts of 3-hour accumulated precipitation for period ending 0300 UTC 12 May 2005. a) observed radar summary valid at 0115 UTC, centered on 3-hour window (courtesy WSI), b) RUC20 forecast, and c) RUC13 forecast. Accumulations are in inches over the 3-hour period.

Gridpoint Statistical Interpolation (GSI) for the Rapid Refresh (RR)

In the new RR, following a design decision in June 2005, the Gridpoint Statistical Interpolation (GSI) scheme will be used for data assimilation instead of the current RUC 3DVAR scheme. FSL first became acquainted with the GSI software through the March 2004 version, and since then has worked with every monthly update. Most of FSL's testing is based on the December 2004 version of GSI. Our initial goal was to get a version running on FSL's standard supercomputer, an Intel 32-bit Linux cluster containing 768 Intel Pentium 4 Xeon nodes (for more details see *http://hpcs.fsl.noaa.gov*). This required modifying the December 2004 version from NCEP to make testing possible at FSL.

By late April 2005, GSI had been installed on FSL's supercomputer. The installation required several other steps including

- Implementation of the MPI-2 I/O system on our supercomputer in order to perform parallel I/O required for input of the ARW binary test file provided by NCEP
- Installation of Message Passing Environment Utilities (MPEU) library
- Modification of the BUFR library
- Modification of the GSI code for I/O and for compatibility with the compiler on the FSL supercomputer.

The adaptation of the GSI libraries to our supercomputer's little-endian environment was time-consuming, but is now complete. In June 2005, GSI was compiled and successfully run on the new, faster 64-bit supercomputer component at FSL. According to expectations, the speed of computation was about double that on the older supercomputer.

GSI has been tested both with a full set of observations and in single observation mode. Individual observations were generated and perturbed to test the impact of single observations on analyses. Inspection of these results and other diagnostics, generated by the code itself, demonstrated that the code is executing properly in FSL's computer environment. All the numbers are close to those generated in NCEP's own experiments. The 32-bit arithmetic has not resulted in a perceptible loss of accuracy in the computations. As of June 2005, additional software was received

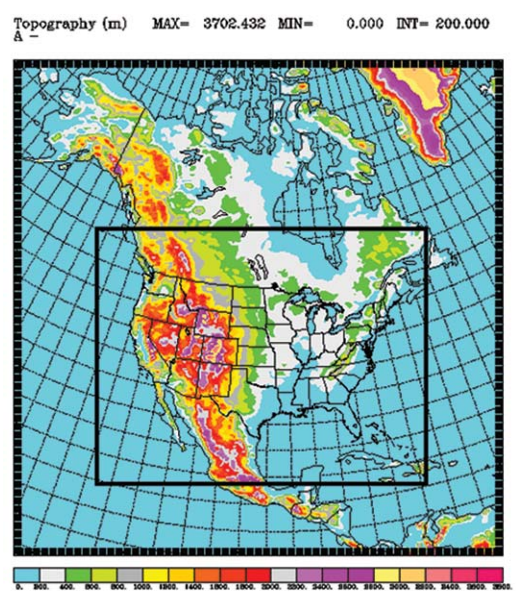


Figure 23. Planned analysis and forecast domain and topography for Rapid Refresh. Inner frame represents present RUC CONUS domain.

from NCEP to support visualization of GSI results in the Grid Analysis and Display System (GrADS) graphical package. GrADS is now being used in visualization of test results.

The GSI is curently lacking some features that are important for the high-frequency 1-hour update cycle of the RUC. FSL will work on development in these following areas:

- Assimilation of surface data within full 3DVAR: analysis of METAR data (and other surface mesonet observations) is an integral part of RUC 3DVAR. The contribution of these observations to the analyses is especially important at nonsynoptic times.
- Cloud/hydrometeor analysis in which 1-hour forecast background three-dimensional hydrometeor fields, are combined with implied observations of hydrometeors derived from GOES cloud-top pressure/temperature, METAR cloud/visibility and radar data.
- Revised balance and background error covariances (standard errors and scales) appropriate for 1-hour rapid updating.
- Calculation (and application) of innovations for METAR and buoy data, including application of similarity theory in the observation operator for 2-m temperature and mixing ratio, and 10-m wind. Use of pseudo-innovations for surface observations through estimated PBL depth.
- QC buddy check, including RAOB/GPS-IPW checks, platform flagging, and limiting the size of innovations.
- Adjustment of background soil temperature/moisture based on surface temperature/moisture analysis increment, depending on the conditions (daytime, no cloud/precipitation, etc.).
- Land-use dependency near the surface.

Model Testing for the Rapid Refresh

Two real-time experimental versions of the WRF model were set up to run at FSL over the present RUC CONUS domain in 2003. Since June 2004, these have been running the Advanced Research WRF (the NCAR Eulerian Mass dynamical core) version 2.0 at horizontal resolutions of 20 km and 13 km twice daily at 0000 UTC and 1200 UTC with forecasts out to 48 hours. These runs are initialized by an analysis from a RUC developmental cycle at FSL that uses the RUC 3DVAR. Of the physics parameterizations provided in WRF as officially supported options, only the land-surface parameterization – RUC Land-Surface Model (LSM, Smirnova et al. 1997, 2000), and shortwave radiation – Dudhia shortwave radiation scheme (Dudhia 1989), are identical to the RUC. The parameterization of convection used in WRF at FSL is an older version of the Grell-Devenyi convective scheme implemented in the RUC at FSL and NCEP. Surface and boundary layer physics in the WRF are the NCEP Eta model parameterizations as configured for WRF. The WRF Single-Moment 5-class bulk, mixed-phase scheme is used for microphysics.

This same WRF configuration has been set up to run at FSL once per day on the larger RR domain of Figure 23. This run is initialized off the NCEP GFS. These forecasts appear reasonable and results are encouraging. The right panel of Figure 24 shows an example from such a forecast, 24-hour accumulated precipitation valid at 0000 UTC 25 June 2005. Also shown on this figure is the corresponding RUC13 forecast (sum of two consecutive 0–12-hour forecasts) and the NCEP/CPC verifying analysis of 24-hour precipitation. The RR run better captures the heavy precipitation across Iowa as well as the precipitation in western Kansas and Nebraska into eastern Colorado, but overforecasts in some other areas, for example near the Nevada-Idaho-Oregon triple point.

WRF Model Verification: Precipitation – The performance of the WRF model run on the RUC domain is routinely compared against the RUC model for such variables as cloud cover and precipitation, temperature and wind in the upper atmosphere, as well as surface wind, temperature, and dew point. Overall, the WRF model shows improvements over the RUC model in the precipitation verification at both resolutions. The WRF runs have better forecasts of mesoscale features in the precipitation field, and areas of intensive precipitation often agree better with the observations. At the same time, the amounts of accumulated precipitation are often overestimated in these areas of intensive precipitation. Comparative precipitation statistics demonstrate the characteristically better skill of the WRF model for 0.10–1.0 inch thresholds. Similar results are obtained for the 20-km WRF model.

WRF Model Verification: Surface – The statistics of surface temperature, dew point, and wind verification averaged over the CONUS domain for the WRF and RUC with both 20- and 13-km resolution demonstrate competitive performance of the two models. The RMS errors from RUC and WRF are comparable for all variables, while nighttime warm and moist biases in RUC are significantly reduced in the WRF model. This result is encouraging toward replacing RUC with WRF, although the daytime cold bias in the WRF model should be reduced.

WRF Model Verification: Upper Air – Temperature and wind forecast verifications in the upper atmosphere indicate that there may be a seasonal dependence on performance of WRF relative to RUC. Because of the importance of the RUC (and the future RR) upper-wind forecasts to commercial aviation, this is a critical area for further investigation. Figure 25 shows that the RUC-WRF13 was slightly better in spring 2005 in prediction of upper winds than the RUC13. However, during earlier fall and winter periods (not shown) the RUC was generally superior to WRF. This seasonal dependence may be related to superior warm-season precipitation forecasts for the WRF.

RUC Support and Development

Support of the Operational RUC at NCEP – FSL monitors performance of the RUC running operationally at NCEP and works with NCEP to make necessary modifications. As part of this work, FSL must maintain expertise on the IBM SP computing system at NCEP and maintain a close, long-term collaboration with many groups in NCEP. FSL also supports a related major ongoing task, that of running in real time a backup version of the RUC, now with the June 2005 13-km version, in a "hardened" computer environment on the FSL supercomputer to assure high-level

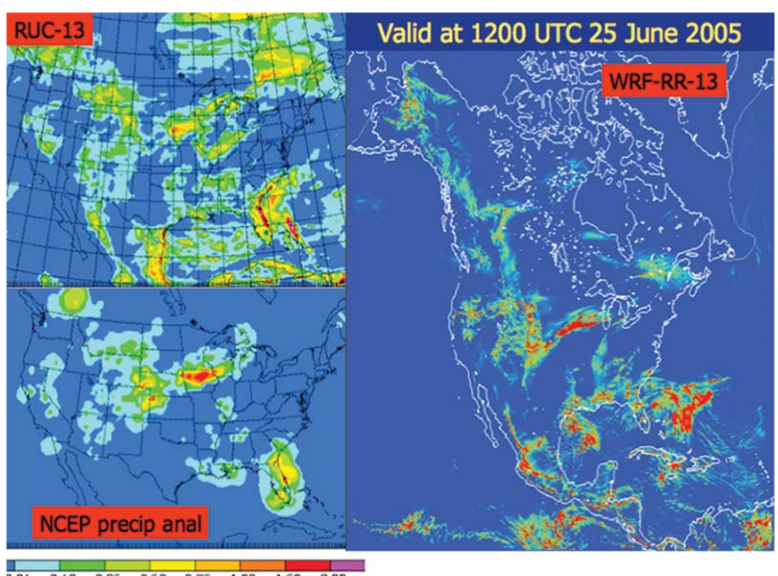


Figure 24. Precipitation for the 24 hour forecast ending 1200 UTC 25 June 2005. Right panel is from the Rapid Refresh test run initialized at 1200 UTC 24 June 2005. Upper left panel shows the sum of precipitation from two consecutive 12-hour FSL RUC13 forecasts (1200 UTC 24 June–0000 UTC 25 June, and 0000 –1200 UTC 25 June) and the lower left panel is the verifying NCEP/CPC analysis. Color table shown applies to all three panels.

reliability. During NCEP outages, RUC grids from FSL are substituted through NWS distribution channels to support all real-time RUC users. This task involves both the RAP Branch and FSL's Information Technology Services, along with NCEP and other organizations of the NWS.

Ongoing enhancements continue on the RUC Website, *http://ruc.fsl.noaa.gov*, including products from the operational 13-km RUC, test versions of the 13-km and 20-km RUC and WRF initialized by RUC analyses, and the use of RUC grids in the FSL Interactive Sounding program.

Improved Version of the Grell-Devenyi Convective Parameterization – A new version of the Grell-Devenyi convective parameterization is used in the RUC13 model and an option in WRF v2.1, including:

- Added ensemble-based version of capping convective inhibition term for 25-, 75-, and 125-mb depths. Also added the 5th ensemble closure to previous 4 closures, using a new modified Arakawa-Schubert formulation.
- Improved quantitative precipitation forecasts via revised ensemble closures, empirically estimated weights, and addition of convection-inhibition members.

Improved Version of Mixed Phase Microphysics in RUC (NCAR/RAP and FSL) – A major revision to the NCAR-RUC microphysics was implemented in the 13-km RUC. The main characteristics are as follows:

- Overall results – averages 10–15% more precipitation, less ice, more drizzle.
- Drizzle approximation added by using lower fall speed when rain water mixing ratio is small.
- Collision-coalescence from cloud water to rain changed (Barry-Reinhardt replacing Kessler formulation).
- Correction to ice-to-snow accretion, resulting in less ice and more snow.
- Snow-particle size distribution now dependent on temperature in RUC13, rather than on snow mixing ratio as in the RUC20.

Improved Ceiling/Visibility Forecasts Through Improvements to the RUC Analysis and Modeling Systems – Changes to the RUC13 in three areas (assimilation, modeling, postprocessing) resulted in improved ceiling and visibility

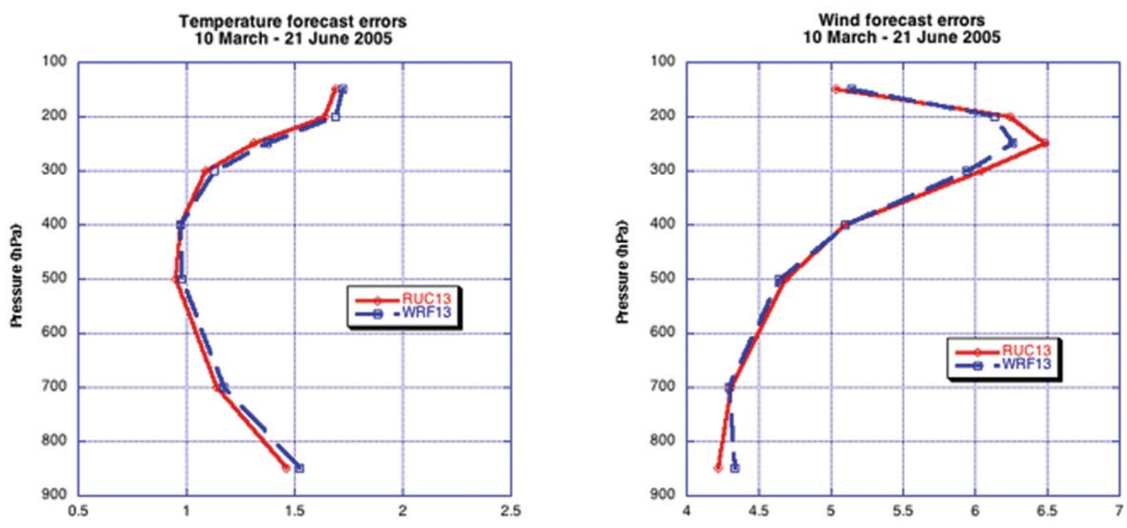


Figure 25. Comparison of forecast temperature and wind RMSE profiles from 13-km resolution runs of RUC and WRF, initialized with the same RUC initial conditions.

forecasts from the RUC, especially important for the aviation community. FSL collaborates with scientists at NCAR and other laboratories to focus on improvements needed specifically for better accuracy in short-range ceiling/visibility predictions. The assimilation component of this work includes incorporation of METAR cloud data (described earlier) and improved use of GOES cloud-top data.

Applications of RUC

Probabilistic Forecasts of Convection from the RUC Model – This project, which began in 2003 in response to a need for automated short-range convective guidance products, grew significantly in stature during the year. The goal of the project is to provide optimal probabilistic thunderstorm forecasts for aviation users, who must make strategic air traffic routing decisions based on anticipated thunderstorm activity. This convective likelihood information is extremely crucial during the summer months, when major U.S. air traffic corridors are frequently blocked by difficult-to-predict convective storms. The paradigm for creating the probabilistic convective forecasts is to intelligently postprocess an ensemble of deterministic model guidance information to provide an optimal forecast that reflects the inherent unpredictability of convective systems. Toward that end, gridpoint and time-lagged ensembles of RUC model-predicted convective precipitation have been used to create a product known as the RUC Convective Probability Forecast (RCPF). Following the initial proof of concept phase in 2003, a more rigorous in-house testing and evaluation was completed during the 2004 summer convective season. Based on this testing, a number of significant enhancements were made to the RCPF. These included adding diurnal and regional variation to the convective precipitation threshold and adding regional variations to the spatial filter size. The result was a forecast product which retained the same forecast skill (as measured by the critical success index), but had a significant reduction in the overforecasting of convection. This is especially important to air traffic managers, as false alarm forecasts are extremely detrimental.

Based on the skill demonstrated by the RCPF during the 2004 convective season, the NWS/NCEP Aviation Weather Center (AWC) invited FSL to provide RCPF forecasts in real time to AWC forecasters for further evaluation. In particular, AWC produces a human generated forecast known as the Collaborative Convective Forecast Product (CCFP), for which the RCPF may provide useful guidance. Automated transfer of GRIB-formatted RCPF forecasts to AWC was accomplished by FSL's Information Technical Services group, and the RCPF was available on the forecasters workstations in real time. Feedback from the forecasters, obtained via a Web-based evaluation form, indicated that the RCPF was valuable to the forecasters as they created the CCFP forecasts. The forecasters also provided several excellent suggestions for improving the RCPF, which are being implemented. This real-time evaluation of the RCPF by AWC forecasters represents a significant milestone in the development of the product.

The other significant milestone for the RCPF was the upgrade from using the 20-km RUC model to using the 13-km RUC model as the source of ensemble information. Real-time production of a 13-km RUC-based version of the convective probability product (RCPF13) began in July 2005. Following a testing and evaluation phase, transfer of the RCPF13 to AWC commenced in early September 2005. The RCPF13 benefits from all the underlying improvements in the 13-km deterministic RUC model, as evidenced by Figure 26. Depicted here are 8-hour RCPF20 and RCPF13 forecasts valid 2100 UTC 26 August 2005. While both forecasts capture the basic convective pattern, the RCPF13 better delineates the dominant squall-line and other features, as reflected in the skill scores. In addition, the RCPF13 includes two other significant enhancements. First, the convective probability forecast is now complemented by a potential echo top forecast (not shown). Based on an ensemble of model-predicted thermodynamic equilibrium levels, this field has been much requested by forecasters. Accurate prediction of anticipated echo tops is very important to air traffic managers, as they can often route air traffic over low-topped convection. Work is ongoing to further calibrate the RCPF13, and to make better use of other model fields including the closure information from the Grell-Devenyi cumulus parameterization scheme.

Use of RUC Wind Forecasts for Estimated Wind Power Potential – Wind energy (Figure 27) is the fastest growing energy source worldwide. FSL continues a collaborative wind energy study with the National Renewable Energy Laboratory (NREL, Department of Energy) now using RUC forecasts. Time-lagged ensembles produced from 20-km and 13-km RUC forecasts out to 48 hours are used to estimate near-surface wind power potential, while variance among forecast ensemble members provides a measure of uncertainty in those forecasts. A major focus in NREL-FSL work during 2004–2005 was studying RUC forecasts of low-level jets in the lowest 300 m above the surface.

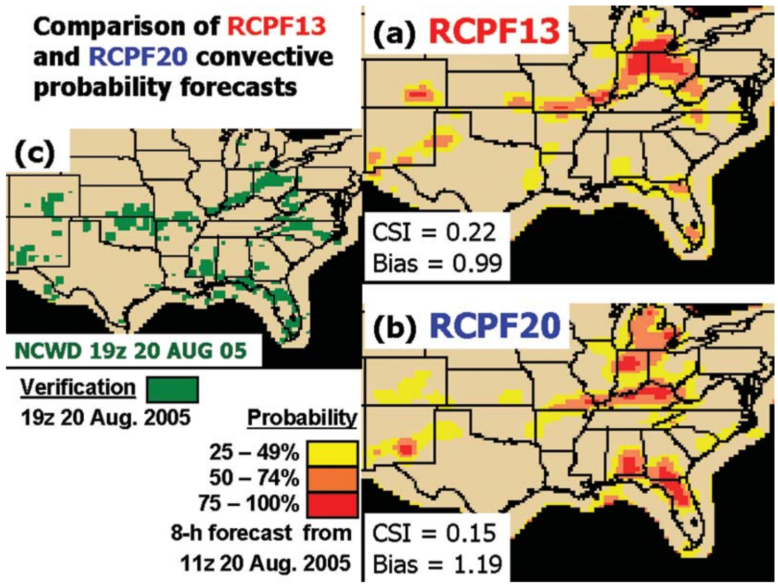


Figure 26. Comparison of (a) the new RUC 13-km based convective probability forecast (RCPF13) and (b) the old RUC 20-km based product (RCPF20). The case shown is for an 8-hour forecast from 1100 UTC 20 August 2005 valid 1900 UTC 20 August 2005. The verification shown is from the national convective weather diagnostic (NCWD). The categorical skill scores shown for the RCPF are computed with respect to the NCWD verification using a 40% probability threshold.

Figure 27. Measurements from wind towers such as these are used for collaborative wind energy studies.

New England High-Resolution Temperature Program (NEHRTP) – Both WRF and RUC with 20-km and 13-km horizontal resolution provided 48-hour forecast grids for NOAA's NEHRTP during summer 2004. This gave us a good opportunity to evaluate and compare the models' performance at and near the surface using the data from a special network of boundary-layer wind profilers and from surface meteorological stations in the New England area. The results of these comparisons emphasize that major challenges remain in obtaining the proper coupling between clouds, radiation, the surface energy budget, land-surface processes, and turbulent boundary-layer fluxes necessary to obtain consistently good forecasts. FSL collaborated closely with NOAA scientists at the Environmental Technology Laboratory (ETL) and the National Severe Storms Laboratory (NSSL) on this project.

Observation Sensitivity Experiments Using RUC to Examine the Impact of GPS – In collaboration with the Demonstration Division, the RAP Branch continues to monitor the impact of GPS precipitable water (PW) data on RUC forecasts. The implementation of GPS-PW assimilation as part of the RUC13 package was a major milestone in this work. The RAP Branch developed a quality control technique inside the RUC13 analysis for identification of GPS satellite orbit position problems affecting GPS-PW. It also developed a method using GPS-PW data to identify intermittent rawinsonde moisture sensor problems, also incorporated in the RUC-13 analysis. The ongoing assessment of the 20-km RUC continues, using a Web interface created by the Demonstration Division.

Other Observational Impact Experiment Projects using RUC Assimilation/Model Systems involve:

- Impact of experimental TAMDAR aircraft observations on regional airline aircraft (more below)
- Development of aircraft/AMDAR optimized observation strategies and related impact experiments
- Overall observation impact experiments for rawinsonde, aircraft, profiler, VAD wind, and surface observations for cold-season and warm-season periods
- Observing simulated system experiments (OSSEs) for proposed national upper-air observing system including a national profiler network complementing existing rawinsonde and aircraft observations.

TAMDAR Evaluation – Under the sponsorship of NASA and FAA, FSL is evaluating TAMDAR (Tropospheric Airborne Meteorological Data Reporting), a new sensor of meteorological conditions. Developed by AirDat, LLC, with support of the NASA Aviation Safety Program, TAMDAR measures winds aloft, temperature, humidity, icing and turbulence. The sensor is currently deployed on regional commercial aircraft flying over the U.S. Midwest. Figure 28 shows flight tracks for TAMDAR-equipped aircraft for 2 August 2005.

TAMDAR data are being ingested in a version of FSL's Rapid Update Cycle, and the forecast skill is being compared with that of an identical assimilation cycle running without these data. Initial results show notable improvement in the skill of 3-hour temperature forecasts at the low altitudes where TAMDAR flies, and slight improvement in wind and humidity forecasts.

TAMDAR data are also being made available on FSL's Aircraft Web Display to operational weather forecasters, and the impact of these data on their forecasts is being evaluated. We are also performing statistical comparisons of TAMDAR data along with data from other airlines, compared with 1-hour forecasts from the RUC.

AMDAR Quality Control System – A computer program to flag and in some cases correct AMDAR (Aircraft Meteorological Data Reporting) weather data from automated sensors on commercial aircraft was upgraded and corrected. Data from several new sources have been decoded, processed, and merged with existing data sources to form a unified and extensive data flow. These sources include:

- Data from aircraft flying with the new TAMDAR sensor
- Humidity data from the NOAA-developed Water Vapor Sensing System, version II (WVSS-II)
- Data from Chinese, Japanese, and Canadian air carriers
- Quality-controlled turbulence (eddy-dissipation-rate) data
- Data from Southwest airlines
- Data from experimental Unmanned Aerial Vehicles (UAVs).

We are now processing and distributing over 240,000 upper-air observations per day.

RUC Ceiling-Visibility Database – Using the mysql database management system, we have developed a database that stores RUC analyses and forecasts of ceiling, visibility and IFR/VFR flight condition at METAR locations, along with METAR observations. This database supports a Website (described below) that generates and displays verification statistics.

RUC Ceiling-Visibility Statistics Webpage (http://ruc.fsl.noaa.gov/stats/cvis/) – This page uses NOAA's Java Scientific Graphics Toolkit, developed at the Pacific Marine Environmental Laboratory, and the RUC Ceiling-Visibility database to interactively generate verification statistics. These statistics are based on RUC analyses and forecasts verified against METAR observations. Performance of three models, the operational RUC, the 20-km RUC, and the developmental RUC, can be viewed, and statistics generated based on VFR/IFR category and several visibility and ceiling thresholds. The page was upgraded to produce data much faster (by an order of magnitude), and a user-selectable date range was added.

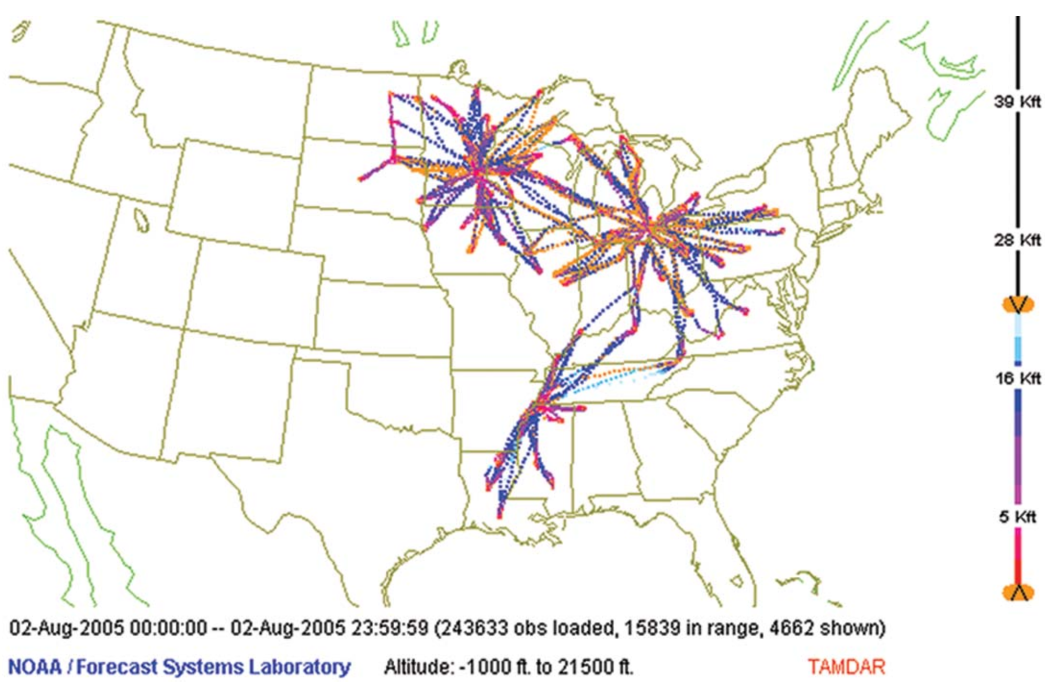


Figure 28. Flight tracks for TAMDAR-equipped aircraft for 2 August 2005.

RUC Ceiling-Visibility Plan View Webpage (http://ruc.fsl.noaa.gov/stats/cvis/plan_view/) – This page provides a zoomable nationwide view of ceiling and visibility from METAR observations and RUC analyses and forecasts for several versions of the RUC. Data and forecasts at individual METAR sites can be interrogated, and regional patterns can be easily distinguished. The site was upgraded to include data from the RUC "dev2" model, which includes TAMDAR data. Figure 29shows a visibility analysis for the FSL development RUC for 0000 UTC on 10 March 2004. Only METAR sites where the RUC analysis showed visibilities to be less than 20 miles are shown.

RUC GRIB Viewer (http://ruc.fsl.noaa.gov/view/) – This site, currently restricted to FSL, provides a zoomable nationwide view of all RUC 20-km model results that are stored in GRIB format. Individual fields can be loaded and compared with one another. Fields that are not routinely plotted may be interrogated on this page. Figure 30 shows 250-mb relative humidity from the RUC development model 6-hour forecast, isobaric output, valid at 1800 UTC 10 March 2004. Relative humidity values and other previously loaded fields for the point near the cursor are shown.

Development of NDFD RUC grids toward Real-Time Mesoscale Analyses (RTMA) – As part of the RUC-13, FSL developed a diagnosis of 5-km grids over the full NDFD (National Digital Forecast Database) domain, with 10 fields (e.g., 2-m temperature, 10-m wind, wind gust, ceiling, visibility) consistent with 5-km terrain data. The RUC13 NDFD grids are produced hourly in real-time at NCEP as background fields for the Real-Time Mesoscale Analyses (RTMA) in progress at NCEP. The RUC NDFD 5-km grids include mesonet data and full observations (including cloud data) from METARs.

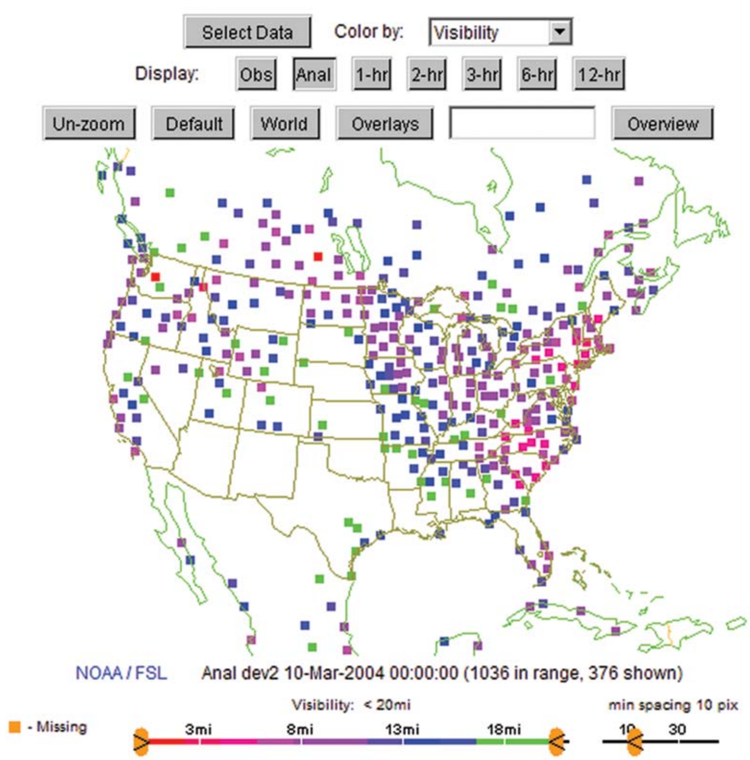


Figure 29. A visibility analysis for the FSL developmental RUC model for 0000 UTC on 10 March 2004.

Collaborative Modeling Projects

Further Development of the Fully Coupled Weather/Air Chemistry Prediction System Based Upon the WRF Numerical Model – FSL is leading the development of a next-generation coupled weather/air quality numerical prediction system based upon the Weather Research and Forecasting (WRF) model (*http://www.wrf-model.org/WG11*). The chemical kinetic mechanism in this numerical model system is embedded within the meteorological model structure, thus the integration of the chemistry is performed as part of WRF (WRF-Chem). In this form, the air quality version of the model is consistent with all transport done by the meteorology model. The same vertical and horizontal coordinates are used (no horizontal or vertical interpolation), the same physics parameterization are utilized for subgrid-scale transport, and no interpolation in time is performed. This allows for easy handling from a data management standpoint, and for the most efficiency with regard to overall CPU costs. Grid-scale advection in the mass coordinate WRF is mass- and scalar-conserving. The model is able to simulate and predict ozone, fine and coarse particulate matter, and many other pollutants.

In addition to simulating the weather or – in its most complicated form – the air quality, this numerical modeling system may also be used as a coupled weather prediction and chemical dispersion model in order to forecast the release and transport of atmospheric tracers (through grid and subgrid-scale transport, emissions, and deposition). At FSL this modeling system was used to produce real-time simultaneous forecasts of air quality and weather on several different domains (see below). Furthermore, the forecasts from this modeling system in addition to many other air quality modeling systems were collected for model comparisons and producing ensemble forecasts.

Real-Time Air Quality and Weather Forecasts Using the WRF-Chem Numerical Model – Evaluation of the WRF-Chem model was performed using a 2-month testbed dataset obtained during the 2004 New England Air Quality Study (NEAQS-2004). During this time period, an intensive meteorological and air quality observation and modeling

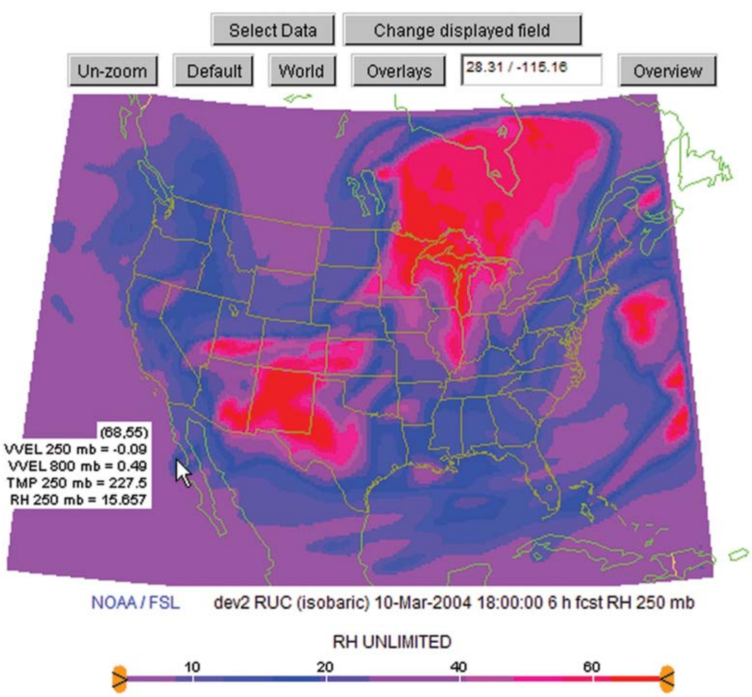


Figure 30. Screen showing 250-mb relative humidity from the RUC developmental model 6-hour forecast, isobaric output, valid at 1800 UTC 10 March 2004. Relative humidity values and other previously loaded fields for the point near the cursor are shown.

program took place in New England. WRF-Chem was used to produce real-time forecasts at FSL. The purposes of the simulations were to ensure model robustness, to perform quantitative analysis of O_3 and PM2.5 forecasts, and for direct comparison with air quality observations.

In 2004, one set of forecasts was made for a 72-hour time period on a numerical grid that is approximately 3600 km x 3000 km and covers the eastern two-thirds of the United States (Figure 31). The numerical grid uses 27-km horizontal grid spacing and is centered at 86°W longitude and 34.5°N latitude. The model domain extends vertically to 18 km with a vertical mesh interval smoothly increasing from 7 m near the surface to approximately 500 m at the domain top.

A second set of forecasts was made for a 36-hour time period on a numerical grid that is approximately 3600 km x 3000 km and covers the eastern two-thirds of the United States (Figure 32). The numerical grid uses 27-km horizontal grid spacing and is centered at 86°W longitude and 34.5°N latitude. The model domain extends vertically to 18 km, with a vertical mesh interval smoothly increasing from 7 m near the surface to approximately 500 m at the domain top.

The 36- and 72-hour forecasts were produced every 12 hours starting at 0000 UTC and 1200 UTC. The meteorological initial conditions were obtained from the Rapid Update Cycle (RUC) model analysis fields generated at FSL, and lateral boundary conditions were derived from the NCEP Eta-model forecast. Atmospheric chemical constituents were initialized from the previous 12-hour forecast, and the chemical lateral boundary conditions for inflow along lateral boundaries were obtained from an idealized atmospheric chemistry profile. Hourly updates were made to the anthropogenic emissions using the EPA national emissions inventory (1999 version) database that is interpolated to the three-dimensional model grid, and biogenic emissions were calculated using the EPA biogenic emissions inventory system version 3.11 data. Information about the WRF-Chem model configuration is provided in Table 1.

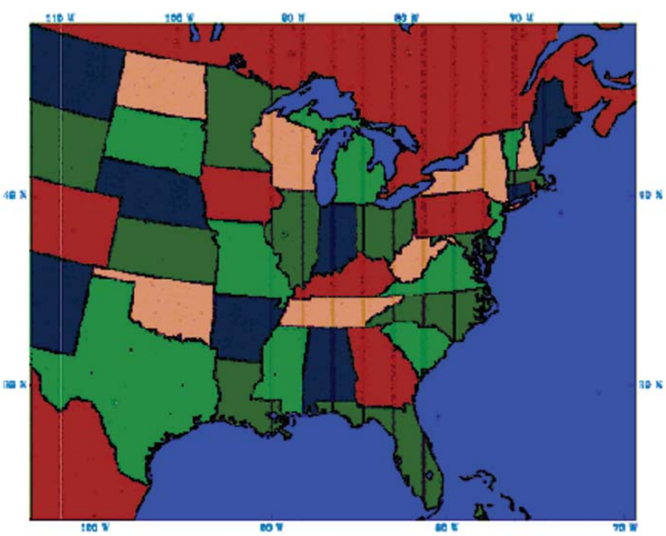


Figure 31. Domain used for the 27-km real-time air quality forecasts using the WRF-Chem numerical model.

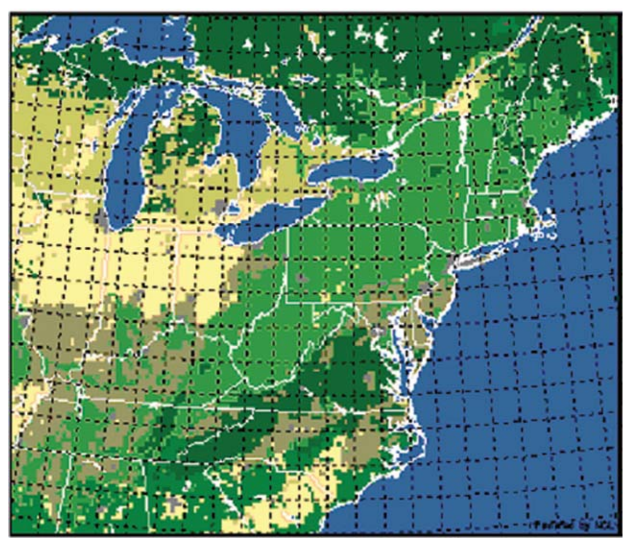


Figure 32. Domain used for the 12-km real-time air quality forecasts using the WRF-Chem numerical model.

Table 1. WRF-Chem Real-Time Forecast Configuration.

Advection scheme	5^{th} horizontal /3^{rd} vertical
Longwave radiation	RRTM
Shortwave radiation	Dudhia
Surface layer	Monin-Obukhov (Janjic Eta)
Land-surface model	RUC-LSM
Boundary layer scheme	Mellor-Yamada-Janjic 2.5 TKE
Microphysics	NCEP 3-Class simple ice
Cumulus parameterization	Grell-Devenyi
Chemistry option	RADM2
Dry deposition	Weseley, 1989
Biogenic emissions	Gunther, 1994 and Simpson, 1995
Photolysis option	Madronich, 1987
Aerosol option	MADE/SORGAM

Graphical forecast products are generated from hourly model output data and freely distributed to federal and state air quality offices at Webpage: *http://www-frd.fsl.noaa.gov/aq/wrf* (see example in Figure 33). The Web images show the concentration of O_3, NO_y, CO, PM2.5 as well as several meteorological fields. In addition, the forecast model data is being made available to universities and national forecast offices through the FX-Net application (*http://www-id.fsl.noaa.gov/fxnet.html*). This application allows the forecaster to simultaneously visualize the three-dimensional structure of the meteorological and chemical forecast as well as surface observations of the same fields.

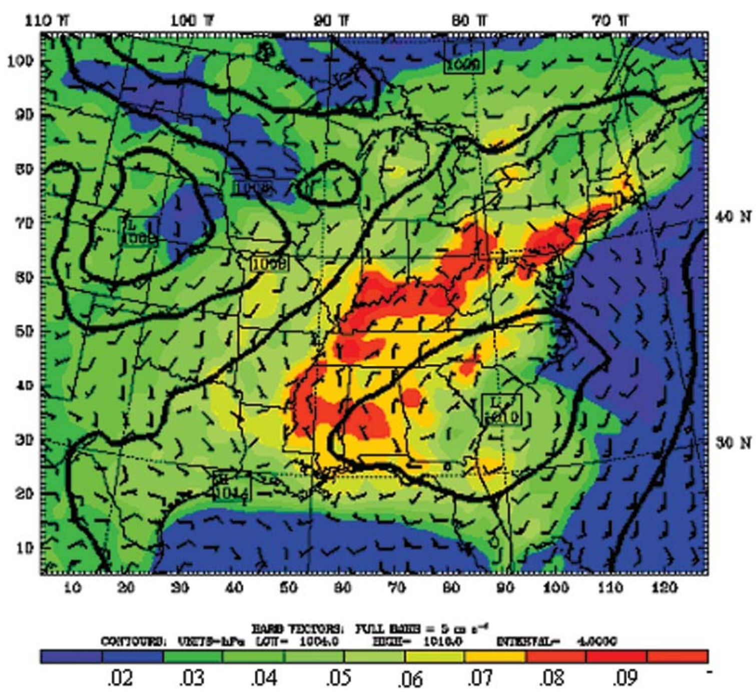


Figure 33. Example of a WRF-Chem forecast image showing O_3 concentration (ppm) and surface winds (barbs). O_3 concentrations (ppmv) are shown by the colorbar.

A set of standard statistical analyses comparing model forecasts to observed surface values were computed for the 27-km horizontal grid spacing forecasts from 14 July 2004–17 August 2004 (see Table 2). The statistical analysis includes correlation coefficient, mean bias and root mean square error of surface ozone, and fine particulate matter (PM2.5). The statistical analysis shows that the WRF-Chemistry model has a good overall performance compared to other air quality forecasting models with some of the highest correlation coefficients, lowest bias, and RMSE. These same statistical analyses were also performed for some other commonly used air quality forecasting models.

Table 2. Statistics for 8 Air Quality Forecast Models with 342 AIRNow Q_3 Monitors: 14 July 2004–17 August 2004 (34 days).

Statistics for maximum 8-hour averages, based on 0000 UTC forecasts only. Medians of 342 monitor comparisons.

	Ozone		PM2.5		
Institute, Model, Horiz. Resolution	r coefficient	RMSE	r coefficient	Mean Bias*	RMSE**
NOAA FSL, WRF-Chem, 27 km	0.73	11.5 ppb	0.65	0.79	1.79
Baron AMS, MAQSIP, 15-km	0.69	11.7 ppb			
MSC Canada, CHRONOS, 21 km	0.68	23.2 ppb	0.67	0.77	2.14
Baron AMS, MAQSIP, 45 km	0.66	12.6 ppb			
NOAA NCEP, CMA Q/Eta, 12 km	0.63	17.9 ppb	0.65	0.75	2.01
Univ. of Iowa, STEM, 12 km	0.60	31.0 ppb	0.65	1.12	1.95
MSC Canada, AURAMS, 42 km	0.54	16.2 ppb	0.49	0.85	2.16

*Model to Observation Ratio

**Multiplicative Factor

Application of Dynamic Linear Regression to Improve Skill of Ensemble-Based Deterministic Ozone Forecasts – During summer 2004 seven air quality models were used in the InternationalConsortium for Atmospheric Research on Transport and Transformation/New England Air Quality Study (ICARTT/NEAQS) conducted over the eastern USA and southern Canada. The models included AURAMS (A United Regional Air-quality Modeling System), BAMS (Baron Advanced Meteorological System) MAQSIP (Multiscale Air Quality Simulation Platform) at 45-km and 15-km resolution, CHRONOS (Canadian Hemispheric and Regional Ozone and NOx System), CMAQ/Eta (Community Multiscale Air Quality Model/Eta), STEM-2K3 (Sulphur Transport and Emissions Model), and WRF/Chem (Weather Research and Forecast model/Chemistry version). These models provided daily forecasts of ozone from 6 July to 30 August 2004. Hourly averaged ozone surface ozone concentration at multiple locations in the eastern USA and Canada are stored in the Aerometric Information Retrieval Now (AIRNow) database. Past forecasts from the ensemble of models and hourly surface ozone measurements from this database are used to issue deterministic 24-hour forecasts using a method based on dynamic linear regression.

In contrast to static linear models, which assume that properties of investigated processes do not change in time, dynamic linear models allow for temporal evolution of the characteristics of these processes. Following the West and

Harrison scheme (1997), the dynamic linear regression problem can be defined as

$$\boldsymbol{O}(t) = \boldsymbol{P}(t) + o(t),\ o(t) \sim N(0; \sigma_O(t))\ .$$
$$\boldsymbol{P}(t) = \boldsymbol{F}(t)\ \boldsymbol{W}(t)\ ,$$
$$\boldsymbol{W}(t) = \boldsymbol{W}\ (t-1) + w(t);\ w(t) \sim N(0, \sigma_W(t))\ ,$$

where O is an observation, P is a model response, vector **F** is a regressor, and vector **W** contains regression coefficients. Observation and model errors are uncorrelated, and have normal distribution with zero mean and variances σ_o and σ_w, respectively. In the case of the ensemble, vector **F** contains ensemble forecasts, vector **W** contains weights for the ensemble members. We assume that the observational variance is constant, but allow the variance of the weights to vary. The Kalman filter (KF) algorithm can be applied to update the weights in the dynamic linear regression equation and issue a prediction. The simplicity of this algorithm and its adaptive nature, which requires very little training, presents an alternative to Model Output Statistics (MOS), where a longer time series (not available for ensemble ozone forecasts) is necessary to establish regression coefficients.

To obtain the deterministic ozone forecast at time t + 24 hours, the KF is applied to ensemble forecasts at time t and then using observations and past forecasts at times t – 24 hours, t – 48 hours, . . . , mod (t, 24) hours. If a forecast of any of the ensemble members or an observation at a site is not available at time t weights computed for the latest of the previous times, t – 24 hours are used to issue a deterministic forecast. Alternatively, a forecast can be issued by applying KF to a smaller ensemble of available members. The above procedure is repeated for each measurement site.

Overall statistics of the forecasts for the KF ensemble, ensemble average, and individual models are given in Table 3 (models are randomly labeled). Bias, root mean square error (RMSE), and correlation (Corr) were calculated for time series at every location and averages for all the sites. It is noteworthy that the KF forecasts evaluate better against the observations than any model or ensemble average. Especially significant is the decrease in bias and RMSE, while the improvement in correlation is more modest. As pointed out previously for this and other data, the ensemble average generally has better correlation than the individual models, but its bias and RMSE can suffer from large errors of some ensemble members.

Table 3. Statistics for Averaged and Weighted Ensembles.

Model	Bias	RMSE	IofA	Corr
KF	0.79	10.51	0.809	0.901
AVE	12.70	17.60	0.765	0.776
A	5.32	17.27	0.668	0.791
B	8.01	17.82	0.616	0.744
C	9.33	18.48	0.631	0.742
D	11.53	23.63	0.696	0.738
E	14.83	21.05	0.651	0.699
F	31.16	37.03	0.549	0.536
G	8.77	16.05	0.721	0.783

The above forecasts were used to calculate daily maxima of 8-hour and 1-hour averaged ozone concentrations and the corresponding model performance scores. To assess the skill of the models, persistence (understood as the matching maximum at the same location on the previous day) was also included. Bias Ratio (BR) and ETS are plotted in Figure 34 for four thresholds equal to 30, 50, 70 and 85 ppbv for the maximum daily 8-hour and 1-hour averaged ozone concentration. Unfortunately, skill of the forecasts cannot be adequately assessed for higher thresholds since elevated ozone was rarely observed. Assessment of the skill of forecasts should account for the fact that larger BR tends to increase ETS. An analysis of Figure 36 reveals that for the daily maximum of 8-h averaged ozone concentration, the ensemble average has very large BRs for the higher thresholds. Even despite that, its ETS's are lower than those for the KF ensemble. The 30-ppbv threshold's skill is even smaller than for the persistence forecasts. The KF ensemble is clearly superior to either of the other two. The assessment of the relative performance of ensembles is more complicated for the daily maximum of 1-hour averaged ozone concentration. Here slightly smaller but still large values of BR for the ensemble average can be seen. Compared to the KF ensemble, its ETSs are lower for the two lower thresholds and higher for the higher thresholds, undoubtedly due to the effect of increased BR on ETS. BR and ETSs of the KF ensemble are comparable to the same measures for the daily maximum of 8-hour averaged ozone concentration except for the highest threshold where the elevated ozone is clearly underpredicted.

While deterministic forecasts based on an ensemble of models are issued to provide the best estimate of a future state, they inevitably result in a loss of information by reducing a probabilistic solution to a categorical one. A future study to address economic benefits of probabilistic forecasts in air quality using the current dataset is being considered.

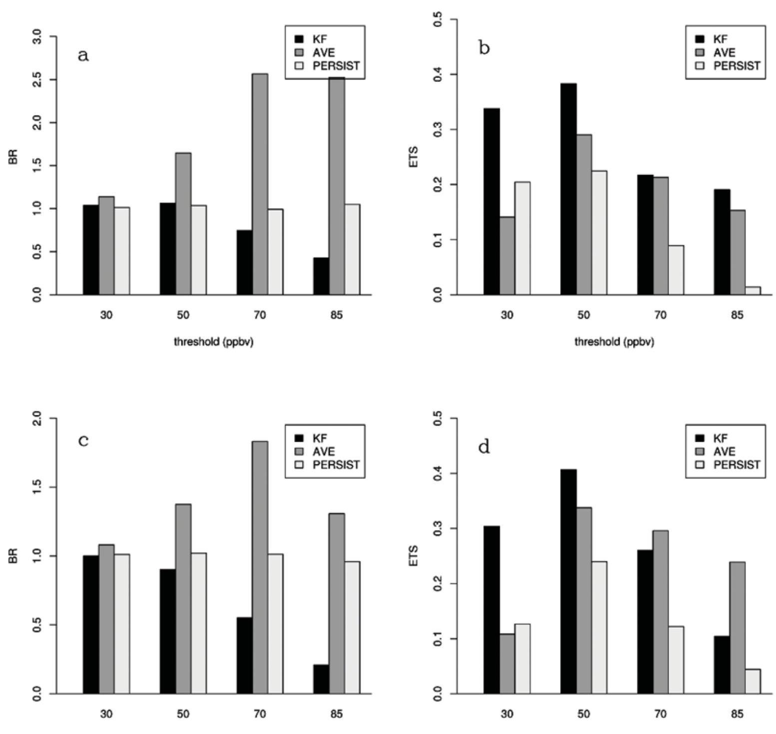


Figure 34. Bias ratio (a, c) and equitable threat score (b, d) for KF ensemble, ensemble average, persistence or the daily maximum of 8-hour (top) and 1-hour (bottom) averaged ozone concentration.

In summary, a method based on dynamic regression fitting of 24-hour forecasts from an ensemble of air quality models to observations was applied to predict surface ozone concentrations. The resulting forecasts had significantly smaller bias and RMSE, and a higher index of agreement and correlation in comparison with the same statistics computed for the ensemble average or single models. Also, with the application of the method, the equitable threat score of the 24-hour forecasts calculated for the maximum daily 8-hour and 1-hour averaged ozone concentration had consistently higher values over a range of thresholds. The most appealing feature of the method is its fast adaptability, giving it an advantage over static regression, which requires a much larger data series for training.

Projections

Scientists within the Regional Analysis and Prediction Branch and other FRD branches will continue to work with colleagues at NCEP, NCAR, and other organizations to improve the RUC and WRF models over the next few years. An overview of the primary near-term tasks follows.

Development of Rapid Refresh to replace current RUC system in 2007–2008 – Future work in preparation for implementing WRF in RR will include setting up a fully cycling WRF run at FSL on the expanded North America domain, using the NCEP Gridded Statistical Interpolation (GSI) procedure modified for the RR frequent-updating application. Monitoring of WRF model performance and verification of WRF versus RUC for surface and upper-air variables will be continued for the expanded domain.

WRF Model Enhancements in Preparation for Rapid Refresh (RR) – Improvements will be made to WRF performance as we gain further experience, and particularly as we go to full, self-contained cycling of WRF. A digital filter initialization will be introduced into WRF, similar to that designed for the RUC model, to improve dynamical balance during the first few hours of the forecast. Extensive comparative evaluation of WRF performance relative to RUC will continue, and will form the basis for the decision on whether an enhanced version of the current RUC model (adapted to the WRF coding framework) or a nonhydrostatic version of the WRF will be used as the initial RR model. Plans are to replace the RUC with the WRF RR model in 2007–2008.

GSI Development with RUC-developed Enhancements – The Gridpoint Statistical Interpolation development toward application in the Rapid Refresh will continue in Fiscal Year 2006. The use of GSI for the Rapid Refresh will allow incorporation of state-of-the-art assimilation for satellite radiances, an area of much effort in NOAA under the Joint Center for Satellite Data Assimilation (JCSDA). FSL will focus on incorporating into GSI unique aspects of the RUC 3-D variational analysis required for the Rapid Refresh, as listed under the previous section on GSI work in Fiscal Year 2004–2005.

RUC-13 Updating and Monitoring – With the June 2005 implementation of the 13-km RUC, FSL will continue a role in monitoring its performance and developing and testing some medium-level changes into 2006. These will include changes to model physics and quality control of surface and aircraft observations used in the RUC. FSL will continue to provide backup real-time grids from the 13-km RUC.

RUC Probabilistic Convective Forecasts for the Aviation Community – In the 2006 convective season, additional ensemble information will be utilized to refine echo top information and improve accuracy of probabilistic convective forecasts. Techniques will be refined as 3-D radar reflectivity data begins testing in FSL-based experimental versions of the RUC. FSL will also continue interaction with NCAR and other FAA Aviation Weather Research Program colleagues toward further improvements toward a seamless probabilistic 0–6-hour forecast using a combination of nowcast and RUC-based NWP forecasts.

Improved Ceiling/Visibility RUC Forecasts – FSL will continue to improve techniques for assimilation of METAR and satellite cloud data toward further improvements in ceiling/visibility forecasts. This will include collaboration with scientists from NASA Langley toward assimilation of experimental improved GOES cloud products.

National Observing System – FSL will complete an observation system simulation experiment (OSSE) with a proposed observation network design for a more detailed United States upper-air observing system. This network includes proposed profiler sites over the U.S. to complement existing commercial aircraft hubs and rawinsonde stations. The OSSE, currently well underway, will be used to assess the possible forecast impact on short-range NWP forecasts over the United States.

Use of Radar Data in a National-Scale Cloud/Hydrometeor Analysis – Initial work is underway to incorporate CONUS Level-2 WSR-88D reflectivity data into the RUC cloud/hydrometeor analysis, already including METAR cloud, GOES cloud, and RUC 1-hour 3-D 5-type hydrometeor mixing ratios (e.g., snow, rain, graupel). Further improvement is expected to short-range precipitation, ceiling, and cloud forecasts using the radar reflectivity data. Our current reflectivity assimilation will be upgraded to use this data. Improvements will be made to the current ceiling and visibility translation algorithm. There is promise that RUC or RR analyses and, particularly, forecasts can form a basis for CONUS ceiling and visibility analyses/forecasts; fruitful interactions with scientists at NCAR and MIT Lincoln Laboratory are anticipated toward this end.

Local Analysis and Prediction Branch

John A. McGinley, Chief

Objectives

Government agencies and the private sector continue to seek out the Local Analysis and Prediction (LAP) Branch for help in the areas of local and mesoscale data analysis, data fusion, data assimilation, quality control, three-dimensional display and visualization, and numerical modeling. Our primary activities include research, development, and improvement of the Local Analysis and Prediction System (LAPS) and the implementation of mesoscale forecast models. This leads to installation of real-time systems operating in a number of venues.

The overarching objective is to provide real-time, three-dimensional, local-scale analyses and short-range forecasts (0–24 hours) for domestic and foreign operational weather offices, facilities, and aviation and other field operations. Activities cover four broad areas:

Data Acquisition – Includes identifying, collecting, and quality-controlling any atmospheric or earth surface measurements of utility to LAPS, such as those provided by satellites, radars, mesonets, aircraft, GPS, rawinsondes, and profilers. This activity also includes developing interfaces to national datasets, such as the gridded data services provided via the Satellite Broadcast Network (SBN) data feed and similar military systems. LAPS is coupled with the Local Data Acquisition and Dissemination (LDAD) System and the Meteorological Atmospheric Data Ingest System (MADIS), specialized data at the U.S. Space Centers, in-flight data from dropsondes, as well as Taiwanese and Korean data sources.

Data Analysis – Accomplished using an integrated software package containing well-documented objective analysis schemes that apply quality control criteria to the data, spatially represent atmospheric conditions, perform spectral filtering, and ensure vertical consistency. The data analysis system is running within AWIPS in National Weather Service (NWS) forecast offices; at the Eastern and Western Space Ranges at Cape Canaveral, Florida, and Vandenberg Air Force Base (AFB) California; for the U.S. Forest Service (USFS) in support of fire mitigation and firefighting; for the U.S. Army in support of precision parachute airdrop activities; and for the Taiwan Central Weather Bureau. The LAPS analysis system is freely distributed and has been downloaded by over 100 users worldwide over the last year.

Mesoscale Model Implementation – Accomplished using an expanding variety of mature nonhydrostatic modeling systems, such as the Regional Atmospheric Modeling System (RAMS) developed at Colorado State University, MM5 developed jointly by NCAR and Pennsylvania State University, and the Weather Research and Forecast (WRF) model under joint development by NCAR (the Advanced Research WRF – ARW), and NCEP (Nonhydrostatic Mesoscale Model – NMM). These models have been adapted to allow initialization by LAPS analyses with time-dependent boundary conditions furnished by all operationally available gridded datasets (RUC, Eta, Global Forecast System, the U.S. Navy Operational Global Atmospheric Prediction System, and three Taiwan background modeling systems). Implementation of the LAPS system at NWS forecast offices has demonstrated the portability and effectiveness of running models locally. One such demonstration sponsored by NWS and NOS at the Jacksonville, Florida, Weather Forecast Office tests the feasibility of local modeling in NWS WFOs. FSL continues to collaborate with the Denver-Boulder NWS Forecast Office to demonstrate the effectiveness of locally run models. Models have the option of being initialized using the LAPS diabatic analysis that allows a full representation of clouds and vertical motion in the initial state. An ensemble of mesoscale models continues to support the weather forecast input to a road maintenance decision support system for the Federal Highway Administration. In the winter of 2004–2005, the focus area was the E-470 Corridor in Denver, Colorado. This was the fourth year that FSL participated in providing time-phased ensemble model output.

Dissemination – Includes delivery of weather products and basic fields developed from LAPS to users in operational forecast offices and state and local government agencies, including emergency managers and other users specializing in fields such as winter highways operations, fire weather, aviation and space operations, and military operations. The U.S. Forest Service now manages the Rocky Mountain Regional Website for acquisition of LAPS products by fire managers in Area Coordination Centers. For fire weather support, LAPS analysis and model fields can be dynamically located to specific fire locations. LAPS has gone through two upgrades as a key part of the Precision Airdrop System (PADS), developed at MIT Draper Laboratory and Planning Systems, Inc. Data from LAPS feed PADS with internal file sharing on a laptop. PADS provides real-time wind analyses and short range forecasts to develop wind profiles for ballistic and guided parachute cargo drops. This system has undergone extensive testing at the U.S. Army Yuma Proving Ground. LAPS continues to be an application available on AWIPS.

Accomplishments

Basic Analysis System Development: Three-Dimensional Analysis Methods – Improvements were made in the Local Analysis and Prediction System (LAPS) to analyze observations from new types of instruments and new data formats – thus expanding the envelope of meteorological data environments in which we can operate and accommodate our ever-growing number of users. It is noteworthy that LAPS and WRF improvements frequently have cross-cutting benefits that leverage toward many of the supported research projects, both within and external to NOAA (described later in this report).

The surface observation ingest can now process LDAD mesonet observations from both the NIMBUS and MADIS databases, using a common read routine with improved error handling. The timing strategy was improved for the selection of radiometer observations to be used in the analyses. Satellite sounding ingest has been made more adaptable, and these data are now routinely ingested into LAPS. ACARS ingest now has a QC check for wind direction. LAPS ingest software is being modified to allow adjustment of the aircraft observation assimilation time window. This supports the Precision Air Drop System (PADS; see below) and other projects.

User adjustable parameters were added to the surface analysis that control the analysis fit to observations of temperature and dew point. A wind analysis RMS threshold scaling factor is now being read in via a namelist and a new data structure. This allows user control over the amount of detail in the surface wind analysis. The need for this control was pointed out in tests for the Space-Time Mesoscale Analysis System project. Additional quality control parameters for comparing the observations to the background first guess are now read in via a namelist for greater user flexibility. Standard deviation QC thresholds were relaxed for wind and MSL pressure based on the analysis of the behavior of Hurricane Charley. Data time weighting was improved for the schemes that assimilate observations in a very wide time window.

GOES Improved Measurements and Product Assurance Plan (GIMPAP) – In 2004, a major effort was undertaken to compare the direct radiance assimilation vs. the moisture product assimilation in the LAPS variational analysis moisture scheme. The conclusion from this research was that for 0000 UTC times, the direct radiance assimilation worked better than the product assimilation. We speculate that the direct assimilation is working better in the afternoon hours when the atmosphere is well mixed. The direct assimilation appears to be working better in the better defined boundary layer at 1200 UTC. This relates to better radiometric modeling of the boundary layer, providing details of the low-level moisture structure, which benefits from the hourly METAR data. It is true that the same METAR data make it into the DPI assimilation scheme, but there is no mechanism in DPI assimilation to influence the simulated radiances used to complement GOES radiance observations in the minimization processing. Given typical convective processes, it is more important for the low-level moisture to be correct in the analysis, leading to subsequent improved precipitation and severe weather forecasts. On this basis, the direct assimilation approach appears superior (Figure 35); the plots show the error differences between direct assimilation of GOES radiances versus using derived product total precipitable water data in the LAPS moisture analysis (red dots). Error is computed using RAOB data as "truth"; these plots illustrate improvement in bias error. The 0000 UTC results are shown on the left and 1200 UTC on the right. Student-t and student-f statistics are provided showing that the comparisons are significant between the surface and 500 hPa except for possibly the 900 hPa value at 0000 UTC.

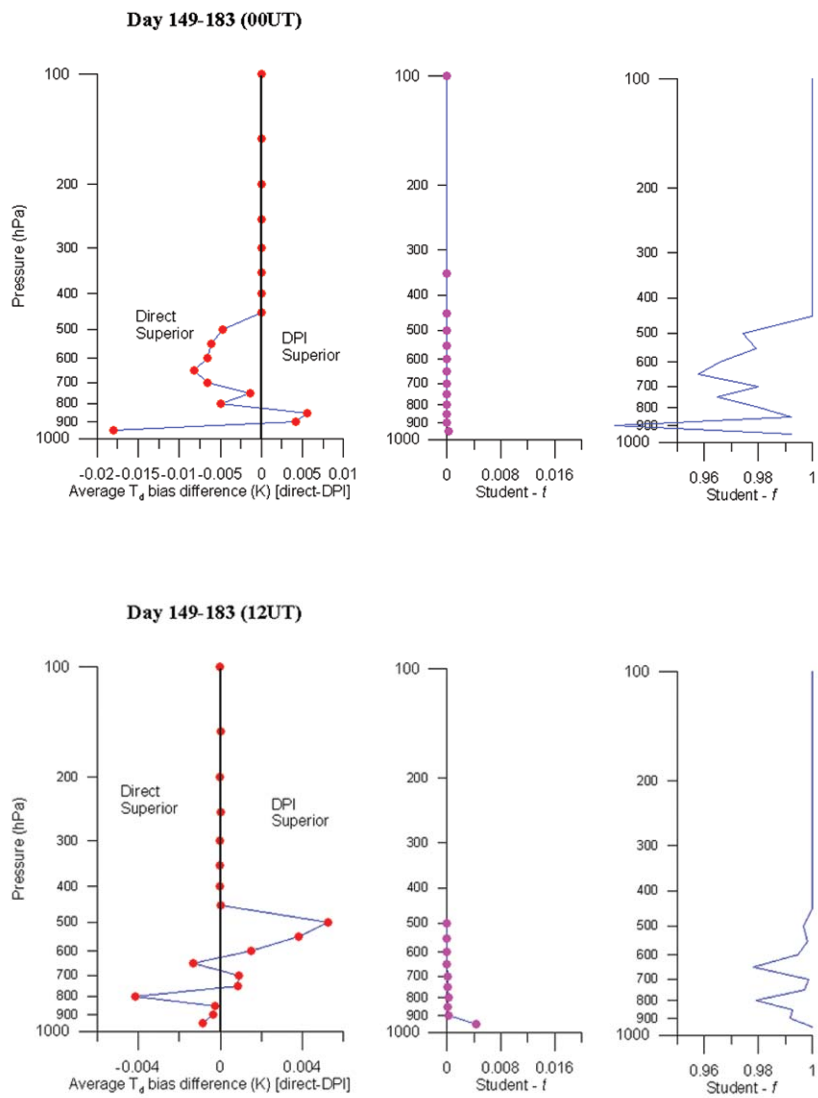


Figure 35. Results of the moisture analysis for 0000 UTC (top) and 1200 UTC (bottom), which clearly show that the direct radiance assimilation allows better determination of low-level moisture at both times. High Student-t statistics indicate that compared distributions are similar in shape. Low student-t statistics indicate that the distributions are indeed dissimilar in mean value. Taken together, the implication is that the differences are genuine and statistically significant.

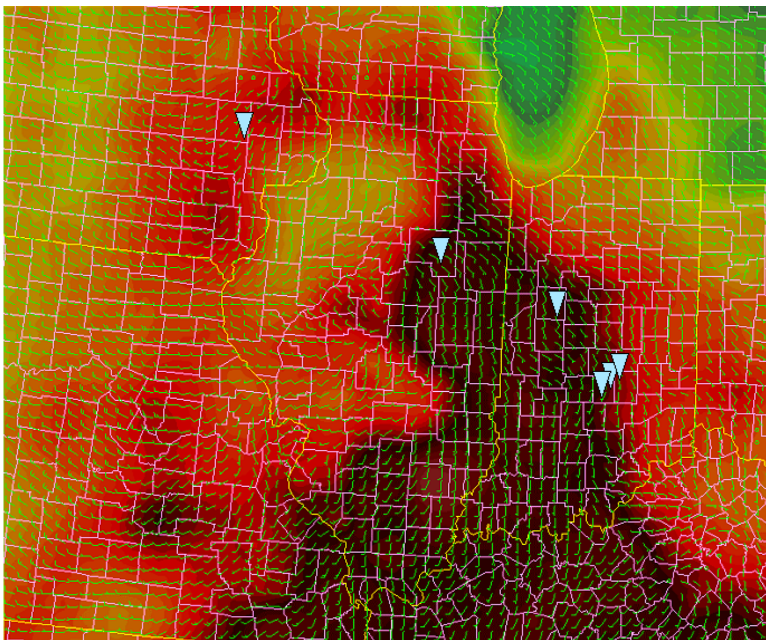
Joint Center for Satellite Data Assimilation (JCSDA) – In 2004, the focus of the Joint Center for Satellite Data Assimilation (JCSDA) project, as with GIMPAP, was to determine the superior avenue to take for satellite assimilation. Earlier comparisons of derived-product GOES moisture data with GPS data were examined for calibration and validation of the satellite products. This work has become one of the main thrusts of satellite research within FSL, in that assimilation of satellite data made a major switch from direct assimilation to gradient assimilation. Direct assimilation would include the biases that the research revealed to be of major significance at asynoptic times. As indicated initially in the International H^2O Project (IHOP) studies, this comparison was expanded to include real-time studies and the full CONUS region. We discovered that the NESDIS product data bias issues observed during IHOP also existed routinely over the CONUS for GOES-12.

To improve the quality and thus the utility of GOES product data, we have been working closer with NESDIS. We also eliminated bias in data assimilation through gradient methods incorporated in our variational scheme. In simplistic terms, the variational function was minimized for agreement with routine observations: instead of using GOES data as a "routine observation," the horizontal gradients in GOES precipitable water fields were minimized against the horizontal gradients in the solved analysis. This work has begun to show great promise.

A new project undertaken in 2004 is the GOES-R Risk Reduction (GOES-RRR). This effort dovetails with GOES JCSDA and GIMPAP research, and is anticipated to become more dominant as GIMPAP is scaled down. The lessons learned from IHOP and GPS/GOES comparisons will be applicable to future hyperspectral satellite systems. Our future research will focus on the gradient technique described above and will be applied to hyperspectral radiances using the Atmospheric Infrared Sounder (AIRS) instrument data as an initial testbed. The intended result of the GOES-RRR research at FSL is an improved GOES-R data application for the operational community. In addition, collaboration within FSL to incorporate a gradient technique into the Weather Research and Forecast (WRF) model's Gridpoint Statistical Interpolation (GSI) procedure is part of this effort, and presents an ultimate pathway to operations.

Space-Time Mesoscale Analysis System (STMAS) — In recent years, surface observations within the U.S. have grown dramatically with dense time and space coverage possible over wide areas. This offers the possibility of performing frequent monitoring of mesoscale features that may generate significant local weather such as severe thunderstorms, heavy snow, high winds, and hazards to aviation such as turbulence, clouds, and icing. The abundance and frequency of these surface data preclude the individual station monitoring that was possible when observations were sparse and infrequent. Recognizing this, the LAPS Branch directed efforts toward developing a space and time analysis scheme that could offer mesoscale analysis products at high frequency, and simultaneously be compatible with the current workstation display capabilities that allow compositing of fields and looping.

We designed the Space-Time Mesoscale Analysis Scheme (STMAS) to fully exploit spatial and time variability in data density and report frequency, allowing small-scale features to be revealed and tracked in a time-consistent manner. With the rapid updating and generally limited computer environment, the scheme had to be computer-efficient and robust. STMAS has three components: data quality control, analysis processing, and product generation. The data quality control is based on a Kalman filter approach operating in observation space. The Kalman filter individually models each observational site based upon self trend, buddy trends, and external forcing. The net result is that each observation in the domain has a unique projection engine that provides a one data-cycle "forecast" value that can be used for data quality control. The analysis engine has two options: a space-time recursive filter or a multigrid approach, both applied to the observational network spatially and temporally. Both schemes use iterative procedures to sequentially add more detail. The recursive analysis scheme iterates uniformly across the grid attempting to minimize a global variational cost function that includes terms for optimum least square matching of the observations and smoothness. The multigrid scheme uses a set of resolutions to retrieve the analysis from long waves to short waves by minimizing a similar cost function at different resolutions. The schemes, run on a 5-km grid at 15-minute intervals, are demonstrated for severe weather events in the north-central U.S. during the convective weather season, and have been important analysis tools at MIT/Lincoln Laboratory and the National Center for Atmospheric Research (NCAR), as well as a verification tool for the DTC Winter Forecast Experiment (DWFE) in 2004–2005 (Figure 36). The STMAS system was set up on FSL's upgraded supercomputer for the purpose of improving product reliability and speed. LAPS timing and Web script functionality was improved in support of this run. We are exploring the possibility of using



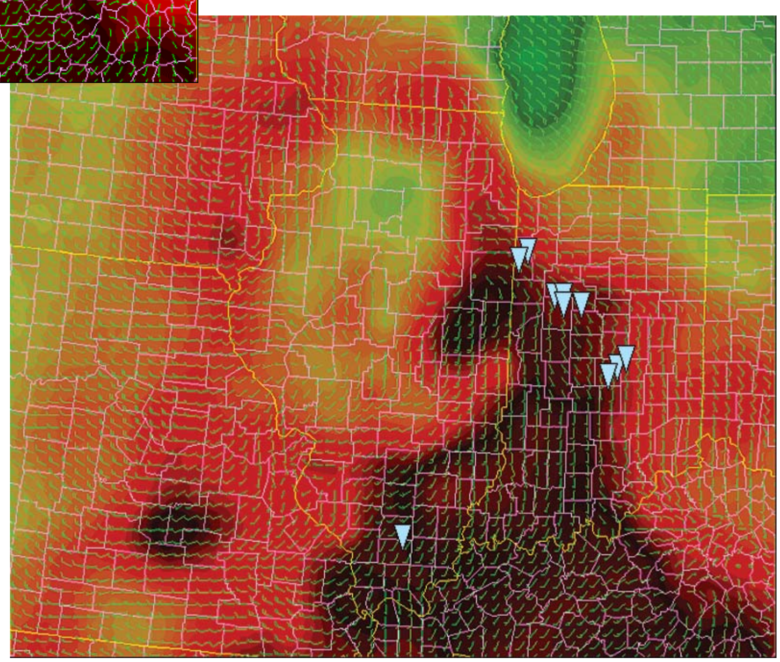


Figure 36. a, above). STMAS surface analysis of winds and equivalent potential temperature (dark red are the highest values; green the lowest) on May 30 at 2345 UTC and b, right) on May 31 at 0015 UTC. Tornado activity occurring at analysis time is indicated by blue triangles. Note how a dry surge into the highly unstable air leads to a massive tornado outbreak. STMAS was able to sustain good time continuity on this feature.

the Scalable Modeling System (SMS) to parallelize the recursive iteration run (and revisiting this for the LAPS wind analysis). LAPS software building scripts were updated and improved to facilitate this testing. Some of the Fortran code was reworked for better SMS compatability, in light of changes to the wind analysis since the last time we built a parallelized version using SMS.

LAPS Diabatic Initialization (Hot Start) Procedure – The LAP Branch continues to improve the Hot Start procedure for diabatic initialization of mesoscale models. This scheme is designed to develop initial conditions for mesoscale models such as the MM5, RAMS, and the two WRF versions ARW and NMM. Our main focus for Hot Start is to improve the accuracy of short-range precipitation forecasts in the 0–6-hour period. This scheme is unique in that it runs on small PC clusters with Linux operating systems and is ideal for applications in local weather offices where accurate short-term cloud and precipitation forecasts are needed. It depends greatly on the accuracy of the background modeling system, currently the NCEP versions of the RUC or Eta models or a number of coarse grid models, for example, at the Taiwan Central Weather Bureau (CWB). The Hot Start scheme uses estimates of vertical motion and cloud water and ice mixing ratios from the LAPS cloud analysis. A variational analysis that applies both mass continuity and mass-momentum balance makes small adjustments to the wind and temperature field to accommodate and sustain the clouds in the first few time steps of the model integration. The cloud retrieval algorithm includes a broad range of microphysical species, cloud-type dependent estimates of cloud vertical motion, and saturation of the cloud environment. The Hot Start procedure has been subject to long-term verification compared to standard models. We have been working with our CWB colleagues in an effort to improve the representativeness of cloud updrafts in deep convection. These new methods have improved the scheme (Figure 37) that contrasts the Hot and Cold Start methods for all the typhoon cases over Taiwan in the summer of 2003. For more information on this subject, see a paper by Jian and McGinley (2003) at *http://www.fsl.noaa.gov/* (click on "Publications" and "Research Articles").

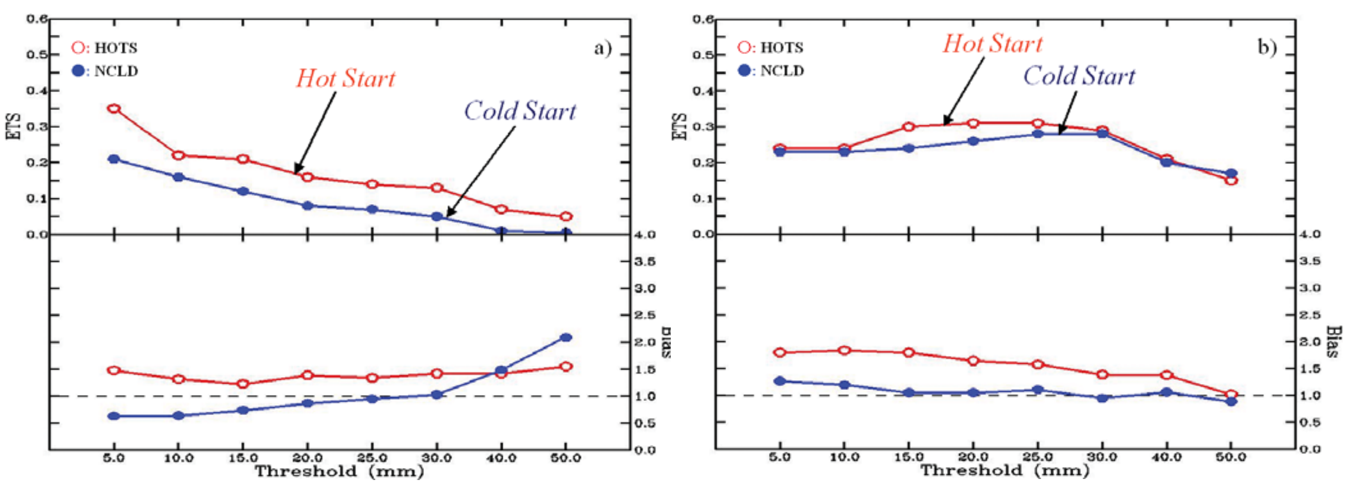


Figure 37. Equitable Threat Scores (left side of each graph) and bias (top) for 6-hour (a, bottom) and 12-hour (b) forecasts at gauge sites for precipitation amounts (x-axis) over Taiwan for all tropical storm events in 2003. Hot Start procedure is in red; Cold Start in blue. Note that major benefit is shown at forecast times shorter than 12 hours. Explict convection on the 9-km grid accounts for the increasing bias in both initializations.

The Hot Start method is used as part of the process of initializing the MM5 and/or WRF models over a variety of domains including the local Denver forecast area, where forecasters use it as an operational tool, and the U.S. Air Force Western Range at Vandenberg Air Force Base and Cape Canaveral Air Force Station as part of the Range Standardization and Automation (RSA) implementation (discussed below). The Hot Start system continues to drive the WRF-ARW model for testing in a local weather service office in conjunction with the Coastal Storms Initiative carried out with the NWS and National Ocean Service (see below). The Hot Start is part of the MM5 modeling system at the Taiwan Central Weather Bureau, and is used in the ensemble runs for the Federal Highway Road Maintenance Demonstration.

Applications of LAPS

LAPS in AWIPS – The LAPS package has long been an integral application of the AWIPS workstation, running to produce a variety of gridded fields that may be combined with satellite imagery and radar on state- and local-scale displays. The LAP Branch has continued to support scheduled AWIPS builds by updating LAPS in each initialization. The LAPS in AWIPS operates off the Local Data Acquisition and Dissemination (LDAD) system which acquires data outside the AWIPS network.

MM5/WRF on AWIPS – The AWIPS workstation at the Boulder Weather Forecast Office receives 10-km resolution MM5 model output from four-times daily LAPS-initiated model runs. Likewise, the WRF model is being run at the Jacksonville, Florida WFO under sponsorship of the Coastal Storms Initiative (see below). Both implementations permit the display of mesoscale model output in a fully integrated fashion, along with radar, satellite, and surface data. Forecasters can check the quality of a model run by directly comparing model output with observations. MM5 model output also is displayable at the Eastern and Western Space Ranges.

U.S. Army Precision Air Drop Project - The Local Analysis and Prediction Branch continues to support a U.S. Army-sponsored (Natick Soldier Center, Natick, Massachusetts) development of the Precision Air Drop System (PADS) to improve the accuracy of mid- and high-level parachute delivery of logistical material to military units. In conjunction with Planning Systems Inc., of Reston, Virginia, FSL has served as the system integrator, merging LAPS analysis onto a laptop with stochastic parachute algorithms developed by the MIT Draper Laboratory. The concept of operations is for the aircraft to make a close proximity pass over the drop zone, release a dropsonde, and circle back while the software processes and assimilates the dropsonde with model background fields, thus creating a high-resolution profile that accommodates time and space displacements from the dropsonde position and time to cargo impact point and drop time, while accounting for flow channeling over rugged terrain. The onboard laptop computes an updated Cargo Airdrop Release Point (CARP) within minutes, reducing the time exposure to potential hostile fire for the aircraft. The PADS system paired with LAPS has consistently demonstrated 60–70% reduction in landing error.

The Range Standardization and Automation (RSA) Project – Several years ago, the Air Force initiated the Range Standardization and Automation (RSA) program to modernize and standardize the command and control infrastructure of the two U.S. Space Launch facilities (ranges), located at Vandenberg Air Force Base, California, and Cape Canaveral Air Station, Florida. In cooperation with Lockheed Martin Mission Systems staff serving as system integrator, we upgraded and maintained the integrated local data assimilation and forecasting system on the 18-processor IBM cluster. The LAPB group also supported a hardware upgrade during the past year. Testing and development has continued with profiler and RASS data from the Eastern and Western Ranges. For these data, we are checking the proper handling of QC flags by the ingest software. SODAR data utilization was improved in the wind analysis, so that we now process all observation levels even when several SODAR levels lie within adjacent LAPS levels. The processing of Meteorological Tower observations was enhanced with changes to read in and utilize the RSA QC flags to keep our software current with the latest range data specifications. We also added a QC test for real-time Automated Meteorological Profiling System (AMPS) soundings. The system produces hourly LAPS analyses and a new MM5 forecast run every 6 hours on a triple-nested domain with 10-km, 3.3-km, and 1.1 km-grid spacing, respectively. These analyses make use of the AWIPS LDAD interface to incorporate data sources unique to the launch facilities, in addition to the radar, satellite, and other datasets available via the AWIPS data feed. FSL maintains a full shadowing system that can be localized at either range. LAPS and the model runs are both performed on this system to emulate the deployed system. All upgrades and modifications are thoroughly checked on this system prior to installation at the ranges. FSL received the 2005 NOAA Technology Transfer Award for its contributions to the RSA project.

High Performance Computing – The FSL High-Performance Computing System (HPCS) has been a critical resource for all of the numerical modeling activity in the branch, including the unique mesoscale model ensemble used for the Federal Highway Administration project described below. This experience continues to provide important feedback to the system developers and computer specialists regarding configuration issues and future upgrade plans.

Collaborative Modeling Projects

Ensemble Modeling of Winter Road Conditions – FSL continued to support the Federal Highway Administration (FHWA) project in road weather, called the Maintenance Decision Support System (MDSS). The objective of the MDSS project is to prototype and demonstrate weather forecasting techniques and decision support algorithms that help snowplow garage supervisors decide where and when to plow, and how much salt to apply to road surfaces. FSL's role in MDSS (Figure 38) is to run regional forecast models to supplement the NWS numerical prediction services provided by the Eta and GFS models. FHWA's intention with the MDSS is to provide software modules and system specifications to private sector vendors of weather support services, including FSL's LAPS-based ensemble of diabatically initialized mesoscale models (MM5 and WRF). The source code for the model, the LAPS data assimilation, and all the postprocessing has been packaged for distribution via CD-ROM, and is being used by at least three weather service firms to support road weather operations. This past year's MDSS demonstration was conducted in the vicinity of Denver, Colorado, after two successful winters of operating in central Iowa. Perhaps the most interesting result is that the Eta model is almost as good as the diabatically initialized mesoscale models at 3-hour precipitation forecasts (Figure 39). We believe this is because terrain forcing of precipitation in Colorado dominates over the dynamically forced precipitation that characterizes midwestern (Iowa) winter storms, where the diabatic initialization provides performance advantages over the 3DVAR-based initialization used by the NCEP models.

Weather Research and Forecast Model Development – The LAP Branch has been involved in development of the WRF Standard Initialization (SI) software, which creates model startup grids from the NCEP national GFS, RUC, or NAM models. A recent new capability of the SI is to process GRIB2 formatted files. The SI graphical user interface

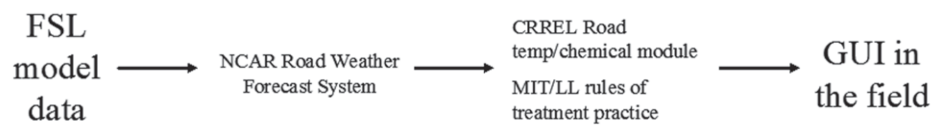


Figure 38. Data flow of ensemble output into the Maintenance Decision Support System processing steps.

(GUI) that the WRF community used for the localization of the WRF has been adapted for the WRF-NMM dynamic core (Nonhydrostatic Mesoscale Model). The SI also handles the land-surface module (LSM) of WRF required "static" fields (such as vegetation greenness, albedo, land use, terrain height, and land fraction) by assembling and reformatting the fields, and making them available with efficient interface software (Figure 40). Six upgraded versions of the SI and GUI software were released to the WRF user community in the spring and fall of 2005. These software components – developed by the LAP Branch and sponsored jointly by the Air Force Weather Agency, FHWA, and FAA – are released routinely to the WRF user community. The SI software matured to the point that it was released to NCAR for ongoing management as part of the WRF suite of utilities. Along with the software releases, we have been involved in presenting WRF SI and GUI training to the community.

NOAA Coastal Storms Initiative – Under the auspices of a nationwide effort led by NOAA, the Coastal Storms Initiative (CSI), a locally run version of the WRF-ARW mesoscale numerical weather prediction (NWP) model, has continued to run at the Jacksonville (JAX), Florida, National Weather Service Weather Forecast Office (WFO). CSI is a collaborative effort with various local, state, and federal organizations to lessen the impacts of storms on coastal communities. The effort to install WRF at Jacksonville is but one component of the initiative, designed to improve accuracy and detail of forecasts of coastal winds, precipitation, and visibility. This local modeling effort represents collaboration between the NWS Office of Science and Technology, the Jacksonville WFO, NOAA/FSL, and the Florida State University (FSU) Department of Meteorology. FSL hosted an FSU graduate student to examine the relative values of large versus small model domains, the advantage of using local data in initialization, and the Hot Start. FSL's Real-Time Verification System (RTVS) has also been used to perform these comparisons. The project sought answers to the following questions: 1) Can public forecast services provided by a WFO be enhanced through the use of a locally run mesoscale modeling system?, 2) Does the use of a data assimilation component improve local model forecasts compared to simply initializing a local model directly from the NCEP national forecast models?, and 3) Can the new WRF model serve as the local model component in the WFO environment in a similar manner to the Eta workstation system in other WFOs? The preliminary answer to all these questions is "yes." Verification statistics, forecaster qualitative comments, and WRF-ARW performance all offer support.

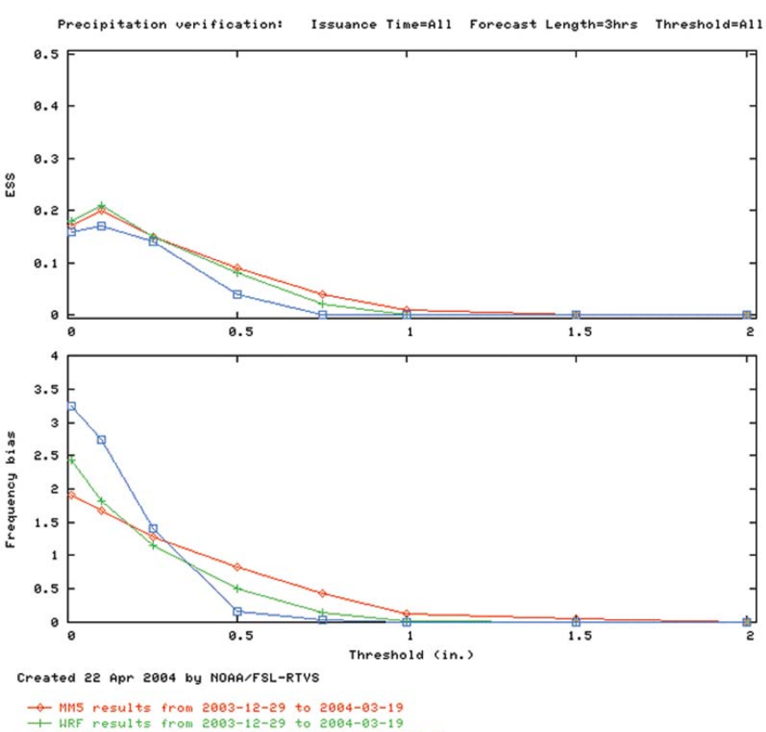


Figure 39. Equitable Skill Score (top) for 3-hour forecasts from MM5 (red), WRF-ARW (green), and NCEP Eta (blue) models for precipitation categories along x-axis. Bottom figure shows bias.

U.S. Forest Service Fire Consortia for Advanced Modeling of Meteorology and Smoke (FCAMMS) – During 2004, the LAP Branch handed over control of the modeling and analysis system, FCAMMS, to the U.S. Forest Service Rocky Mountain Research Station in Ft. Collins, Colorado. The goal of this project was to develop and deploy an analysis and modeling capability that encompassed needed fire-specific (both planning and incident) support products. The MM5 model was used to develop an 18-km Rocky Mountain domain and 6-km nests for large sections of Arizona, New Mexico (the Southwest Area Coordination Center), Colorado, and Wyoming (the Rocky Mountain Area Coordination Center). For more information, see *http://www.fs.fed.us.rmc/*.

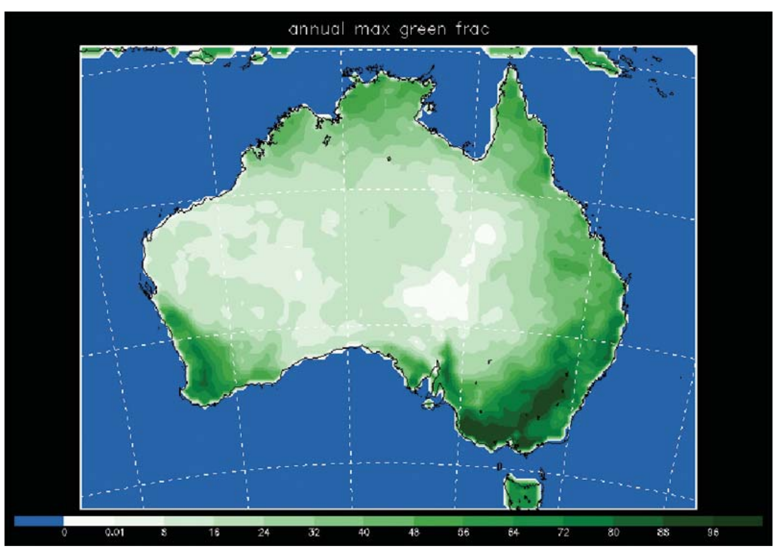


Figure 40. An example of the WRF Standard Initialization (SI) graphical user interface selecting a nested grid for Australia a) top, and a greenness factor Land-Surface Model product generated from the specified grid b) bottom.

International Collaborations – LAPB scientists continue an active collaboration with the Central Weather Bureau (CWB) of Taiwan. The branch hosts long-term visitors from Taiwan, forming working relationships that are very beneficial in improving the real-time data preprocessing for LAPS, the analyses, and the modeling components. As part of continuing support to the MM5 modeling activities, we have delivered an improved Schultz Microphysics Module for use in the LAPS/MM5 run at the CWB. We are also testing the staging of the parallelized version of the LAPS wind analysis on a CWB Linux cluster using the Scalable Modeling System. Another task involves continued FSL shadow runs with 9-km and 3-km LAPS analyses, including LAPS initialized MM5 9-km shadow runs. Development continues on the WRF initialization with and without LAPS. Our real-time analysis graphics now have support for precipitation plots in metric units. Improvements were made to error handling in the observational databases with an associated increase in the number of allowed stations for mesonet data. This was a key part of upgrading the LAPS Forecast Verification System to include precipitation verification. Training activities also continued in November 2004 as the CWB sent two meteorologists to FSL for extensive training with the Integrated Forecast Preparation System (IFPS). This system is being used at all Weather Forecast Offices in the National Weather Service to create gridded and text forecasts, and may be implemented at the CWB in the future.

Additional collaborative efforts and contacts have been sustained with the Korean Meteorological Agency (KMA), Hong Kong Observatory (HKO), Finnish Meteorological Institute (FMI), and the Wuhan PRC Institute for Heavy Rain (IHR). All of these agencies have versions of LAPS running for various weather support and experimental purposes.

WWW LAPS Interface

Scientists in LAPB understand that dissemination is critical for attracting and supporting users, internal testing, and demonstrations. Various improvements were made to pregenerated analysis Web products and scripts. These include greater portability, ease of use, Web security, support for the STMAS project, larger image size, robustness, and logging information. Analysis fields shown on the Web (e.g., helicity and radar reflectivity) were adjusted to be more consistent with the forecast fields being displayed. A slight change was made to LGA/FUA temperature contour/image scaling. Labels and user selections were improved for altitudes above 50 mb as well as for surface background divergence plots. Plotting of latitude and longitude lines was set up to work with the newer mapping routines. Color coding of upper air temperature observation plots (e.g., radiometer and satellite) was updated and improved.

Pregenerated analysis Web products were improved and more fully integrated into LAPS software so that they can be produced via the main LAPS scheduler script. Precipitation type was added to our pregenerated radar reflectivity image plot. Precipitation type plots are now more generalized for handling larger domains. Various additional plotting modules were streamlined. Specific humidity plots are now more robust. Soil moisture plots were added in support of the RSA project. Display capability for perturbation pressure was added in support of the STMAS project. Cross-section height fields were added and cross-section labeling was improved. Scripts used for product monitoring as well as “on-the-fly” Web display were refined. We have updated the export version of the on-the-fly Web page scripts to benefit our external users.

Experimental Forecasting Facility (EFF) Activities

We continued our interaction with the local NWS Weather Forecast Office in Boulder and other sites. This involves FSL staff working some forecast shifts, as well as involvement in cooperative projects. An ongoing project has been running a local model, the MM5, initialized in a Hot-Start configuration with LAPS, out to 24 hours four times a day (as described above). During the winter in 2004, we also helped the Boulder WFO transfer the 5-km experimental NMM model onto AWIPS, where it remains.

Another project that continued, with some funding from the NWS, involves the Boulder WFO serving as one of three test sites for an experimental infrasound system developed by the NOAA Environmental Techology Laboratory in Boulder. The system is able to detect infrasound signals from phenomena that include tornadoes and developing tornadoes. We are hopeful that it can provide a significant enhancement to Doppler radar in both detecting tornadoes and reducing false alarms, both critical National Weather Service goals.

D3D (three-dimensional display) continues to be supported at Weather Forecast Offices that are interested in testing the software. Interest in D3D remains constant across the NWS, but current AWIPS systems were deemed insufficient to support D3D. However, FSL is testing a new workstation that should be able to support the D3D application for testing in the future. Additionally, D3D is used at the UCAR Cooperative Program for Operational Meteorology, Education, and Training (COMET™) during their training, and for training at some WFOs. Our overall achievements for AWIPS D3D support compare favorably with the goals projected in the statement of work.

Projections

During 2005, the Local Analysis and Prediction Branch plans to:

- Improve LAPS to make use of ensemble-generated mesoscale model error via 3-D variational methods.
- Continue to support LAPS in AWIPS, interacting with the AWIPS contractor and the NWS to achieve this goal.
- Support the U.S. Army Precision Air Drop System (PADS) by developing a dropsonde deployment planning tool to allow aircrews to determine the optimum position of the dropsonde release points for minimum variance in the retrieved wind profile and acceptable CEP dimension.
- Continue the cooperative effort with Lockheed-Martin in maintaining the RSA weather support systems for the Space Flight Centers at Cape Kennedy and Vandenberg Air Force Base. Implement the WRF-ARW as a replacement for MM5. Install a verification system and begin to compile performance statistics to drive future requirements.
- Continue investigating and improving the Hot Start techniques, try to reduce the number of cloud-dropout episodes, and publish the results.
- Continue development of the multimodel/time-phased ensemble methodology, and determine the optimum configuration for the best forecasts and user-friendly products. Improve the postprocessing to develop optimum ways to provide consensus forecasts and statistically based products. Focus on forecast bias removal. Seek new applications and projects requiring a mesoscale model ensemble approach.
- Support the WRF Standard Initialization GUI. Offer help to NCAR as needed on SI transition issues.
- Sustain the CSI project to serve as a reference in an NWS study on distributed local modeling using the LAPS/WRF modeling system. Offer services to multi-region local model assessments.
- Support the Federal Highway Road Weather Program, and provide input into planning for 2006 and beyond.
- Become active in the Hydrometeorological Testbed (HMT). Support planning for the HMT demonstration in the American River Basin, California.
- Continue development of Kalman filter QC and multigrid analysis techniques for STMAS, and include an automated surface boundary detection algorithm.

Special Projects Office

Steven E. Koch, Acting Chief
303-497-5487

Objectives

The Special Projects Office (SPO) performs diagnostic studies of weather-related phenomena, including mesoscale convective systems, gravity waves, and clear-air turbulence. A springboard of these studies is the development of diagnostic tools that are applicable to routine observations, data from experimental networks or model grid-point data, and that utilize statistical methods, fundamental dynamical relationships, and derived parameters relating to unobserved variables. These studies often result in products of value to forecasters and are transferred to the National Weather Service (NWS). Research quality datasets of operational sounding and precipitation data and of commercial aircraft atmospheric data are assembled to support FSL modeling and diagnostic activities, and are shared with other NOAA laboratories and NWS research groups. The SPO also conducts field tests and computer simulations to study the basic processes that produce clear air, convectively induced, and mountain wave turbulence in support of the FAA Aviation Weather Research Program (AWRP).

Accomplishments

DTC Winter Forecast Experiment

The Weather Research and Forecasting (WRF) model Developmental Testbed Center (DTC) is a new distributed facility consisting of nodes in Boulder, Colorado, at FSL and the National Center for Atmospheric Research (NCAR), and at the Naval Research Laboratory (NRL), in Monterey, California. The DTC was established so the numerical weather prediction (NWP) research and operational communities can interact to accelerate testing and evaluation of new models and NWP techniques having promise for operational implementation at some point in the future. Idealized, retrospective, and real-time forecast methods are used for this purpose. The DTC Winter Forecast Experiment (DWFE) ran from 15 January to 31 March 2005, and was the first real-time NWP experiment ever conducted by the DTC. The objectives of DWFE were to:

- Provide experimental model guidance for winter weather forecasting over a large domain using two variants of the WRF model run at 5-km grid spacing with explicit convection only (no convective parameterization scheme).
- Expose forecasters to the nature and behavior of the WRF modeling system at very high-resolution prior to the March 2006 scheduled implementation of the WRF-NAM (North American Mesoscale) model.
- Using objective verification methods, determine whether encouraging results seen in earlier 4-km WRF models providing warm season forecast value extend to the winter for lead times out to 48 hours.
- Determine the extent to which various mesoscale phenomena can be skillfully forecast.

The design, conduct, and evaluation of DWFE were performed in close consultation with operational National Weather Service (NWS) forecasters, and with the Hydrometeorological Prediction Center (HPC). The DWFE employed an end-to-end forecast system containing the model preprocessor, forecast model, postprocessor, product dissemination, forecast verification, and archival. Each of these components required development and/or porting of software from NCEP to FSL and NCAR. All porting, modification, development, and testing of software had to be completed in a short time in order that the DWFE could commence by January 2005. DWFE served as a testing platform for high-performance computing at FSL and NCAR, where the WRF models were run. The version of the

WRF run at FSL was by far the largest job ever run on its massively parallel Linux cluster. The DWFE experimental design consisted of two dynamic cores: the WRF-Nonhydrostatic Mesoscale Model (NMM) developed by NCEP and run on the High-Performance Computing System at FSL, and the Advanced Research WRF (ARW) developed by and run on the supercomputer at NCAR. The WRF-NMM model was run over the full CONUS domain using 529 Xeon 2.2 GHz processors, each with 1 GB of memory. Forecasts were made once daily at 0000 UTC with the goal of having the complete set of 48-hour forecast products distributed to the NWS servers by no later than 1430 UTC. A fault tolerant automated workflow management system was developed by FSL to run the WRF-NMM and address these requirements.

Although the grids for both WRF dynamic cores were set up to cover a virtually identical area, a post-processing system was necessary to bring the forecasts onto a common grid for display and verification purposes. NCEP assisted FSL in porting its WRF-Post system to FSL, which was used to postprocess WRF forecasts. The output of the WRF-Post was converted from its native GRIB1 format to GRIB2, since GRIB2 is significantly more compact, and thus is superior for data transfers. The model forecasts were disseminated to NWS users in four different ways: Web displays, FX-Net, AWIPS (limited number of two-dimensional displays), and full GRIB data. The WRF model forecasts on their native grids were stored in netCDF format and the post-processed model grids were archived in GRIB1 format on the NCAR Mass Storage System (MSS) for use in future research studies. All verification statistics and observations were also stored on the MSS (surface and upper-air data in PrepBUFR format, precipitation data in GRIB format). Approximately 26 terabytes of data exist on the MSS from the DWFE project. These data have already been found to be very useful to visiting scientists at the DTC in the summer following the end of the DWFE for sensitivity tests with different configurations of model physics and numerics.

WRF forecasts were verified both subjectively and objectively. Subjective evaluation was collected from the operational and research communities using online forms created specially for the DWFE. Objective verification of surface and upper-air fields was performed using both the NCEP Verification System (a grid-to-grid verification approach) and the FSL Real-Time Verification System (a grid-to-point approach). The results of the precipitation verification for Equitable Threat Score (ETS) shown in Figure 41 demonstrate the comparable results achieved from the two verification systems, and the fact that ETS differences between the two WRF models and compared to the Eta model were not significant for any precipitation threshold <2 inches. However, as discussed below, the true value of high-resolution model forecasts is not measured by such metrics as ETS, which give benefit to smoother forecast fields, but rather, by fields that relate more directly to observed radar and satellite imagery.

An unforeseen challenge was how to present very detailed forecast fields to forecasters. Some of the traditional ways of looking at model forecasts (e.g., unsmoothed vertical velocity and quasi-geostrophic forcing) were found to be of relatively little use in DWFE. In an attempt to respond to these problems, novel displays of the forecast fields, such as nonlinear scaling of absolute vorticity, were created with the intention of showing both the superb mesoscale detail forecast by the WRF models, and at the same time, the vorticity field associated with synoptic-scale cyclones. Other innovative forecast products developed during DWFE included simulated radar reflectivity, precipitation type distributions, and integrated precipitable water fields. The composite radar reflectivity product was easy to verify in real time by directly comparing with readily available observed reflectivity displays; also, it allowed one to more easily see the mesoscale structures forecast by fine resolution models, such as snowbands (Figure 42) – structures that tend to get lost in precipitation fields (which are always accumulated over some length of time such as 1 hour or 3 hours). There were instances when the strength and persistence of mesoscale phenomena were so pronounced that the precipitation forecasts were adequate in highlighting their existence. An example of stationary bands in mean sea level pressure and precipitation fields is presented in Figure 43. This event is the severe New England blizzard of 23 January 2005, wherein hurricane-force winds and snow accumulations in excess of two feet occurred. Pronounced north-south bands were forecast by both WRF models to the north of the storm center (Figure 42a). These bands were stationary, fixed to the terrain (the Hudson and Connecticut River Valleys separated by the Adirondack and Berkshire Mountains) for 9 hours during the peak of the storm. The observations agreed with this prediction. Not only did the FSL 5-km resolution Space-Time Mesoscale Analysis System (STMAS) reveal similar features in the surface fields (Figure 42b), but also the accumulated snowfall for this storm showed pronounced north-south bands, with the heaviest snowfall along the mountains and much less snowfall reported in the low-lying areas. This example demonstrates the value of running high-resolution models over a large domain. The ability of models to correctly represent the mesoscale forcing hinges on their ability to also correctly forecast the synoptic scale, which is more likely to happen when the influence of boundary conditions does not dominate the forecast solution too quickly.

Forecasting Turbulence

Diagnostic-Algorithm Development – Aircraft encounters with turbulence are the cause of a significant number of occupant injuries, and in the case of general aviation, of fatalities and loss of aircraft. Many such incidents occur above 20,000 ft (6.1 km), where clear-air turbulence (CAT) is the most probable cause. Instrumented aircraft and wind profiling radar measurements have suggested that CAT arises from shearing instability in thin sheets of large vertical wind shear. The horizontal scale of the overturning eddies responsible for CAT experienced by commercial aircraft is approximately a few hundred meters, i.e., from a meteorological perspective turbulence is a "microscale" phenomenon. To the extent that most of the energy associated with microscale eddies cascades down from the larger scales of atmospheric motion, and that the forecasts of the larger scales made from current numerical weather pre-

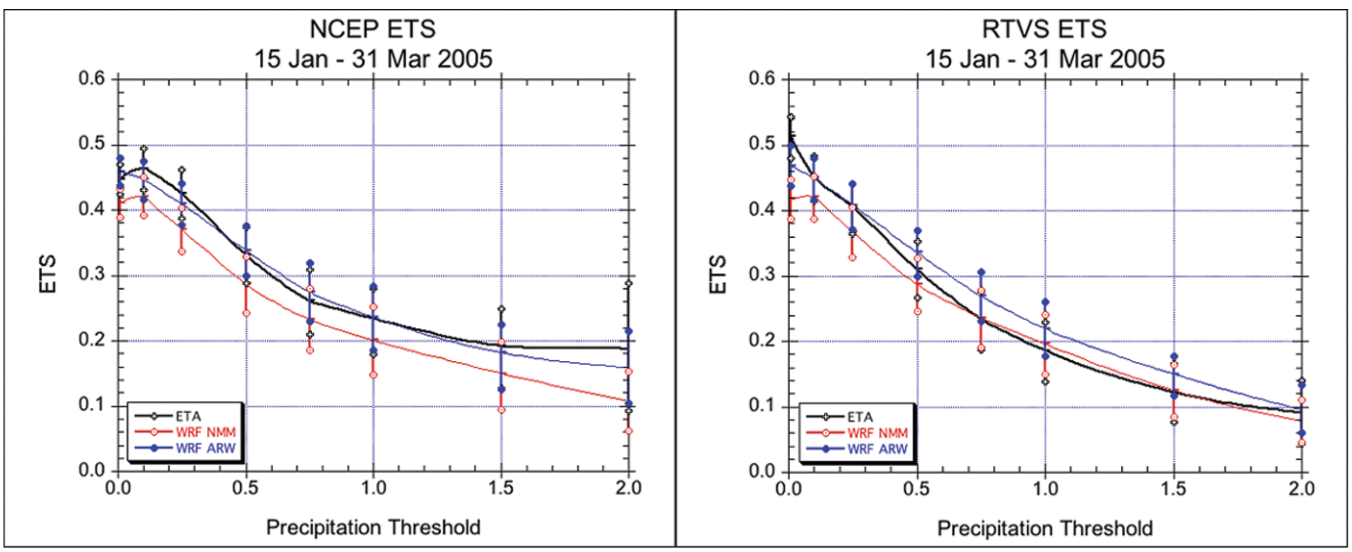


Figure 41. Comparisons between NCEP 24-hour forecast precipitation verification results and RTVS precipitation verification results for ETS showing the Eta-12 (black), WRF NMM (red), and WRF ARW model (blue) for the entire DWFE period over the CONUS domain. Vertical lines with small circles represent the ±95% confidence intervals (CI). Overlaps between CI at a given precipitation threshold indicate that differences between model curves are not significant.

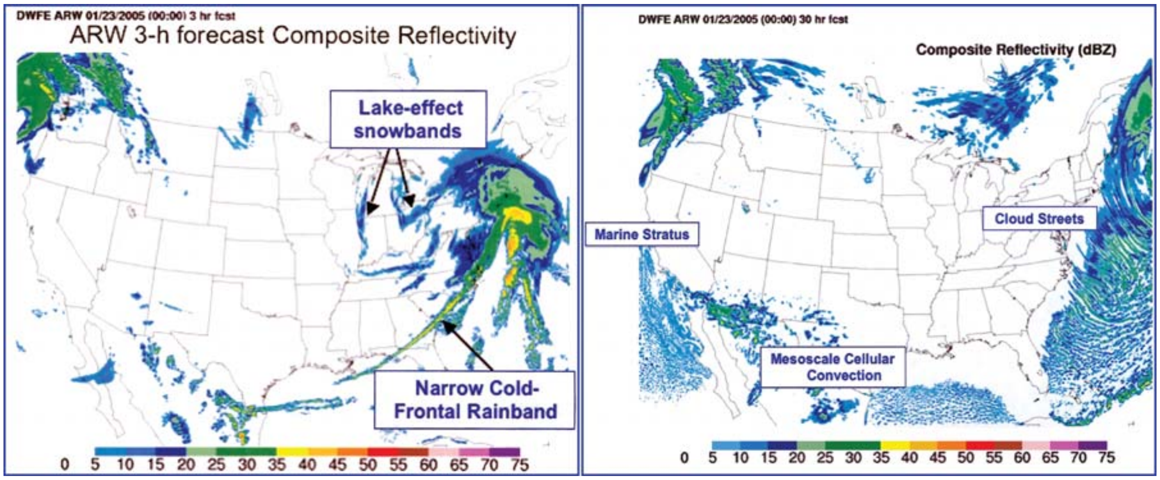


Figure 42. Experimental composite reflectivity product showing examples of mesoscale phenomena forecast by the 5-km ARW model at a) 0300 UTC 23 January 2005 (3-hour forecast) and b) 0600 UTC 24 January 2005 (30-hour forecast). These phenomena were not nearly as obvious (nor even apparent) in conventional precipitation forecast displays.

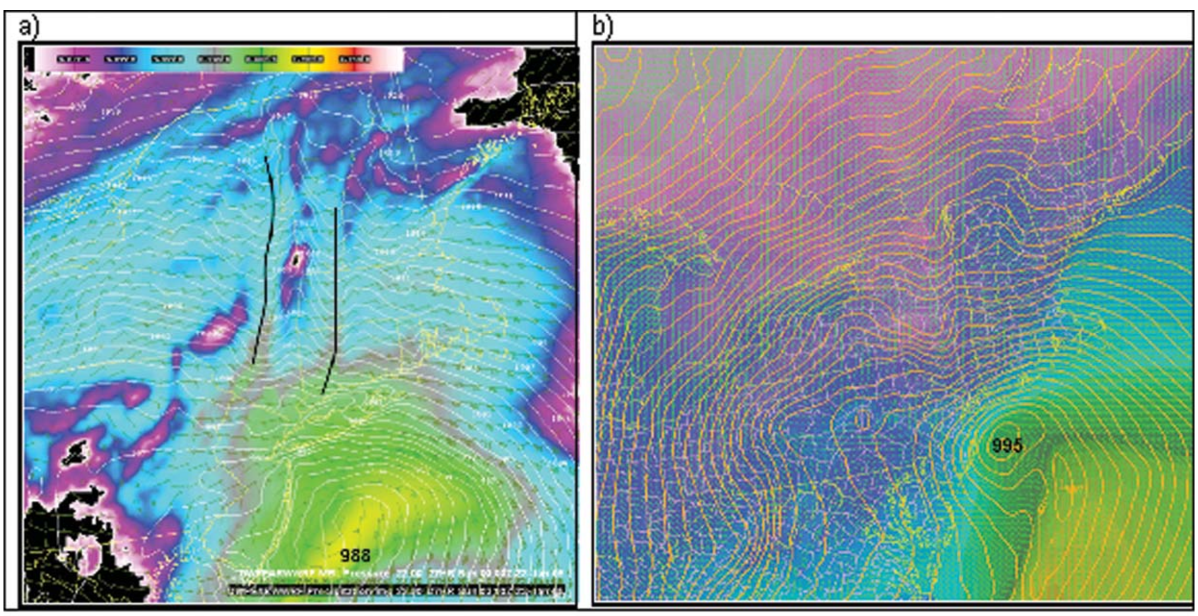


Figure 43. Mesoscale bands in the mean sea level pressure (MSLP) and precipitation fields observed and forecast by the ARW model for the New England blizzard of 23 January 2005: a) 27-hour forecast of MSLP field (1 hPa intervals) and 3-hour accumulated precipitation valid for 0300 UTC 23 January and b) STMAS mesoanalysis of isobars (1 hPa intervals) and isotherms (color-filled). Maximum precipitation forecast of ~2.0 inches in 3 hours east of the New Jersey coast. Thick north-south lines in (a) highlight the stationary bands. Minimum pressure in the cyclone at this time was observed to be 995 hPa (actually, the analysis over the oceanic regions reflects more the RUC model background analysis than pure observations), whereas the WRF-ARW forecast is 7 hPa deeper.

diction models are sufficiently accurate, then the turbulence forecasting problem using operational models (notably the 13-km Rapid Update Cycle (RUC) model) becomes one of identifying model predicted features conducive to the formation of microscale eddies.

The most common methods used to estimate turbulence associated with unresolved scales from RUC forecast fields are based on various approximations to the subgrid-scale turbulent kinetic energy (TKE) equation, such as the Diagnostic TKE Function (DTF) approach developed at FSL, which uses a steady state approximation to the TKE prognostic equation. Operational model guidance for forecasting CAT is currently based on a statistical combination of ~12 turbulence diagnostics (including DTF) computed from the RUC. This model-based forecasting system developed at NCAR and FSL, and known as the Graphical Turbulence Guidance (GTG), weights each model-derived diagnostic so as to obtain the best agreement with turbulence pilot reports (PIREPs).

Scientists in the Special Projects Office of FRD have developed and successfully implemented within the operational GTG a new Unbalanced Flow (UBF) diagnostic. The basic idea behind the UBF technique is that imbalance in the larger-scale flow pattern associated with an upper-level jet approaching a ridge in the height field results in the generation of a packet of gravity-inertia waves with horizontal wavelengths of 100–200 km. The relationship between turbulence and gravity waves in upper-level jet/frontal systems is not well understood, nor is it clear why such waves with scales considerably longer than those associated with CAT should be associated with turbulence. Nevertheless, evidence in support of a causal relationship between mesoscale gravity waves and CAT is becoming increasingly compelling, based on recent results from detailed case studies, diagnostic analysis of numerical model fields, and idealized modeling performed at FSL and elsewhere. Our working hypothesis is that turbulence is associated with mesoscale gravity wave activity immediately downstream of regions of diagnosed flow imbalance at jet stream levels and that since nonlinearity leads to shortening of the horizontal wavelength, eventual wave breaking, and concomitant generation of TKE, turbulence occurs as the wave fronts become steeper and break due to nonlinear advection of the dominant wave in a wave packet.

Models such as the RUC include all kinds of mesoscale phenomena, including gravity waves, but cannot resolve turbulence explicitly. We have found the UBF algorithm results using the RUC to be highly scale-dependent, showing imbalances associated with a broad spectrum of processes; however, mountain waves and convection at smaller scales dominate the UBF fields. This makes determination of the underlying larger-scale imbalance responsible for the generation of propagating gravity waves (as opposed to stationary mountain waves) difficult to isolate. Our research shows that either band-pass or wavelet filters can effectively separate these scales. The pattern recognition challenge then becomes one of linking upper-level jet streak imbalances at the larger scales with areas immediately downstream at low-levels that can support propagating gravity waves through the process known as "wave ducting," which prevents the upward leakage of gravity wave energy and thereby maintains the waves far downstream. An experimental version of the UBF being tested at FSL contains a Duct Factor (DF) computed by multiplying the imbalance field by the wind speed, using the positive portions as a modified UBF predictor field to form a mask, and advecting the leading portion of the mask downstream into new areas a specified distance along the flow while maintaining all former portions of the mask. The areas of overlap between the mask and those with a favorable DF would target threat areas of turbulence. We are currently testing threshold values for outlining degrees of threat for turbulence.

Idealized Studies of Turbulence Generation by Gravity Waves – Further study is needed to understand how relatively large-scale wave phenomena can produce conditions necessary for turbulence to be generated at horizontal scales smaller than ~1 km. Results from our SCATCAT (Severe Clear Air Turbulence Colliding with Aircraft Traffic) field study (see below) and numerical simulations performed with the RUC and the NCAR Clark-Hall (CH) models suggest that gravity-inertia waves may act to increase vertical wind shear and reduce static stability locally as the waves become steeper and their horizontal wavelengths are shortened due to nonlinearity. Nevertheless, the basic process by which gravity-inertia waves create conditions suitable for turbulence to occur, and the conditions under which such a process may or may not develop, is not well understood.

It was for this reason that scientists at FSL conducted more controlled, idealized studies of the process by which jet imbalance may spawn gravity waves, and how such waves may culminate in the generation of turbulent kinetic energy of sufficient intensity that it could be disruptive to commercial aircraft. To study the turbulence generation from gravity waves, we first sought a way to have a set of gravity waves be generated in an idealized atmospheric dynamic environment from an initially balanced flow. The initial condition is derived from the specified potential vorticity (PV) field. By inverting the PV field, which implies that the initial state is balanced, the initial model fields (wind, temperature, and pressure) can be derived. Doing so guarantees that we did not have any undesirable initial noise or unbalanced signals (such as artificial gravity waves) in the initial state of the model, so that the gravity waves generated during the model simulation are physically related to the baroclinic development in association with the upper-level jet system. Grid nesting down to a horizontal resolution of 3.3 km was used to simulate the baroclinic wave development. Gravity waves were spawned with a wavelength of 15 times the horizontal grid spacing, regardless of the model resolution, within a region of imbalance in the exit region of the upper-level jet streak as it approaches the ridge axis.

The finest resolution studied so far (3.3 km) is still quite large compared to the spatial scale of turbulence, which is on the order of a few hundred meters. Turbulence generation was inferred by estimating the subgrid kinetic energy (SKE) production as the difference of the total kinetic energy minus the kinetic energy larger than the grid-size scale. The evolving 50-km scale gravity waves and computed SKE production are displayed in Figure 44. Two things are noticeable: 1) although the SKE is generated in the vicinity of gravity waves, some gravity-wave activity was not associated with any SKE production, and 2) the level of SKE increases as the gravity waves intensify, suggesting that turbulence should increase as the gravity waves amplify.

Field Studies: SCATCAT – This past year, we completed publication in the Journal of the Atmospheric Sciences of a major multiyear study of a strong turbulence event sampled by the NOAA Gulfstream-IV (G-IV) research aircraft in the North Pacific region. High-resolution dropwindsonde and in-flight measurements collected by the aircraft during the SCATCAT experiment and simulations from numerical models were analyzed for a clear-air turbulence event associated with an intense upper-level jet/frontal system. Spectral, wavelet, and structure function analyses performed with the 25-Hz in-situ data were used to investigate the relationship between gravity waves and turbulence. Mesoscale dynamics were analyzed with the 20-km hydrostatic RUC model, and a nested 1-km simulation with the nonhydrostatic CH cloud-scale model.

Turbulence occurred in association with a wide spectrum of upward propagating gravity waves above the jet core. Inertia-gravity waves were generated within a region of unbalanced frontogenesis in the vicinity of a complex tropopause fold (Figures 45 and 47). The wave source region was highly unbalanced, ageostrophic, and frontogenetical, suggesting that the mesoscale gravity waves (displaying wave vectors normal to the northwesterly upper-level flow) may have been generated by geostrophic ("balance") adjustment associated with streamwise ageostrophic frontogenesis.

Turbulent Kinetic Energy fields forecast by the RUC and CH models displayed a strongly banded appearance associated with these mesoscale gravity waves. Smaller-scale gravity wave packets within the mesoscale wave field perturbed the background wind shear and stability, promoting the development of bands of reduced Richardson number conducive to the generation of turbulence. Wavelet analysis revealed that brief episodes of high turbulent energy were closely associated with gravity wave occurrences. Introduction of a wavelet cross-spectrum technique into the traditional Stokes parameter analysis showed that small-scale gravity waves possess distinctive polarization signatures, that the turbulence production is closely related to an enhanced level of polarization and coherency in the two components of the horizontal wind in the gravity waves, and that the turbulence surge is accompanied by a tendency of an instantaneous reduction of polarization and abrupt shift of horizontal wave vector of the progenitor gravity waves. These results were recently published in the Journal of Geophysical Research.

Fluctuations in ozone measured by the aircraft correlated highly with potential temperature fluctuations and the occurrence of turbulent patches at altitudes just above the jet core, but not at higher flight levels, even though the ozone fluctuations were much larger aloft. These results suggest the existence of remnant “fossil turbulence” from earlier events at higher levels, and that ozone cannot be used as a substitute for more direct measures of turbulence. Our results support the growing evidence that upper-level frontal zones are prolific producers of gravity-inertia waves, which propagate upward into the lower stratosphere from their origins within the highly sheared region just above the tropospheric jet stream. The implication is that automated turbulence forecasting algorithms should include some reliable measure of gravity wave activity.

Field Studies: BAMEX – The occurrence of large mesoscale convective systems (MCSs) during the warm season over much of the central United States presents another hazard to aviation. In addition to lightning and hail, the extensive mid- to upper-level anvil clouds that form in these systems may cause severe convectively induced turbulence (CIT). Despite the fact that avoidance of the most intense convection in these areas by passenger aircraft and general aviation is usually possible, it is advantageous to know the risk of CIT in regions within and close to the anvil clouds, so that an algorithmic estimate of this risk could be developed. Although avoidance also means that observations within

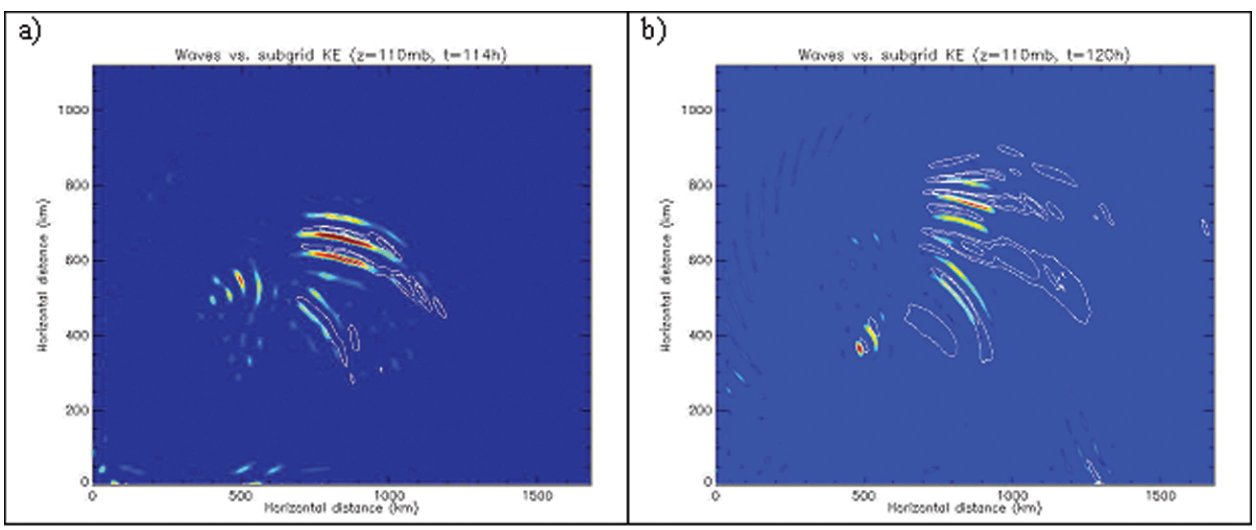


Figure 44. Gravity-wave activity with wavelength of 50 km (image) and subgrid kinetic energy (white contour) at times a) 114 hours and b) 120 hours from an idealized model of baroclinic wave development. The wave activity is occurring within the exit region of a highly diffluent upper-level jet streak.

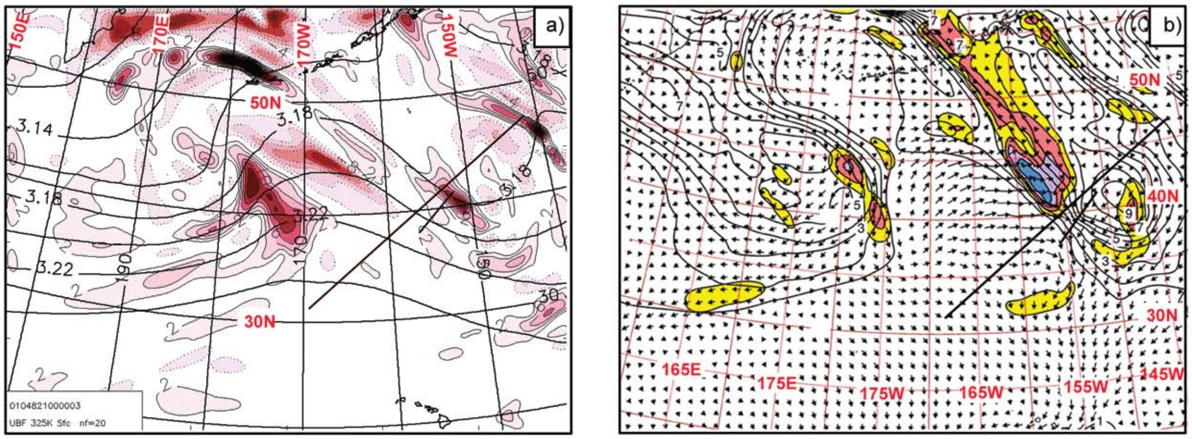


Figure 45. Diagnostic analyses performed from RUC forecast fields for the SCATCAT gravity waves-turbulence event: a) unbalanced flow (UBF) regions diagnosed from the residual of the nonlinear balance equation (intervals of $2x10^{-8}$ s^{-2}, positive (negative) regions denoted by solid (dotted) contours) on the 325K isentropic surface (pressure is indicated by black contours at intervals of 4 Pa) for the 3h forecast valid at 0000 UTC 18 February 2001; b) potential vorticity (PVU), contours), ageostrophic wind vectors, and frontogenesis function (color shading, ^oK (100 km)$^{-1}$ (3h)$^{-1}$) from the RUC analysis at 0000 UTC 18 February. Long and short line segments depict the locations of the RUC cross-sections and G-IV tracks, respectively.

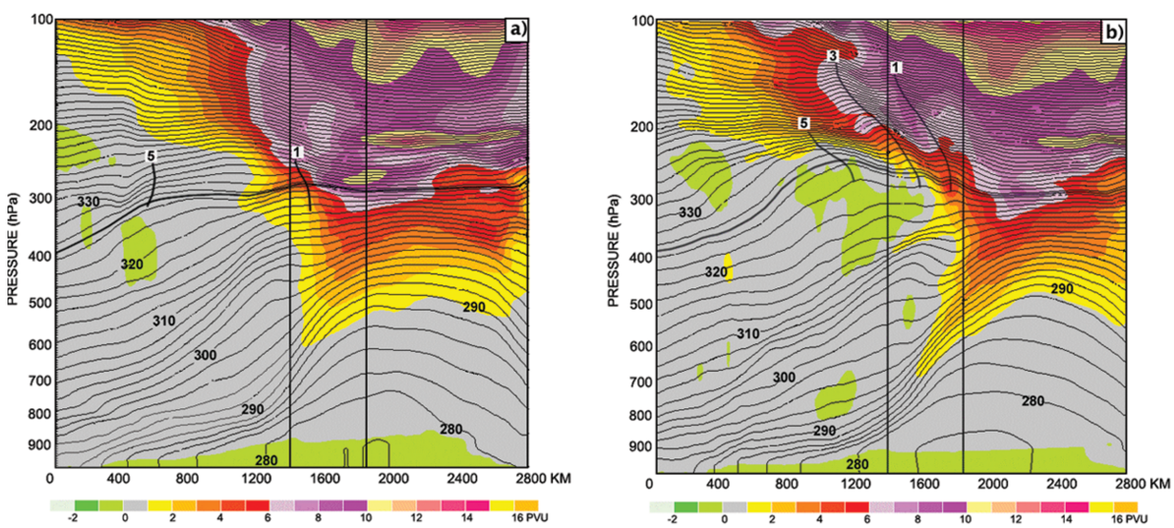


Figure 46. RUC vertical cross sections taken along a 2800-km path perpendicular to the upper-level jet steak (Figure 44) near the flight track of the Gulfstream-IV (G-IV) research aircraft over the North Pacific (vertical lines denote the ~400-km segment over which the G-IV took measurements). Shown are isentropes (2-K contours) and Ertel's potential vorticity (1 PVU = 1 x 10^{-6} K kg^{-1} m^2 s^{-1}, PVU values given by color shading, see color bar). The cross section in (a) is from the RUC analysis at 2100 UTC 17 February 2001, whereas that in (b) is from the 6-hour forecast valid at 0300 UTC 18 February 2001. The 325-K isentrope is highlighted to emphasize the fluctuations associated with gravity waves 1, 3, 5. Tropopause fold is defined by values of potential vorticity >1.5 PVU.

MCSs are rare, during the Bow Echo and Mesoscale Convective Vortex Experiment (BAMEX) held in the central United States in summer 2003, research aircraft flights were made under and near the edges of large mesoscale anvils. Perhaps as many as ten BAMEX missions offer the opportunity to relate CIT episodes to the analysis of dropsonde data and in situ aircraft measurements at midlevels in anvil regions where the intensity and frequency of turbulence is still relatively unknown.

The FSL research team has analyzed one case study rather thoroughly. Three BAMEX aircraft made observations of a bow echo from the time of its initial development in eastern Nebraska at 0100 UTC 10 June 2003 until 1100 UTC, when the anvil of the MCS had already reached its greatest extent (Figure 47a). Good confirmation of turbulence was provided by the NOAA P-3 accelerometer data (Figure 47b). Much of the turbulence experienced by the research aircraft was undoubtedly of convective origin. This would be expected during the close approaches to the convective line; however, within the anvil at a considerable distance from the leading convective line, other turbulence-generating mechanisms might also be present. The most likely mechanism suggested by our research is shear-generated turbulence above and below a rear inflow jet that was present in the dropsonde observations behind the leading convective edge, which was associated with a minimum of Richardson Number (a proxy for the existence of turbulence) in a layer of strong vertical wind shear. Spectral analyses performed upon the horizontal wind components during the period 0740–0800 UTC (red arrow) revealed a $k^{-5/3}$ slope at scales smaller than 300 m in wavelength, which is typical of the turbulence subrange. In contrast, spectral analyses at 0845–0904 UTC (black arrow) depart from the $k^{-5/3}$ slope, from which we tentatively conclude that turbulence did not occur during this section of the flight track. Other turbulence mechanisms requiring further investigation include turbulence associated with gravity waves, and instability mechanisms near the anvil top and the freezing level. Spectral and structure function analyses will be performed to give definitive “maps” of turbulence during this and other mission flights, from which it might be possible to develop GTG algorithms to help to forecast turbulence in convective anvil situations.

Climatological Distribution of Turbulence at Low to Midlevels – Smaller aircraft that fly and cruise at lower altitudes are susceptible to turbulence. By examining diagnostic fields from the RUC model that form the basis for the GTG product, as well as pilot reports of turbulence, over an extended period of time, some indications of the temporal, spatial, and vertical nature of such fields have become apparent. RUC-20 diagnostic analyses were conducted for every hour during the 12-month period covering 2003–2004. The analysis of the Richardson Number fields indicates that wave breaking frequently occurs over mountainous areas. The location of Denver International Airport, in the lee of the Rocky Mountains, produces relatively higher amounts of air traffic and clusters of turbulence reports than any other part of the Rocky Mountain region. This research suggests that heavier weighting for forecasts of possible turbulence based on predicted Richardson Number values in the GTG may be warranted in the Rocky Mountain area, given the relatively lighter air traffic volume beyond the Denver region; on the other hand, turbulence could be overforecast using Richardson Number as a predictor in the eastern U.S., producing many "false alarms."

Mesoscale Diagnostic Studies

Entity-Based Verification of Mesoscale Model Precipitation Forecasts – Verification of a quantitative precipitation forecast (QPF) made by a fine-grid numerical model for mesoscale convective systems (MCSs) is not a straightforward exercise. Standard grid-based measures often result in scores that are not consistent with the subjective impression of the forecaster. Traditional verification statistics severely penalize a precipitation system that may have been forecast with a small positional error or incorrect shape, yet this type of forecast could still be useful to a forecaster or modeler if the model has known biases with its QPF. Fine resolution models are typically penalized more for spatial errors than coarser models. Common verification measures, such as the Equitable Threat

Score (ETS), reward smoothly varying forecast models more than those with relatively high-amplitude structures. Therefore, operational models have tended to be designed to produce smoothly varying QPFs, despite the preference of some human forecasters for more realistic-looking detail and the increasing simulation by research models of finer representations of QPF.

The Ebert-McBride technique (EMT) is an entity-based method that employs the concept of matching individual forecast and observed areas. The EMT utilizes contiguous rain areas (CRAs), defined as the areas of contiguous observed and forecast rainfall enclosed within a specified isohyet. The goal of this study was to use the EMT objective verification measures in concert with an observed morphological classification scheme to reveal systematic errors for each type of MCS. The EMT method was modified to optimize its ability to identify CRAs during the International H2O Project (IHOP), and then used to identify systematic sources of error as a function of observed convective system morphology in three 12-km model simulations run by FSL over the IHOP domain: Eta, MM5, and WRF. The MM5 and WRF were both initialized with the LAPS "Hot Start" procedure. A detailed morphological analysis of observed systems was performed using 2-km resolution composite base reflectivity radar imagery for all CRAs identified in the IHOP domain. The radar-based convective systems were divided into seven general types: continuous linear (CL), continuous linear bowing (CLB), continuous non-linear (CNL), discontinuous areal (DA), isolated cells (IC), orographically fixed (OF), or false alarms (FA). The linear types were subdivided into trailing stratiform, leading stratiform, parallel stratiform, or combinations, and also subclassified by evolutionary behavior.

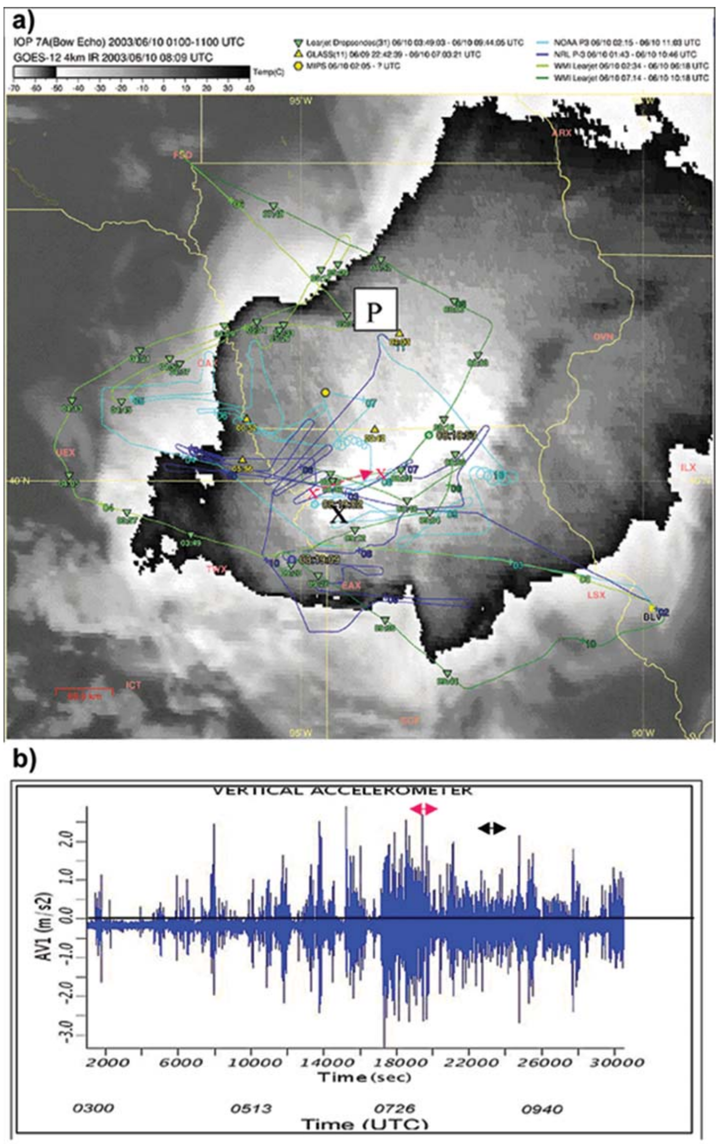


Figure 47. a) Infrared satellite image at 0809 UTC 10 June 2003 showing the location of research aircraft tracks (note the NOAA P-3 track in magenta) and dropsonde observations taken during the entire BAMEX mission, and the location of the Slater, Iowa, wind profiler that showed evidence of a rear inflow jet. b) NOAA P-3 accelerometer observations from 0300 UTC–1000 UTC 10 June. Periods marked by red and black arrows were selected for spectral and structure function analyses, with the red being found to be turbulent and the black nonturbulent episodes.

Application of the modified EMT to the IHOP model datasets indicated that the Eta model produced average rain rates, peak rainfall amounts, and total rain volumes that were significantly lower than observed for almost all types of convective systems. This systematic behavior is likely due to the production of overly smoothed QPF fields in the Eta model. By contrast, the MM5 and WRF typically produced average rain rates and peak rainfall amounts that were larger than observed for linear convective systems. However, the rain volume for these models was too low for almost all types of convective systems, due to an underestimate in area coverage. These models also forecast linear system rainfall northwest of their observed positions. These rain area, rainrate, and displacement errors for the WRF and MM5 are consistent with previous observations of mesoscale models run with explicit microphysics and no convective parameterization scheme, suggesting systematic problems with the prediction of MCS cold pool dynamics. In particular, delayed strengthening of the cold pool occurs with explicit models run at resolutions coarser than 4 km. Since the cold pool is crucial to the evolution of an MCS into an upshear-tilted mature system, such models can be expected to underestimate the trailing stratiform precipitation region commonly produced by the upshear-tilted front-to-rear flow, while overpredicting the precipitation in the convective leading line.

Moisture Transport by the Low-level Jet in IHOP – The Plains Low-level Jet (LLJ) is responsible for transporting moisture northward into the center of the U.S., thereby playing a critical role in the location and intensity of precipitation. However, neither radiosondes nor profilers adequately observe the detailed boundary layer moisture distribution. As a result, numerical initialization fields may not accurately represent moisture transport, with inevitable but unknown implications for QPF. A combination of aircraft-deployed dropsonde observations, airborne lidar moisture and wind fields, and several kinds of surface-based remote sensing observations in IHOP offered an unprecedented opportunity to determine moisture transport at a variety of scales resolved by the different measurement systems. The dominant scale at which the greatest transverse component of the moisture transport occurred was found to be well below that resolved by the operational radiosonde network, and in some parts of the sampled domain, even occurred at scales not resolvable by the 40-km resolution dropsondes.

Initialization of 12-km WRF model runs with IHOP data enabled us to address two fundamental modeling questions: 1) How well would the LAPS-initialized WRF represent LLJ moisture transports as seen in the lidar and dropsonde data, and 2) How great an impact would result in the short-term forecasts of moisture and precipitation from the inclusion of research data (e.g., dropsonde profiles)? The model initial fields captured well the general structure of the LLJ and the dropsonde-observed transports. However, the analyses lost some sharpness in horizontal resolution, and within a few hours, the forecast underestimated the sharp horizontal gradient in moisture transport, though WRF model boundary layer physics built an LLJ with strong features. Parallel analyses with and without dropsonde data showed no significant difference in LLJ transport structure. Although it is possible that this particular LLJ was so well captured by the operational observations that the dropsondes were superfluous, we believe it more likely that the analyses themselves are relatively insensitive to the existence of extra research data, at least as it is arrayed in this study. To address either of these two questions, it is likely that better vertical resolution in both analyses and models will be necessary before jets like these with such shallow features can be adequately represented.

Research Quality Datasets

NCEP Gauge Observation Quality Control System – A quality control system to screen hourly gauge precipitation observations from the Hydrometeorological Automated Data System (HADS) has been developed for NCEP. This system has been installed at FSL and results as applied to the Real Time Verification System (RTVS) are being analyzed to assess performance and make adjustments. First results included an application to verify precipitation forecasts from the DTC Winter Forecast Experiment (DWFE), where the screening resulted in allowance of roughly 5,000 stations per day out of a full set of approximately 6,000 reporting stations, twice the count of good stations allowed by the previous (very conservative) system applied by RTVS. At NCEP, installation and revision to accommodate the different computing infrastructure is proceeding.

As the flow chart in Figure 48 illustrates, the screening algorithms include a set of tests based on hourly and daily accumulations that address known systematic problems such as extreme values, stuck gauges, and telemetry errors. A second set of checks (which result in the bulk of the screening) consists of neighbor checks that use a set of high-quality daily total precipitation from gauges observed and processed by the NWS River Forecast Centers. This second set of checks actually proves to be the critical component of the QC system. Early examination of the systems reveals that adjustments to thresholds for these tests may need to be seasonal as well as regional.

RUC Upper-Air Verification Database – Using the mysql database management system, we have developed a database that stores RUC skill scores (bias and RMS) verified against radiosondes. Verifications are available for the variables height, temperature, humidity, and winds for levels from 850 hPa to 100 hPa. Time-histories of these skill scores are available on the Web (see below) as pregenerated or interactive plots.

RUC-AMDAR Database – Using the mysql database management system, we have also developed a database that stores RUC analyses and forecasts of wind, temperature, and humidity, compared with in-situ measurements from commercial aircraft (AMDAR). These data may be displayed on the RUC-AMDAR Website (described below), and statistics may be generated. Statistics from all AMDAR aircraft that fly in the RUC domain are generated, and are available in several forms on various Websites. In addition, detailed queries of the data have been made in order to more fully evaluate the behavior of various sensors and aircraft fleets. For instance, we are using this database to perform detailed evaluations of the TAMDAR and WVSS-II sensors, and of data from Canadian turboprop and regional jet aircraft.

Websites for FSL Data

FSL's recent implementation of a Web firewall has necessitated changes to many of our Websites/ pages to make them consistent with the firewall. This effort was quite time-intensive, but the result is a more secure Web presence.

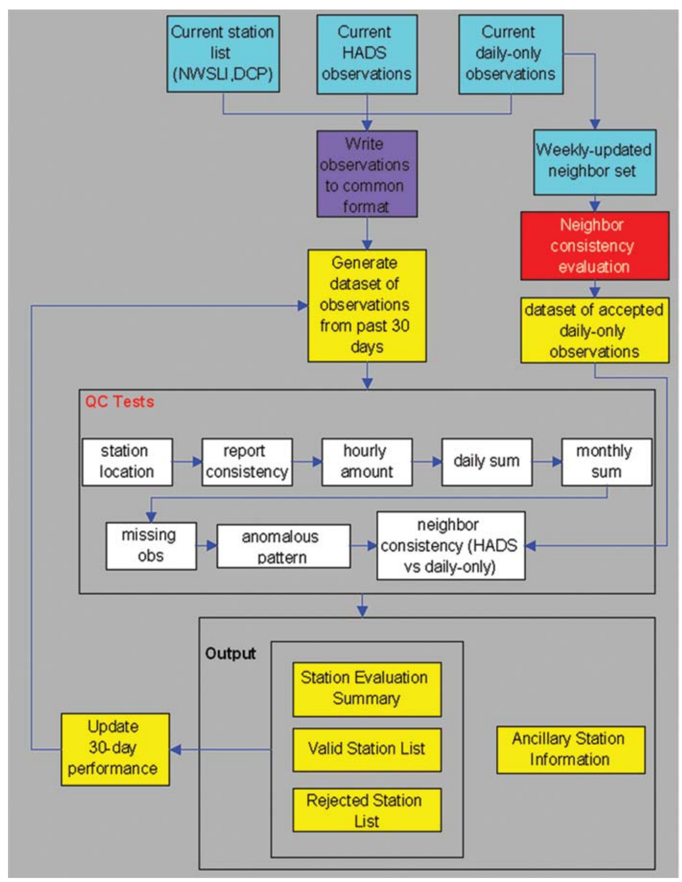


Figure 48. Flow chart describing the NCEP Raingauge Quality Control System developed at FSL.

Rapid Update Cycle Website (http://rapidrefresh.noaa.gov/) – This site was rewritten to eliminate the use of "frames." An index structure was developed that was easily added to all RUC Webpages, thereby simplifying navigation.

AMDAR Website (http://amdar.noaa.gov/) – This site, which is restricted to government and certain other users, displays plan and profile views of automated weather reports taken by commercial aircraft. The following upgrades were made to this site:

- Plots of aircraft-generated and other soundings have been improved, and some small errors in the thermodynamic properties of hypothetical air parcels have been corrected.
- Archival data dating back to July 2001 are now available on demand. With a time delay of several seconds, they are retrieved from the MADIS archive and displayed.
- Locations of the wind profilers that are part of the National Profiler Network have been added as an optional overlay.,
- Capability to display special radiosonde soundings produced by the University of Wisconsin CIMSS program was added, in order to support evaluations of both the TAMDAR and WVSS-II sensors.
- Worldwide RAOB sites locations have been added as an optional overlay.
- Computer code was simplified and made more robust. This code, available under Open Source Definition (http://www.opensource.org/osd.html), has been successfully implemented by AirDat LLC to use with data from their new aircraft-borne sensor.

Interactive Soundings Website (http://www-frd.fsl.noaa.gov/mab/soundings/java/) – This Website interactively displays RUC past and forecasted soundings from profilers, radiosondes, and aircraft. This page continues to be popular, with more than 120,000 accesses from over 700 major domains (such as "noaa.gov" or "delta.com"). The easily adaptable Java code that runs this site has been requested by more than 80 organizations, and has been released to them under FSL's open-source software license/disclaimer. The site was upgraded to display data from the new 13-km version of the RUC, as well as two research versions: "dev" and "dev2." These latter models differ only in that dev2 includes TAMDAR data. Comparisons of soundings from the dev and dev2 models have been very useful in assessing the impact of TAMDAR on the RUC model.

National Mesonet Website (http://www-frd.fsl.noaa.gov/mesonet/) – This page interactively displays observations from 39 networks (up from 28 last year), including mesonets, maritime buoys, and the METAR network— more than 21,000 stations from around the world (up from 10,000 last year). The site displays weather data and quality control information from FSL's Meteorological Assimilation Data Ingest System (MADIS). The site is now able to display wind gust and precipitation data from those stations that report those parameters. During July 2005, the site was accessed more than 17,000 times from more than 1,500 unique domains.

RUC Upper-Air Statistics Webpage (http://ruc.fsl.noaa.gov/stats/) – This page provides pregenerated and interactive statistics for RUC analyses and forecasts, and persistence forecasts, verified against radiosondes. Plots are pregenerated weekly, and show a time history of bias and RMS error for the past month. Interactive plots can show skill history from the present back to 26 Jan 2001.

RUC-AMDAR Website (http://amdarl.noaa.gov/ruc_acars/) –This site provides statistics for AMDAR data with respect to various RUC model 1-hour forecasts ("background fields"). It contains several pages:

- Three-day and seven-day running statistics that show a variety of measures of aircraft data quality, including average and rms differences between data and model background for temperature, wind, and relative humidity.

The 7-day statistics page is sortable by any one the presented statistics. This is proving very useful in discovering individual aircraft and entire fleets of aircraft that appear to be providing suspect data.
• The interactive statistics time series page allows users to call up a time history of the statistics of any particular aircraft. This is proving useful in discovering when particular sensors malfunction.
• Daily and weekly statistics text files are available for users to download and process locally.
• A Java-based interactive map shows a plan view of individual AMDAR data points. The observed data, model background values interpolated to each data point, and difference values may be displayed as color-coded points or as wind barbs.

Projections

Research Quality Datasets

AMDAR Quality Control System – This system, currently fully understood by only one employee, will be well documented and passed on to a group of programmers so that there is no single point of failure for the system.

RUC-AMDAR Database – Analysis of the data in this database will result in several papers in the literature on the quality of data from various new sensors, such as TAMDAR and WVSS-II, and from various aircraft fleets. In addition, the quality of various versions of the RUC model will be compared to determine how well each model's background fields match with AMDAR data.

Websites for FSL Data

AMDAR Website (http://amdar.noaa.gov/) – This system, currently fully understood by only one employee, will be well documented and passed on to a group of programmers so that there is no single point of failure for the system.

Interactive Soundings Website (http://www-frd.fsl.noaa.gov/mab/soundings/java/) – This site will continue to be maintained and the data flow into it monitored. Pending identification of resources, scripts will be written to ease the reloading of past data cases, upon request. Currently, only approximately 16 hours of RUC data are available for display.

National Mesonet Website (http://www-frd.fsl.noaa.gov/mesonet/) – New mesonets will be added to this site as they become available, and pending resources, additional display options will be provided.

RUC-AMDAR (http://acweb.fsl.noaa.gov/ruc_acars/) – The plan view part of this display will receive several upgrades, and the following capabilities will be added:
• Observed and background dewpoint displays.
• Color-coding by the absolute value of the temperature difference.
• Ability to load several different versions of the RUC model .

Pending identification of resources, this site will be expanded to include additional RUC forecasts longer than 1 hour, such as 3-, 6-, and 12-hour forecasts. Skill statistics will be generated.

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Objectives

The Demonstration Division evaluates promising new atmospheric observing technologies, such as the NOAA Profiler Network (NPN) and the GPS-Met Integrated Precipitable Water Vapor Monitoring Network developed by the NOAA Research Laboratories and other organizations, and determines their value in the operational domain. Activities range from the demonstration of scientific and engineering innovations to the management of new systems and technologies. In support of NOAA's mission to serve society's need for weather and water information, new upper-air observing techniques are used to create and disseminate reliable assessments of weather, climate, space environment, and geodetic phenomena. The division also develops and implements data and techniques to support seasonal to interannual climate forecasts as well as the prediction and assessment of decadal to centennial climate change. The GPS-Met Network also promotes NOAA's Safe Navigation program by providing Global Position System (GPS) and other observations to the National Geodetic Survey network of continuously operating reference stations (CORS), the U.S. Coast Guard (USCG), U.S. Department of Transportation (DOT), and other GPS users in the public and private sectors.

These activities represent an investment in scientific research, the development of new technologies to improve current operations, and NOAA's preparation for the future. The division has successfully demonstrated all major elements of three reliable, low-cost continuous upper-air observing systems – wind profilers, Radio Acoustic Sounding System (RASS) temperature profilers, and the ground-based atmospheric water vapor sensing observing system (GPS-Met), shown in Figure 49. These systems complement other operational and future ground- and space-

Figure 49. Profiler located at Ledbetter, Texas: antenna (horizontal grid), equipment shelter containing all electronic components (upper left), RASS temperature profiling components (crown-like instruments), and GPS-Met Integrated Water Vapor Monitoring system (bottom center).

based observing systems. New information network tools and techniques have been adapted to acquire and process data from Cooperative Agency Profilers (CAPs), GPS, and surface meteorological observations from NOAA and other public/private organizations and international partnerships. This capability allows rapid expansion of observing system coverage at extremely low cost. The division has been heavily involved in transferring environmental expertise and technologies to improve NOAA's ability to serve its customers and forge stronger ties with its partners, especially the National Weather Service (NWS), DOT, and Department of Defense (DOD).

The NPN has been providing important upper-air data to a variety of customers since it became fully operational 13 years ago. For example, NWS routinely uses data from the NPN, CAP, and GPS networks in computer-generated forecasts and numerical weather prediction (NWP) models, and its field forecasters tailor model guidance to local conditions. The datasets are accessible to interested users via the Global Telecommunication System (GTS), and to the public via the Internet. Many other federal, state, and local organizations need these data to support weather forecasting, aviation, and monitoring climate and air quality and Homeland Security programs.

When it was announced that funding for the NPN and all other programs within the division would be eliminated for Fiscal Year 2004, briefings were held on the proven uses of this technology. Following a tremendous effort on the part of many people and organizations, Congress restored funding at the previous level. The restored funding was transferred from the Office of Oceanic and Atmospheric Research (OAR) to NWS, demonstrating that the NPN is valuable to the nation and should become part of NOAA's systems operated by NWS. As previously noted, weather forecasting is improved because wind profilers provide information not available through other observing systems. Some of the many advantages to the forecaster are: 1) increased lead time allows deployment of emergency response resources, 2) greater detail concerning storm onset and location results in the public heeding warnings to seek shelter, 3) fewer false alarms generate higher public confidence in watches and warnings, 4) early identification of conditions supporting wind shear and turbulence increases the margin of safety for the aviation community, and 5) better precipitation forecasts for the public and agriculture to limit flash flood impacts. Data from the division's NPN, CAP, and GPS networks, all of which are integrated into daily forecast activities, most important during periods of severe weather, and continue to provide important meteorological information to the NWS and other customers.

Funding for Fiscal Year 2005 was significantly less than that allocated in previous years; however, it was consistent with the general decrease in the federal budget – especially for programs that are not related to DOD activities. Though it has been challenging to operate with reduced funds, we are proceeding well with our collaborative efforts to begin transition of the NPN to NWS. A frequency change of the NPN transmitters and antennas from 404.37 MHz to 449.0 MHz will be an integral part of the transition. After many years of demonstrating the value of profiler technology, it is rewarding to begin the transition process for the NPN to become an NWS operational system. Network performance continues to improve because of the program's continuous monitoring, assessment, evaluation, and improvement of the NPN operations.

The Demonstration Division is engaged in the following major projects:

- Operation, maintenance, and enhancement of the 35-station NOAA Profiler Network (NPN), which includes three systems in Alaska, and the CAP sites.
- Collection, quality control, and distribution of wind and temperature data from the CAP sites.
- Development, deployment, and evaluation of the all-weather GPS-Met integrated precipitable water (IPW) vapor observing system.
- Development of plans for transition of the GPS-IPW observing system to full operations in NWS.

- Ongoing evaluation of newly certified GOES high data rate (1200 baud) communication systems for network deployment, which provides back-up data communications from the profiler sites to the Central Processing Center in Boulder, Colorado.
- Assessment of alternative, low-cost data communication technologies, including satellite Internet.
- Upgrade of the surface meteorological sensor package at NPN sites to improve winds and precipitation measurement capability, supportability and reliability. Upgrades include replacement of analog sensors with digital sensors and incorporation of surface wind measurement instruments.
- Coordination with NWS operational staff on issues of transitioning the NPN and profiler technology to standards required by NWS for operational systems.
- Collaboration with NWS to plan and support activities for an Integrated Upper-Air Observing System (IUOS), which will include profilers and GPS-Met systems.

Though organized into five branches, the division works in a fully integrated team mode to support our overall objectives, as follows.

Network Operations Branch – Monitors the health of the systems and data quality, and coordinates all field repair and maintenance activities.

Engineering and Field Support Branch – Provides high-level field repair, coordinates all network logistical support, designs and deploys engineering system upgrades, and redeploys GPS or profiler systems as needed.

Software Development and Web Services Branch – Provides software support of existing systems, and develops new software and database systems as needed, including new tools to assist in monitoring tasks and advanced quality control functions. Also provides Web support of the division's extensive Web activities, and designs software to support future upgrades of the current network and national deployment of additional profilers.

GPS-Met Observing Systems Branch – Supports development, deployment, and evaluation of the GPS-Met Integrated Precipitable Water Vapor Monitoring Network, and provides software development and scientific support.

Facilities Management and Systems Administration Branch – Manages all computers, data communications, network, and computer facilities used by the staff and projects of the division.

Network Operations Branch

Douglas W. van de Kamp, Chief

Objectives

The Network Operations Branch is responsible for all aspects of NOAA Profiler Network (NPN) operations and monitoring, including the coordination of logistics associated with operating a network of 35 radars and surface instruments. Activities within the branch, in direct support of the NPN, are a cooperative effort of all five branches within the division. The NPN is primarily known for its ability to measure tropospheric and lower-stratospheric winds in real-time, but also measure profiles of temperature in the lower troposphere at 11 NPN sites using the Radio Acoustic Sounding System (RASS) technique, and GPS integrated precipitable water (GPS-IPW) vapor systems for moisture measurements at all NPN sites. In addition to the 35 NPN sites, another 300+ NOAA and other-agency sites are monitored for timely GPS positions and surface meteorological observations to produce real-time IPW measurements. Additional wind and RASS data have been acquired from a growing number of independently operated profiler sites, now totaling about 100. These Cooperative Agency Profilers (CAPs) include mostly lower tropospheric boundary layer profiler sites. The data from these CAP sites are available to the meteorological community in real-time via the division's Website, *www.profiler.noaa.gov*. The branch directly supports NOAA's mission to improve weather products and services by providing real-time comprehensive, high quality upper-air and surface observations to NWS forecasters and numerical weather prediction models.

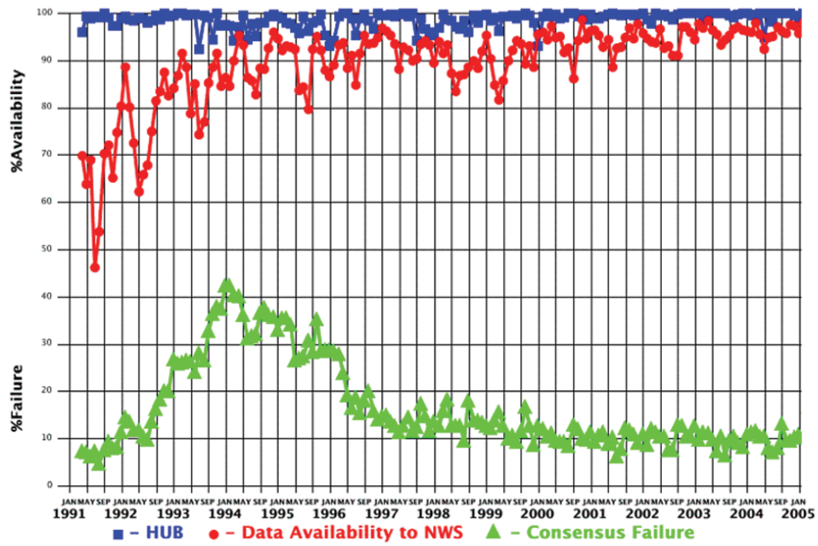
Accomplishments

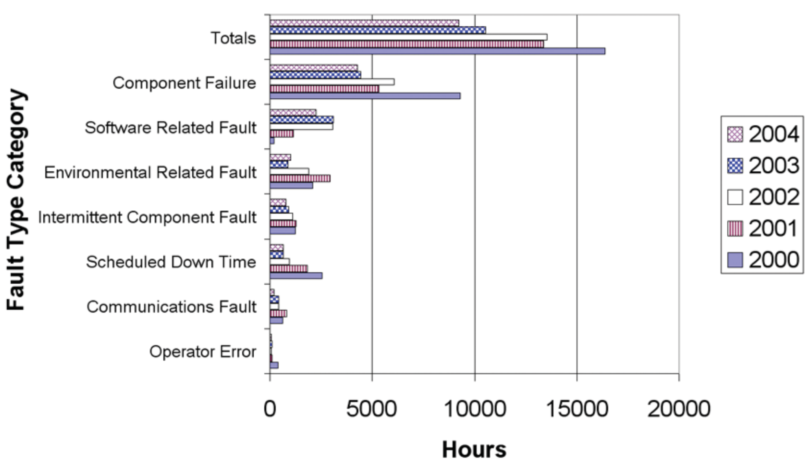
A variety of tracking tools are used to assess the strengths and weaknesses of the NPN. The availability of hourly NPN winds to the NWS continued to increase slightly during 2004, averaging 96.4%. Typical NWS-commissioned systems such as NEXRAD, ASOS, and radiosondes have a data availability of 97% or better.

Figure 50 summarizes the overall performance of the network for the last 14 years. It is interesting to note the general pattern of decreased availability of hourly winds each year during the spring and summer months, compared to slightly higher availability during the fall and winter months. An analysis attributes this pattern to increased lightning activity and severe weather during the convective season (causing more commercial power failures and lightning-induced profiler site hardware damage) and air conditioner failures during the summer months.

A significant portion of personnel time involves the day-to-day operations and monitoring tasks related to the NPN hardware, communications, and meteorological data quality. Constant attention to these tasks has resulted in high data availability rates for the past few years. Other ongoing work includes initial diagnosis of equipment failures, coordination of all field repairs and maintenance activities, and the documentation of all faults that have resulted in a one hour or longer profiler data outages. Figure 51a shows the total number of hours of profiler data lost by fault type (such as component failures, scheduled downtime for maintenance, and power and air conditioner failures) for the past five fiscal years. The duration of each data outage is broken down into many different categories, including how long it took to identify a failure, diagnose and evaluate the problem, wait for repair parts to be sent and received, restore commercial power or communications, and document when and how the fault was ultimately repaired. Figure 51b shows the distribution of these categories of downtime (normalized over the past seven years). Analysis of all these states reveals important information on the operation of the network and allows the identification of its strengths and weaknesses. Other work involves the financial aspects related to the continued operation of the NPN, including tracking land leases, communications, and local commercial power and phone bills for all the profiler sites.

Figure 50. NOAA Profiler Network 404-MHz profiler data availability from January 1991–January 2005.





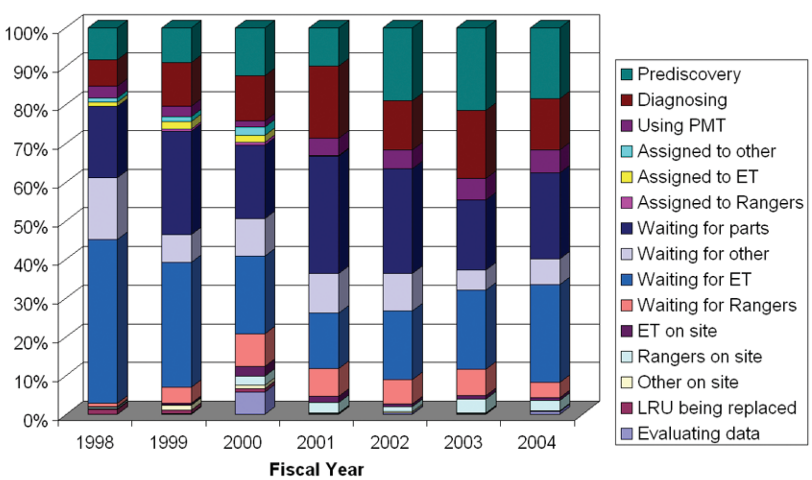


Figure 51. (a, above left) hourly NPN data lost by fault type for the past five fiscal years, from 2000–2004, (b, below left) distribution of NPN downtime by categories (normalized over the past seven years).

Personnel in the Profiler Control Center (PCC) routinely monitor the NPN, whose data are used operationally by the NWS, only during normal working hours, 7:30 a.m.– 4:30 p.m. local time (27% of the total hours in a week). The remainder of the time, the profilers, dedicated communication lines, and Profiler Hub computer system operate unattended. Significant improvements have been made in our ability to remotely monitor activity within the NPN, Hub processing, and data communications via Web displays and other tools. Routinely monitored activities on the Web include information on profiler real-time status and data flow to the NWS Telecommunications Gateway (NWSTG). The use of these tools to remotely diagnose problems as they arise outside normal work hours has increased the availability of NPN data.

Examination of several years of data showed that a significant number of lost hours of data were attributed to the local main power breaker (200 amps) being tripped to the off position, usually the result of lightning related power surges. Simply resetting the breaker restores operation, but a site visit is still required, typically by an NWS technician or the local landowner. From this analysis, the division's Engineering and Field Support Branch designed and installed a device several years ago that allows the main breaker to be remotely reset via a phone call to the site. This method is routinely used to restore profiler operations, as well as to "power cycle" a site in an attempt to clear software "hangs" and other problems. During Fiscal Year 2004 (October 2003 through September 2004), the breaker reset capability was activated 215 times outside normal work hours in an attempt to restore operations. It was successful 151 times (70%), resulting in an additional 3,800+ hours of profiler and GPS-IPW data availability to our customers. These resets, performed outside normal work hours, alone increased data availability by 1.3%. This is quite impressive considering our data availability is already normally >95%. The capability to remotely reset the main breaker via a phone call to the site was proven so successful that the procedure has been partially automated for use by the PCC staff during normal work hours.

Eleven NPN sites have RASS capabilities that typically provide temperature measurements from about 2.5–4 km above the ground. In general, the velocity of the lower tropospheric wind limits the maximum height coverage of RASS by blowing the acoustic signal outside the radar beam. Each RASS-equipped site has four acoustic sources that are located inside the antenna field fence near the corners of the wind profiler antenna. Ongoing experiments are conducted at Platteville, Colorado, Purcell, Oklahoma, and Neodesha, Kansas, to investigate the impact of acoustic sources placed upwind of the profiler sites, and the impact of reduced acoustic output power.

Low-power profilers that measure winds and temperature in the boundary layer to the lower troposphere (60 m to ~3 km above ground) have been operating in greater numbers around the Northern Hemisphere in recent years. These profilers, part of the CAP network, primarily support air quality measurements and meteorological forecasting and research programs, and typically operate independently or in small groups. Approximately 100 CAP sites are currently operating and providing data to the Profiler Control Center in Boulder. Mostly located in coastal regions of the eastern and western United States, the CAP sites provide valuable additional geographic coverage outside the NPN. The division is collaborating with other agencies to acquire CAP wind and RASS temperature data that are processed into hourly and subhourly quality-controlled products. They are ultimately distributed along with products from the NPN, and are available on the division's Website. The CAP data are primarily used for air quality monitoring and forecasting, but have applications to homeland security, and numerical weather prediction and subjective weather forecasting in support of NOAA's mission.

To better understand how and when profiler data are used by the National Weather Service (NWS), the branch is monitoring the Area Forecast Discussions (AFDs) from the field offices. Forecasters at each NWS office typically write two AFDs every day which describe the current forecasting issues, both in the short-term and longer-term forecast period. These AFDs are generally technical in detail, and more of a “thought process” to share among the forecasters, both within a forecast office between shifts and in adjacent NWS forecast offices.

A search was performed to see how many times the word “profiler” was used in all AFDs for a one-year period. Forecasters at 79 (out of a possible approximately 120) NWS offices mentioned the use of profiler data in at least one of their AFDs from 6 January 2003–5 January 2004 (Figure 52). The NWS offices located in the central United States are, of course, primarily using NPN data, while those offices near the East and West Coasts are all using CAP data. Of the 79 offices indicating the use of profiler data, a total of 1,882 AFDs (about 5 per day) mentioned the use of profiler data in their decision-making process, thus demonstrating that the use of profiler data is well integrated into NWS operations. Detailed results of the study were presented at the 2005 Annual Meeting of the American Meteorological Society.

Projections

Many of the tasks slated for 2004 have been carried over to 2005 because staff resources were directed to the transition of the current VAX-based Profiler Hub to a PC-based processing and dissemination system. Limited resources related to this work, along with budget related distractions, thwarted progress in testing and implementing new ideas and tasks originally planned for last year.

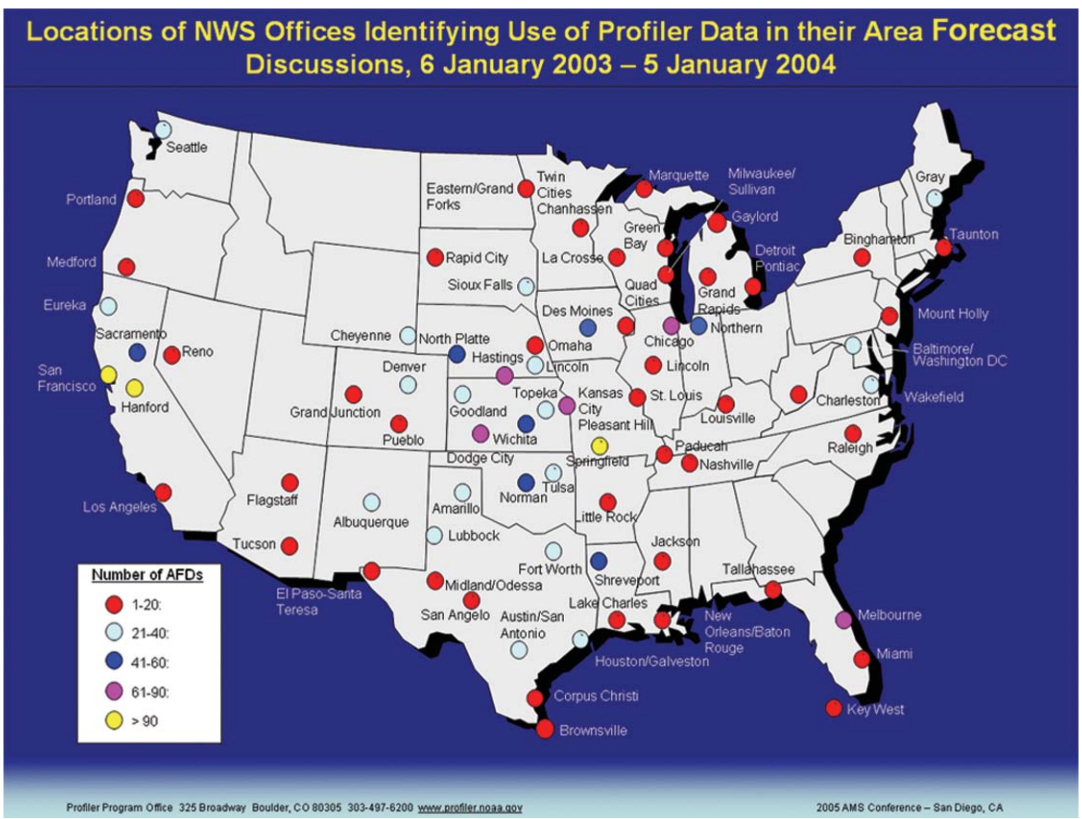


Figure 52. Locations of National Weather Service Offices identifying use of NPN data in their Area Forecast Discussions, from 6 January 2003–5 January 2004.

The Bird Contamination Check algorithm will be examined for potential improvements. The original algorithm analyzed only the hourly averaged north and east beams to detect the broader spectral widths caused by migrating birds. The next significant improvement is likely to involve more sophisticated processing of the 6-minute moment data. Additional QC development is limited, since the current Profiler Hub cannot incorporate anymore processing at this time.

The Demonstration Division will continue to operate and maintain the 11 RASS-equipped profiler sites. Experiments will continue at Platteville, Purcell, and Neodesha to investigate the optimum acoustic source locations (distance upwind) and acoustic output power. Improvements are expected in the quality control of RASS data, mainly during periods of internal interference, and in the presentation (i.e., contouring specific temperatures) of RASS data on the Profiler Webpage.

The operations of the CAP Hub will be used to acquire additional tropospheric profiler data from targets of opportunity, provide quality control for these datasets, and distribute them to users via the Web and the NWS Telecommunications Gateway. Additional automated monitoring procedures will be investigated to handle the increasing number of CAP sites available and monitored by the PCC.

The capabilities of the new hybrid 449-MHz profiler at Platteville will be investigated further. This will include data quality and height coverage of different data processing methods (standard consensus versus a multiple peak tracking algorithm), three beams compared to five beams in terms of data quality and cost/complexity issues, higher temporal resolution data, and reduced height of the first sample height. All of these issues are related to the design and implementation of a national profiler network.

The branch will continue to collaborate with other Demonstration Division staff in the operation and maintenance of the NPN to help maintain consistently high data availability statistics. This ultimately supports NOAA's mission of improving weather products and services, resulting in reduced loss of life and property damage from weather related events.

Engineering and Field Support Branch

Michael K. Shanahan, Chief

Objectives

The primary focus of the Engineering and Field Support Branch is to carry out the operation, maintenance, and improvement of the NOAA Profiler Network (NPN). Through collaboration with the FSL Profiler Control Center (PCC), the branch monitors the 35-site NPN network to assure data quality and reliability. Constant network upgrades, identification of network problems, using remote diagnostics analysis, and prompt corrective actions result in increased data availability.

Most of the preventive and remedial maintenance is performed by electronics technicians from the National Weather Service (NWS) in accordance with network maintenance agreements. The PCC uses remote diagnostic capabilities to recognize failed components, order line replaceable units, and coordinate with the NWS electronics technicians regarding field repairs. More complex problems are handled by a team of specialized engineer/technicians, called Rangers, who are experienced in the design and operation of the profiler systems. Based in Boulder, the Rangers can be mobilized to the field on short notice to repair the profilers.

Accomplishments

The Alaska 449-MHz Profiler Network has been operating continuously and delivering data to the NWS for over five years. Because of above normal snow accumulation on the antennas this winter, the NWS technicians have had to work diligently to keep up with snow removal (Figure 53). Heavy snowfall on the antenna normally does not hinder the performance of the profiler; it is only when the snow melts and refreezes to form a layer of ice that we see any data degradation.

Figure 53. National Weather Service technician removing snow from the profiler antenna at Talkeetna, Alaska.

A profiler electronics technician training seminar was provided for NWS employees associated with the NPN. The seminar was held at the Boulder Assembly Facility (BAF), which houses a working profiler without the antenna and serves as a local test bed, repair facility, and training center. The three-day event covered material from the "NOAA Wind Profiler Guide to LRU (Line Replaceable Units) Replacement" manual which was distributed to NWS offices in CD format to aid the technicians in profiler maintenance. The training also included the repair of GPS-IPW (Global Positioning System-Integrated Precipitable Water vapor) and GSOS/PSOS (GPS Surface Observing System/Profiler Surface Observing System) systems.

The 449-MHz profiler at Syracuse, New York, has been operating continuously and delivering data to the NWS for over a year. It is the only 449-MHz profiler in the network to operate with a redesigned transmitter. The new transmitter design is being evaluated for use in the future generation of profilers and to address reliability issues of the past.

The NOAA Profiler Network continues to operate in the 404-MHz band without any interference to the Search and Rescue Satellite (SARSAT). A 3-year extension to the 404-MHz Radio Frequency Authorization, valid until September 2006, is testament to the quality of profiler maintenance which has resulted in no interference events in more than 8 years.

Projections

In 2005, the 449-MHz profiler at Syracuse, New York will be transferred to support NWS operations around the Washington, D.C. area. The final location is being coordinated with the NWS.

More RF amplifiers and drivers are being purchased to upgrade the existing 449-MHz transmitters. The new amplifiers and drivers used in the Syracuse profiler are meant to be a functional replacement for the previous version, and can be used in conjunction with the older version amplifiers.

The Engineering and Field Support Branch will install an all-digital surface meteorological sensor package, the PSOS-II, to replace the GSOS and PSOS units operating at some profiler sites. A 10-meter mast with an anemometer and rain gauge will be added to sites currently without surface wind measuring capability. The mast is being designed so that a lone technician can raise and lower instrumentation. When this implementation is accomplished, each of the 35 profiler sites will operate identical equipment, resulting in additional meteorological data.

Training seminars for NWS technicians will continue to be conducted at the BAF in the summer of 2005.

Operations and maintenance support will be provided to the ten quarter-scale profilers to be installed for the Air Force Tethered Aerostat Radar System (TARS). Only one site at Ft. Huachuca, Arizona, is currently operational, but other sites are expected to become operational in 2005.

New signal processing techniques at the Platteville, Colorado, profiler will continue to be tested to determine the best method for acquiring quality data. These techniques are expected to help alleviate the problems associated with ground and sea clutter and bird contamination.

Plans are underway for the conversion of all 404-MHz profilers to the designated 449-MHz frequency in support of the NWS Cost and Operational Effectiveness Analysis.

Software Development and Web Services Branch

Alan E. Pihlak, Chief

Objectives

The Software Development and Web Services Branch provides software support for existing systems, develops new software and database systems as needed, provides Web support for the division's extensive Web activities, and designs software to support a national deployment of profilers. To help improve short-term warning and forecast services, up-to-the-minute profiler data are provided on the NOAA Profiler Network (NPN) Website, *http://profiler.noaa.gov* – the first place to go for wind profiler data. This Website also provides historical archives of wind, temperature, and other profiler information beneficial to researchers for forecasting and modeling both long- and short-term climate change. A perpetual goal is to improve the timeliness of profiler data delivery and distribution through work on existing software systems and development of new software.

Branch resources are used in the operation of the Cooperative Agency Profiler (CAP) network (Figure 54), comprising profiler sites operated by external agencies and organizations. Profiler data produced in near real time by sources ranging from the Environmental Protection Agency to the Japanese Meteorological Agency are acquired by the branch and become part of the shared data system. The CAP sites are operated in many different ways, owned by about 30 different agencies, and optimized for different applications. FSL acquires the data, applies its own quality control algorithms to the data, and makes the value-added data available on the Web and to the National Weather Service (NWS). The data from these profilers, distributed primarily via the Profiler Website, contribute significantly to NWS forecasts in areas where the NPN does not operate tropospheric profilers.

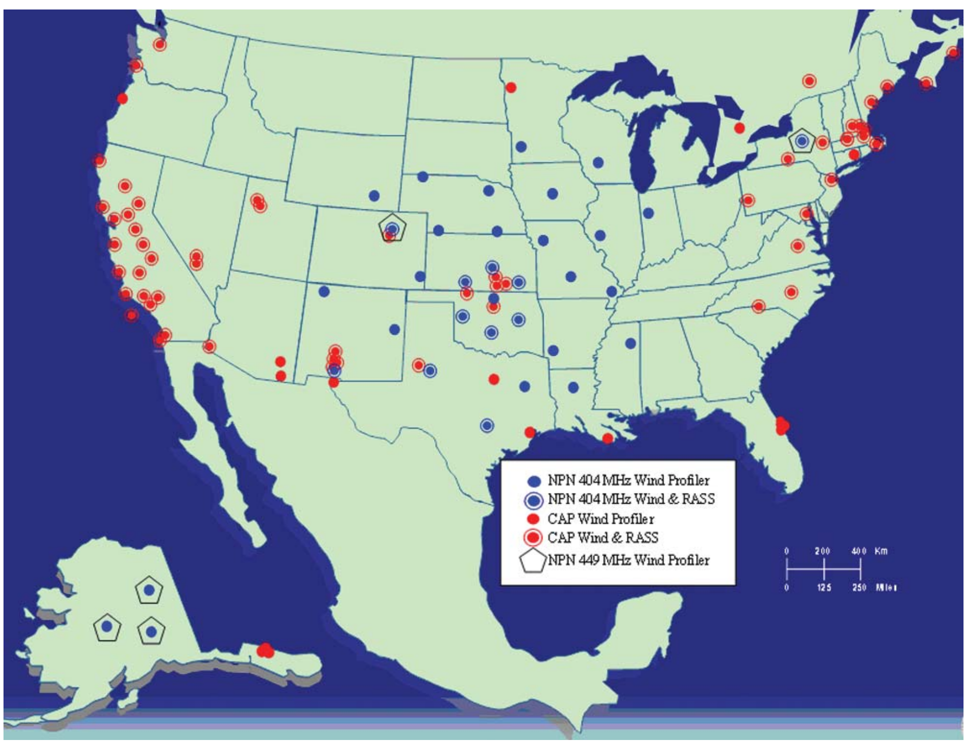


Figure 54. NOAA Profiler Network and Cooperative Agency Profiler locations.

Accomplishments

In 2004, a continuing project involved developing systems to replace the aging VAX Cluster-based Hub. The first major release of the software was put into production.

The CAP processing system was prototyped using a combination of Perl, shell scripts, Java, and various file transfer methods. We will continue to develop software that fits the station-instrument-product model, which will eventually replace the prototype. The number of profilers in the CAP network remained static last year.

NWS forecasters around the country routinely use CAP data, and to accommodate all users, a new CAP Web address has been added to the NOAA Profiler Network's Website. This site (*www.profiler.noaa.gov/cap/*) provides a central focal point for CAP owners, operators, and other interested parties to exchange information about the status, operation, and uses of profilers in forecasting and air quality prediction.

The Local Receive Ground Station (LRGS) supporting DOMSAT (domestic satellite) operations was upgraded. The LRGS provides backup communications via GOES for all NPN profiler sites.

Parallel satellite Internet communications were installed at four NPN profiler sites for studying the feasibility of using this technology in lieu of expensive dedicated landline circuits. This issue will be closely studied, since satellite Internet can be adversely affected by weather, unfortunately, when the profiler data are most needed.

The Demonstration Division Website was separated into two sites: the NOAA Profiler Network Website (*http://profiler.noaa.gov*) and the Demonstration Division Website (*www-dd.fsl.noaa.gov/*).

Work on other subsystems required to eliminate the aging NPN Hub is estimated to be 90% complete. Progress on this goal continues to be affected by the growth of the CAP network and staff shortages.

Work related to the National Climatic Data Center's (NCDC) profiler data archive has been completed. These data, covering the last 12 years, have been reprocessed into a modern storage format and are being sent back to NCDC as of this writing.

Projections

The NPN Hub is expected to be operating in parallel with its replacement system, based on Red Hat Linux and running on off-the-shelf Intel-based standard systems, by September of 2005. The NPN Hub is expected to be replaced by December 2005.

Archived NPN and CAP data will be placed online (*www.profiler.noaa.gov)* and available for downloading or viewing. At least one year of data will be available online, and requests for older historical data will be processed as received.

GPS-Met Observing Systems Branch

Seth I. Gutman, Chief

Objectives

The GPS-Met Observing Systems Branch was formed in response to the need for improved moisture observations to support weather forecasting, climate monitoring, and research within NOAA. Though the focus of our activities is on science, technology, and infusion into NOAA's weather and water programs, we also provide valuable observations and products that support NOAA's climate, commerce and transportation, ecosystems, and environmental satellite services goals.

The primary objectives are to define and demonstrate the major aspects of an operational ground-based GPS integrated precipitable water vapor (IPW) monitoring system, facilitate assessments of the impact of GPS meteorological data on weather forecasts, assist in the transition of GPS-Met to operational use within NOAA, and encourage the use of GPS in atmospheric research and other applications. Utilization of the resources and infrastructure established to operate and maintain the NOAA Profiler Network (NPN) helps to achieve these objectives at low cost and low risk. We collaborate with other FSL divisions and the director's office to achieve objectives of mutual interest and benefit the laboratory, its customers, and its partners.

The GPS-Met project represents an investment in scientific research, the development of new technologies to improve current operations, and assistance in helping NOAA prepare for the future. We have successfully demonstrated all major elements of a reliable, low-cost continuous upper-air observing system that complements other operational and future ground- and space-based observing systems. Newly adapted network tools and techniques acquire and process GPS and surface meteorological data from NOAA and other public, private, and international partnerships. This capability has permitted rapid expansion of GPS-Met coverage at extremely low cost. The GPS-Met team has been heavily involved in developing and implementing environmental expertise and technologies to improve NOAA’s ability to serve its customers and forge stronger ties with its partners, especially the National Weather Service (NWS), National Environmental Satellite Data Information Service (NESDIS), Department of Transportation (DOT), and National Aeronautics and Space Administration (NASA). In the past year, our collaborations have extended to government agencies and institutions in Canada, Europe, and Japan.

Accomplishments

The GPS-Met project team concentrated on the following activities in 2004:

- Continued expansion of the GPS-Met network to facilitate assessment of GPS-IPW observations on weather forecast accuracy
- Continued investigation of how integrated observations (of which IPW is just one of many) are handled in numerical weather models
- Facilitated independent evaluations of the utility of using meteorological models to improve GPS positioning accuracy
- Evaluated GPS-rawinsonde IPW differences over CONUS to establish a baseline for comparison and thresholds for using GPS to quality control radiosonde moisture soundings
- Established a GPS-IPW site at the Caribou, Maine, upper-air site to assist NWS in evaluating Radiosonde Replacement System improvements
- Established a GPS-IPW site at the NOAA Climate Monitoring Diagnostic Laboratory’s Mauna Loa Observatory

to investigate the use of GPS for long-term climate monitoring and for satellite calibration and validation
- Continued investigation of satellite total precipitable water (TPW) estimation characteristics using GPS as a proxy for rawinsonde moisture measurements
- Started developing a strategy and supporting PPBES (Program Planning, Budgeting and Execution System) documentation for the transition of GPS-Met to operations in Fiscal Year 2008.

The branch chief was named to the Tropospheric Working Group of the International GPS Service (IGS), under the auspices of the International Association of Geodesy and of the Federation of Astronomical and Geophysical Data Analysis Services. He participated in the 10th Anniversary Meeting and Workshop held in Bern, Switzerland. Two peer reviewed papers were published in refereed journals, four papers were presented at the annual American Meteorological Society Meeting, and briefings and presentations were made to numerous organizations throughout the year.

Expansion of the GPS-Met Network

The installation of GPS Surface Observing System (GSOS) meteorological packages at three Nationwide Differential GPS sites and four U.S. Coast Guard sites during 2004 brought the number of "backbone" sites in the network to 117, with a goal of reaching about 200 sites nationwide by 2005. The installation of an additional 72 "infill" sites (mostly belonging to state departments of transportation) brought the total number of sites in the network to 289. Figure 55 shows the configuration of the GPS-Met network, including backbone sites operated by U.S. federal agencies (identified by triangles) and infill sites operated by other government agencies, universities, and the private sector (circles).

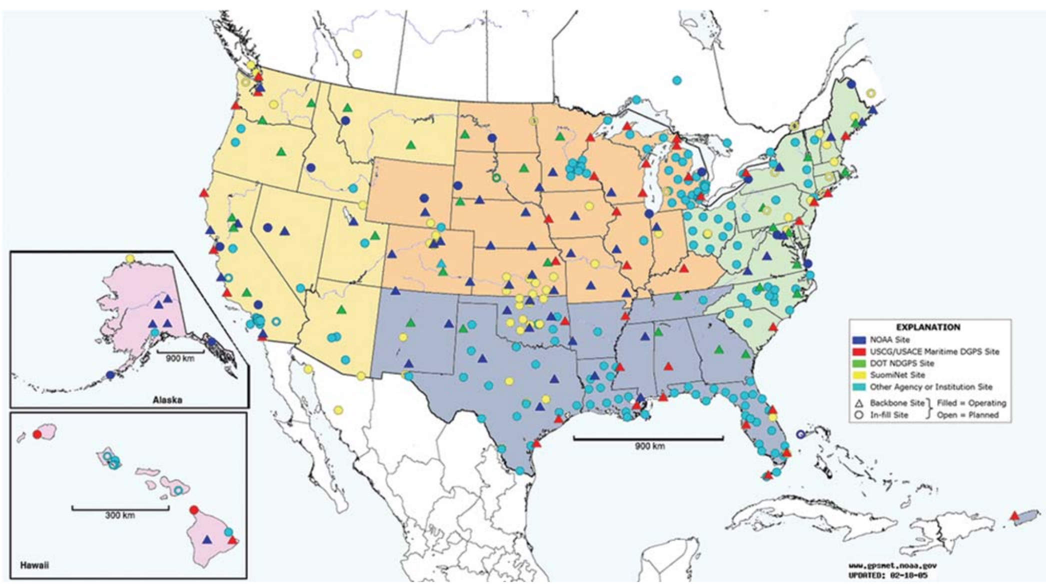


Figure 55. GPS-Met network, totaling 289 sites. Triangles identify "backbone" sites, owned and operated primarily by U.S. federal agencies. Circles identify "infill" sites, belonging primarily to state departments of transportation.

Impact of GPS Water Vapor Data on Weather Forecast Accuracy

The Forecast Research Division's Regional Analysis and Prediction Branch performed the seventh consecutive assessment of the impact of GPS- IPW retrievals on weather forecast accuracy in 2004. These annual assessments are data denial experiments using the 60-km version of the Mesoscale Analysis and Prediction System (MAPS), a research version of the operational Rapid Update Cycle numerical weather prediction model (RUC2) currently running at the National Centers for Environmental Prediction (NCEP). The 60-km MAPS model was again run in a 3-hour data assimilation/forecast cycle over the central U.S (not shown). Each forecast cycle used the same boundary conditions and observations (including rawinsondes, surface, aircraft, wind profiler, and GOES precipitable water); the only difference was the addition of GPS-IPW (integrated precipitable water) observations in a second "parallel" run. The 3-hour relative humidity (RH) forecasts with and without GPS were compared with twice daily rawinsonde observations at 17 NWS upper-air sites to assess the improvement in the RH forecast accuracy at four pressure levels (850 hPa, 700 hPa, 500 hPa, and 400 hPa 300 hPa).

The results of the data denial experiments are summarized in Table 1, which compares GPS-Met impact assessments over the past 6 years. The improvement in 3-hour forecast accuracy as a function of the number of GPS stations used in the data denial experiments was 18 in 1998 and 1999, 56 in 2000, 67 in 2001, over 100 in 2002, over 200 in 2003, and 275 in 2004. Since the only significant variable in the 60-km RUC data denial experiments is the number of GPS stations providing IPW data to the model, Table 1 indicates that the assimilation of hourly GPS water vapor measurements into the RUC is responsible for continuous 3-hour RH forecast improvements at all levels at and below 500 hPa; improvements to 400 hPa have also been observed for the past two years. The method used to assimilate GPS data into the RUC has been optimal interpolation (OI), in which the increment between the observed precipitable water and the model-derived PW is calculated and applied as a correction to the mixing ratio below 500 hPa. Adjustments are applied to correct for over- and under-saturation. This simple and straightforward technique does not utilize any other information available in the model, such as wind speed and direction. It has long been recognized that some form of variational analysis should be superior to OI for the assimilation of most quantities, especially integrated parameters such as radial velocities, brightness temperatures, and precipitable water vapor, but difficulties in implementing variational techniques have resulted in no net improvement in moisture forecast accuracy until recently.

Table 1.
Comparison of seven years of GPS impact on RH forecasts in the 60-km RUC.
Numbers expressed in terms of percent of improvement, normalized by total error.

Level	1998–1999 18 sites	2000 56 sites	2001 67 Sites	2002 >100 sites	2003 >200 sites	2004 275 sites
850	1.5	3.8	3.9	5.0	5.4	7.7
700	1.1	4.1	6.3	6.5	7.0	9.9
500	0.7	2.1	2.0	2.4	3.1	3.7
400	0.3	0.1	-0.4	-0.5	1.0	1.9
Mean						
850–500	1.1	3.3	4.1	4.6	5.2	7.2
850–500	0.9	2.5	3.0	3.4	4.1	5.8

The ability to improve the assimilation of GPS-IPW measurements into numerical weather prediction models has been a long-standing goal. In 2004, significant steps were taken by the Forecast Research Division to achieve this goal, mostly in conjunction with the migration from a 20-km developmental version of the RUC to an operational 13-km version. The latter, which will be the first operational model to assimilate GPS-IPW, is scheduled to enter service at NCEP in June 2005. The first step involved the implementation of improved quality control of moisture soundings, and the second involved an improved unified variational moisture treatment which uses in situ (i.e., rawinsonde moisture soundings) and integrated precipitable water observations simultaneously to calculate three-dimensional moisture analysis increments. The new quality control scheme compares rawinsonde IPW with nearby GPS-IPW values and flags an entire radiosonde moisture profile if radiosonde IPW varies substantially from nearby GPS stations using the criteria defined by Gutman et al. 2004 (IOS AMS Conference). There is also a check performed to ensure that no systematic errors exist in GPS-IPW retrievals, such as those caused by a bad satellite orbit prediction. IPW innovations are now calculated using a new “IPW-RH” variable developed for the 13-km RUC analysis, which exhibits much better spatial coherence than PW itself over regional variations of terrain elevation.

Another improvement implemented this year involves the way that surface observations (METARs) influence the boundary layer, coupled with the positive impact of GPS-Met observations on moisture in the lower levels of the atmosphere. Substantial improvements are shown in 3-hour RUC forecasts of convective available potential energy (CAPE). Since CAPE represents the amount of buoyant energy available to accelerate a parcel of air vertically in the atmosphere, improvements in these forecasts will lead to improved thunderstorm, tornado, and hazardous weather forecasts and warnings. The results from a particularly interesting tornado outbreak that occurred in Indiana and Illinois in April 2004 show that these tornadoes were not well predicted by any model (see Figures 56 and 57).

Using NOAA Atmospheric Models to Improve GPS Positioning Accuracy

Since the procedure called Selective Availability (SA) was curtailed by a Presidential Order in 2000, the largest source of GPS positioning and navigation error became the Earth's atmosphere. (SA is the denial of the full accuracy of GPS signals by deliberately dithering the satellite clock and degrading the navigation message or broadcast ephemeris.) The constituents of the upper and lower atmosphere (free electrons in the ionosphere and temperature, pressure, and water vapor in the lower atmosphere) slow and bend the GPS radio signals through a process called refraction. Changes in the refractivity of the ionosphere and troposphere can vary greatly in time and space, leading to large errors and rapid changes in GPS positional accuracy under certain circumstances. These circumstances are usually associated with space and tropospheric weather events, including solar or geomagnetic storms in the upper atmosphere, and weather events in the lower atmosphere ranging in scale from tens of kilometers (thunderstorms) to hundreds of kilometers (tropical storms).

The ability to accurately define and remove the effects of ionospheric and tropospheric signal delays will have significant impact on countless civilian and military activities. The first and most obvious impact will be on rapid high accuracy GPS positioning and navigation: meter-level accuracy for single frequency receivers, decimeter accuracy for carrier phase differential surveying, and centimeter Real Time Kinematic (RTK) over arbitrarily long baselines. Facilitating the CORS (Continuously Operating Reference Stations) height modernization, and improvements in the accuracy of elevation determination will follow immediately which will aid in transportation planning for evacuations and identifying critical transportation infrastructure. Sufficiently accurate ionospheric and tropospheric signal delay models will permit the correction of interferometric synthetic aperture radar (InSAR) data from satellites and aircraft for building more accurate digital elevation models, monitoring changes in land surface due to subsidence or vertical motion, and mapping variations in soil moisture with unprecedented accuracy.

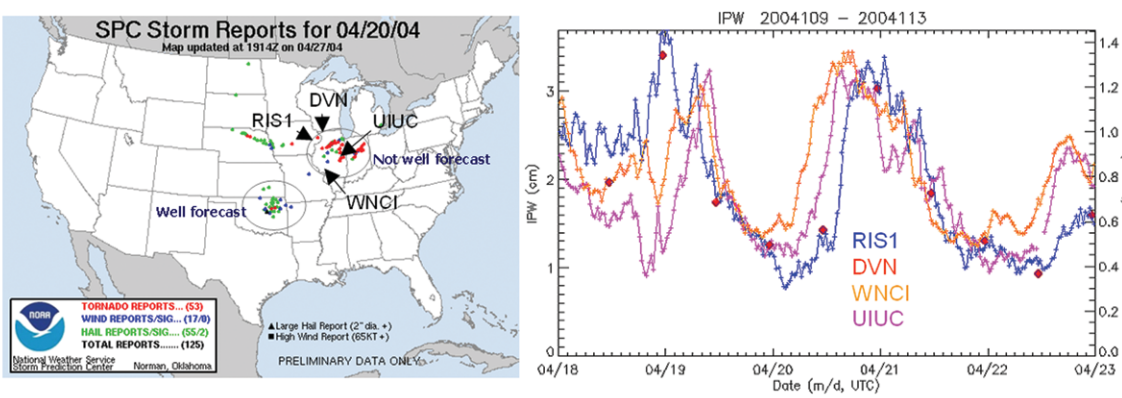


Figure 56. Location of a tornado outbreak (left) that occurred in Indiana and Illinois on 20 April 2004 and was not well forecast by any NOAA model. Water vapor time series (right) centered on the event. Integrated radiosonde moisture data from the Quad Cities NWS Upper-Air site (DVN) are portrayed as red dots. GPS-IPW data from Rock Island, IL (RSI1); Winchester, IL (WNCI); and Urbana, IL (UICU) are presented in blue, orange, and magenta, respectively. They portray the passage of the storm through the region marked "not well forecast."

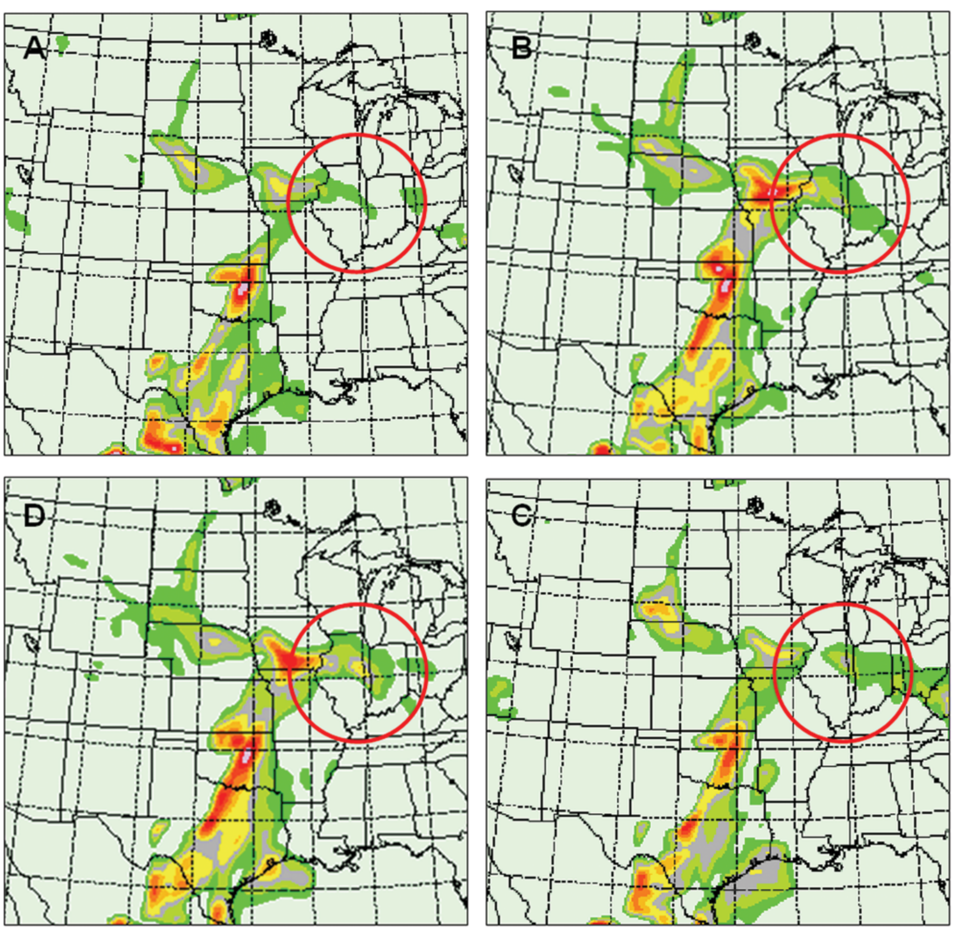


Figure 57. CAPE 3-hour forecasts from the 20-km version of the Rapid Update Cycle (RUC20). Panel A (upper left) is the original CAPE forecast valid at 0000 UTC on 21 April 2004 from the operational RUC20 running at NCEP. Panel B (upper right) is the operational RUC20 plus the new PBL 3-hour forecast of CAPE valid 0000 UTC 21 April 2004. This increased CAPE by 500 J/Kg. The additional contribution of GPS-IPW to the CAPE in Panel C (lower right) brought the total available potential energy into eastern Illinois (Panel D lower left) above 1000 J/Kg.

Current single and dual frequency stand-alone positional accuracy is 5 to 10 meters during normal conditions and up to 30 meters for disturbed atmospheric conditions, such as during geomagnetic storms. Geomagnetic storms introduce extremely sharp gradients in total electron content (TEC), as indicated by Figure 58. The large increase in TEC over southern California during this solar storm on 29 October 2003 is a factor of 4 greater than normal. In the central continental United States (CONUS), another physical process in the ionosphere has produced a reduction in electron density by a factor of two to three. The combined effect of the large enhancements and depletions introduce extreme gradients in electron content, which introduces errors in GPS positioning close to 30 meters. During severe weather conditions in the lower atmosphere, changes in GPS signal delays (Figure 59) caused by variations in temperature, pressure, and water vapor can introduce similar errors that severely impact GPS positioning and navigation accuracy, especially in the measurement of the vertical (height) coordinate.

Centimeter-level positioning accuracy over long baselines currently requires many hours of data to resolve the integer ambiguity in the carrier phase measurement. The main causes of error in the real-time positioning and in rapid resolution of integer ambiguities pertain to the unknown phase delay caused by the electron density in the ionosphere and pressure, temperature, and water vapor in the troposphere between a given receiver and the GPS satellites. If the combined ionospheric and tropospheric signal delays can be estimated to significantly less than 50 cm, immediate stand-alone (point) positioning could routinely achieve decimeter accuracy under most conditions. If the ionospheric and tropospheric delays can be constrained to less than 20 cm, then centimeter accuracy for geodetic applications could be achieved with a substantially reduced number of observations over arbitrarily long baselines. The potential cost savings to federal, state, and local government organizations as a result of productivity improvements alone will be significant. Further, the impact of new military and homeland security and civilian applications is potentially far-reaching.

Initial tests of NOAA's Tropospheric Delay Model produced hourly by the GPS-Met Observing System Branch, the University of Calgary, and the University of Southern Mississippi have shown small but consistent improvement in high accuracy GPS positioning using the NOAA correctors. This is encouraging, since these tests involve techniques that already provide real-time decimeter-level accuracy. Clearly, we are on the right track, especially when it comes to making improvements in lower accuracy (decimeter-meter level) surveying.

Using GPS to Calibrate, Validate, or Quality Control Other Moisture Observations

In many cases, measurements made by satellites and radiosondes in remote areas of the Earth are the only upper-atmospheric information available for weather forecasting and climate monitoring. As NOAA's reliance on measurements from remote sensing systems grows, the need also increases for improved quality control and independent ways to verify these measurements and model predictions based on these measurements. Because of the low cost, high reliability, high accuracy, and high measurement stability of GPS water vapor observations, and their potential for worldwide dissemination under the Global Earth Observing System of Systems (GEOSS), we wanted to see if it is feasible to use an integrated measurement to verify the accuracy of a sounding system. To do this, we selected radiosondes. After more than 60 years, measurements made by radiosondes still provide the standard upper-atmospheric dataset for numerical weather prediction, regional weather forecasting, climatology, research, and other applications. Radiosonde measurements also form the basis of intercomparison, calibration and validation of most other atmospheric observing systems, and serve as the benchmark or "ground-truth" for satellite-derived estimates of temperature, moisture, and other atmospheric parameters. Because of the unique characteristics of radiosonde observations and the fact that many of the parameters measured by radiosondes (such as moisture) are poorly observed by other techniques, verification of radiosonde soundings can be difficult under some circumstances.

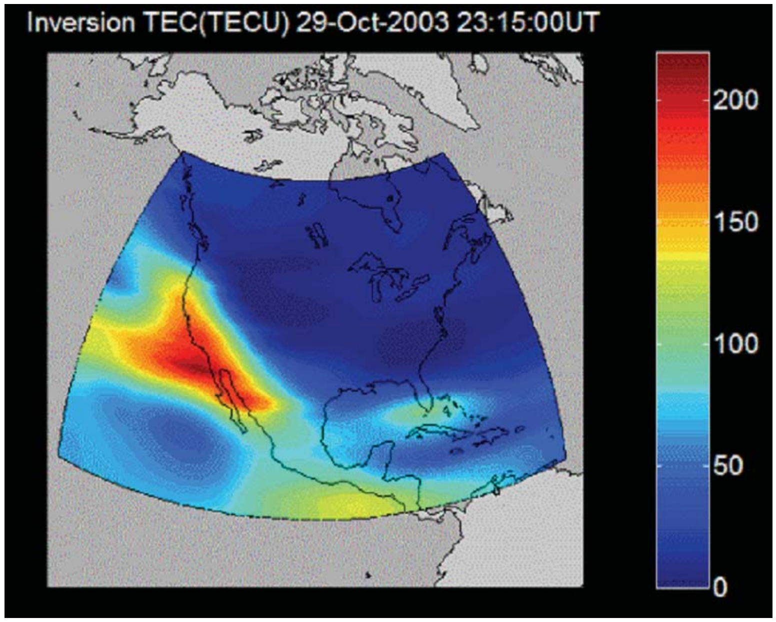


Figure 58. Total electron content (TEC) gradient associated with a geomagnetic storm on 29 October 2003 observed from GPS observations made at about 150 Nationwide Differential GPS facilities over the lower 48 United States.

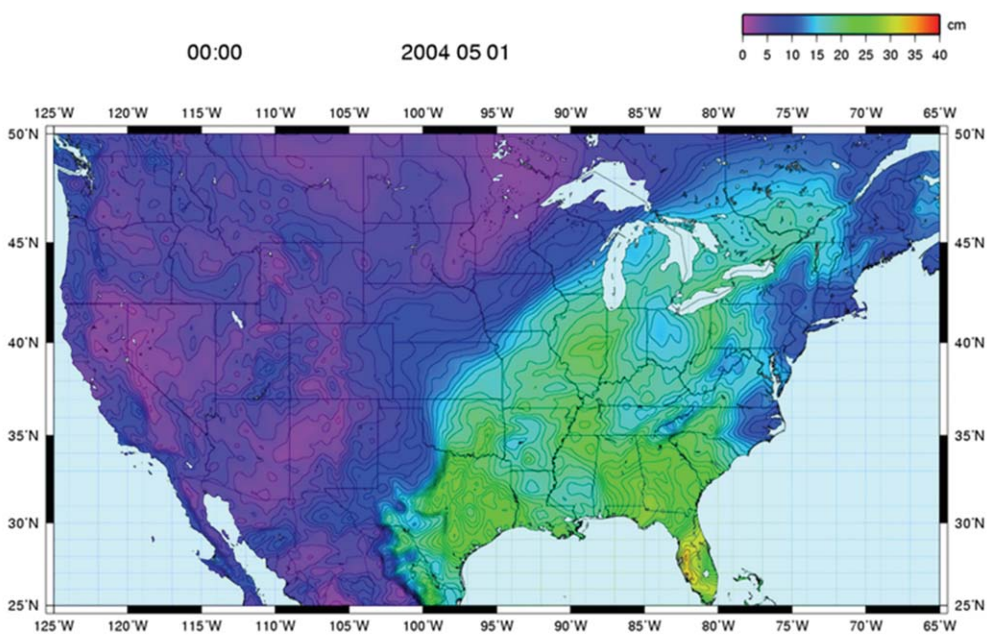


Figure 59. The wet signal delay component of the tropospheric signal delay caused by water vapor in the lower atmosphere. This wet refractivity map was derived from the NOAA 20-km RUC atmospheric model assimilating GPS observations at 300 sites across the lower 48 United States, southern Canada, and northern Mexico on 1 May 2004.

To assess the relative behavior of GPS and operational radiosondes, and determine if GPS-IPW measurements could be used to reliably detect questionable radiosonde moisture soundings, we identified 17 GPS sites within 10 km of an upper-air facility and calculated IPW differences (sonde-GPS) for one year, from 1 August 2003–31 July 2004. The radiosonde-GPS comparisons conducted for this study revealed two types of nonsystematic behaviors: the short-term recurring instances (Figure 60) and the isolated or nonrecurrng instances (Figure 61). Note that the 1200 UTC radiosonde observation (RAOB) measurements at Del Rio, Texas, from 4–8 November 2004 are about 40%–50% higher than the GPS measurements, but the 0000 UTC soundings are all within 1 mm of each other. We observed an isolated RAOB moisture problem at Lake Charles, Louisiana, on 20 October 2004 that went undetected in the numerical weather prediction mesoscale models not assimilating GPS-IPW. This problem had significant negative impact on the 0000 UTC numerical weather prediction analyses and subsequent forecasts until observations assimilated in the next cycle corrected the problem. Models assimilating GPS observations and applying quality control methods that down-weight these types of United Airline observations were unaffected.

This suggests a straightforward empirical approach to quality controlling radiosonde moisture observations: simply compare the totals. The physical basis for this is that sensor malfunctions are likely to impact the accuracy of the moisture sounding at all levels, not just those at upper levels where moisture, while exceedingly important in climate studies, is scarce. Even if we cannot anticipate the types of radiosonde moisture sounding problems encountered in this study in the future, the availability of an independent observation of comparable accuracy to radiosonde moisture soundings makes it possible to reliably identify and flag questionable moisture soundings for the first time. A real-time demonstration of this capability is underway at Sterling, Virginia, (IAD) and Caribou, Maine, in a collaborative effort with the Observing Systems Branch of the NWS Office of Operational Systems, the Science Plans Branch of the NWS Office of Science and Technology, and the GPS-Met Observing Systems Branch of FSL.

Projections

Expansion of the GPS-Met network, as resources permit, will be a major concentration during 2005. The emphasis, as always, will be on adding “backbone sites” to the network.

We will continue to work with the Forecast Research Division on the assessment of GPS impact on weather forecasts, and incorporation of GPS water vapor observations into NOAA operational models.

Importance will be placed on exploration of GPS-Met applications, especially trying to understand the events and causes of erroneously high rawinsonde moisture observations and the causes of diurnal variability in Viasala sondes in the warm months.

High priority also will be given to working with the NWS Storm Prediction Center and National Severe Storms Laboratory to produce an index that anticipates the occurrence of severe weather by monitoring the time rate of change of precipitable water.

An integral ongoing collaborative goal is to contribute to risk reduction activities related to NPOESS and GOES-R. This involves the use of GPS observations for global satellite calibration and validation, a GPS-Met application that has significant operational utility for NOAA. GPS provides a totally independent estimate of integrated moisture, and is a powerful constraint on the simultaneous retrieval of moisture and temperature from satellite radiances. To meet this goal, we will continue to work with the NESDIS Office of Research and Applications on AIRS (Atmospheric Infrared Sounder) comparisons and on GOES sounder comparisons.

Finally, we will continue to collaborate with the Space Environment Center in two areas of mutual interest. The first is development of an operational ground-based GPS observing system for space and tropospheric weather observations. The second is on the use of space and tropospheric weather models to improve lower-accuracy (10–100 cm) real-time GPS positioning and navigation accuracy.

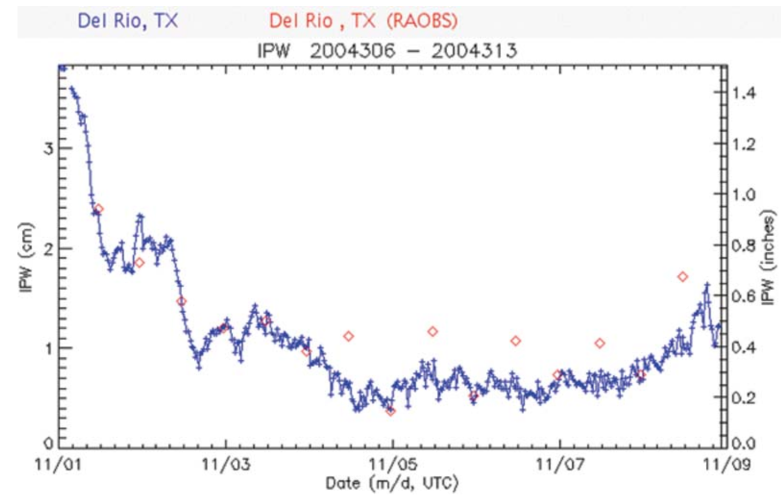


Figure 60. GPS-IPW time series at Del Rio, Texas, 1–8 November 2004. Integrated radiosonde moisture observations are plotted as red diamonds. Note the 24-hour oscillatory behavior in the radiosonde differences beginning at 1115 UTC 4 November.

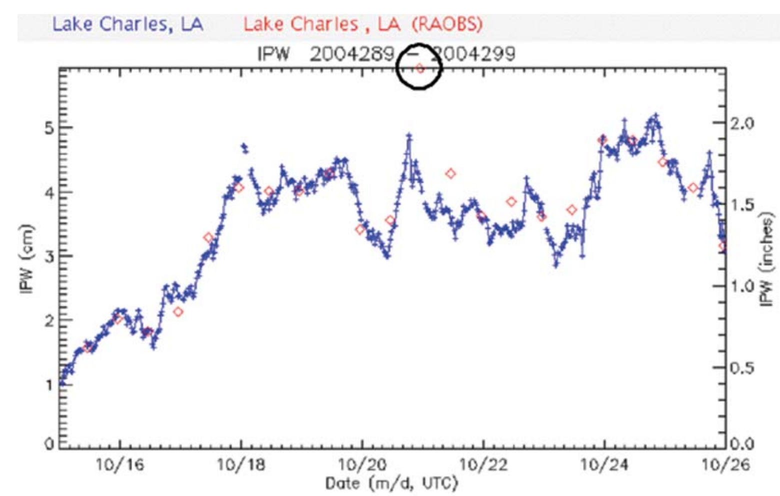


Figure 61. GPS-IPW time series at Lake Charles, Louisiana, 15–25 October 2004. An undetected problem in the 1115 UTC moisture sounding on 21 October resulted in a substantial negative impact on forecasts along the Central Gulf. Models assimilating GPS detected the problem and were unaffected.

Facilities and Systems Administration Branch

Jean Tomkowicz, Chief

Objectives

The objectives of the Facilities and Systems Administration Branch are to manage and support the Demonstration Division communications, computer, and network infrastructure. Duties involve systems operations, systems maintenance, systems administration, network administration, security activities to ensure NOAA standards, NOAA Profiler Network (NPN) telecommunications administration, and GPS-Met project support.

Accomplishments

Progress is underway toward decommissioning two micro-VAX clusters, running VMS 5.5, that have been used for processing and distributing NPN data for about 16 years. This work, to be completed late 2005, is part of a plan to modernize the NPN processing system for more robust production, backup, and development environments. The backup environment is a mirror image of the production environment. Any component of the backup environment can be implemented in place of production components when needed, providing the ability to perform routine or urgent system maintenance. Also, real-time processing can be switched to the entire backup environment if and when necessary. The development environment comprises a separate set of equipment used for software development, modification, maintenance, and testing. The processing systems in each environment are off-the-shelf PC workstations or servers usually running Red Hat Linux, except for one workstation running Microsoft Windows XP Professional in each environment that handles interprocess communication, which is being migrated to a Red Hat Linux machine. As a first step toward configuration management of the new processing system, baseline system configurations were established to ensure stability and reliability. Ongoing configuration management requires testing of system and application software installations, updates, and patches in the development environment before installing on the production and backup environments, and before creating a new system configuration baseline.

Day-to-day work includes new component installations and system configuration on the division network, network problem isolation and maintenance, system configuration modifications to meet division requirements, system problem isolation and maintenance, in-house telecommunications maintenance or coordination of contracted maintenance, peripheral installation and configuration, computer and network security, preventive maintenance, information technology purchasing, and routine file system backups. Open source monitoring software is being investigated for use within the division to increase operational uptime, and to allow a more robust method to diagnose system and network issues.

A high-availability environment is being developed for active failover services, for all systems, utilizing commercial hardware and open source software, along with in-house applications. We are reengineering and redesigning the infrastructure to allow for high-availability, greater upgrade capacities, and easier maintenance. Older hardware was replaced and services (per host) were combined.

A primary focus is computer and network security responsibilities: ensuring system and data integrity and maintaining dependable NPN and GPS-Met data acquisition, processing, and distribution. IT security and the firewall hardware implemented in the FSL network both require constant vigilance. Full-time (24/7) operations coverage is provided on normal workdays through the division staff and via pager during nights, weekends, and federal holidays.

The NPN backup data collection system keeps data availability and reliability high. The system consists of a Local Readout Ground Station (LRGS) component that constantly receives NPN data transmitted hourly via a GOES Data Collection Platform transmitter from each remote profiler site to the GOES satellite, which then downloads the data to the NESDIS Data Collection System downlink facility located at Wallops Island, Virginia. NESDIS then uplinks the data to a commercial domestic satellite, DOMSAT, which is then received by a 1.3 meter disk (Figure 62) connected to the LRGS. The LRGS software, previously running on a Redhat 7.2 Linux workstation, has been ported to Redhat Enterprise Linux 3 to ensure continued compliance with DOC security standards.

Data telecommunications responsibilities cover 36 NPN point-to-point landline data circuits within the lower 48 states and in Alaska. Thirty-five of these circuits are dedicated between the remote sites and the Profiler Hub in Boulder. One circuit is dedicated between the Hub and the National Weather Service Telecommunications Gateway (NWSTG). Investigation is ongoing to determine the viability and cost effectiveness of alternatives such as satellite-based Internet to provide future communications services. Satellite-based communications testing is ongoing at four geographically dispersed sites in order to determine performance reliability and effectiveness during varying meteorological conditions. The sites are Medicine Bow, Wyoming; Wood Lake, Minnesota; Haviland, Kansas; and DeQueen, Arkansas. Satellite-based Internet could provide excellent flexibility for adding new sites, offer greater bandwidth than existing landline circuits, and reduce communications costs by as much as 50%.

Figure 62. DOMSAT disk connected to the LRGS located on the roof of the David Skaggs Research Center in Boulder.

Projections

We will maintain current operations and ensure continuous and dependable acquisition, processing, and distribution of NPN and GPS-Met data to all customers. Development and testing of the modernized NPN processing system will continue. IT security is a necessary and ongoing commitment, as is continuous updating of security patches. Various archival systems for our data are being investigated. Alternative communications options will be evaluated for NPN and GPS-Met data acquisition and remote system control, with the goals of increasing bandwidth and reducing future communications costs. Plans for reconfiguration (Figure 63) of the computer room are underway to accommodate the removal of the VAX computer systems. During the next year, power and cooling needs will be reevaluated as well as reconfiguration of the system areas.

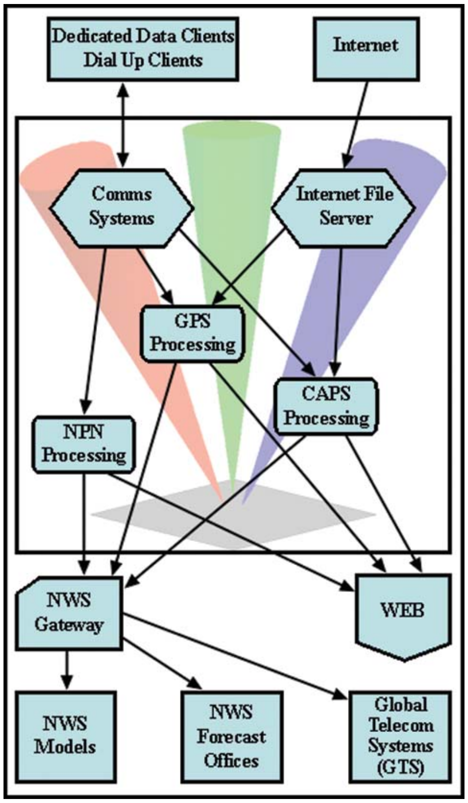


Figure 63. Demonstration Division systems configuration (right).

Systems Development Division

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Objectives

The Systems Development Division (SDD) performs exploratory development of advanced system concepts and technology for meteorological display systems, and works closely with other FSL divisions in transferring these into operations. Past explorations have included investigation of new techniques for user interfaces, data display, system architectures, and software design and programming. The most recent exploratory work includes the use of Linux for meteorological workstation development, interactive 3D data visualization, and graphic tool development for remote collaboration. SDD develops operational prototype systems using these new techniques and technologies, and performs limited operational evaluation and testing of these systems. In collaboration with other FSL groups, we extend these prototype systems and incorporate capabilities developed in other divisions to meet the operational needs of forecasters. Customers of these systems are domestic agencies such as the National Weather Service (NWS) and the U.S. Air Force (USAF), and international organizations such the Taiwan Central Weather Bureau (CWB) and the Korean Meteorological Administration (KMA).

Another focus is the development of scientific applications for these meteorological display systems. A key activity is the development of advanced analysis and quality control techniques for real-time observational data. The objective is to provide real-time observations, dependable quality control information, and the necessary tools to access and view the data. The Quality Control and Monitoring System (QCMS) provides users and suppliers of hydrometeorological observations with readily available quality control statistics. Two surface assimilation systems, the MAPS Surface Assimilation System (MSAS) and the Rapid Update Cycle Surface Assimilation System (RSAS), provide direct measurements of surface conditions and give crucial indicators of potential for severe weather. In addition, the Meteorological Assimilation Data Ingest System (MADIS) provides quality-controlled observations and data access software to university and government data assimilation researchers.

FSL's continuing support to AWIPS includes an exploratory development project called FX-Collaborate (FXC), which provides interactive features such as drawing and annotation tools, a chatroom, and a capability for sharing local datasets between sites. FXC applications include weather briefings to emergency managers, interoffice/interagency coordination, Web weather chart creation, and training.

The Systems Development Division comprises three branches and one group:

Advanced Systems Development Branch – Designs and develops interactive weather display systems for operational use and prototype systems for operational demonstration.

Scientific Applications Branch – Develops and implements scientific software systems designed to improve weather forecasting by taking advantage of opportunities offered by recent advances in meteorological observations and information systems.

System Evaluation and Support Branch – Provides software testing, configuration management, and support services to the division that include staging of major new systems and assisting project leaders with their data and display needs.

NWS Projects Group – Conducts research and develops technology for the exchange of critical weather information among all of the NWS offices, and between the NWS and the community.

Advanced Systems Development Branch

Darien Davis, Chief

Objectives

The Advanced Systems Development Branch (ASD) designs and develops software that enables weather forecasters to display and interpret meteorological data, and efficiently monitor and control the functions of ingest and display systems. State-of-the-art hardware and software technology is explored, while also supporting operational National Weather Service (NWS) systems.

Accomplishments

FX-Advanced/AWIPS

During 2004, we continued to work with NWS on the AWIPS (Advanced Weather Interactive Processing System) two-dimensional meteorological display (D2D) and text components of the AWIPS Weather Forecast Office (WFO) system. AWIPS Operational Builds (OBs) 3, 4, and 5 were addressed, as discussed below. A major component of development included the introduction of the Valid Time Event Code (VTEC) to the watch/warning/advisory statements issued by WFOs.

AWIPS OB3 was deployed to most NWS field offices in spring 2004. The key features that FSL developed include:

- Ingest and display of tropical cyclone marine products for WFOs with marine and coastal responsibilities. These data provide a guidance product to assist with forecasting tropical cyclone events.
- Many new radar Volume Coverage Patterns (VCPs), and a schema to store and retrieve those datasets.
- New radar products to display the digital vertically integrated liquid water (VIL), enhanced echo tops, and the digital storm total precipitation products.
- Ingest and display of the scatterometer winds from the QuikSCAT sensor on the NASA polar-orbiting satellite.
- Delivery of the first VTEC software for WarnGen to the field. (More details on VTEC are available in the Modernization Division section of this document.)
- Infrastructure changes for porting to the gcc3.2.3 compiler, functional changes for fading between images, and an enhanced VAD (Velocity Azimuth Display) wind profile display.

AWIPS OB4 was installed at most NWS field offices in 2004. The key features that FSL developed include:

- New radar products that display the Tornado Rapid Update and the Mesocyclone Detection Algorithm.
- Infrastructure changes such as computer security upgrades for creating individual user accounts so that forecasters can launch the various AWIPS graphical user interfaces for visualization tools. The ASD Branch vetted the software, and developed additional user interface tools to assist with this transfer.

Development for AWIPS OB5 was completed late last summer, and the software was readied for deployment in early 2005. The main OB5 upgrade involved new radar VCPs.

Other Projects

Range Standardization and Automation (RSA) Project – As part of the Air Force Range Standardization and Automation (RSA) project, FSL works with Lockheed Martin to provide an AWIPS-like weather workstation that supports space launch operations. During 2004, additional local datasets were added to the RSA Build 5.2.2 system, with the focus on products that support lightning display and detection. The system integrates three types of lightning displays: a field mill instrument outputting electric voltage, a local lightning position analyzer, and a lightning detection system. It can integrate a real-time dataset with a 3D display of the lightning detection output. More than 30,000 points can be detected every minute, which requires a display within seconds of the database population. Though integration of this system into the AWIPS software used for deployment proved quite challenging, the tasks have been completed and it is undergoing tests and upgrades along with the new AWIPS builds. FSL received the NOAA Technology Transfer Award for its contributions to the RSA project.

Advanced Linux Prototype System (ALPS) – During 2004, FSL developed the ALPS software to assist in the transition of field systems from Hewlett-Packard workstations and servers to Linux PCs. Meetings were held with Northrop Grumman personnel in charge of deploying AWIPS, and FSL did exploratory work on new architecture concepts and a roadmap for technology infusion for the NWS. The targeted end-system from this roadmap has been staged at FSL, and is heavily used for testing new database functions and a new data paradigm for the NWS. FSL allows users from NOAA offices in Silver Spring, Maryland, access to this system to help accelerate integration for the AWIPS OB6 development.

Northrop Grumman – A brief contract with Northrop Grumman Information Technology included porting event-server software to Linux and adding a more sophisticated purging schema for AWIPS. These software changes will help accelerate removal of aged Hewlett-Packard systems from the AWIPS sites as well as enhance performance.

Projections

FX-Advanced/AWIPS

The Advanced Systems Development Branch will continue to provide support to the National Weather Service during the fielding of AWIPS OB4 and OB5, and development and testing of OB6. The key development tasks will include implementation of new VTEC warning support, and ingest of Terminal Doppler Weather Radars. In addition, system performance issues will continue to be addressed.

Other Projects

ALPS – After completing tests of a full Linux-based WFO architecture, it will be deployed at the Boulder NWS office in 2005. An important aspect of this project is collaboration with laboratories that contribute to the AWIPS baseline architecture, and demonstration of the enhanced performance gains from this hardware technology infusion.

RSA – We will install software based on AWIPS OB4 at the U.S. Air Force Ranges, and assist Lockheed Martin with installation and testing. Two other related tasks include the continued development of additional functionality (such as archiving and new data displays), and the provision of user training and documentation.

Scientific Applications Branch

Patricia A. Miller, Chief

Objectives

The Scientific Applications Branch was established to develop and implement scientific software systems designed to improve weather forecasting by taking advantage of opportunities offered by recent advances in meteorological observations and information systems. Support is provided for the AWIPS Mesoscale Analysis and Prediction System (MAPS) Surface Assimilation System (MSAS), the NCEP Rapid Update Cycle (RUC) Surface Assimilation System (RSAS), and FSL's Meteorological Assimilation Data Ingest System (MADIS).

MSAS and RSAS

The MSAS and RSAS exploit the resolution of surface data by providing timely and detailed gridded fields, or analyses, of current surface data. Surface analyses are critical to weather forecasting because they provide direct measurements of surface conditions, permit inference of conditions aloft, and often give crucial indicators of the potential for severe weather. MSAS runs operationally at modernized NWS Weather Forecast Offices (WFOs) as part of the AWIPS workstation. RSAS runs operationally at the National Centers for Environmental Prediction (NCEP), and also runs quasi-operationally in the FSL Central Facility to provide backup to the NCEP system.

As surface analysis-only systems, MSAS and RSAS have the advantages of speed and closer fit to the observations. The systems produce one-level, analysis-only grids and, therefore, require very few compute resources. Also, because the systems do not initialize a forecast model, their analysis is performed on the actual surface terrain and not along a model topography. Hence, no model surface-to-station elevation extrapolations are required, all surface observations may be used, and the fit to the observations is maximized. In addition, MSAS and RSAS incorporate elevation and potential temperature differences in the correlation functions used to model the spatial correlation of the surface observations, which help to take into account physical blocking by mountainous terrain, and improve the representation of surface gradients.

Stations typically ingested by MSAS and RSAS include Meteorological Aviation Reports (METARs), Surface Aviation Observations (SAOs), Coastal Marine Automated Network (C-MAN) observations, surface reports from fixed and drifting buoys, ships, and the NOAA Profiler and Ground-based GPS Networks, as well as surface observations from available local mesonets and the NWS modernized Cooperative Observer Program (COOP) network. Sophisticated quality control techniques are employed to help screen the surface observations. On AWIPS, the results of these techniques are passed to the AWIPS Quality Control and Monitoring System (QCMS).

MADIS

MADIS was established at FSL for the purpose of supporting meteorological research and operations by sharing observations and observation-handling technology with the greater meteorological community. Observations are essential to all areas of weather analysis and prediction. When viewed by trained forecasters, for example, they provide a direct indication of the current atmospheric conditions and enable the forecasters to detect and follow weather disturbances and to interpret critical detail about the formation and movement of major meteorological phenomena such as precipitation, severe storms, and flight-level turbulence. Observations also form the initial conditions for data assimilation systems which produce the objective, numerical weather prediction outputs heavily used in all areas of weather forecasting. Outside the world's major meteorological centers, however, easy access to these observations has not always been readily available. To fill this need, MADIS was established to make value-added data available from FSL's Central Facility with the goal of improving weather forecasting, by providing support for data assimilation, numerical weather prediction, and other meteorological applications and uses.

Observations in the database are stored with a series of flags indicating the quality of the observation from a variety of perspectives (e.g., temporal consistency and spatial consistency), or more precisely, a series of flags indicating the results of various quality control (QC) checks. Users of MADIS can then inspect the flags and decide whether or not to ingest the observation.

MADIS also includes an Application Program Interface (API) that provides users with easy access to the observational information. The API allows each user to specify station and observation types, as well as QC choices and domain and time boundaries. Many of the implementation details that arise in data ingest programs are automatically performed. Users of the MADIS API, for example, can choose to have their wind data automatically rotated to a specified grid projection, and/or choose to have mandatory and significant levels from radiosonde data interleaved, sorted by descending pressure, and corrected for hydrostatic consistency.

Accomplishments

MSAS and RSAS

Staff in the Scientific Applications Branch released several versions of MSAS and RSAS in 2004 to support the operational requirements of the NWS at NCEP and on AWIPS. The new versions included an AWIPS OB4 Linux port, improved program synchronization and error handling, and the separation of mesonet and COOP observations into two distinct datasets. Work was also completed on the development and configuration of high availability (HA) pairs for many of the components of the RSAS system running in the FSL Central Facility. The HA pairs are used to increase reliability by providing redundant hot backups for the key processing components, and by guaranteeing that a secondary computer will immediately detect the failure of a primary computer.

Work also continued on the testing of the QCMS Browser, a new AWIPS software package for the display of observation QC results produced by MSAS for the AWIPS QCMS. The QCMS has been running at WFOs as part of the AWIPS workstation, since 1999, to provide forecasters and suppliers of hydrometeorological observations with quality control information and statistics. Two types of automated QC checks are utilized: static checks, which are single-station and single-time checks such as validity checks; and dynamic checks that take advantage of other hydrometeorological information, such as temporal and spatial consistency checks. The QCMS also provides the capability for users to override the results of the automated checks through subjective intervention procedures, and keeps hourly, daily, weekly, and monthly statistics on the frequency and magnitude of the observational errors encountered for all surface stations ingested into AWIPS.

The new user interface for the QCMS, called the QCMS Browser, is an integral part of the AWIPS D2D (Display Two Dimensional) component, and will enhance QCMS capabilities by implementing an interactive text and graphics display system to improve QC visualization and subjective intervention. Users of the QCMS Browser can select all or portions of the AWIPS QC information provided by MSAS and display the information on D2D as plan view and/or time series plots, or also see the same information in tabular form on the user interface. Overall, the Browser allows NWS personnel easy access to the QCMS information for the purposes of 1) monitoring station performance;

2) locating persistent biases or failures in surface observations; 3) evaluating observation/QC accuracy; and 4) subjectively overriding QC values. In 2004, SAB personnel continued to work with the NWS on the testing of the AWIPS QCMS Browser in an operational environment. Initial versions of the Browser are now installed at nearly a dozen WFOs for evaluation purposes. Figure 64 shows QCMS Browser-produced AWIPS displays detailing the detection and correction of a persistent bias in the sea-level pressure observations reported by a METAR station in Ypsilanti, Michigan. The QC statistics gathered before the correction indicated that the Ypsilanti sea-level pressure observations failed the QC checks 100% of the time, and exhibited persistent RMS and mean errors of approximately 2.1 mb. After the observations were corrected, both the errors and the percentage failure fell to zero.

MADIS

MADIS supports observation distributions to many government, research, and education institutions, as well as private companies. Organizations already receiving MADIS datafeeds include NWS forecast offices, NCEP, the National Center for Atmospheric Research, the National Ocean Service, NASA's Marshall and Kennedy Space Flight Centers, the Massachusetts Institute of Technology Lincoln Laboratory, and several universities, meteorological companies, and local government agencies. MADIS subscribers have access to a reliable and easy-to-use database containing real-time and archived datasets available via either ftp or by using Unidata's Local Data Manager (LDM) software.

In 2004, access to the MADIS database through a text/XML Web interface was added as a distribution mechanism, and the MADIS API was upgraded to include XML-formatting capabilities for surface datasets. Aircraft profiles at airports and satellite wind datasets were added to the MADIS database. The satellite wind dataset consists of multiple wind products from different satellites that are integrated into a single dataset at FSL. Currently these products consist of data from the GOES satellites, and include 3-hour winds that are produced on an operational basis by NESDIS, as well as rapid scan experimental winds that are produced hourly. Work was also begun on the ingest and QC procedures necessary to add Tropospheric Airborne Meteorological Data Reporting (TAMDAR) system data to the MADIS aircraft dataset.

In addition to the new datasets, over 2,600 new stations were added to the existing MADIS mesonet dataset, a unique collection of surface stations provided by local, state, and federal agencies and private firms. Major contributors to the mesonet dataset are AWS Convergence Technologies, Inc.; the NOAA Cooperative Institute for Regional Prediction at the University of Utah, which provides MesoWest data from the Cooperative Mesonets in the Western United States; the Boulder NWS Forecast Office, which provides mesonet data from the local Denver/Boulder area; and also data from the Remote Automated Weather System (RAWS) network run by the National Interagency Fire Center, and volunteer citizen weather observers who report observations from commercially available weather stations through the Amateur Radio Operators Automated Position Reporting System. New data providers include the Wisconsin Department of Transportation, the West Texas Mesonet, Louisiana State University, Mississippi State University, and the Colorado E-470 Public Highway Authority.

Work with the NWS to ingest, integrate, quality control, and distribute observations from the modernized COOP network was also continued. In 2004, ingest was added for COOP Phase II stations, which include observations from several different types of data loggers distributed from two separate processing centers.

With the new observations added in 2004, MADIS now supports standard maritime and land surface observations, such as METARs, SAOs, C-MAN, ship, and buoy observations, as well as observations from the modernized COOP network and mesonet observations from over 14,500 surface stations. Upper-air observations supported by MADIS include satellite winds, radiosonde and radiometer observations, automated aircraft reports, wind profiler data from the NOAA Profiler Network (NPN), and multiagency profiler data contributed by a number of different organizations such as the Environmental Protection Agency, NOAA research laboratories, and several major universities. The

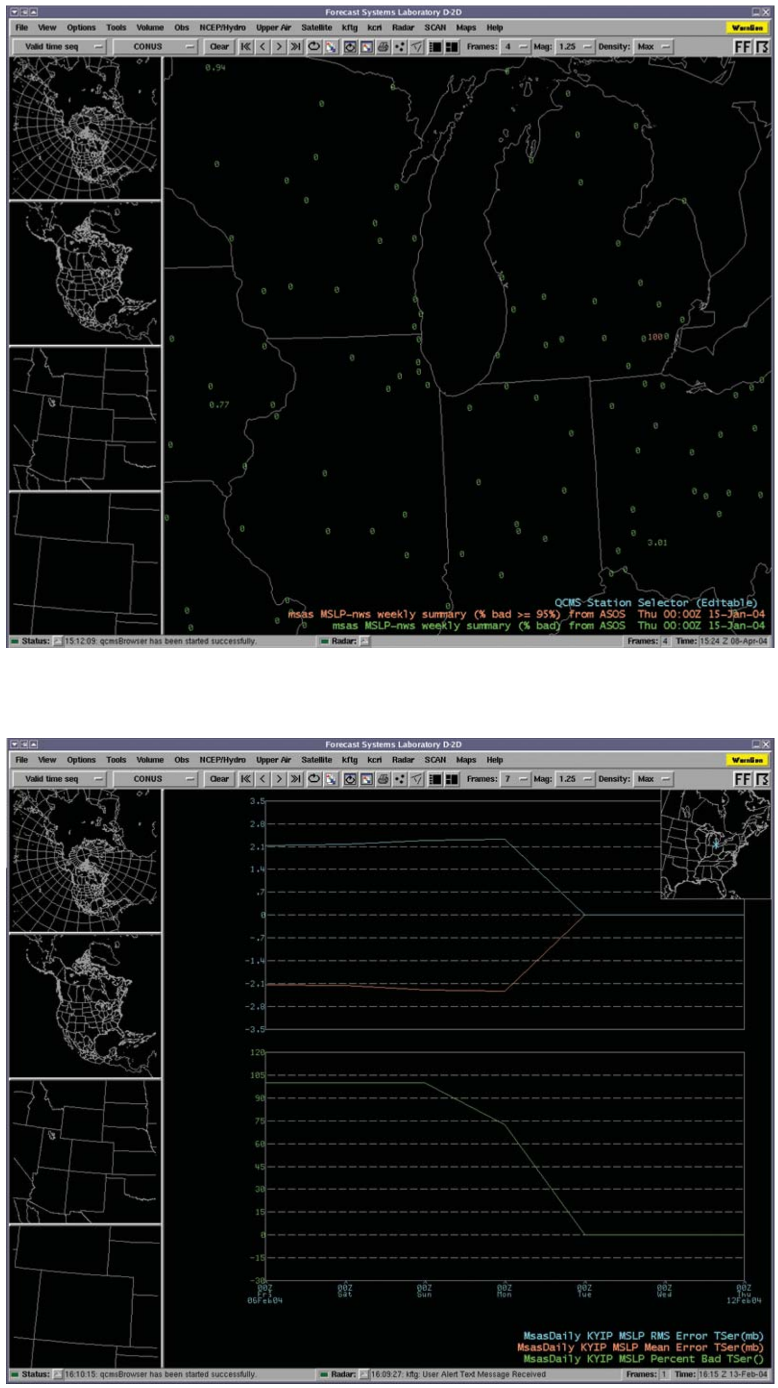

Figure 64. QCMS Browser-produced AWIPS displays detailing the detection and correction of a persistent bias in the sea-level pressure observations reported by a METAR station in Ypsilanti, Michigan. a) plan view display of the weekly percentage of QC failures indicating a 100% failure for the Ypsilanti sea-level observations before NWS personnel were alerted to the problem. Percentage failures above 95% are highlighted in red. b) time series display of the daily RMS (blue) and mean (red) errors for the observations, and the percentage failure (green) over the days both before and after NWS personnel corrected the problem. The QC information before the correction indicated a persistent RMS and mean errors of approximately 2.1 mb and a continuous failure rate near 100%. After the observations were corrected, both the errors and the percentage failure fell to zero.

latter dataset is supported by MADIS as a joint effort with the Cooperating Agency Profiler (CAP) project in FSL's Demonstration Division, and consists largely of data from 915 MHz boundary layer profilers.

MADIS data files are compatible with AWIPS, with the FX-Net workstations developed by FSL's Technology Outreach Division, and with the analysis software provided by the FSL Forecast Research Division's Local Analysis and Prediction System (LAPS). In 2004, we also completed two version upgrades for the MADIS software interface to the data ingest system of the community-developed Weather Research and Forecasting (WRF) Model 3D-Variational (3DVAR) Data Assimilation System. By downloading and installing the MADIS WRF 3DVAR interface, users of the WRF 3DVAR packages can now ingest MADIS observations supplied by FSL directly into the 3DVAR analysis.

The FSL MADIS database and API are freely available to interested parties in the meteorological community. For more information on MADIS, or to apply for a real-time MADIS datafeed, or access to the MADIS online archive (which supports observations from 1 July 2001 to the present), see *http://madis.noaa.gov*. Also available to NWS WFOs are instructions on how to ingest and display MADIS datasets on their AWIPS systems.

Figures 65 and 66 show all of the MADIS observations available for a 1-hour period over the Northeast region of the country.

Projections

During 2005, the Scientific Applications Branch will continue to support NWS staff in the operational implementation of the MSAS and RSAS systems. Development of new capabilities, including the implementation of the QCMS Browser on AWIPS, will also be supported.

We will also continue to add observations and capabilities to MADIS. Emphasis will be on increasing the number of observations in the mesonet database, working with the FSL Demonstration Division to continue support for multiagency profiler data, and continuing support to the NWS in their COOP modernization efforts.

In 2005, MADIS will also support the Great Lakes Fleet Experiment to be conducted jointly by NOAA, NASA, Airdat Inc., Mesaba Airlines, and the FAA by ingesting, quality controlling, and distributing TAMDAR data to the NWS Weather Forecast Offices and other organizations.

Access to MADIS will continue to be provided through the Web interface which provides the forms necessary to request real-time and archived data, and also allows users to download the MADIS API, a "README" installation guide, documentation, and sample programs and data.

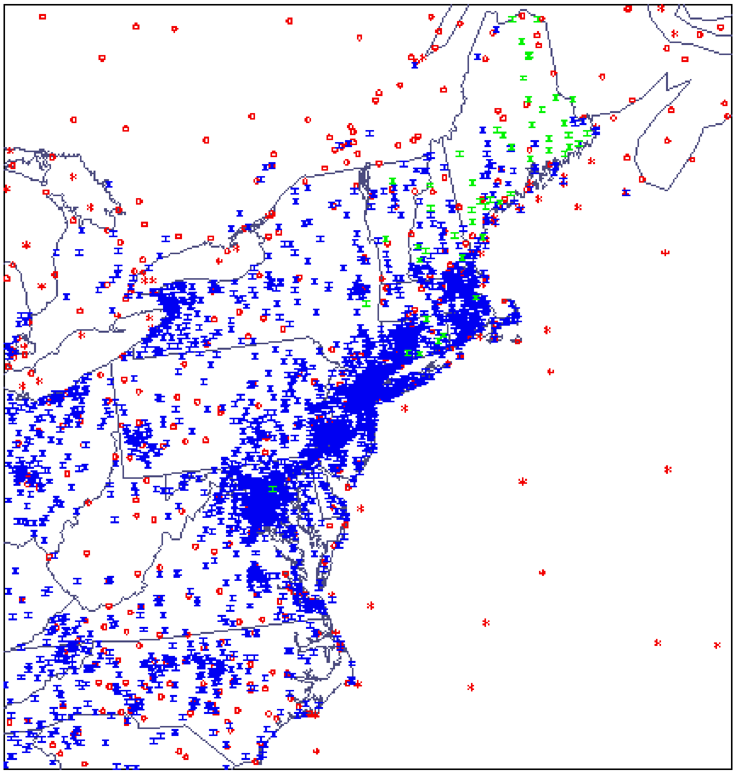

Figure 65. MADIS surface observations available in a 1-hour period over the Northeast region of the United States. METAR and maritime observations are shown in red, modernized COOP stations in green, and other-agency mesonet observations in blue.

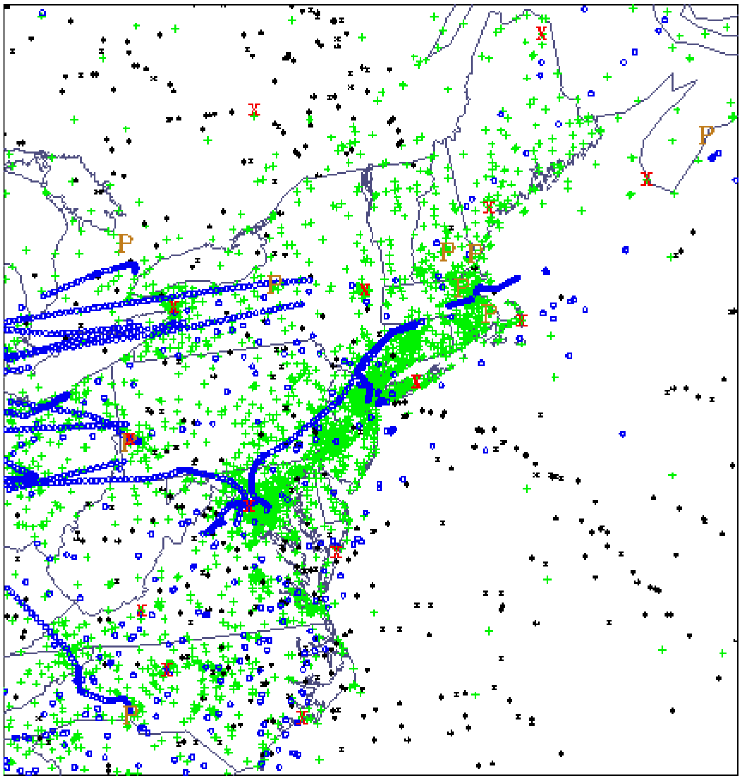

Figure 66. MADIS observations available in a 1-hour period over the Northeast region of the United States. Surface observations are shown in green, aircraft observations in blue, satellite winds in black, profiler locations in orange, and radiosonde launch points in red.

System Evaluation and Support Branch

Joseph S. Wakefield, Chief

Objectives

The System Evaluation and Support Branch provides testing, configuration management, and support services for the Systems Development and Modernization Divisions.

Accomplishments

During 2004, development versions of AWIPS Operational Builds (OBs) 3, 4, and 5 were installed on FSL test systems. The development cycle for each OB includes receipt of requirements from the National Weather Service (NWS), preparation and review of a design approach for each requirement (including user interface issues, when appropriate), development of the software and test plans, testing, refinement of the software, and system and user documentation of the capabilities. We continue to participate in the design/UI review and documentation tasks, and develop and execute test plans. The AWIPS test plans are also used at NWS and Northrop Grumman Information Technology (NGIT), the AWIPS prime contractor.

In each cyle, we install and test numerous iterations of each OB as development proceeds. In each case, we test two types of systems: one like the current NWS field installation, on mixed Hewlett Packard and Linux equipment, and one on an all-Linux set of machines, representing the future AWIPS field architecture. FSL also maintains a field-release system, connected to the NWS AWIPS Wide Area Network, on which is run an official copy of the AWIPS software. This is used to verify documentation, investigate problems reported by users, and test patches.

A staff member serves as FSL's liaison to NGIT/NWS, and performs duties that involve tracking problems discovered during AWIPS testing, maintaining our local software development environment, and keeping file versions synchronized between FSL and NGIT/NWS software repositories.

We continued support activities in 2004 for the U.S. Air Force Range Standardization and Automation (RSA) program and a customized AWIPS setup for the Johnson Spaceflight Center. Space launch operations at Cape Canaveral are critically dependent on a variety of atmospheric conditions – wind, rain, clouds, and electrical activity. The display shown in Figure 67 is used by Launch Weather Officers to monitor electric potential measured by instruments known as field mills. The user can select a launch pad, distance, time window, and measurement thresholds, and receive alerts if launch criteria are exceeded. In this example, the sites being monitored are highlighted in yellow, with those exceeding or having exceeded the limits in red.

A branch member served on a team that designed the layout of the NOAA exhibit space at the 2004 American Meteorological Society Annual Meeting. In addition to coordinating the collection, shipping, and setup of all FSL equipment and furnishings, this included working with AMS and Convention Center staff to assure that all power and data communication requirements were met.

Other tasks carried out during the past year concern systems administration functions, such as overseeing hardware installations and maintaining and updating the utility and operating system software on computers used by Systems Development and Modernization Division staff. Some user machines in these two divisions were upgraded to Red

Hat Linux v9 or Fedora, while many stayed at RH 7.2, which is the version still used at NWS field offices. Our Systems Administration staff applied security patches and other upgrades as necessary to allow development work to continue at high efficiency. We also maintain the configuration files for our data ingest machines in order to deliver appropriate data to our test systems, and occasionally assist other FSL divisions by providing temporary data feeds for special projects, testing, etc.

Projections

As the NWS continues to move functions from the aging Hewlett Packard systems to new Linux servers, FSL will support and lead the effort with our development and test systems. To assist with testing and field support, we will continue to update our software as new AWIPS releases are made available by NWS. With OB 6, NWS plans to migrate to Red Hat Enterprise Linux 3 and the PostgreSQL database; much of the configuration and testing accompanying these changes will be carried out by our staff.

During 2005, new software repositories will be created for AWIPS OB6 and OB7 development. We will support the development, testing, and documentation of these OBs as described above, with OB6 testing and predeployment support occupying the first half of the year, and OB7 testing expected to commence in early summer.

The Air Force has specified Red Hat Advanced Server 2.1 as the RSA operating system, so we will install that version on our RSA development systems and test the new configuration. We will also migrate the RSA software to merge in AWIPS OB4 capabilities, which will require time for the merge and build, testing, and documentation.

For the American Meteorological Society Annual Meeting in San Diego, we will again help to coordinate the FSL and NOAA exhibits at the trade show.

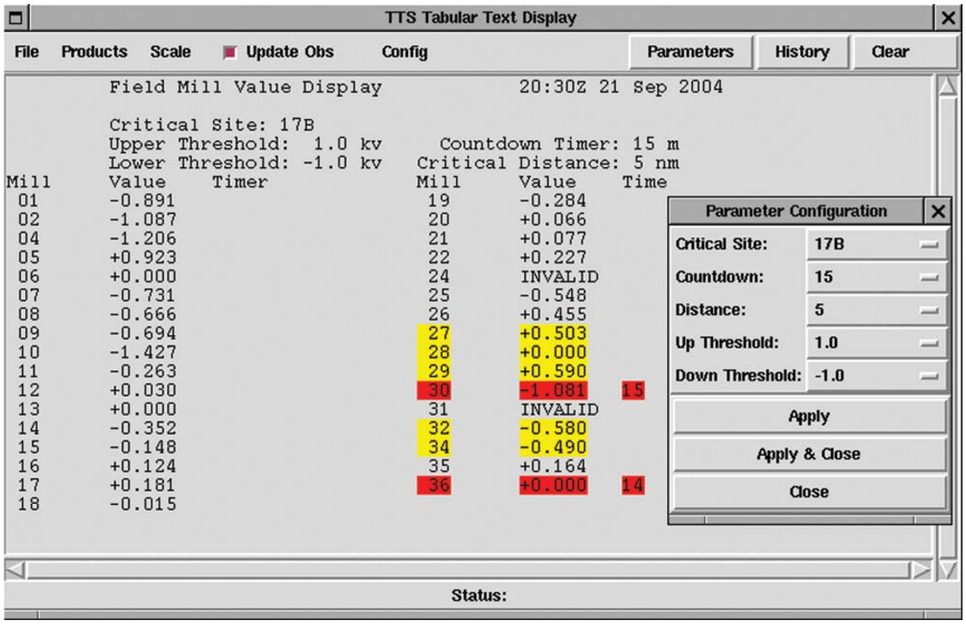

Figure 67. This display example is used by Launch Weather Officers to monitor electric potential measured by instruments known as field mills. The sites being monitored are highlighted in yellow, with those exceeding or having exceeded the limits in red.

NWS Projects Group

Richard T. Jesuroga, Lead

Objectives

The NWS Projects Group conducts research and develops technology for the exchange of critical weather information among the National Weather Service (NWS) Weather Forecast Offices (WFOs), and federal, state, and local governments. This team explores evolving technologies that can be used to disseminate critical weather information to the emergency management community and the public.

Our current focus encompasses three new types of weather dissemination systems. The FX-Collaborate (FXC) application supports shared awareness of critical weather situations among numerous remote users. As an interactive meteorological display system, FXC provides users access to a variety of meteorological data stored in remote AWIPS databases, on Web servers, and on local disks. Its strength is its ability to interlink a number of remote systems to conduct real-time weather briefings, live meteorological discussions, or long distance learning through its collaborative capabilities. Another area of exploratory research involves dissemination of life threatening warnings via reverse 911 telephone calls from WFO forecasters. Reverse 911 telephone technology is rapidly evolving in the U.S. with the goal to provide a quick means of disseminating information about severe life threatening weather events. We explore how NWS might some day integrate reverse 911 technology into the AWIPS warning function. Finally, a "City Escape" demonstration project is underway to learn more about how drivers in highway traffic respond to an emergency threat. We are developing a model to determine optimum routing solutions for a citywide evacuation before severe weather events occur.

Accomplishments

FX-Collaborate (FXC) – With FSL assistance, the Texas Department of Public Safety and the NWS Southern Region Headquarters implemented the FXC workstation as their weather display and coordination tool to facilitate collaboration with the NWS during severe weather situations. Redundant FXC servers have been installed at NWS Southern Region Headquarters that provide weather information to FXC client systems at Denton, Texas, and other state emergency management offices. A temporary server was set up at FSL to test various aspects of network security and to allow system preparation and testing.

An increasing number of NWS offices are also using FXC to meet their graphical annotation requirements. Of particular interest is FXC's ability to access real-time data in the AWIPS database, annotate the meteorological display, and then create JPEG images. The Norman, Oklahoma, WFO and others have used this capability very effectively to generate Web displays during severe weather situations.

Reverse 911 Dissemination – The NWS has increased its tornado warning lead time from 7 to 14 minutes; indeed, warning lead times of up to 26 minutes have been achieved during tornado outbreaks. As warning areas get smaller and lead times improve, a new targeted call-for-action warning using reverse 911 telephone technology should be positioned to help save lives. Various proof-of-concept experiments have been conducted to determine how targeted warnings and reverse 911 technology can be used in future AWIPS software releases. These experiments centered around the basic concept that specific residences and businesses in the direct path of a life threatening weather event (such as a tornado or a flash flood) could be targeted by a forecaster for a reverse 911 call-to-action message. The message would contain information on what action should be taken to avoid injury or death in a severe weather event. In this research, we explored how well AWIPS state-of-the-art warning systems match up with leading edge reverse 911 technologies. If it takes 20 minutes to make outbound calls to all the addresses in the warning area and the warning lead time is 15 minutes, obviously that would be unacceptable. The issues here involve how to "target" warning areas at specific locations, improve warning lead time, and improve the nation's communications infrastructure to maximize the number of calls per minute from a high-capacity outbound calling platform. Several test case scenarios were performed to determine the relationship between a life threat warning area and the number of minutes needed to complete the outbound callout. To perform these experiments, FSL contracted with Intrado Inc., located in Longmont, Colorado, (close to the FSL campus). Intrado maintains the nation's 911 address/telephone number database, and provides reverse 911 services to the community.

During our experiments, forecasters would draw a targeted tornado warning area (much smaller than a typical severe thunderstorm warning area) on their AWIPS workstation, and the system identified the specific addresses/telephone numbers located in the warning box. A verbal test message was used for reverse 911 callout to the public within the targeted area. The table below shows the results from several trials.

Table 1. Results of Reverse 911 Experiment.

Event ID	Number of Telephone Numbers	Time Started	Time Ended	Duration	Messages Delivered	Message Length	Call Attempts	Number of Retries if Busy
1828	2,294	17:21:11	17:25:56	00:04:45	1,682	32 sec	6,882	5
0031	72,567	17:03:21	18:39:41	01:36:20	43,740	30 sec	150,260	3
4609	20,975	16:49:10	17:06:00	00:16:50	4,647	28 sec	43,591	3
3140	424	11:45:36	11:51:13	00:05:37	299	24 sec	599	2
5030	3,430	12:01:09	12:04:02	00:02:53	1,433	24 sec	5,828	2

As the table above shows (under "Duration"), there is much variation in the time it takes to complete reverse 911 outbound calls. This is due to the size of the warning box, which helps to determine the number of addresses/telephone numbers captured, the population density within the warning area, and the time it takes to search the 911 database, given population density and size of the warning area.

City Escape – The release of an airborne toxic substance in a large metropolitan area could kill hundreds of thousands of people in only a few hours. A disorderly reaction to a toxic release could result in an immediate gridlock of the transportation system, leaving the city population exposed to an airborne hazard. It is possible with current technology to design and implement an emergency notification system that would allow orderly evacuation, in which those residents most threatened are evacuated first, and all individuals are given specific actions that will minimize their chances of death or injury. The purpose of this project is to explore concepts of how the creation and dissemination of location-specific instructions for all citizens of a city in such an emergency can be used to provide optimum demand/capacity routing of the transportation infrastructure. Various features of the prototype system under development are shown in Figures 68–70.

Projections

The NWS Projects Group will perform various activities to validate the utility of the FX-Collaborate workstation to coordinate federal, state, and local government response for public safety. We plan to integrate FXC collaboration and reverse 911 public notification technologies into the Geo-Targeted Alerting System (GTAS) for the Department of Homeland Security (DHS). GTAS will be developed as a joint NOAA-DHS project to demonstrate how the NOAA nationwide public warning infrastructure can support DHS operations in the event of a biological, chemical, or radiological release in the National Capital Region (proof-of-concept area). AWIPS is ideally suited for this project, and as the primary forecast and warning system for NOAA, it will serve as the backbone for GTAS. Other technologies that are being considered for integration into GTAS include the Meteorological Assimilation Data Ingest System (MADIS) developed by FSL, the HYSPLIT dispersion model developed by ARL, and the NOAA Weather Radio. Performance data collected from this one-year demonstration project will give both agencies the information necessary to define future deployments and follow-on projects.

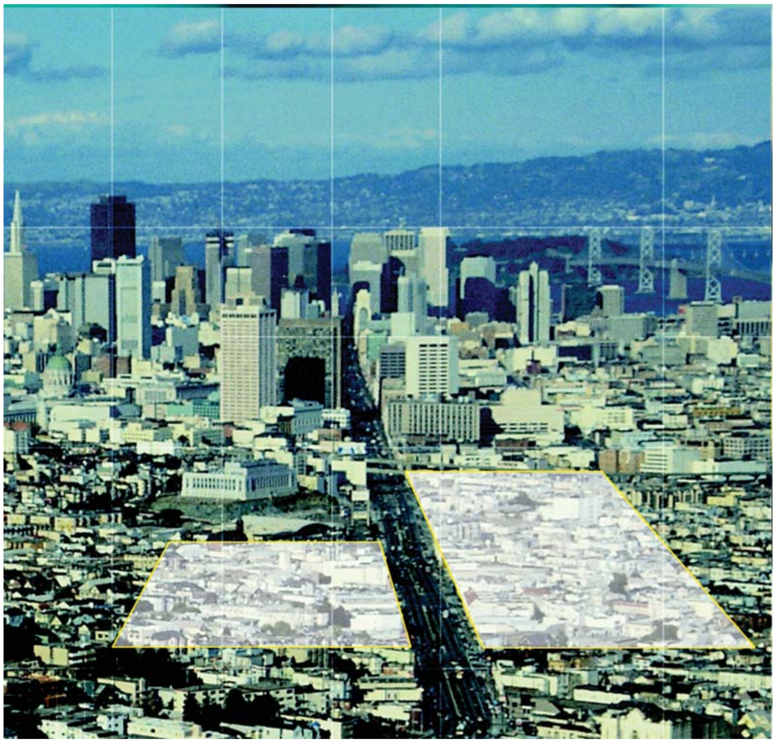

Figure 68. creen from FSL's City Escape prototype system highlighting targeted areas for notifying a designated population of evacuation in case of a toxic release.

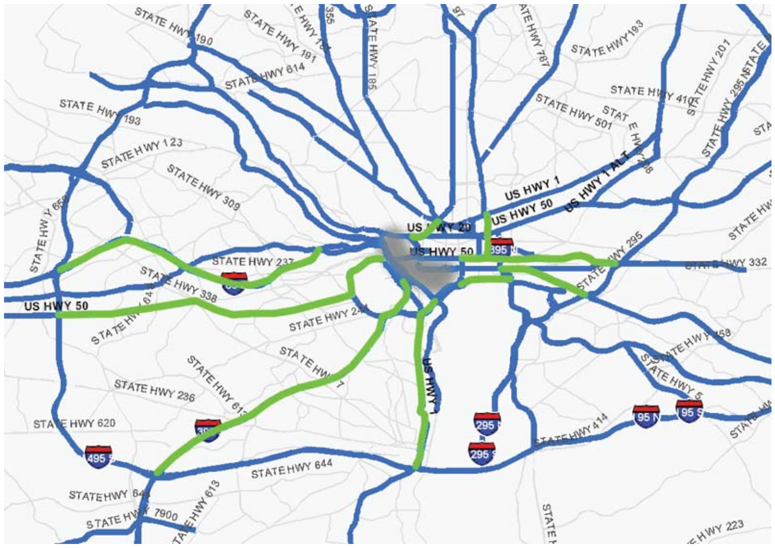

Figure 69. Graphical image of a simulated toxic cloud (gray) in the Washington, D.C., area with escape routes highlighted (green).

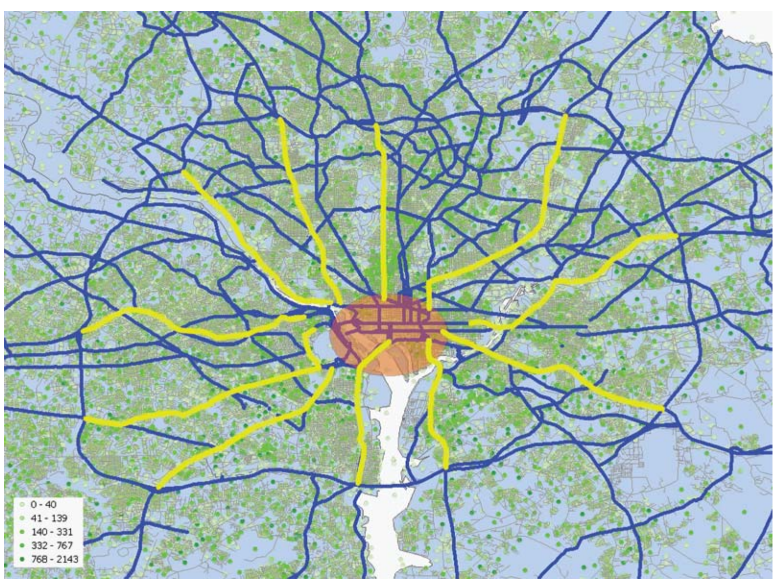

Figure 70. Same as above except for population density (lower left side) and additional City Escape routes (yellow) overlaid on existing traffic routes.

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Objectives

The Aviation Division collaborates with the Federal Aviation Administration (FAA), the National Weather Service (NWS), and the Department of Transportation. The product of these collaborations is an improved weather forecasting and visualization capability for use by forecasters, air traffic controllers, air traffic managers, airline dispatchers, and general aviation pilots. More opportunities to develop better weather products now exist because of new observing systems, recent advances in understanding the atmosphere, and higher performance computing capabilities.

The Aviation Division comprises four branches:

Aviation Requirements and Applications Branch – Defines requirements for generating and disseminating aviation weather products; develops the capability to assess the quality of products generated automatically and by aviation weather forecasters, and the "guidance" forecasters use to generate those products.

Aviation Systems: Development and Deployment Branch – Manages enhancement, testing, fielding, and supporting of advanced meteorological workstations for the NWS Aviation Weather Center (AWC) and Center Weather Service Units (CWSUs); develops Traffic Management and Volcanic Ash Coordination products for use by the aviation community.

Advanced Computing Branch – Assures the continuing improvement of high-resolution numerical weather analysis and prediction systems through research and development in high-performance computing.

Forecast Verification Branch – Develops verification techniques, mainly focusing on aviation weather forecasts, and tools that allow forecasters, researchers, developers, and program leaders to generate and display statistical information in near real time using the Real-Time Verification System (RTVS).

In addition to its own activities, the Aviation Division provides funding for other FSL divisions to assist in achieving these goals.

Aviation Requirements and Applications Branch

Lynn A. Sherretz, Chief

Objectives

The Aviation Requirements and Applications Branch develops requirements for advanced products and software tools for the aviation community. These include flight planning tools for pilots, air traffic controllers and managers, and airline dispatchers, as well as product generation and grid interaction tools for aviation weather forecasters.

The branch serves as the focal point for coordinating activities with the FAA Aviation Weather Research Program (AWRP) and the National Weather Service (NWS) Aviation Services Branch, funding organizations for the development efforts. Another key function is leading the AWRP Product Development Team for Aviation Forecasts.

Flight Planning Tools

In collaboration with the National Center for Atmospheric Research (NCAR) and the NWS Aviation Weather Center (AWC), we continue to develop the Aviation Digital Data Service (ADDS). Aviation decision-makers use this Internet-based system to access text, graphics, grids, and images of up-to-the-minute weather observations and forecasts tailored to specific flight routes. The operational ADDS is available at *http://adds.aviationweather.noaa.gov* (Figure 71). The experimental ADDS (at *http://weather.aero*) includes advanced forecasts that are undergoing final testing and evaluation.

Figure 71. Screen of the operational ADDS Website at http://adds.aviationweather.noaa.gov.

Product Generation and Grid Interaction Tools

The branch is a focal point in developing and evaluating the utility of advanced weather display products for the FAA Traffic Management Units (TMUs), where management of air traffic in enroute and terminal environments takes place.

We also work with the NWS Aviation Services Branch, National Centers for Environmental Prediction (NCEP), and Meteorological Development Laboratory (MDL) to develop and test concepts for a National Digital Forecast Database (NDFD) for aviation use. The aviation version will be patterned after the NDFD designed for public forecasts, which has recently been implemented at the NWS Weather Forecast Offices. A particular challenge in developing the aviation version of the NDFD involves incorporating the vertical dimension, which is not included in the public forecast design.

Volcanic Ash Coordination Tool

Responding to the need for better coordination among operational organizations that forecast volcanic ash, the branch coordinates development of the Volcanic Ash Coordination Tool (VACT). This technology enables forecasters to simultaneously view identical displays of meteorological information and collaborate in real time to generate consistent time-critical advisories and forecasts for ash.

Accomplishments

Flight Planning Tools

During 2004, staff worked with NCAR to implement a more efficient ADDS data server in support of the forthcoming "application" version of the ADDS Flight Path Tool.

Product Generation and Grid Interaction Tools

We continued to develop and test a prototype graphical convective forecast tool, the Tactical Convective Hazard Product (TCHP), for FAA traffic managers. This product combines–into a single graphic–key attributes of 1) Convective SIGMETs, which are generated each hour by forecasters at NWS AWC, and 2) the National Convective Weather Forecast (NCWF), an automated product that is generated every 5 minutes and is based on NEXRAD and lightning observations. (For more information on the TCHP project, see the Development and Deployment Branch (DADB) section.)

Volcanic Ash Coordination Tool

For the VACT project, our major focus is working with other agencies to help create technology to improve forecasts related to volcanic ash, which is a severe hazard to aviation because it can cause the failure of aircraft engines and critical instruments. We developed specific requirements for the VACT system in collaboration with representatives from the Anchorage Air Route Traffic Control Center (ARTCC), Anchorage Volcanic Ash Advisory Center (VAAC), and Alaska Volcano Observatory (AVO). A version of VACT was implemented in 2004. (See the next section for more details.)

Projections

Flight Planning Tools

During 2005, we will collaborate with NCAR to develop the application version of the ADDS Flight Path Tool. Based on the latest Java software, this new version will provide faster starting, common look and feel across platforms, many new capabilities such as printing and saving preferred configurations, and an environment to build custom graphics for specific flight routes.

Product Generation Tools

The Aviation Requirements and Application Branch will assess the utility of an enhanced version of the Tactical Convective Hazard Product, and further efforts will be commensurate to the results of the study. Software will be developed to display prototype inflight icing products for FAA traffic managers. The initial product will be an automated Current Icing Potential (CIP) and a Forecast Icing Potential (FIP) that complements conventional AIRMETs and SIGMETs for icing.

Volcanic Ash Coordination Tool

During 2005, the VACT system will be enhanced to display additional products (such as the one shown in Figure 72) required by the Anchorage Air Route Traffic Control Center, Anchorage Volcanic Ash Advisory Center, and Alaska Volcano Observatory. We will assess the utility of the tool for support of real-time collaboration and product generation. Assuming that VACT proves to be as useful as expected, consideration will be given to implementing it at the Volcanic Ash Advisory Center in Washington, D.C., and AWC, which generates SIGMETs for volcanic ash. (See the next section for more details.)

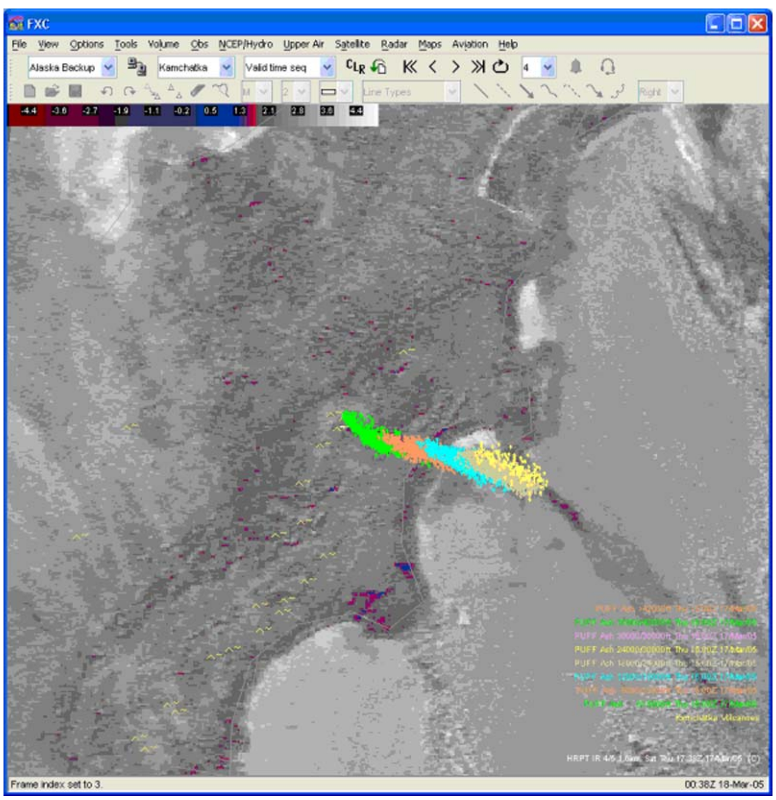


Figure 72. Output from the PUFF Dispersion Model mapped to the Kliuchevskoi volcano eruption on 17 March 2005.

Aviation Systems: Development and Deployment Branch

Greg Pratt, Chief

Objectives

The Aviation Systems: Development and Deployment Branch prototypes new or enhances existing meteorological information systems for use by the aviation community. To address the safety and utilization of the National Air Space (NAS), the goals are to improve the tools that aviation forecasters use, create temporally and spatially seamless aviation weather forecasts through forecaster collaboration, and deliver aviation weather products tailored for nonmeteorologists to support air route traffic controllers, dispatchers, and pilots in their decision-making process. The current concentration is on convection forecasting and volcanic ash identification and forecasting.

Traffic Management Unit Project

The Traffic Management Unit (TMU) project is currently in Phase 1 of a 4-phase effort to tailor aviation meteorological products for use by nonmeteorologists, as follows:

Phase 1: Convection
Phase 2: Icing
Phase 3: Turbulence
Phase 4: Ceiling and Visibility

Each phase will address the tactical (0–1 hour) and the strategic (2–6 hour) application of the above products to help the TMU decision-maker in directing air traffic into and out of the Air Route Traffic Control Center (ARTCC) airspace. All phases will be subjected to the iterative process of defining, developing, demonstrating, and evaluating the weather related hazard graphic and its presentation to the traffic manager user.

The Center Weather Service Unit (CWSU) forecasters will help define the first version of each product based on their understanding of the needs of the traffic manager. The tactical and strategic products will be refined according to results from the evaluation of the utility of the product in the traffic manager's decision-making process. In the creation of both the tactical and strategic graphic products, forecasters will be able to add value by interactively editing the products before they are disseminated to the traffic manager.

The project is sponsored by FAA Air Traffic System Requirements (ARS-100), FAA Aviation Weather Research Program (AWRP)(AUA-430), FAA Southwest Region Headquarters, and National Weather Service Southern Region Headquarters. The purpose of the project is to address the requirements that were found in the in-depth study performed by FAA ARS-100 on “Decision-Based Weather Needs for the Air Route Traffic Control Center (ARTCC) Traffic Management Unit.” In response to these needs, FSL is working closely with the Dallas/Fort Worth (ZFW) Traffic Management Unit (TMU) and the CWSU.

Volcanic Ash Coordination Tool Project

The National Weather Service and the FAA Aviation Weather Research Program are sponsoring the creation of a Volcanic Ash Coordination Tool (VACT). This is a proof-of-concept effort to bring consistency, accuracy, and expediency to volcanic ash forecasting. The FX-Collaborate (FXC), a tool developed by the FSL Systems

Development Division, will be enhanced to allow participants from the Anchorage CWSU, the Alaska Aviation Weather Unit (AAWU), and the Alaska Volcano Observatory (AVO) to simultaneously view volcanic episodes to determine if a volcanic event has occurred, coordinate forecasts of the ash movement, and help disseminate the required products for each participating agency. This enhanced FXC-based system will become the Volcanic Ash Coordination Tool. The three participating agencies will help define and refine requirements for the VACT. Once a set of baseline requirements is defined and met, a collaborative test of the system will be made to verify whether it can facilitate timely coordination among participants in support of the Alaska Interagency Operating Plan for Volcanic Ash Episodes. Another test will determine if the VACT includes the critical mass of information required for participants to generate required warnings/forecasts for volcanic ash events. Future generations of the VACT will incorporate the requirements gathered from this initial evaluation.

Accomplishments

Traffic Management Unit Project

During 2004, the focus was on refining the Tactical Convective Hazard Product (TCHP), based on feedback gathered during the previous summer's evaluation (Interim report to FAA traffic managers, "Accessing the utility of an automated 0–1 hour Tactical Convective Hazard Product," by NOAA Forecast Systems Laboratory in collaboration with the NWS Prototyping Aviation Collaboration Effort (PACE) in Fort Worth, Texas).

The following enhancements to the TMU Web-based system were implemented to address the suggestions and comments in the TCHP evaluation (see *http://www-ad.fsl.noaa.gov/asdad/index.php* for more information):

- Added the 2-, 4-, and 6-hour Collaborative Convective Forecast Product,which starts to address strategic convective weather requirements.
- Updated the impacted jet route graphic, so that a jet route segment will move to an alarm state of red (closed) whenever the National Convective Weather Forecast detection field of level-3 or higher is within 10 nautical miles of a jet route segment. It will also move to an alarm state of yellow whenever the National Convective Weather Forecast predicts a storm to impact a segment of a jet route.
- Implemented the software at FSL for a Crosswind Hazard Product (Figure 73), developed by forecasters at the Dallas/Fort Worth CWSU. It is now part of the TMU Web-based suite of tactical decision aid tools.
- Added a performance graphic for the National Convective Weather Forecast product, so that users can see at a glance how well the automated NCWF product is working during different types of convective weather events.
- Changed the TMU Website (Figure 74) to allow the traffic managers to see at a glance if there is an impact to their airspace, and if additional information is required, they can click on the icon for the actual weather hazard.
- Enhanced looping displays to contain the 2-hour CCFP product and the 1-hour Convective SIGMET graphic.
- Added descriptions for all graphical products to the Web interface for ease of use and to help improve or refresh the traffic manager's understanding of the products.
- Updated the FX-Collaborate system, which is used by the forecasters at the Dallas/Fort Worth CWSU, to handle all of the above products.

Implementation of the above tasks earned staff in the Aviation Systems: Development and Deployment Branch the National Weather Association Aviation Meteorology Award “for sustained superior performance in enhancing and developing new methodologies for displaying aviation weather information resulting in improved flight safety and efficiency in the National Air Space System."

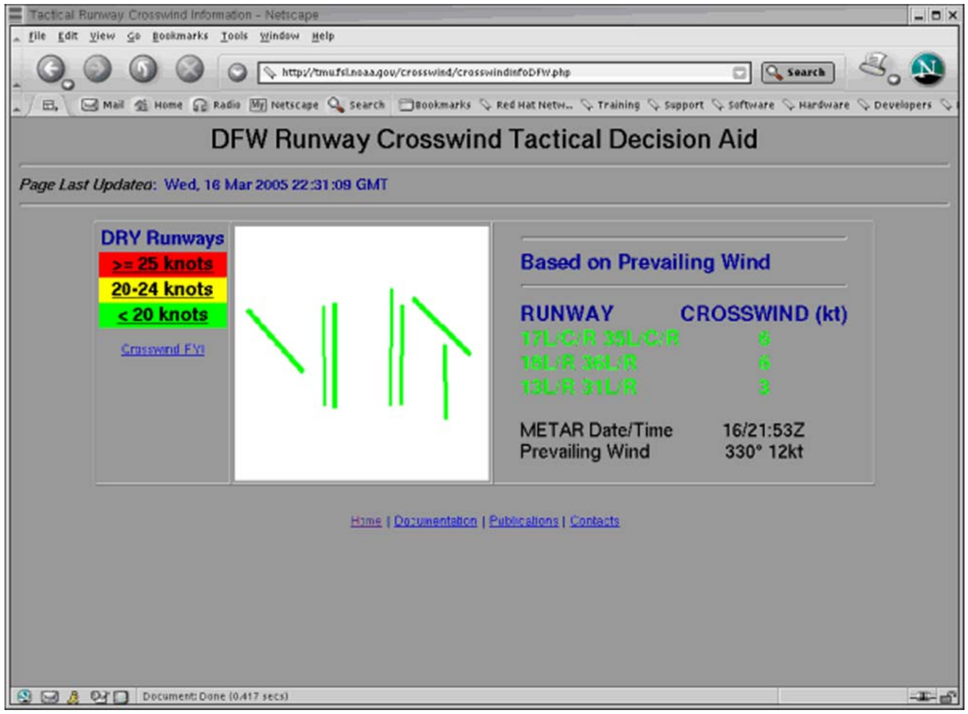


Figure 73 . Screen from the Crosswind Hazard Product, part of the Traffic Management Unit Web-based suite of tactical decision aid tools.

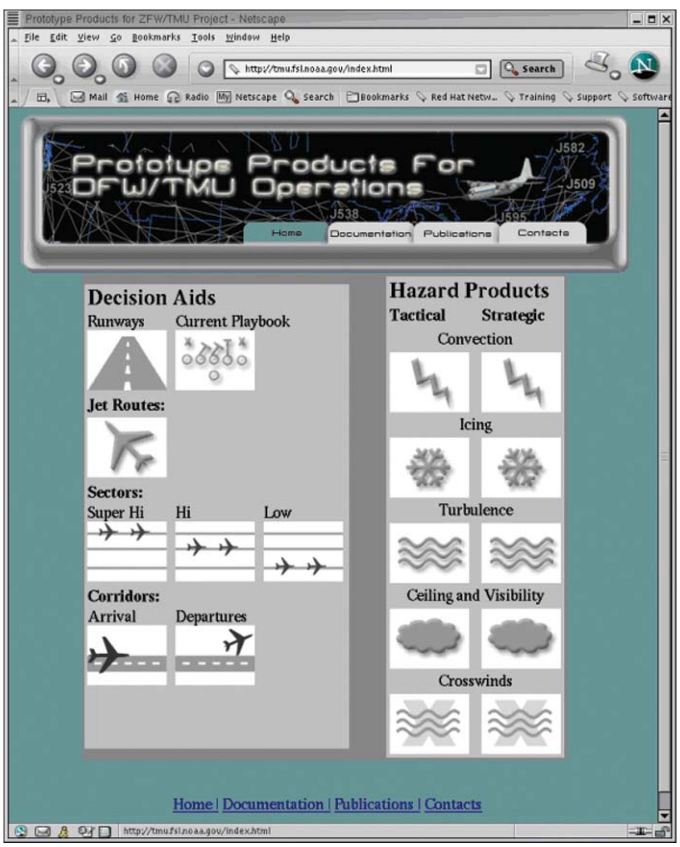


Figure 74 . Screen from the TMU Website showing icons that traffic managers can click to see the actual weather hazard.

Volcanic Ash Coordination Tool Project

During 2004, we delivered two versions of the VACT software, trained users, and gathered feedback on these releases. Version 2.0 of the VACT software was developed and installed on all client and server systems. This version included new data display scales. Radar datasets were reduced to include just the Alaska and Seattle radars. Satellite products were added for data, including visible, IR Band 4, IR Bands 4 and 5; 3 channel differencing for POES, GOES, DMSP, and China satellites for sectors that include the Alaska mainland, north-central Alaska, south-central Alaska, southeast Alaska, eastern Aleutians, western Aleutians, Bering Strait, Kamchatka, and Kamchatka-Kuriles. Version 2.0 also includes the PUFF ash dispersion model displays.

Version 2.1, installed in October 2004, included training, user feedback, and enhancements to:

- Launch the PUFF dispersion model from a VACT client machine.
- Display color-coded output (Figure 75) based on ash height in 6,000-ft increments for three grid types: MesoEta 216, UKMET, and AVN Global.
- View full resolution polar-orbiting satellite imagery (Figure 76) from a VACT client box.
- Query volcano map background files to obtain volcano name, latitude and longitude, last eruption date, catalog number, whether seismically monitored, and elevation.

This software version allows the user to perform minor satellite image enhancements to help create signatures of volcanic ash events. Once a satellite image is enhanced to show volcanic ash, the user can then iteratively run the PUFF dispersion model so that the output at time “T” from the dispersion model mapped to the satellite imagery at time “T.” The forecast ash movement images can be given to traffic managers for initiating airway avoidance plans. This methodology was used to capture the Kuichevskoi eruption on 17 March 2005.

Projections

Traffic Management Unit Project

A second evaluation of the Tactical Convective Hazard Product is planned for late spring through early summer 2005. The developers and users will determine its usefulness to the traffic managers at the Dallas/Fort Worth Air Route Traffic Control Center. This evaluation will focus on the enhancements that were made in 2004 and early 2005 based on the 2003 evaluation. The following graphical upgrades will be available to the traffic managers:

- Aircraft positions updated every three minutes.
- Impacted sectors for the Dallas/Fort Worth ARTCC.
- New version of the National Convective Weather Forecast (NCWF-2) running at the Aviation Weather Center in Kansas City. NCWF-2 was created by the Convective Weather Product Management Team.
- Enhancements made to the Collaborative Convective Forecast Product (CCFP) made by the AWC.
- Impacted sectors of the Houston ARTCC.
- Impacted high-use jet routes for the Houston ARTCC.
- Web displays will be moved to a Java application to help solve limited bandwidth issues at the Dallas/Fort Worth ARTCC.
- Updated decision aid tools on our Website will include better visual cues.

We plan to obtain feedback from the traffic manager on these tools in the late 2005 or early 2006 time frame. Development work will begin on the Tactical Icing Hazard Product (THIP). Plans are to identify and install FX-Collaborate and TMU displays at a new ARTCC facility willing to support these prototype efforts.

Volcanic Ash Coordination Tool Project

Version 2.2 of the VACT system will be delivered in spring 2005. The new software includes the baseline system requirements identified by the VACT participants. This system will be evaluated in May 2005 to determine if it meets baseline system requirements, and if it helps facilitate coordination among participating organizations. If the above requirements are met, we will make additional enhancements to the tool based on feedback from the evaluation, and continue to develop the VACT system based on our original requirements. Development efforts include creating the Volcanic Ash SIGMET Generation Tool, Volcanic Ash MIS (Meteorological Impact Statement) Tool, a HYSPLIT model from NCEP, and an Anchorage CWSU Website that includes impacts to airspace related to volcanic ash.

Our client base will also be increased with the deployment of VACT systems to the Volcanic Ash Advisory Center (VAAC) in Washington, D.C., and the Aviation Weather Center in Kansas City. Talks will begin with the Canadian VAAC about potential participation in this effort.

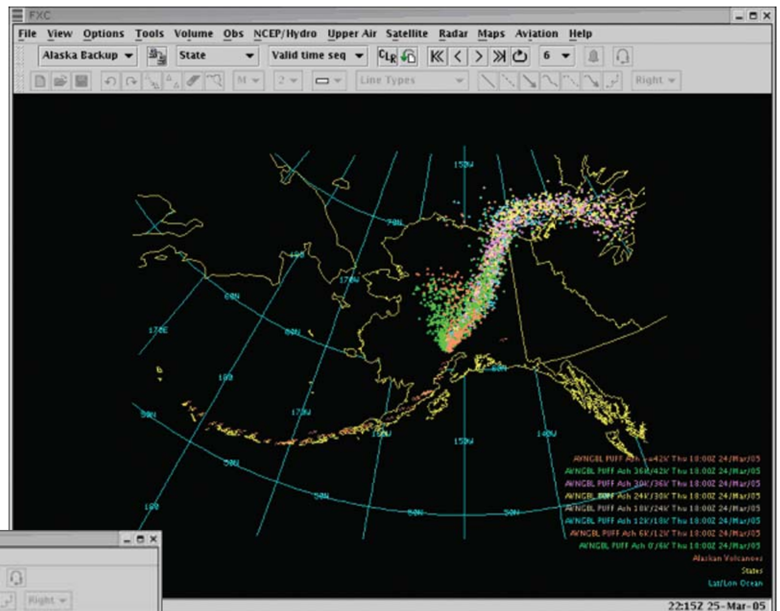


Figure 75. Display of color-coded output based on ash height in 6,000-ft increments.

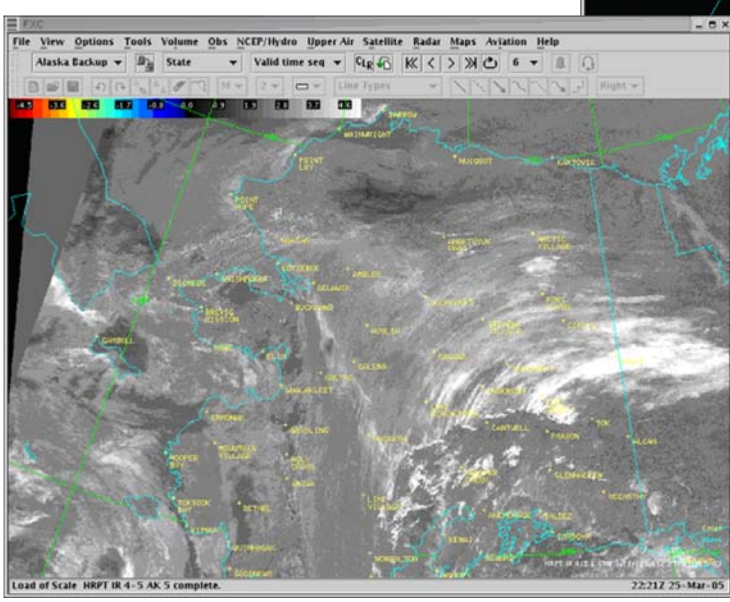


Figure 76. Polar-orbiting imagery from a VACT client box.

Advanced Computing Branch

Michael Kraus, Chief

Objectives

The Advanced Computing Branch (ACB) enables new advancements in atmospheric and oceanic sciences by making modern high-performance computers easier to use. Central to meeting this goal is its support of the Scalable Modeling System (SMS), developed at FSL to parallelize numerical geophysical models and port code to multiple platforms. An expanded role in this area includes building a grid computing infrastructure to help NOAA cost-effectively support new scientific challenges to run and verify more complex models, such as integrated Earth observation systems, using next-generation high-density data streams.

Grid computing is an emerging field in high-performance computing, and is being explored as a means to provide better integration of NOAA's growing data and compute and network resources. Grid computing promises significant benefit to NOAA, with the availability of very high-speed networks, industry-backed grid software, and the potential for better utilization of IT resources. Indeed, the roadmap for implementing grid computing has arrived with the recent development of grid standards and the coalescing of industry support around Globus software. This toolkit is designed to handle resource sharing and discovery, data movement, security, access, and other operations required in distributed computing environments.

The ACB is engaged in several investigative projects concerning how grid computing can be utilized at NOAA. The Model Assimilation and Portability Project (MAPP) will provide portability of major models across the three NOAA supercomputer platforms at the National Centers for Environmental Prediction (NCEP), Geophysical Fluid Dynamics Laboratory (GFDL), and FSL. Two aspects of portability include the actual porting of the models and the creation of a portal that will first make it easier to run, test, and verify a model on one of the three platforms, and eventually make it transparent to do so on any of the three platforms. The graphical user interface will be used in both the NOAA MAPP portal, and the LEAD (Linked Environments for Atmospheric Discovery) portal under development. These activities are performed in collaboration with the National Center for Atmospheric Research (NCAR), Fleet Numerical Meteorology and Oceanography Center (FNMOC), and the NSF-funded (National Science Foundation), university-oriented LEAD project.

We are collaborating with two other NOAA laboratories in building a simple prototype NOAA grid. This project is funded by NOAA High Performance Computing and Communications (HPCC). Tasks include exploring ways to construct a working grid; handle administrative and technical issues related to resource allocation, security, and job scheduling; and run real scientific applications across wide area networks.

Finally, we are studying longer term issues related to developing a NOAA grid that spans the entire organization as a means to provide better integration of NOAA's growing data, compute, and network resources and to meet the expected needs of these projects in the future. The acquisition and dissemination of data is critical to NOAA's mission to 1) build and maintain observational platforms such as radars, satellite-based instruments, aircraft, profilers, weather balloons, ships, and buoys; 2) create data products for weather and climate prediction and disseminating these products; and 3) archive the data for use by research laboratories to develop new prediction capabilities and forecast products. NOAA's IT investment directly relates to the volume of data it receives, processes, and disseminates. Within the next decade, the volume of data is expected to grow 100 fold. To handle this enormous increase, grid technologies are being explored to help 1) provide better utilization of NOAA's IT assets; 2) provide a more efficient way to ingest, disseminate, and archive data to NOAA constituents and to the general public; 3) reduce costly duplication in data archival, product generation systems, and networks; 4) improve the usability of data handled by NOAA; and 5) provide more efficient access to compute facilities and storage facilities.

Accomplishments

The branch began working on the NOAA HPCC-funded proposal to develop a full prototype NOAA grid that would enable grid users to submit a job to a grid-wide queue and run it on any available platform. A GFDL Linux cluster was added to the rudimentary grid constructed in 2003. The grid now consists of nodes at the Advanced Computing Branch and at the FSL supercomputer, and two nodes (one each) at the Pacific Marine Environmental Laboratory (PMEL) and the GFDL cluster. We deployed the SILVER meta-scheduler developed by Cluster Resources, Inc. which enables jobs to be submitted and run on any of the grid nodes. Most of the computer errors have been fixed, but more testing is required using suites of realistic model runs. See Website *http://www-ad.fsl.noaa.gov/ac/GridComputing.html* for more information on grid computing at FSL.

We continued collaborative efforts in support of the Weather Research and Forecast (WRF) model and the related WRF Test Plan. The WRF-NAM (WRF-North American Mesoscale) forecast model and its pre- and postprocessing codes and verification software were ported to the FSL supercomputer in preparation for the WRF retrospective experiments, which were completed successfully last summer. NCEP’s new physics scheme was added to the WRF-NAM code in support of the DTC Winter Forecast Experiment (DWFE), January 14–March 31, 2005. We also documented the WRF Registry, a computer aided software engineering mechanism built into the WRF software framework.

As part of MAPP, we are in the process of porting the Global Forecast System (GFS) model to the FSL supercomputer. We have surveyed potential users and developed a requirements document for the WRF portal. The ACB team is now developing a prototype of the portal, which will be used for testing, evaluation, and verification of modifications made to the WRF model.

The Scalable Modeling System (SMS) tool was used to develop a two-dimensional horizontal data domain decomposition parallel version of the NFS (Nonhydrostatic Forecast System) model at the Taiwan Central Weather Bureau (CWB). This SMS parallel version will be used in the 2005 CWB supercomputer procurement benchmark suite. We demonstrated that for higher processor counts, the SMS version performed significantly better than the extant one-dimensional decomposition hand-coded MPI version of NFS. In the process, we extended SMS to handle nested models with more than two nest levels (removing a previous limitation). SMS was also extended in other ways, as will be explained in the upcoming release of version 2.9.

Some of the ACB staff continue to serve on the FSL computer procurement committee, and are engaged in activities to purchase a new High-Performance Computing System (HPCS).

Projections

Plans for the Advanced Computing Branch during 2005 include:

- Complete development of a grid meta-scheduling capability for the prototype NOAA grid. Other meta-scheduling approaches, such as the Community Scheduling Framework (CSF) and the Job Scheduling Hierarchically

(JOSH) multisite job management tool, will be analyzed for suitability. This meta-scheduling capability will be tied to the model testing portal being developed at FSL. Another task involves extending the WRF/ROMS (Regional Ocean Model System) coupled model experiments so that the ROMS model will run on the GFDL Linux cluster while the WRF model runs on the FSL supercomputer. These experiments will also be tested on the NSF TeraGrid with assistance from PMEL staff.

• Continue support of the Weather Research and Forecasting (WRF) model and work with the FSL Information and Technology Services (ITS) on WRF issues.

• Continue support of ITS procurement activities to acquire the next HPCS.

• Continue support of the Rapid Update Cycle model.

• Work on the Model Assimilation and Portability Project

– Finish porting the NCEP Global Forecast System code to the FSL supercomputer.
– Develop a prototype WRF Portal.
– Port the next NCEP operational model to the FSL supercomputer.

• Collaboration with the Taiwan Central Weather Bureau (CWB)

– Port the Scalable Modeling System-Nonhydrostatic Forecast System (SMS-NFS) to one or more CWB machines.
– Develop a regression test comparing the serial and SMS parallel codes.
– Support CWB efforts to integrate SMS-NFS into the procurement benchmark suite.
– Support CWB efforts to further develop the NFS model.
– Further tune the performance of SMS-NFS.
– Use SMS to parallelize other atmospheric and oceanic models including the Taiwan CWB-NFS model.

• Further extend SMS in support of SMS-NFS and possibly other SMS users, and release a new version of SMS.

• Continue support of SMS users and FSL's supercomputer.

• Publish results in conference proceedings and journals.

Forecast Verification Branch

Jennifer Luppens Mahoney, Chief

Objectives

The objective of the Forecast Verification Branch (FVB) is to provide specific verification information that can be used to improve weather forecasts. To this end, the FVB team develops verification tools, such as the Real Time Verification System (RTVS), and assesses techniques that allow weather forecasters, decision-makers, researchers, and end-users at the Federal Aviation Administration (FAA) and National Weather Service (NWS) to generate and display statistical information in near real time. The RTVS is the tool used to integrate new verification techniques and forecast and observation datasets to 1) help the FAA Aviation Weather Research Program (AWRP) improve the safety and efficiency of the National Airspace System, 2) provide verification measures for all NWS aviation products, 3) help the USWRP Developmental Testbed Center (DTC) meet its goals for extending numerical models (such as the Weather Research and Forecast (WRF) model) to higher resolutions, and 4) help the Coastal Storms Initiative program evaluate the skill of locally produced weather forecasts.

Some of the projects underway include redeveloping and transferring the RTVS to NWS operations; conducting verification exercises to advance aviation weather products in the areas of convection, turbulence, ceiling and visibility, and icing over national and oceanic domains; incorporating new observation datasets such as satellite observations into verification approaches; and developing new verification methodologies for addressing the operational relevance of aviation forecasts. Verification techniques are developed for evaluating precipitation forecasts and capabilities to support local-scale numerical modeling efforts at FSL. We lead AWRP's Quality Assessment Product Development Team and participate in the FAA Weather Applications Work Group (WAWG).

Real-Time Verification System (RTVS)

The RTVS verification and analysis system is used to nationally distribute forecast verification information to end-users, decision-makers, and weather forecasters. The system is used extensively to support the goals of the AWRP and the NWS. Information provided by the RTVS contributes to improved aviation safety, increased efficiency for planning and routing air traffic within the National Air Space (NAS), and rapidly transferring weather research products for use by aviation weather end-users such as pilots and NWS.

The RTVS system provides feedback and statistical information describing the skill and quality of weather forecasts. The components and functional architecture of the RTVS are shown in Figure 77. The system currently includes aviation weather forecasts (such as icing, turbulence, ceiling and visibility, and convection), as well as precipitation, winds, temperature, and relative humidity forecasts. The forecasts include automated gridded aviation weather products (such as Current Icing Potential, Graphical Turbulence Guidance, National Convective Weather Forecast), numerical weather prediction model forecasts, such as WRF and the Rapid Update Cycle (RUC), and human-generated forecasts (such as those from the Collaborative Convective Forecast Product). The observations used by RTVS currently include voice pilot reports, radar, satellite-derived observations, and other observations from surface and upper-air sensors.

Once the forecasts and observations are processed within the RTVS, they are stored in the Relational DataBase Management System (RDBMS). The evaluation algorithms extract information from the forecasts and observations for direct and/or inference-based evaluations of aviation forecast skill. New forecast evaluation algorithms, techniques, and approaches must be developed and implemented for each forecast parameter or observation type that is introduced into the RTVS; for instance, those that will support the introduction of satellite observations into the RTVS architecture. The combined forecast and observation information obtained from the forecast evaluation algorithms and techniques is stored in the RDBMS. The resulting statistical scores, user-specific graphics, and tabular information are computed and provided to users through an interactive Web-based graphical user interface.

The RTVS is currently developed and maintained by FSL, with funds provided mainly by the AWRP. Though the system presently supports several operational organizations, it will be physically transferred to the NWS within the next two years. Following this transition, the information from RTVS will be distributed and supported nationally by the NWS, but development and support of the system will continue at FSL.

Accomplishments

Real-Time Verification System

During 2004, the Forecast Verification Branch continued to develop and extend the capabilities of the RTVS. New observation datasets and forecasts were added to the system and, using satellite-derived observations, techniques were implemented for assessing forecasts of cloud-top height. Staff completed the procedures for establishing the hardware architecture in preparation for the eventual transfer of RTVS to the National Weather Service.

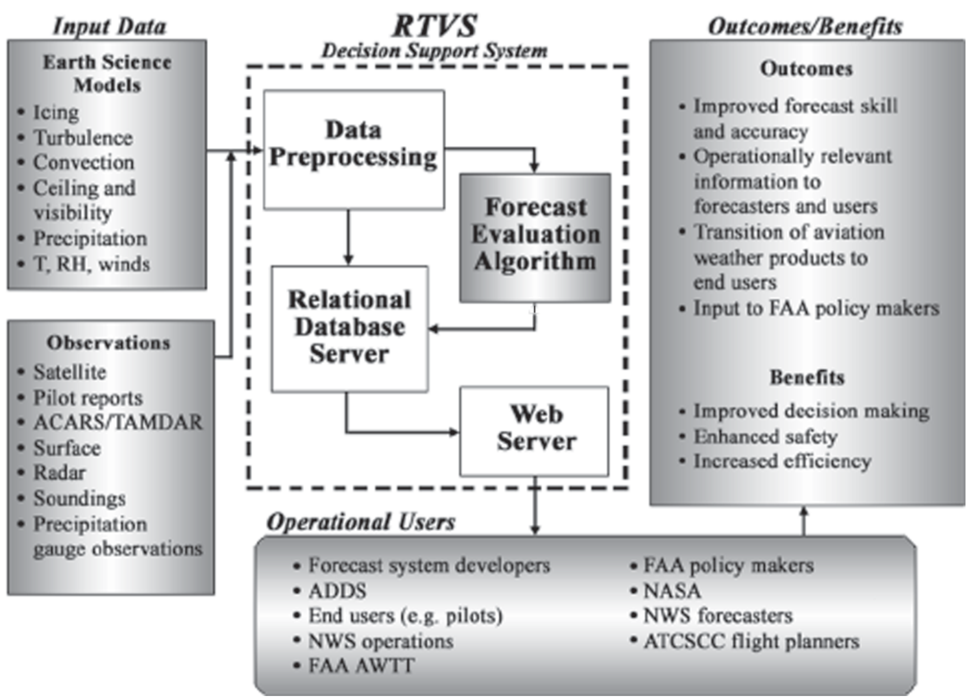


Figure 77. Components and architecture of the RTVS, including 1) the forecasts and observations made available for ingest (shown within the dotted lines), 2) input datasets (left), RTVS users (bottom), and verification outcomes (right).

During the year, we participated in various statistical evaluations that culminated with written reports to the FAA/NWS Aviation Weather Technology Transfer Technical Review Panel. We completed verification activities that support the transition of version 2 of Graphical Turbulence Guidance (GTG2) and National Convective Weather Forecast (NCWF-2) products, and investigated the usefulness of the Collaborative Convective Forecast Product (CCFP). A brief summary or a complete report on the performance of the GTG2, NCWF-2, and CCFP algorithms are available at http://www-ad.fsl.noaa.gov/fvb/rtvs/publications.

Graphical Turbulence Guidance Forecast – The GTG2 algorithm was developed by the AWRP Turbulence Product Development Team. The FSL Forecast Verification Branch and the National Center for Atmospheric Research (NCAR) jointly evaluated the performance of GTG2 from January–April 2004 (ongoing real-time and long-term evaluations of GTG2 are available at *http://www-ad.fsl.noaa.gov/fvb/rtvs/turb/index.html*). The forecasts were verified using Yes/No turbulence observations from pilot reports (PIREPs) indicating either “moderate or greater” turbulence severity or “no turbulence.” GTG2 and its previous versions (GTG and ITFA) and the Ellrod turbulence index were evaluated as Yes/No turbulence forecasts by applying a threshold to convert the output of each algorithm to a Yes/No value. A variety of thresholds were applied to each algorithm. The verification analyses were primarily based on the algorithms’ ability to discriminate between Yes and No observations, as well as the extent of their forecast coverage. Forecasts based on AIRMETs, the operational forecasts issued by the Aviation Weather Center, were also evaluated to provide a standard of comparison. For this evaluation, more than 1,200 individual GTG2 forecasts were considered for both middle and upper levels.

The basis for the verification approach known as the Signal Detection Theory (SDT) is the relationship between PODy and 1-PODn for different algorithm thresholds. This relationship can be represented for a given algorithm by the curve joining the points (1-PODn/PODy), resulting in the ROC (Relative Operating Characteristics) curve. The area under this curve is a measure of overall forecast skill, another measure that can be compared with the algorithms. Examples of the results computed for the GTG2 algorithm are shown in Figures 78 and 79, with the curves representing the skill of the forecast for a variety of thresholds. The curves of the forecasts with the best skill lie closer to the upper left-hand section of the plot. The summary of overall results indicate that GTG2 is skillful at discriminating between Yes/No turbulence conditions at both upper and middle levels, and that it is significantly more skillful than GTG, ITFA and the Ellrod-1 Index. GTG2 also provides relatively efficient forecasts, covering comparatively small volumes for a given turbulence detection rate. Other results indicate that the forecast performance is relatively insensitive to lead time (not shown), especially at middle levels, and is consistent through the atmosphere (10,000 ft and higher). Skill and efficiency measures vary somewhat from day to day, but less than for some other types of turbulence forecasts. Regional analyses indicate that the best performance is in the western region for mid-level forecasts and in the eastern and central regions for upper-level forecasts.

National Convective Weather Forecast – The NCWF-2 algorithm was created by the AWRP Convective Weather Product Development Team as a 1- and 2-hour probabilistic convective forecast tool, which is considered to be the next-generation National Convective Weather Forecast. An early version of the NCWF-2 was evaluated from 15 June–31 August 2003. A probabilistic forecast was produced by the NCWF-2 every 5 minutes. NCWF-2 forecasts issued on the hour were evaluated using the RTVS system. Forecasts were verified against two observation datasets: a convective observation product based on radar-derived vertically integrated liquid (VIL) and combined with lightning observations, the National Convective Weather Detection (NCWD-VIL) product, and a convective reflectivity-based version of the NCWD, referred to as NCWD-Ref. The algorithm probabilities were transformed into Yes/No convective fields by determining if the probability at a grid point exceeded or was less than a prespecified threshold; different thresholds were utilized to examine the full range of performance of the NCWF-2 algorithm.

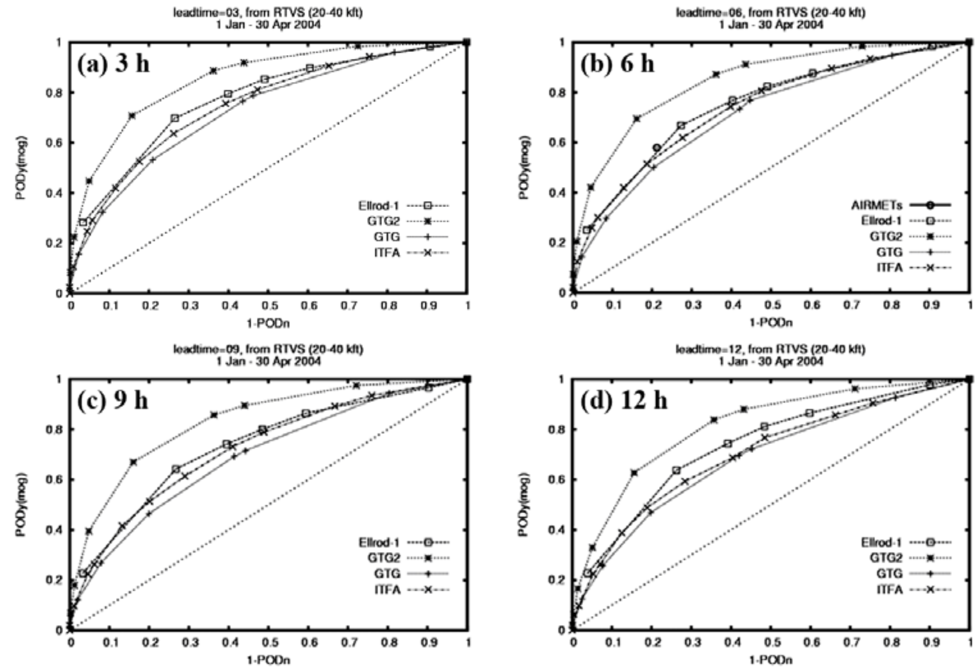


Figure 78. Graphical Turbulence Guidance (GTG-2) algorithm based on the Signal Detection Theory, showing ROC diagrams for Ellrod-1, GTG2, and ITFA for levels 20,000–40,000 ft for lead times: (a, top left) 3 hours, (b, top right) 6 hours, (c, bottom left) 9 hours, and (d, bottom right) 12 hours provided by the Real-Time Verification System.

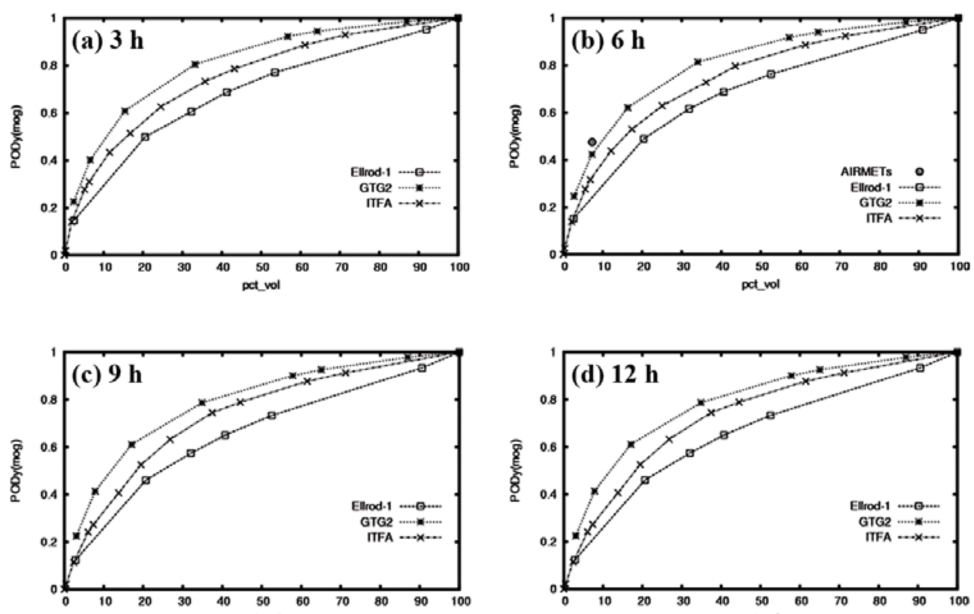


Figure 79. ROC diagrams for Ellrod-1, GTG2, and ITFA for levels 10,000–20,000 ft for lead times: (a) 3 hours, (b) 6 hours, (c) 9 hours, and (d) 12 hours provided by the RTVS.

Overall RTVS verification results for the 1-hour NCWF-2 forecasts for 15 June–31 August 2003 as compared to the original version of NCWF-1 are shown in Figure 82. The statistics (i.e., PODy, CSI, and FAR) are shown as a function of Bias, whereas the curves represent the quality of the NCWF-2 at a variety of thresholds in 0.1 increments ranging from 0.0 at the top of the curve to 1.0 at the bottom of the curve. The single points represent the statistics for the 1-hour operational NCWF (NCWF-1) forecast.

These results show that, overall, NCWF-2 is skillful at capturing convective activity at 1 hour. Positive skill is noted in all scores. It also suggests that NCWF is slightly more skillful than the NCWF-2 at a threshold of 0.3, since the PODy and CSI values for NCWF are larger, and the FAR value is smaller than the corresponding values for the NCWF-2. However, after closely investigating these differences, it became apparent that the observation field (i.e., NCWD-VIL versus NCWD-ref) had an important impact on the relative skill of the NCWF-2. Additional analyses of the NCWF and NCWF-2 based entirely on VIL-based radar observations are also summarized.

The results summarized in the final report suggested that NCWF-2 is a skillful convective product. In particular, the NCWF-2 forecasts are provided in probabilistic terms, allowing for better decision-making procedures. One-hour NCWF-2 forecasts are as skillful as the operational NCWF when NCWD-VIL is used to derive and verify the

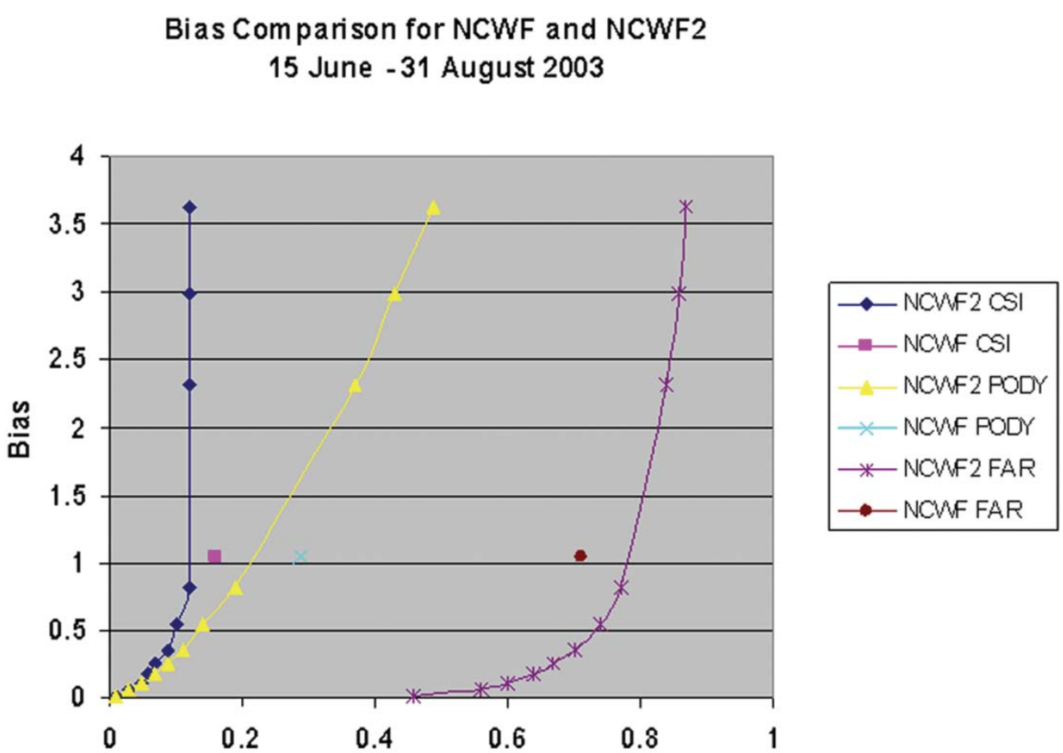


Figure 80. National Convective Weather Forecast verification comparison, showing statistical results from 15 June–31 August 2003 as a function of Bias for the 1-hour NCWF-2 (CSI, diamond; PODy, triangle; FAR, asterisk) and NCWF (CSI, square; PODy, "x"; FAR, closed circle). Thresholds for NCWF-2 are 0.0 (top of plot) to 1.0 (bottom of plot) in 0.1 increments.

algorithm. An elliptical filter of 60 km seems to be better suited for capturing the correct amount of convective activity. Currently, 2-hour NCWF-2 forecasts are nearly as skillful as 2-hour forecasts produced by the Collaborative Convective Forecast Product.

Collaborative Convective Forecast Product – The FVB team is involved with evaluating the objective quality and subjective usefulness of the Collaborative Convective Forecast Product (CCFP). As in previous years, statistical results and graphical displays were provided through RTVS to end-users, such as decision-makers at the Air Traffic Systems Control Command Center (ATCSCC) and forecasters at the Aviation Weather Center. All relevant reports are available at Website *http:/www-ad.fsl.noaa.gov/fvb/rtvs/*.

In addition, the subjective usefulness of the CCFP, as determined by the ATCSCC daily operational impact reports, was analyzed with respect to operational impact, type of forecast error, and impact of forecast on flight operations. The results, as shown in Figure 81a, indicate that for for 81% of the time the CCFP was useful (with some exceptions) for decision-making by traffic flow managers. The results shown in Figure 81b indicate that the CCFP was accurate only 14% of the time, while the forecast error was mainly due to the placement of forecast coverage and underforecasting of the convective weather.

DTC Winter Forecast Evaluation – The Forecast Verification Branch will continue to collaborate with the National Center for Atmospheric Research and the National Centers for Environmental Prediction in support of the WRF Developmental Testbed Center (DTC). Using the RTVS, near real-time statistics are provided for two 5-km versions of the Weather Research and Forecasting (WRF) model in support of the DTC Winter Forecast Evaluation (DWFE).

The RTVS system generates the statistical results for precipitation forecasts. The statistics are based on the Hydrometeorological Automated Data System (HADS) hourly precipitation observations, with the model forecasts interpolated to the HADS station locations. The time frame of the evaluation is from 15 January through 31 March 2005. Statistical results of the evaluation of the precipitation forecasts are available at *http://www-ad.fsl.noaa.gov/fvb/rtvs/* and then link to "DWFE."

Projections

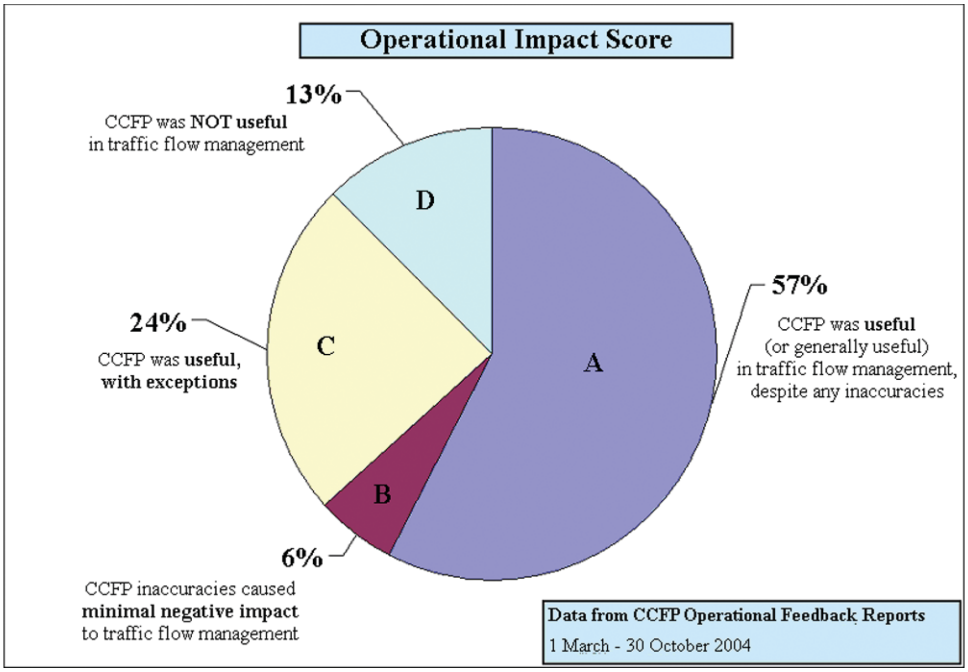
Real-Time Verification System

During 2005, the Forecast Verification Branch will continue verification exercises for global and national scale forecasts of cloud-top height, convection, turbulence, icing, and ceiling and visibility. Satellite observation datasets will be utilized to evaluate these products, as well as new entity-based and diagnostic verification techniques.

We will continue to redesign and develop the next-generation RTVS for transition to the National Weather Service.

A key effort involves ongoing collaboration with the DTC to provide statistical results for the DTC Winter Forecast Exercise. The RTVS will be utilized for the Coastal Storms Initiative program and for a variety of convective weather summer evaluations.

Other integral activities include ongoing participation in workshops, conferences, and FAA Air Traffic Committees.



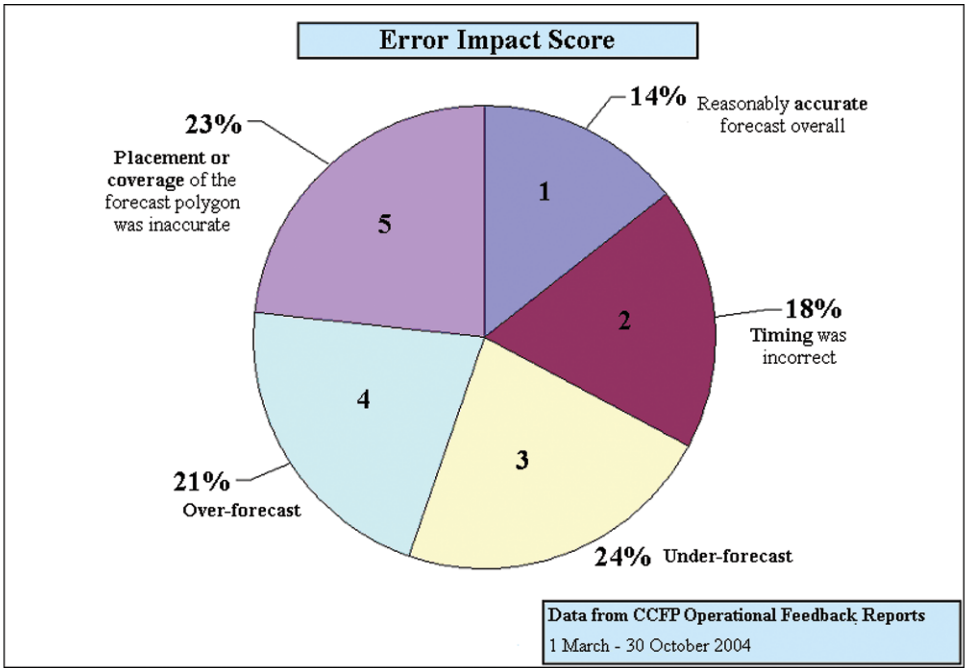


Figure 81. Collaborative Convective Forecast Product verification results indicating (a, above) operational impact of CCFP, and (b, below) type of forecast error.

Modernization Division

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Objectives

The Modernization Division produces functional designs, or working prototypes of techniques, workstations, and systems that may be implemented into the National Weather Service (NWS), or other agency operations up to a decade later. The process includes selecting, tailoring, and implementing advanced techniques and devices produced by the research and development community, industry, or elsewhere. Developments are state of the art and continually evolve along with new technological advances, such as the Graphical Forecast Editor (GFE) techniques (Figure 82).

The modernization of NWS operations involved the development of a new radar system, an automated surface observing system, a new series of geostationary satellites and products, and a communications and forecaster workstation system, the Advanced Weather Interactive Processing System (AWIPS). FSL participates in risk reduction activities to help the NWS meet its goals in the continued development of AWIPS.

The Modernization Division comprises two branches:

Risk Reduction Branch – AWIPS support and evaluation

Enhanced Forecaster Tools Branch – AWIPS Forecast Preparation System.

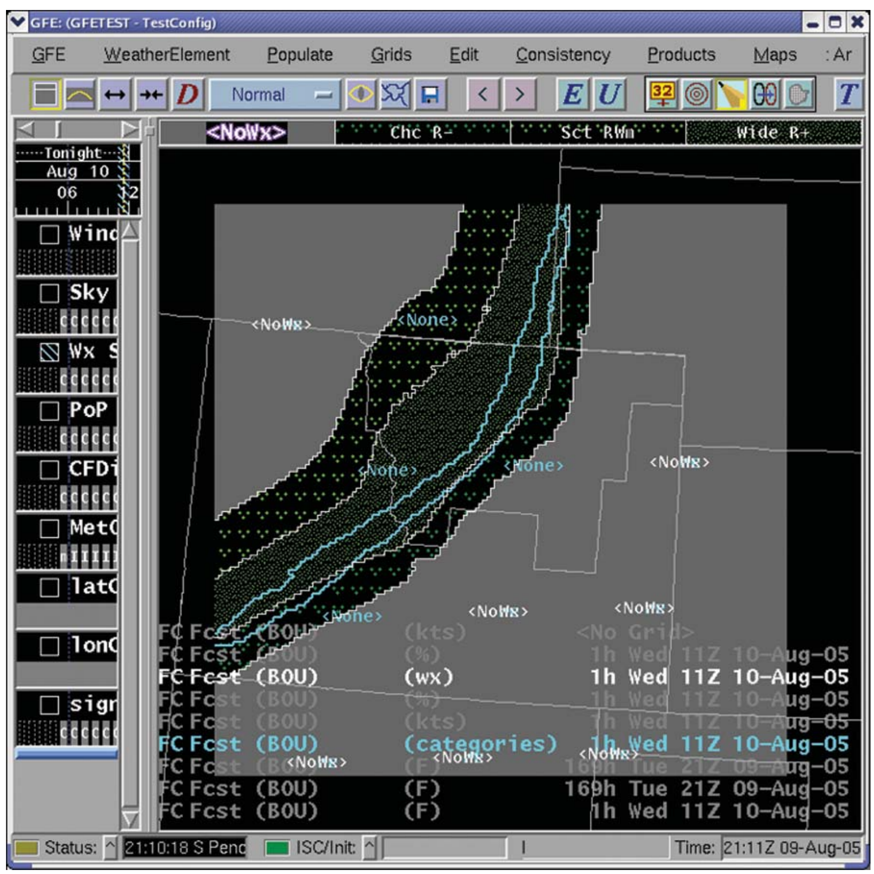

Figure 82. An example of new Graphical Forecast Editor techniques such as defining meteorological objects help forecasters maintain consistency between elements. The areal extent of rain (green) is defined based on the location of a cold front (blue).

Risk Reduction Branch

Carl S. Bullock, Chief

Objectives

Work in the Risk Reduction Branch is directed toward helping the National Weather Service (NWS) evolve. The two focus areas include operation and evaluation of risk reduction activities and the continued development of AWIPS. Since NWS announced in 1996 that the FSL-developed WFO-Advanced system would form the core of the AWIPS software to run at all Weather Forecast Offices (WFOs) and River Forecast Centers (RFCs), the development and evolution of AWIPS has been our primary activity.

Accomplishments

AWIPS Software

During 2004, AWIPS Operational Builds (OBs) 3 and 4 were deployed, and the development for OB5 was completed. A focus of development centered on the Valid Time and Event Code (VTEC), scheduled for implementation by the National Weather Service (NWS). VTEC allows NWS customers and partners to keep better track of hazardous weather events such as watches, warnings, and advisories by identifying the particular hazard (giving it a tracking number) and a start and end time. VTEC also captures the life cycle of a particular event as it evolves, increasing or decreasing in intensity. This capability was added to the WarnGen application and to a few products generated by the Graphical Forecast Editor (GFE). After performing extensive testing, NWS then scheduled VTEC from Warngen to enter operations in February 2005. Our prototype development with the GFE/VTEC infrastructure showed that GFE could create VTEC codes for all remaining products.

OB4 included implementation of a new decoder for gridded model output, which enables AWIPS to acquire much more gridded data. Another feature of OB4 is correction of the limited quantity of gridded data that AWIPS could send, providing a new decoder that processes grids in GRIB2 format. The full 12-km Eta model data are now sent out to 84 hours, and an extension of the Eta model (using boundary conditions from the Global Forecast System) out to 8 days. This represents almost an order of magnitude more of model data than could be accommodated previously.

To comply with more stringent security policies, OB4 software was modified to require individual user accounts. Users are now required to log in as they begin their operational shift, for individual user traceability, previously lacking. This could be a problem, however, during active weather when there may not be time to log out or log in.

To keep current with improvements in the radar observations, new radar products were introduced in each build. An important new radar dataset from FAA's Terminal Doppler Weather Radar (TDWR) was added for OB5 at 45 locations near major airports around the country. This provides higher temporal and spatial resolution radar data for the areas covered. These data are processed into products that mirror WSR-88D radar products for easy incorporation into AWIPS. They also can be used just like other radar data, with access to the same display capabilities AWIPS provides, such as integration with other datasets, data interrogation, automatic updating, radar mosaics, etc.

The "all-tilts" display of radar products was enhanced in OB4. Previously a user could only display all the radar tilt angles from a single volume scan, stepping through them vertically. This is very useful for identifying severe weather features such as high reflectivity cores that tilt in the vertical dimension. However, there was no easy way to get a sense of how a storm system was evolving through time while in this display mode. Users of the improved version can display tilts from multiple radar volume scan, and can step or animate through time at a particular tilt.

A new radar product generated by the WSR88D was added in OB5. In addition to graphics depicting mesocyclones, a set of parameters for each mesocyclone identified by the algorithm is now sent to AWIPS after each radar tilt is completed. This is the first of new generation information that will be available on AWIPS from the WSR88D radar. The data can be displayed on AWIPS with greater user control, and is used by decision assistance applications such as the System for Convection Analysis and Nowcasting (SCAN). Since mesocyclones move with the thunderstorm, a new data display method was required. Before implementation of OB5, users had to select the point of interest using the mouse, then the system would generate the product of interest. The points were stationary then, but another method of point selection was incorporated in OB5 that allows identification by name of feature (i.e., a feature tag generated by the radar). Since the selected point need not be stationary, a time series graph of selected parameters can now be generated for a moving point.

An important aspect of OB5 is not what was added, but what was removed. Legacy Hewlett Packard hardware from the original AWIPS is gradually being replaced by PCs running the Linux operating system. The legacy application servers were removed in OB5, and a new network with an attached storage device was introduced. This will provide a significant boost in performance and data storage. FSL continues to work with NWS in an early replacement of legacy AWIPS hardware with Linux PCs, and helps implement this hardware suite at the 30 locations that experienced performance problems during severe weather episodes last year.

An enhanced version of data management was introduced in OB5. Previously, data and products were purged from the system based on the number of versions. The new, more flexible approach allows particular products to be kept for a certain length of time after the version limit is reached. Radar products can now be kept for 24 hours at a reduced time frequency, which is useful when reviewing the previous day’s weather.

In 2004, Congress appropriated funds to improve NOAA Weather Radio for handling all hazards, not just weather related hazards. Emergency managers in local and state offices will be able to prepare text messages for transmission on NOAA Weather Radio and NOAA Weather Wire. FSL implemented many of the changes needed at local AWIPS sites, such as preparing a design and performing prototype tests.

Projections

Operational Build 6 will be developed and tested during Fiscal Year 2005. This build will include porting the databases to PostgreSql, so that the Hewlett Packard data servers can be removed. This will complete the AWIPS transition to Linux. All systems will be upgraded to run Red Hat Enterprise 3 version of Linux as their operating system, allowing AWIPS to stay current.

Delivery of the actual software for improving NOAA Weather Radio and NOAA Weather Wire is scheduled as part of an AWIPS maintenance release in 2005.

Enhanced Forecaster Tools Branch

Mark A. Mathewson, Chief

Objectives

The focus of the Enhanced Forecaster Tools Branch is the development of the Interactive Forecast Preparation System (IFPS). In consultation with a working group of National Weather Service (NWS) forecasters and partners in the NWS Meteorological Development Laboratory, we are designing and building the graphical forecast support system for AWIPS. A basic NWS concept driving the design of the IFPS is that NWS forecasts are now based on a suite of grid-based digital data. Forecasters are responsible for the creation and maintenance of a digital database containing all forecast elements over a 7-day forecast period. IFPS permits forecasters to spend the bulk of their forecast shift focusing on meteorology rather than typing text products. At each Weather Forecast Office, a team of forecasters interacts with the database by applying tools that manipulate the gridded data employing meteorologically sound techniques. Once the forecast is complete, this gridded weather information can be communicated in disparate formats tailored to customer needs ranging from automatically formatted text products, to simple images that represent a particular weather forecast element, to a highly interactive user interface in which customers query the forecast database to get precise information.

Accomplishments

The Graphical Forecast Editor (GFE) became operational throughout the NWS, and is used by forecasters to generate digital grids of sensible weather elements. A number of important enhancements were made to GFE to facilitate its operational use. We added virtual weather elements (such as wind chill) that are automatically calculated based upon other elements (wind and temperature). This opens the door to dramatically improving forecaster efficiency by eliminating mundane tasks. Another accomplishment involved merging GFE's graphical user interfaces: zone combination tools, a product editor, and formatter process management interface. Unifying and consolidating these tools into a single user interface permits forecasters to work more efficiently, thus providing more time to focus on meteorology.

A new smart tool that deals with tropical cyclones was implemented in time for the hurricane season in 2004. It converts textual Tropical Prediction Center (TPC) guidance into gridded wind fields, which saves considerable time for the forecaster in preparing gridded wind during tropical events. These enhancements were made with a series of builds labeled IFPS 15.

Projections

NWS has committed to use the Valid Time and Event Code (VTEC) in all their hazardous weather products by the end of 2005. To accomplish this, a new Graphical Hazards Generation (GHG) module will be added to the GFE suite. The GHG Monitor (Figure 83) consists of a spreadsheet showing various information about each hazard, a map showing the spatial location of each hazard, a text displaying the contents of some of the products, and an alert system to inform forecasters when products are about to expire. Users can define various display filters to show the information desired, and can save configurations for later use. The GHG Monitor may be launched either from the command line directly, or from the GFE Products menu. The GHG Monitor is based off the VTEC Active Table, which is created by the VTEC Decoder.

In 2005, we will continue work on a new prototype system in 2005, and plan to deploy an early version of this system at the Boulder WFO. A key feature of this system will be the use of a distributed data paradigm. Under this concept, data will not need to be locally stored and managed in order to be accessible by the workstation, but can reside at a remote site elsewhere on the network.

The popularity of smart tools in the GFE has pushed the system beyond its original design. A new infrastructure will be designed which will significantly enhance the current tools. The design will allow forecasters to associate weather with meteorological features, such as cold fronts. The forecaster will need only identify the location of the cold front in the forecast period, and the tool will interpolate the weather associated with the front from earlier time periods.

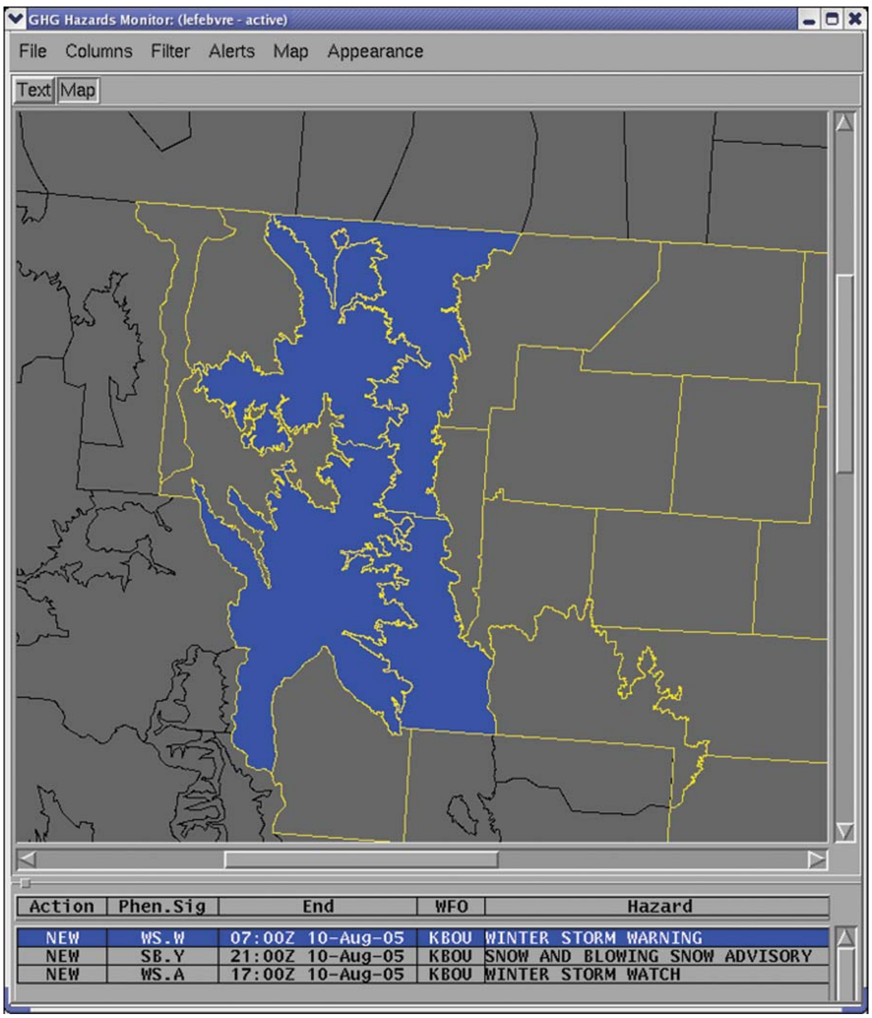

Figure 83. Screen showing the Graphical Hazards Generation (GHG) Monitor, which allows forecasters to quickly view currently valid weather hazards within and adjacent to their area of responsibility.

Technology Outreach Division

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Objectives

The Technology Outreach Division (TOD), develops and promotes new FSL project opportunities and emerging technologies to NOAA and other government organizations and the private sector. It facilitates international technology transfer programs through cooperative agreements. Support is provided for the following major activities:

- *Science On a Sphere™* – Conceived by FSL Director Dr. Sandy MacDonald, Science On a Sphere™ (SOS) is a NOAA program to develop a revolutionary system for educating the public on the holistic nature of Earth's ever-changing oceans, atmosphere, and land. SOS presents an engaging three-dimensional representation of our planet as if the viewer were looking at the Earth from space, offering a new and exciting way to learn about NOAA's global science programs.

- *CWB Technology Transfer Project* – The Technology Transfer Project at the Central Weather Bureau (CWB) of Taiwan is FSL's longest standing cooperative project. The 15-year CWB-FSL partnership has resulted in mutual benefits and cooperation in the areas of information systems, data assimilation and modeling, high-performance computing, and observing systems.

- *Korea Meteorological Administration (KMA) Project* – Working under agreement, FSL is collaborating with the Meteorological Research Institute (METRI) of the Korea Meteorological Administration (KMA) to design a nowcasting system based on FSL's WFO-Advanced meteorological system, support startup and operation, and implement a training program for forecaster systems and operations staff.

- *FX-Net Program* – FX-Net is designed as an inexpensive PC workstation system for use in a variety of forecast, training, education, and research applications not requiring the full capabilities of a WFO-Advanced type system. FX-Net makes AWIPS products accessible over the Internet via high and low bandwidth communication lines.

- *Gridded FX-Net (W^4) Project* – Weather forecasters at the National Interagency Fire Center (NIFC) and 11 Geographical Area Control Centers (GACCs) utilize the latest model and observation data to produce national outlooks identifying critical fire weather patterns. The Gridded FX-Net System will improve the weather forecasters' abilities to provide long-term fire behavior and fire potential products.

- *Wavelet Data Compression Project* – Integral to the FX-Net technology is a wavelet compression technique that can reduce and transmit product file sizes with minimal loss of resolution.

NOAA Science On a Sphere™ Project

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Objectives

Human understanding of large-scale, Earth System processes has benefited from our ability to collect, analyze, and display global planetary data. Scientists use data gathered from satellites and other remote sensing devices to study the Earth and Sun. Through the use of computers and visualization techniques, we are able to better see and understand environmental processes that affect our planet.

Accomplishments

Science On a Sphere™ (SOS) is a visualization system that NOAA uses to increase the public's understanding of the dynamic forces of nature that impact our oceans, atmosphere, and land and affect our collective future. Using computers coupled with video projectors, SOS displays NOAA's global science in an engaging three-dimensional representation of the Earth's features as if they were viewed from space. Nearly any global dataset can be displayed on the surface of the sphere, including the weather, climate, and geology, as well as images of other planets in the solar system. At exhibition centers featuring NOAA's Science On a Sphere™ (Figure 84), audiences enter a display area and move freely around the suspended globe to see and hear an explanation of how warm water pushing over from the western Pacific signals the onset of an El Niño. Hurricanes, as viewed from weather satellites, can be observed forming off the coast of Africa and moving across the Atlantic Ocean toward the United States. Data from

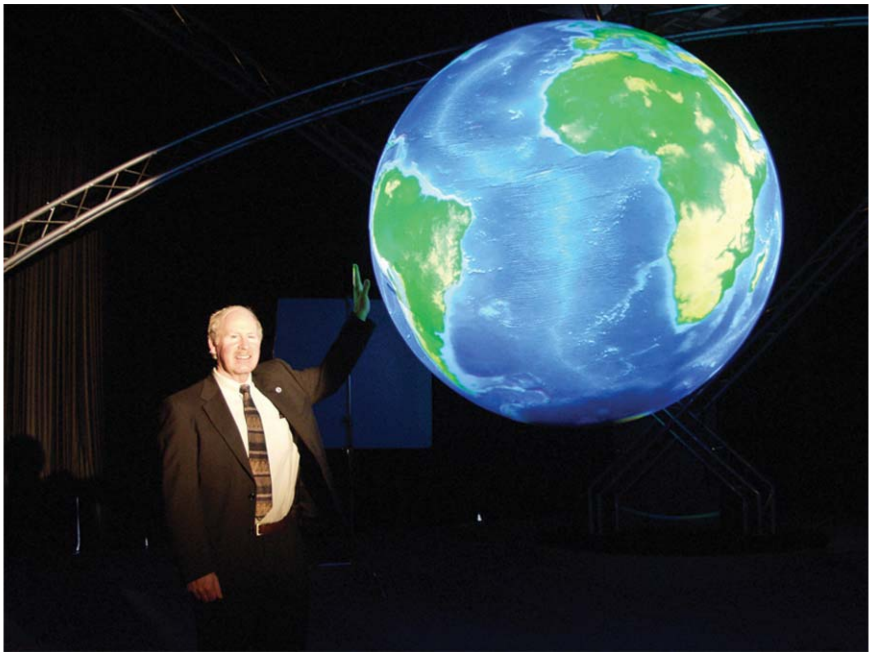


Figure 84. Dr. A.E. MacDonald discussing Science On a Sphere™ at a conference.

military satellites show the spectacular lights of our planet at night. Other popular displays include massive, churning solar flares of the Sun, geological objects on the surface of Mars, and the cloudy atmosphere of Jupiter. Science On a Sphere™ technology provides a means to educate the public on many important issues, both environmental and economical, and enhances NOAA's capacity to advance science.

Under development at FSL since 2001, Science On a Sphere™ has been shown to thousands of viewers, children and adults, at its home location at NOAA's David Skaggs Research Center in Boulder. Since its 2002 public viewing at the NOAA Science Center, it has been exhibited at numerous scientific and educational conferences around the United States.

NOAA was invited to exhibit Science On a Sphere™ at the Sea Island G-8 Summit June 4–10, 2004, to emphasize to the world press the global nature of the problems addressed at this venue. In addition, NOAA broadcast a press conference on Global Ocean Day from the site of the Titanic. Both of these events were designed to demonstrate the efforts made by the United States to provide stewardship and understanding of the common atmosphere and oceans we share. Demonstrations of Science On a Sphere™ started when the media center opened June 4, and continued through June 10, the last day of the G-8 Summit. The display of Science On a Sphere™ dominated the press center, with almost every major news organization at the Summit devoting airtime or column space to this new and innovative display. The FSL director and other NOAA team members were available for interviews and demonstrations. Interviews were held on and off camera by local, national, and international reporters, and broadcast on TV stations such as BBC TV and Italian TV. These demonstrations allowed NOAA to showcase its technology (Figure 85), applications, and global partnerships to a worldwide media audience.

Figure 85. A data display of ocean buoys shown on Science On a Sphere™.

In April of 2005, NOAA installed a permanent SOS system at the National Maritime Center (Nauticus) in Norfolk, Virginia. Nauticus is a maritime-themed science center featuring theaters, aquaria, and a variety of hands-on exhibits. Science On a Sphere™ is used to enhance the visitor experience at Nauticus and provide museum patrons with a global view of the environment. The system is used to deliver staff lead presentations as well as run in an unattended mode.

Partnerships – NOAA and FSL developed a partnership program that enables Science On a Sphere™ to be permanently installed at a number of science centers and museums around the world. The partnership is structured on a cost recovery basis, in which the participating organization purchases all of the parts (hardware and software) needed to build Science On a Sphere™, and then provides NOAA with funds to install, configure, and support the system. The negotiations so far have resulted in agreements with three sites to participate in the program with several other sites under consideration. In conjunction with the partner program, NOAA is actively soliciting licensing agreement proposals that would enable the transfer of all or part of the technology supporting Science On a Sphere™ to a private organization for marketing and commercial distribution. A patent has been granted for Science On a Sphere™.

System Features – The visualization system of Science On a Sphere™ consists of video projectors, computers, and custom display software. Four computers drive the video projectors that shine separate images (from data) onto each quadrant of the sphere, and a separate computer controls the whole system. This fifth computer synchronizes the four displays and runs the user interface and automation controls. The general development goal was to make Science On a Sphere™ a robust visualization system to present a museum-quality exhibit for deployment in museums and science centers.

Science On a Sphere™ can be controlled interactively through a user interface or run in an unattended mode of operation. The system supports the concept of a playlist to organize sphere content for the end-users. After being created, a playlist can automatically sequence through a specified number of visual displays to create an entire Science On a Sphere™ presentation. The system can be programmed to stop at the end of the playlist or loop through it forever. Combined with an automatic mode of operation, the playlist function allows Science On a Sphere™ to work well in a museum setting, where the system is started at the beginning of the day, run all day long, and shut down at the end of the day.

Another important feature of SOS is the ability to play audio streams that are coordinated and frame-synchronized to the media being shown on the sphere. Audio files, such as an MP3 or WAV file, can be created independently and associated with display data to be shown on Science On a Sphere™. The playlist associates the audio file with a specific visual presentation, thus enabling the system to run soundtracks along with the visuals.

Automation control systems, generally purchased from commercial vendors, are used by many museums and organizations to operate exhibits for public viewing. Sometimes called "show floor control systems," this technology is ideally used to automatically control functions such as turning lights on and off, opening doors, or starting video presentations. The show floor control system connects to the device to be controlled across a network, or through a serial line, and then sends commands to control a particular function. Science On a Sphere™ supports the standard protocols used by most commercial show floor control systems. This feature allows SOS to be operated and controlled by commercial show floor control systems as well as work with various remote control devices, such as touch screens, hand-held remotes, and other software applications.

The ability to display PowerPoint-created slides on external display devices is a feature of the Science On a Sphere™ system. The slides for a presentation are associated with media being shown on the sphere through the playlist. As the visualization is shown on the sphere, the system advances through the slides. The slides are typically displayed on a separate display device, such as a large plasma monitor or a series of LCD screens. This feature adds flexibility to the system and enables the enrichment of any particular presentation with additional, perhaps more detailed information about what is being displayed on the sphere.

An alternate configuration of SOS is being developed that uses five display projectors. The five-projector version of the system increases the projector coverage of the sphere while reducing the overall footprint of a complete SOS installation (this is a feature requested by some museums).

Projections

As Science On a Sphere™ continues to evolve and mature, new partnerships will be formed through negotiations with museums, science centers, and other organizations. It is anticipated that FSL will contribute significant effort toward the support of Science On a Sphere™ at remote locations as more institutions sign on for the partner program. Planning and organization activities will continue in support of exhibitions of the system at scientific, educational, and other special venues.

New system development is proceeding toward software robustness, ease of use, increased sophistication in the treatment of audio, 3D graphics, and investigation of new technology. Future enhancements will include capabilities that make the system more useful for museums.

FSL is working cooperatively with NOAA's Office of Education and Sustained Development (OESD) to support NOAA's Environmental Literacy Grants program. This program creates an opportunity for a museum, science center, or any other organization that has informal education programs in place, to get a NOAA sponsored Science On a Sphere™ at their organization. If the program proceeds as expected, NOAA will sponsor four Science On a Sphere systems in 2005/2006.

Looking even further into the future, FSL is in discussion with the Smithsonian Museum of Natural History to install an SOS system in the new Ocean Hall (scheduled to open in 2008).

NOAA and FSL will continue to cooperate in finding ways to maximize the usefulness of this powerful visualization system, and to enhance the partnership program to provide broader public exposure of NOAA's accomplishments and goals.

Central Weather Bureau of Taiwan Technology Transfer

Fanthune Moeng, Program Manager

Objectives

FSL's collaboration with the Central Weather Bureau (CWB) of Taiwan is a 15-year success story in technology transfer of weather forecasting applications. Since formal cooperative agreements were approved in June 1990, the CWB and FSL partnership has grown to include major initiatives for improving CWB forecasting capabilities. Together they have developed a series of PC-based forecast workstations. The latest workstation is the Weather Information and Nowcasting System (WINS II), now operational at the CWB Forecast Center. The system was incorporated into the CWB central facility, including data sources, communication, preprocessing, and product generation. WINS II provides data and products to outside users, such as the Civil Aeronautics Administration (CAA), universities, the Environmental Protection Agency (EPA), and the Taiwan Hydrology Bureau.

The strong forecasting infrastructure that has been built at CWB provides greater data collection, improved observation systems, high-performance computing, and management capabilities – all combining to empower CWB with new and more useful forecast products. CWB is positioned to take advantage of this infrastructure in new ways, with more powerful techniques under development within FSL and other NOAA laboratories. The effectiveness of the CWB-FSL cooperation is based in large part on CWB's willingness and ability to develop and use customized products with associated technical support. FSL's mandate to provide useful technologies fits with CWB's real-world forecasting needs.

Accomplishments

The goals to improve forecasting capabilities at CWB during 2004 involved three major areas:

- Local Analysis and Prediction System (LAPS)
- Forecast Assistant System (FAS)
- Continuing interaction on earlier cooperative projects.

Local Analysis and Prediction System – During 2004, FSL staff remotely updated (on a weekly basis) Taiwan's LAPS software code on the CWB computer with the latest MM5 Hot Start model and multiple background model options. FSL completed the transition of the 15-km Nonhydrostatic Forecast System (NFS), the Typhoon Forecast System (TFS), and the Global Forecast System (GFS) into our shadow system. The 15-km NFS is now the primary background for the 9- and 3-km shadow runs at FSL. When available, the Typhoon Forecast System (TFS) data constitute top priority among all background models.

Establishing a shadow Hot Start LAPS/MM5 system at CWB was a big step in diagnosing the technical issues discovered during daily operational runs, especially for typhoon cases. Figure 86 shows a CWB LAPS Hot Start 3-hour precipitation forecast using the Weather Research and Forecast (WRF) model and the NCEP Global Forecast System (GFS) as background for Typhoon Mindulle, 1 July 2004.

FSL added a verification system for state variables fully integrated into the ported LAPS model system. A prototype Web-based user interface was also developed for the LAPS Real-Time Verification System (LRTVS). This prototype software was delivered to a CWB visiting scientist in October of 2004. Figure 87 shows an example of the CWB–

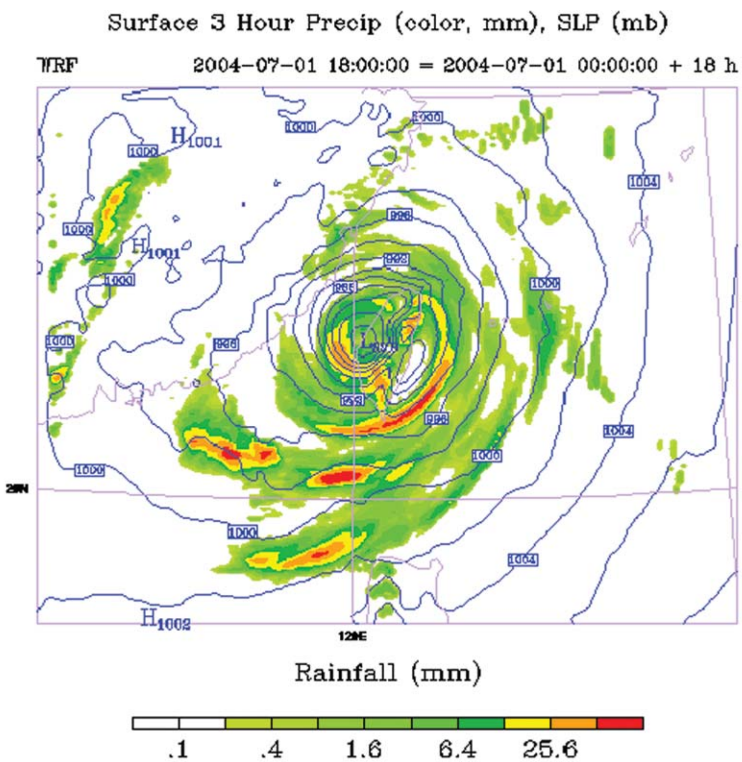


Figure 86. WRF-CWB 3-hour precipitation forecast using the NCEP Global Forecast Model for Typhoon Mindulle, 1 July 2004.

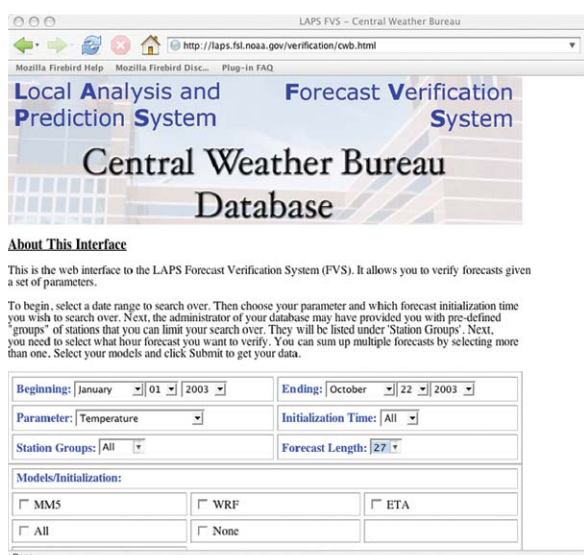


Figure 87. Screen from the CWB-LAPS verification user interface Webpage.

LAPS verification user interface Webpage. A CWB scientist visited FSL for 5 months to work on a multi-Doppler scheme to improve wind analysis, and on widening the time window to improve cloud drift wind ingest.

LAPS now includes these two analysis schemes, and FSL is testing CWB's radar dealiasing scheme for possible future operational use, and other schemes such as the Vertical Profile of Reflectivity (VPR) tool for radar mosaic analysis and velocity azimuth display (VAD) wind analysis. We are working to improve quantitative precipitation estimates (QPEs) in order to combine radar-derived precipitation estimates and rain gauge data for adjusting and ingesting GPS surface meteorological observation data. FSL integrated improvements made by a visiting scientist from CWB for better precipitation fall velocity, and also helped improve GOES-9 navigation at the Taiwan Central Weather Bureau.

Last November, FSL provided a two-week training course for two CWB forecasters on a variety of topics, as well as the practical use of LAPS/MM5. The training included background on the Graphical Forecaster Editor, Hurricane Smart Tool, WarnGen, D3D, SCAN, SAFESEAS, and daily weather briefings. The CWB forecasters also worked the short shift at the Denver-Boulder Weather Forecast Office to get first-hand experience in the NWS operational environment.

FSL continued to improve the real-time LAPS running on CWB's WINS-II system, and provided support to CWB staff on the daily running of Taiwan’s LAPS system. FSL hosted three long-term visiting scientists from CWB for 5–9 months last year, and helped one of those scientists set up the LAPS-WRF environment and test the Cold and Hot Start models with recent Taiwan typhoon cases.

Other Ongoing Cooperative Projects – During 2004, FSL continued its support to improve CWB’s WINS II system in the areas of severe weather warning and forecast capability. FSL staff visited NWS to collect information on existing 0–3 hour statistical QPFs, and then transferred the software and documentation to CWB.

During July 2004, NOAA/MDL staff provided SCAN user training on AWIPS Operational Build 3.2 with SCAN software.

Last October, FSL staff visited CWB to provide technical support for the FX-Collaborate (FXC) workstation (including the latest version, FXC-300 beta release), and discuss various drawing capabilities for potential use by CWB forecasters.

FSL continued to provide NOAAPORT data and necessary data transmission computer equipment, as well as additional AWIPS-related information such as WarnGen and technical support to parallelize CWB’s NFS model with an SMS derivative for the AWIPS-related information such as WarnGen and technical support to parallelize CWB’s NFS model with a SMS derivative for the CWB future high performance computing procurement. Another FSL scientist visited CWB to train model developers on the NFS model parallelization.

Projections

During 2005, the FSL-CWB team will continue to focus on three ongoing tasks:

- Local Analysis and Prediction System (LAPS), which performs high-resolution analyses and provides short-range weather forecasts using locally and centrally available meteorological observations.

- CWB's current forecast workstation (WINS-II) and the new System on AWIPS for Forecasting and Evaluation of Seas and Lakes (SAFESEAS), which will provide short-range forecasts of precipitation from remote-sensor observations.
- Interaction on earlier cooperative projects.

LAPS – In 2005, FSL and CWB will continue to improve the LAPS analysis in the areas of cloud microphysics (Water In All Phases) and assimilation of vertical motion estimates from convective and stratus cloud analysis. We will also investigate any new motion retrieval algorithms based on the horizontal convective wind field using radar winds. Work will begin on adapting the Weather Research and Forecast system link to Taiwan LAPS. Together we will explore higher model resolution to improve model performance for typhoon rain bands, and FSL will implement the typhoon bogussing system into the shadowing system. The LAPS real-time verification system (LRTVS) will be improved for point verification of precipitation and for gridded verification of model quantitative precipitation forecasts with LAPS quantitative precipitation estimates. We will continue running the CWB shadowing system at FSL.

SAFESEAS – FSL will assist in porting the SAFESEAS code to WINS II, so that CWB can expand SAFESEAS to monitor general point observations. SAFESEAS is another integrated nowcast assistance tool for monitoring weather conditions that threaten marine vehicles (ships, buoys, etc), and for helping forecasters decide when to alert the marine community about existing dangerous conditions.

Interaction on Earlier Cooperative Projects – FSL will provide support to CWB in customizing the 0–3 hour probability QPF system using statistical data collected in Taiwan. Similar to the System for Convection Analysis and Nowcasting (SCAN), the Flash Flood Monitoring and Prediction (FFMP) system is another integrated nowcast assistance tool for analyzing and monitoring precipitation and other datasets in order to detect and predict flash flood events. FFMP automatically alerts forecasters of flash flood potential. It uses small basin areas to improve accuracy of the basin average rainfall, and provides a better estimate of accumulation and, therefore, flash flood potential. FFMP also provides forecasters with accurate, timely, and consistent heavy precipitation warnings, serve CWB as a "first alert" warning system, and minimize false alarm reports (FARs). FSL will provide design approach information to CWB that follows the AWIPS/FFMP implementation document, so that CWB can assess the future value of implementing FFMP in the Taiwan area.

FSL will provide technical support to customize FXC as a drawing tool for CWB forecasters. FXC has been successful in providing collaborative functions and elaborate drawing capabilities (analogous to white-boarding) to forecasters in the United States.

Technology has been transferred successfully on other cooperative tasks, which are now being used operationally at CWB. FSL's development in these areas continues, and further CWB/FSL interaction is important to keep CWB staff up-to-date on current developments. This effort will allow continuing interaction at an appropriate level, including new software releases of the forecast information system for the internet-based forecast workstation, data assimilation, forecaster training, exchange of visits, copying papers and reports, and e-mail interaction.

Korea Meteorological Administration Forecaster's Analysis System

Fanthune Moeng, Project Manager

Objectives

The Technology Outreach Division is under agreement with the Meteorological Research Institute (METRI) of the Korea Meteorological Administration (KMA) to design a nowcasting system based on FSL's WFO-Advanced meteorological system. The development of an integrated workstation, the Forecaster's Analysis System (FAS), is the capstone of years of modernization at the KMA to provide better weather information to its citizens. Researchers and engineers from both organizations will carry out the cooperative effort.

Accomplishments

In meeting the goals to improve forecasting capabilities at KMA during 2004, three major tasks were completed:

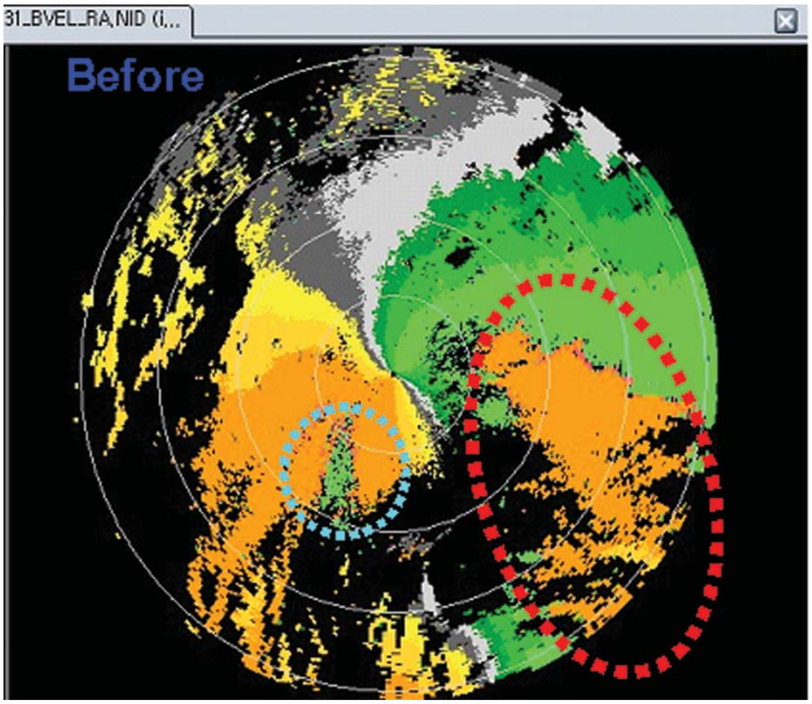
- Development of the nowcasting technique, the System for Convection Analysis and Nowcasting (SCAN)
- Quality control and standardization of domestic remote sensing data
- Enhancement of the Forecaster's Analysis System (FAS).

SCAN Nowcasting Technique – The goal of this task was to implement the AWIPS System for Convection Analysis and Nowcasting (SCAN) algorithms (such as SCIT, CZ and VIL) on the KMA Forecaster's Analysis System. These algorithms are based on the centroid identification and tracking technique that detects, analyzes, and monitors convection, and generates short-term forecasts and warnings for severe weather. This task involved three components: real time radar data ingest, automated radar data processing, and SCAN processing and display on FAS workstations. A KMA visiting scientist worked with NCEP Meteorological Development Laboratory (MDL) and FSL staff to implement the radar data processing component of this task. FSL and MDL helped set up a proper working environment with the latest AWIPS Operational Build (OB3), so that the CWB visitor becomes more knowledgeable about complex systems, such as FAS, Open Systems Radar Product Generator (ORPG) software, and AWIPS OB software localization.

FSL and KMA developed the radar processing component for SCAN so that the KMA system can ingest real-time KMA radar data. SCAN uses the Storm Cell Identification and Tracking (SCIT) radar products to estimate the present location, magnitude, and velocity of each storm cell. The future location of each storm cell is predicted based on its previous positions. FSL completed the SCAN localization and created required GIS (Graphical Information System) datasets so that the localization can be displayed properly on the FAS system. FSL tested SCAN with recorded data from KMA and performed verification work. The KMA visitor also created the test dataset using KMA archive radar data.

Quality Control and Standardization of Domestic Remote Sensing Data – The goal of this task was to establish the framework and integrate prospective NSSL radar quality control algorithms, thereby designing and implementing a prototype system for the KMA Data Quality System (DQS). Candidate algorithms were the NEXRAD (WSR-88D) ORPG and NSSL-developed quality control algorithms. Currently, three QC-related algorithms from ORPG (velocity dealiasing, the echo classifier, and DQS) are being evaluated. Also under investigation are NSSL radar quality control components such as ground clutter, AP removal, sea clutter, velocity dealiasing, point echo, clear air echo, line echo, and ring and disc-shaped echoes.

A KMA visiting scientist at FSL studied basic NEXRAD components, improved software techniques, and received radar training on the development of the KMA Data Quality System (DQS) prototype. The scientist continued to maintain and evaluate the performance of DQS using different radar systems upon return to KMA. Figure 88 shows an example of the Radar Quality Control Dealiasing algorithm using the KMA radar data from Jindo, Korea.



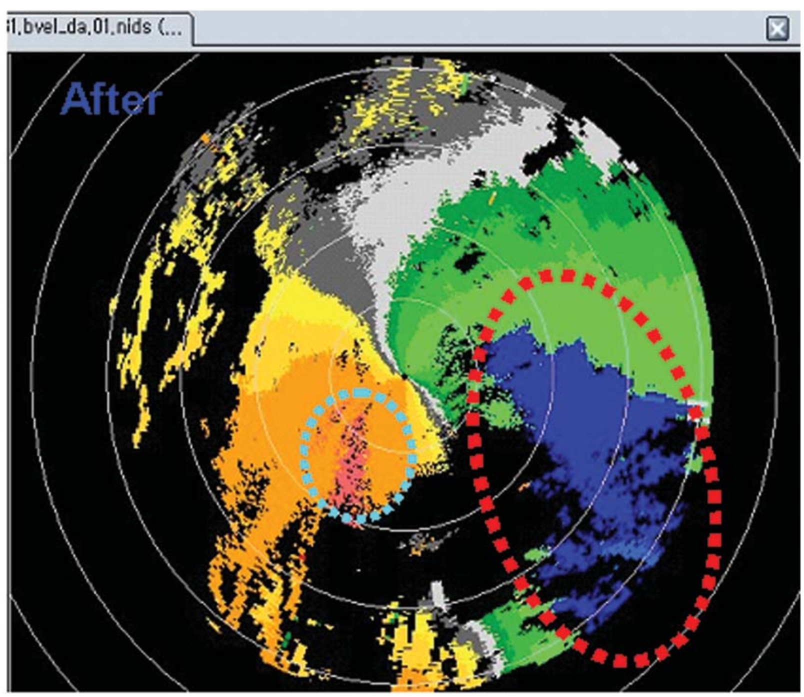


Figure 88. An example of "before" and "after" images of the Radar Quality Control Dealiasing algorithm using KMA radar data from Jindo, Korea.

Forecaster's Analysis System (FAS) Enhancement – The goal of this task was to provide KMA with periodic upgrades of FAS with new AWIPS Operational Build (OB) releases, with new products (such as ACARS wind in OB2), significant changes in radar data processing capabilities (such as new radar scan strategies, the small beam approach, and TDWR data in OB3), and with other software improvements. FSL provided a short-term visiting scientist from the KMA with the new AWIPS Operational Builds (3 and 4) for KMA/FAS enhancement work.

Three NOAA staff members participated in a KMA workshop on FAS, and gave talks on the "Basic Concept and Critical Issues for Operational Nowcasting," "The Future of Global Weather Observing," and the "Use of the FX-Collaborate (FXC) Workstation for Aviation Applications."

FSL hosted training sessions for nine KMA senior forecasters. The training covered many topics, including an FSL overview, FXC, NOAA Science On a Sphere™, MAPS Surface Assimilation System, improved features of AWIPS Build OB, interactive Skew-T application, use of satellite data, radar data analysis, SCAN guide for users, FFMP, wind profilers and the NOAA Profiler Network, GPS Network, weather modification, and hydrological applications. Each forecaster received a CD of all materials used during the training. In addition, FSL invited two KMA translators to participate in the training, and they provided an invaluable service during the sessions. Figure 89 is a photo of the KMA forecasters and participants of the training at the FSL campus.

Projections

During 2005, the FSL/PG-NOW team will focus on tasks involving development of the SCAN nowcasting technique, QC and standardization of domestic remote sensing data, and enhancement of the Forecaster's Analysis System (FAS).

Development of Nowcasting Technique – FSL and KMA will verify the SCAN code for different KMA radars, and prepare for the final operational test. The SCAN components will undergo a series of operations, including storm detection and prediction algorithms plus data integration techniques for KMA forecasters to use during severe weather warning operations. FSL and the NCEP Meteorological Development Laboratory will provide SCAN training and technical support on testing/validation of SCAN.

QC and Standardization of Domestic Remote Sensing Data – FSL and the National Severe Storms Laboratory (NSSL) and KMA will continue to evaluate the performance of selected quality control algorithms for the KMA radar system (additional S band and C band radar data), adjust adaptable parameters and/or make minor code modifications to improve algorithm performance in mitigating KMA radar data QC issues. FSL and NSSL will deliver the KMA RDQS software and provide training to the KMA visiting scientist on the high-level code structure and operational use of the RDQS.

FAS Enhancement – FSL will continue to provide technical support on FAS evaluation and improvement, periodic upgrades to the AWIPS OBs 4, 5 and 6, and system modification to meet KMA's needs. AWIPS upgrades will include new product display tools for cold and warm fronts. We will train KMA forecasters on the use of the FAS and SCAN applications. FSL staff will also evaluate the proficiency of forecasters who receive training, and identify topics needing further training. FSL will work closely with KMA forecasters in developing their workstation skills and their understanding of workstation use during various meteorological events. Case studies will be reviewed in order to determine which meteorological fields enhance forecaster understanding for nowcasting and forecast purposes.

Figure 89. Forecasters from the Korean Meteorological Administration attending training sessions at the Boulder FSL campus in October 2004.

FX-Net Program

Sher Schranz, Project Manager

Objectives

The FX-Net program was established to develop a network-based meteorological workstation that provides access to the basic display capability of an AWIPS workstation via the Internet. The design goal was to offer an inexpensive PC workstation system for use in a variety of forecast, training, education, and research applications not requiring the full capabilities of a WFO-Advanced-type system. Although designed primarily for Internet use, FX-Net will also accommodate local network, dialup, and dedicated line use. The system consists of an AWIPS data server, an FX-Net computer file server, and a PC client. In the case of a completely redundant system, a load balancer is also part of the system. The FX-Net server, a modified AWIPS workstation, is locally mounted next to the AWIPS data server via a high-speed link. The FX-Net client sends product requests via the Internet to the FX-Net server, which responds by sending the products to the client. The user interface of the FX-Net client closely resembles the AWIPS workstation user interface, except for reduced resolution and complexity to allow for rapid Internet response. Some of the FX-Net client features related to functionality include load, animation, overlay, toggle, zoom, and swap. Although the client Java application can be run on a number of standard PC platforms, the system performs best under Windows 2000, or Windows XP. The minimum client hardware configuration consists of a 500-MHz processor with 256-MB memory. Internet bandwidth down to 56 kbps is considered sufficient to transmit FX-Net products.

Data are received by the FX-Net data server (Figure 90) through the AWIPS NOAAPORT broadcast, FTP servers, and LDM data feeds. The available FX-Net products are categorized into four groups: satellite imagery, model graphics and observations, radar imagery, and model imagery. A wavelet transform technique is used to compress model and satellite imagery. The application of this relatively new compression technique is critical to the success of delivering very large-size imagery via the Internet in a reasonable amount of time. The small loss of fidelity in the imagery is acceptable in exchange for very high compression ratios. Processing time is further minimized by pregenerating and compressing all satellite data on the FX-Net server. In contrast to the satellite imagery, the radar imagery is encoded in a standard lossless image compression format (GIF), and the small-sized model graphics are represented in a standard vector graphics format.

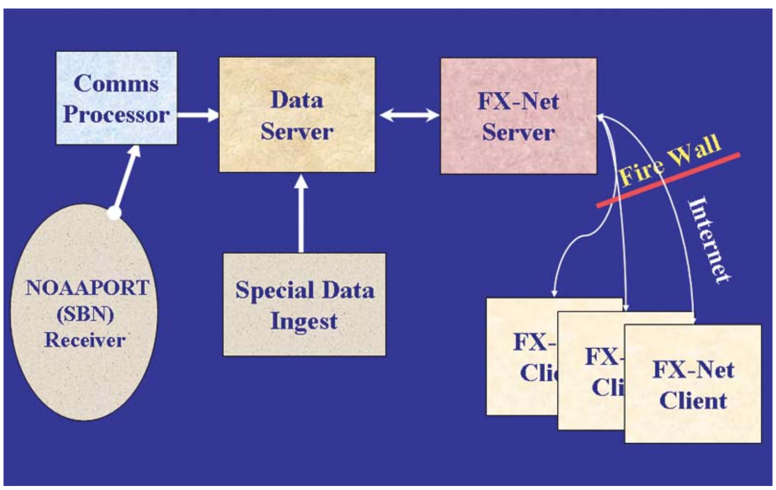


Figure 90. FX-Net system configuration.

Accomplishments

FX-Net for Fire Weather/All Hazards at the National Weather Service – The primary goals of collaborators in the NOAA National Fire Weather Program are to eliminate weather-related land wildfire fatalities and injuries, and to reduce fire suppression and land management costs by providing more timely and accurate weather information. NWS forecasters at Weather Forecast Offices and the Storm Prediction Center utilize the latest model and observation data to produce national outlooks identifying critical fire weather patterns. The NOAA mission is to provide tools to support the forecasters producing these long- and short-range forecasts in support of fire-management decision-makers.

When a wildfire does erupt, the NOAA mission to provide services in support of public safety becomes critical. Forecasters must produce very short-range "nowcasts" of weather hazards that will directly affect firefighting activities. Forecasters need tools that they can carry with them to the fire, and their ability to function effectively as part of a firefighting coordination team is indeed dependent on these tools.

Even though the ultimate all-hazards system is not a complete reality, the development team has been very successful in providing key elements to the users. Significant changes to the basic FX-Net system were made in the past year. The system was upgraded to a RedHat Linux Enterprise operating system, and the latest operational version of the AWIPS server software. This provided users with FX-Net database upgrades, newly released model grids, and additional observing systems as well as increased system security. The AWIPS server code was modified to provide specialized, nonlocalized map scales to accommodate local model data and added observational data. A new version of the Apache (Internet request-handling) software was also installed.

This new version of the FX-Net system was considered a major upgrade by the NWS regional offices in the Western, Southern, Alaska, and Pacific regions.

A new version of the Wavelet Compression Code was added to the system, providing higher resolution satellite imagery and improved product retrieval response. New datasets were added through the MADIS system, and locally generated high-resolution model output was added to the system.

New tools were added to the FX-Net client to provide an automated text, dataset, and menu update capability, and display screen to printer-direct capability.

Infrastructure upgrades included new versions of Java, Install Shield, and the Star Team version control software.

FX-Net for Fire Weather at the National Interagency Fire Center (NIFC) – Via a technology transfer Memorandum of Agreement which was initiated in 2002, the latest version of the FX-Net Client was installed at the Bureau of Land Management (BLM) Federal Test Center in Lakewood, Colorado. The latest version of the FX-Net client software (v. 4.0) passed the rigorous network and security tests administered at the BLM Test Center, and was certified for use by the 11 Geographical Area Coordination Centers (GACCs), NIFC, National Forest Service, and Ag Outlook Board. The FX-Net servers and clients are distributed and maintained by the FX-Net Project team.

BLM users at the above locations provide long-range fire predictions, daily fire indexes, and drought outlook products for various BLM Websites, and for operational use by fire weather forecasters. Custom maps and scales were added to the FX-Net system for these specialized users.

FX-Net and the EPA Air Quality Pilot Project – In Fiscal Year 2004, NOAA and the EPA signed a Memorandum of Agreement to pursue a pilot project that provided a special air quality FX-Net system to select state and local air quality forecasters on the East Coast. The success of that project led to a second pilot project Agreement in Fiscal Year 2005, which allows state and local air quality forecasters across the U.S. access to the FX-Net Air Quality System. The core FX-Net system was used to build the servers for the specialized air quality users. Additional datasets such as the EPA's AIRNow real-time air quality observational data, the NOAA/EPA air quality forecast model data (CMAQ), and experimental air quality forecast models such as FSL's WRF/Chem model were included in this new system. EPA users who participated in the pilot project use this system as their primary forecast preparation system during significant air quality forecasting seasons. Figure 91 shows the air quality dataset menus on FX-Net.

FX-Net in Atmospheric and Air Quality Research – The FX-Net system has been used by the University of New Hampshire and Plymouth State University for the past four years. These groups have used the system in the classroom as well as the primary forecast system for field experiments such as the 2004 NEAQS-ICARTT study. Other universities using the system in the classroom and the field include the University of Northern Iowa, Florida State University, and the University of Northern Florida.

Researchers from the U.S. Air Force, NOAA Research, Boeing, NASA, and the weather modification community have also used the system for model verification, field studies, and experimental weather forecasting. Figure 92 shows a cross section of WRF/Chem ozone field using the FX-Net gridded data cross-section tool.

FX-Net and the Public Sector – In Fiscal Year 2004–2005, a formal Memorandum of Understanding was signed with ENSCO, Inc. to evaluate the FX-Net system for commercial use. The evaluation results of this ongoing project will be reported in Fiscal Year 2006.

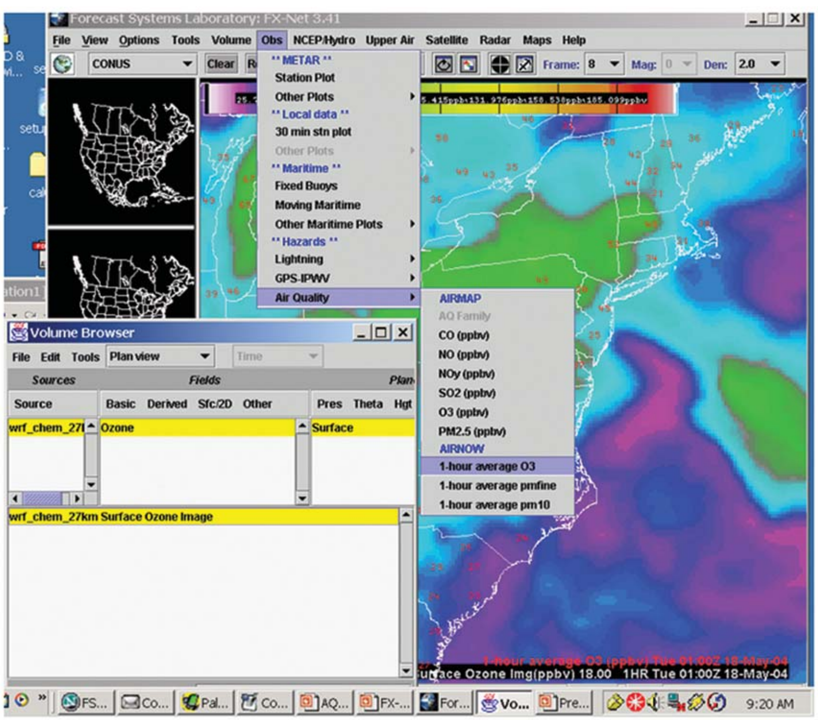


Figure 91. Air quality dataset menus on FX-Net showing the Volume Browser window open with the WRF-Chem model selected, and the Observations window open with the Air Quality AIRNow Ozone field selected.

Projections

General – During 2005–2006, the primary focus of the FX-Net project is to maintain the reliability and integrity of the FX-Net systems that support critical field operations, such as the NWS IMETS and the state and local air quality forecasters. A secondary, yet very important focus will be on collaborating with FSL's System Development Division and the NWS to design a new system that combines the FX-Net and FX-Collaborate programs in a way that accommodates all current users and prepares for the future needs of NWS operations.

University and Research – The FX-Net team will continue to operate and maintain a system to support university meteorology classes and meteorological research at Plymouth State College in New Hampshire, University of New Hampshire, and the University of Northern Iowa. FX-Net will support the summer 2004 New England Air Quality Study (NEAQS) field experiment, and we will add the FSL-developed WRF/Chem model to the system.

Real-time Air Quality Forecast Workstation – FX-Net will increasingly focus on adding products to support real-time air quality forecasting. Products to be added include the NWS operational air quality model grids (CMAQ) and additional data sets from the EPA AIRNow program.

Fire Weather Forecasting – The FX-Net team will continue to support the NIFC and GACC offices as they continue to use the system as their primary meteorological workstation to support the fire weather forecasters.

NWS: Western, Southern, Alaska, and Pacific Region – Upgraded data servers, new security software, NOAAPORT broadcast changes, and an upgraded FX-Net client will be delivered to these four NWS regional offices.

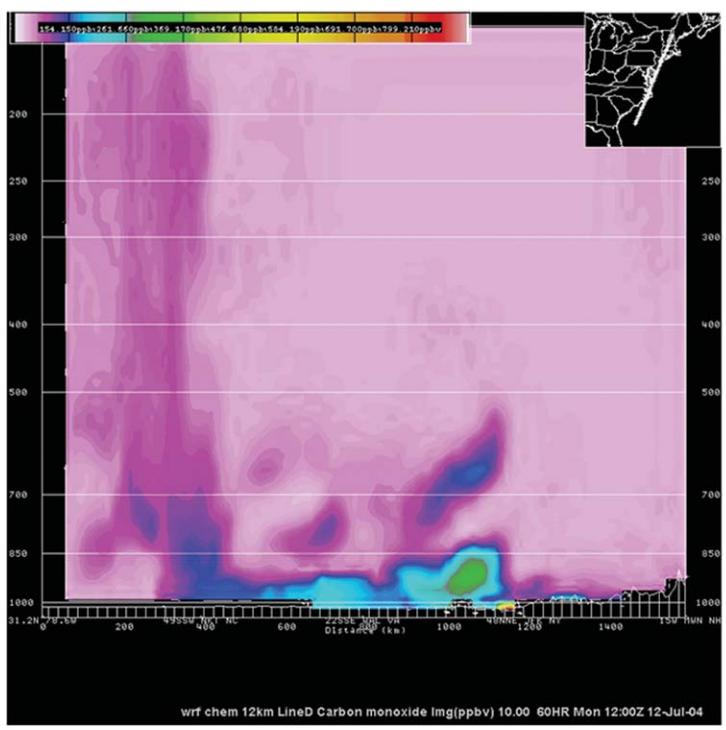


Figure 92. Cross section of WRF/Chem ozone field using the FX-Net gridded data, cross-section tool.

Gridded FX-Net (W^4) Project

Sher Schranz, Project Manager

Objectives

Gridded FX-Net is a highly leveraged technology transfer research project proceeding in collaboration with the National Interagency Fire Center (NIFC) and the FX-Net development team. Fire weather forecasters at NIFC and the 11 Geographical Area Control Centers (GACCs) utilize the latest model and observation data to produce national outlooks identifying critical fire weather patterns. The NOAA mission is to provide tools to support the NWS and NIFC forecasters producing these long- and short-range forecasts in support of fire-management decision-makers.

As a technology transfer program, the NIFC Gridded FX-Net system aims to improve the capability for GACC forecasters to provide long-term fire behavior and fire potential products. Essential to producing these products is the numerical prediction models delivered via the NOAAPORT to the AWIPS data servers. The central focus of this research is combining the enabling technologies from the FX-Net and AWIPS systems. The goal is to deliver gridded model output data, satellite, and radar imagery, as well as all the observational data available via NOAAPORT to AWIPS D2D (Display 2D) clients.

Accomplishments

In 2004–2005, our goals were to build a prototype system demonstrating the ability to host multiple remote D2D users from one AWIPS server. The system components include:

- Data and file servers (based on AWIPS data and file servers).
- Client (based on the AWIPS D2D display system), which manipulates and displays the data.
- Wavelet Compression code, used to reduce the size of the datasets for transmission to remote D2D clients.
- LDM "push" data delivery, used to distribute the data from the server to the remote client.

Research centered on developing a prototype remote AWIPS client based on the AWIPS data and applications servers. A prototype system was developed and tested at FSL using existing hardware.

Completed development tasks included:

- Server software: 1) We created new file server data managers, monitoring code, a compression manager, an integrated LDM data delivery system, and modified METAR and RAOB decoders. 2) Overall server system processes, including startup and shutdown scripts, and data bundling were modified for the prototype system.
- Wavelet Compression: 1) Direct compression of these products will not achieve the desired compression efficiency, since products in these formats contain information that requires both lossless and lossy compression. In order to separate this group of information for compression, stage it, and combine it in the decompression stage, several pairs of application data format decoders and encoders must be developed to handle different products. 2) To meet the requirements of reliability and robustness in an operational environment, a few error resilient checks and safeguards were added to the software.
- A Gridded FX-Net prototype was installed at the BLM National Test Center, Lakewood, Colorado. The system has passed all security and network tests and will be certified for installation at NIFC and all 11 GACC offices.

Projections

The next phase of the project requires installation of three clients at three GACCs to monitor bandwidth utilization, server IGC loading, and multiple-client auto-updating.

Wavelet Data Compression Project

Sher Schranz, Project Manager

Objectives

A primary objective of the Wavelet Data Compression project is to improve the gridded wavelet compression technology for use in the Gridded FX-Net system. Compared to imagery datasets, gridded numerical weather prediction (NWP) datasets usually have higher numbers of dimensions, but each dimension is of much smaller size. Therefore, special treatments are needed to exploit the correlation among all dimensions. This required development of a multidimensional data arrangement and transform scheme to accommodate the special features of the model dataset. An experimental encoder and decoder package has been implemented to test various datasets with different standard wavelets and different post-transform compression algorithms..

Accomplishments

During 2004, wavelet-based data compression techniques were developed to compress both satellite images and model grids. These techniques have demonstrated their abilities to significantly reduce the meteorological products file size, and, therefore, the transmission time of the products. To apply the wavelet data compression to the Gridded FX-Net project, several adaptations and optimizations were made in order to meet the requirements of the operational environments and to achieve desired results.

For the Gridded FX-Net project, we need to transmit a large number of meteorological products in the application data format. Direct compression of these products will not achieve the desired compression efficiency, since products in these formats contain information that requires lossless and lossy compressions. To separate this group of information for the compression stage and combine them together in the decompression stage, several pairs of application data format decoders and encoders were developed to handle different products.

Among the model output grids used in the project, some of them have rather high spatial resolutions. An important task is to create an efficient codec for large datasets, without using too much memory and processor resources. We have optimized both transformation and quantization software to reduce the memory usage and computation time. The resultant codec runs well on moderately configured Linux systems. To meet the requirements of reliability and robustness in an operational environment, a few error resilient checks and safeguards were put into the software. In case of bad datasets, we made sure that the codec will encode as much as it can, exit safely, and flag correctly for the application that invokes it.

Projections

We will continue to address issues related to the data compression task for the Gridded FX-Net and possibly other applications. First, a new and more robust data compression scheme, which has recently been implemented and tested for grid dataset, will be adopted in the project. Second, special algorithms need to be developed for data fields with an irregular boundary (theta level data, for example), and data fields that are derived from some "basic" fields. Last, for observation datasets (site observations and radar, etc.), more efficient data compression algorithms are needed to losslessly reduce their size, because eventually they will delay product delivery as frequency and resolution of these products increases.

Nita Fullerton, Writer-Editor/Publications Coordinator (Retired as of October 1, 2005)

Special Notices

Publications

As the number of projects at FSL increases, so does the length of this report. To keep publishing costs at a minimum, individual bibliographies of published articles during the past year are no longer printed in this document. A current list of FSL publications is available at the main FSL Website, *http://www.fsl.noaa.gov;* click on "Publications" and then "Research Articles."

Acronyms

A current list of acronyms and terms related to projects and programs at FSL is available at Webpage *http://www.fsl.noaa.gov;* click on "Publications" and then "*FSL in Review, 2004–2005*."

Subscriptions

This document is available online at the FSL Website, *http://www.fsl.noaa.gov*, click on "Publications" and "*FSL in Review*." If you no longer wish to receive a hard copy of this report, please e-mail *Susan.C.Carsten@noaa.gov*.

Figures

One last measure to limit the length of this report is to discontinue listing figures at the back.