Final Report for UCAR Cooperative Project

Development of a Web-Enabled Mesoscale Weather Station Network for Northeast Florida

UCAR Award Number: S01-32798

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July 1, 2005

SECTION 1: PROJECT OBJECTIVES AND ACCOMPLISHMENTS

The focus of this project, which was originally a 2-year research initiative, was on the evaluation, development, and testing of an enabling technology called "impromptu" or "ad-hoc" wireless networking. Our goal was to help eliminate one of the most vexing problems in mesoscale meteorology—the scarcity of data due to the high recurring costs of conventional data communications. In addition to developing new technology that could potentially be used by any forecasting office, this project also resulted in new mesoscale weather stations in the Northeast Florida region, albeit not in the manner originally envisioned. This network provided the NWS Jacksonville Office as well as Tallahassee and Melbourne offices with the additional data needed to develop and test mesoscale weather forecasting methods for the Northeast Florida region.

In fact, the project was quite successful in that it was the keystone in building an improved weather forecast capability in both the North and Central Florida area. This project led to not one, but several developments that have come to fruition to support mesoscale data assimilation and modeling, development of the Florida Road Weather Information System (RWIS), installation of instrumentation (ultrasonic wind sensors) on Hurricane Evacuation bridges, and led to extensive verification of the new Weather Research and Forecast (WRF) Model by modern feature-based methods. While these results were finally achieved by the development of additional grants and funding sources, those grants were developed from the conceptual framework of the impromptu wireless network, data assimilation and modeling that this project initiated.

In addition, the continued working relationship between the University and the NWS offices in Florida have fostered a continuing dialogue and joint efforts toward accomplishing the stated goal of improving the local forecast and warning services throughout Florida. This was particularly relevant to the active 2004 Hurricane Season.

The Goals of the Project were updated to include:

PROJECT OBJECTIVES	
Scientific Goal(s):	• Evaluate the ability of various electronic and weather station sensor hardware alternatives to meet the special requirements of the prototype operational mesocale web-enabled impromptu network. • Develop new software to enable an impromptu network solution. • Assimilate data from the operational network into the Local Analysis and Prediction Scheme (LAPS) then initialize a forecast model, namely the Weather Research and Forecasting (WRF) model. • Compare the model forecasts to the mesoscale weather patterns in northeast Florida to improve future mesoscale forecasting. • Develop research methods and conduct studies of comparative mesoscale feature recognition and mesoscale model diagnostics.
Operational Forecasting Goal(s):	• To design, build, and evaluate an operational web-enabled mesoscale weather station network in northeast Florida. • To provide data (collected by the operational system) to the NWS Jacksonville Office for use in mesoscale weather modeling (using the Weather Research and Forecasting model).
Educational Goal(s):	• To disseminate the results of the project to operational forecasters and other researchers. • To disseminate the results to the general public.

FUNDING REQUEST		
Year 1	COMET funds (CY): $38,965	NWS funds (FY): $17,400
Year 2	COMET funds (CY): $39,230	NWS funds (FY): $15,300

Results Related to the Prototype Mesoscale Weather Station System

1.1 Evaluate the ability of various electronic and sensor hardware alternatives to meet operational requirements.

UNF researchers evaluated the specifications of several alternative microprocessors and radios that could be used in the system to find the best mix of power efficiency, range, programmability, etc. Based on these initial evaluations, several development kits were ordered. The prototype development work was based on the Jstamp microprocessor (jstamp.systronix.com) a Real-Time Native Java(tm) Technology Module that uses the aJile aJ-80 32-bit, low-power, Java technology-based embedded microcontroller. This system was integrated with a TCP/IP packet radio network and deployed at field sites. We are also currently evaluating other alternative prototype approaches: embedded linux-based microcontrollers, the MSP430 series microprocessors by Texas Instruments, the ZigBee/IEEE 802.15.4 wireless software suite, and the use of other Digital Signal Processing ASIC chips. The radio choices were narrowed down to primarily 900 MHz spread spectrum type radios and several alternatives were tested. We are currently using radios from both Freewave, Inc. and Microlinear, Inc. (a very inexpensive (<$2/chip) 900 Mhz radio) in two versions of the prototype while also testing 400 MHz and UHF solutions where spatially required and feasible.

The UNF and NWS researchers evaluated nearly every weather sensor package that is available in the context of our special operational and networking requirements, and our limited budget. Based on these evaluations, we decided to work with Columbia Weather Systems, Inc. (www.columbiaweather.com) and Coastal Environmental Systems (www.coastalenvironmental.com) on the design of a mix of low-end and high-end sensor packages. We purchased sensors from both companies, using funds from other sources, and have been field-testing the alternatives with prototype systems and the Florida RWIS sites.

1.2 Develop and evaluate alternative network protocols, data management, and web interface software.

The major efforts in this area have been related to the evaluation of the alternative wireless data transmission protocols **(See Appendix A for a more detailed discussion of this effort),** the further development of the "impromptu network" (JINI) software, and on testing the network software on the prototype systems. The data management and web interface software requirements have been established and the development of this element of the system is complete. The entire JAVA/JINI based package is available from the UNF Advanced Weather Information Systems Lab website as a compressed UNIX "GZIP" file.

1.3 Build and evaluate prototype versions of the system.

The first prototype, consisting of one "base station" at UNF and one remote station, was completed. Note that the first operational prototype weather sensors and hardware development kits were ordered using funds from other sources. The NWS funds for equipment were used to purchase the alternative hardware development kits that we wanted to evaluate and additional sensor packages. These prototypes were used to refine

and test different hardware and software configurations before we built and deployed the extant system.

1.4 Build and install the final version of the prototype system

The final system included a mix of 10 meter and 2 meter sensor stations. The original plan proposed two "base stations", located at UNF and the NWS Jacksonville Office, and 7 "remote stations" that would be installed on public land in northeast Florida. We have installed one base station at UNF and the other sites and systems were installed in cooperation with the Florida Road Weather Information System project, though not in the originally envisioned sites, as real estate (site) negotiations proved to be more difficult than the integration of the sensor and network technology. In particular, changes in the political landscape of the area cut off our access to sites owned by the Parks and Recreation Department, forcing other sites to be investigated and negotiated. Finally, the use of Florida Department of Transportation tower sites proved appealing as they proved both power and backup power. These sites now report via the NOAA Forecast Systems Laboratory MADIS site, and are available in NWS AWIPS systems to the Florida offices.

1.5 Operate and evaluate the system.

The system has been in operation for over a year and has had it share of difficulties from lightning strikes to sensor failures to changes in hardware necessitated by changes to the Florida DOT tower architecture. Overall the system has achieved only adequate performance, not due to failure of the principles involved, but rather to the inadequate funds for the physical hardware and concomitant loss of reliability of low–cost sensors.

<u>Results Related to Data Assimilation and Numerical Model Research</u>

1.6 Deliver Data to NWS WFO for Modeling

An important task was to operationalize the network by developing software and hardware systems capable of delivering the data to the NWS JAX AWIPS. This required the development of a Linux-based PC system to connect to the network server at UNF, download and initially screen the data for timeliness, use the LAPS software and its inherent spatial Kalman filter to provide quality control (QC), then store the data locally and prepare it for ingest into the Local Display And Dissemination (LDAD) server of AWIPS at the WFO.

Since this data stream will not be from nationally supported synoptic systems, it was kept in a separate stream and file structure from the national datasets. The precedent for this approach has previously been set for similar data by the procedure developed by the Florida offices for the ingest of the Florida Automated Weather Network (FAWN) data generated by the University of Florida. The complimentary data from the local COMET funded network was treated in a separate but parallel data stream like the FAWN data, and eventually merged into the Florida RWIS dataset.

Initially, the workstation version of Mesoscale-ETA model was run in parallel with the WRF Model in order to verify the proper configuration of the WRF model, and assess the

ability of the WRF model to forecast the sea breeze phenomena correctly. Such comparisons are clearly necessary to aide in the proper set-up of the WRF, which was still in development. While it was hoped that this phase would be short, development of significant discrepancies in WRF prognostic output required correction after discovery in 2003, prior to further research in data assimilation and associated model development.

This phase was completed with the completion of the FSL RTVS verification, and the third-party (Florida State University) verification by feature-based methods. These were well beyond the original scope of the COMET project and were separately funded by NOAA as part of the Coastal Storms Initiative. Both are now complete and the FSU verification portion has been submitted for refereed journal publication, as well as Peter Bogenschutz"s Masters Thesis available from Florida State University's online page at: http://etd.lib.fsu.edu/theses/available/etd-11122004-131729/unrestricted/bogenschutz.pdf

In reality these processes overlapped to some extent, since setup for the LAPS data assimilation and the network data handling development was done in parallel with the initial WRF setup and configuration. Once the WRF was performing adequately, parallel runs with, and without, local surface data assimilation were run to quantitatively measure the improvement or degradation from the local data assimilation process for an entire year for an excellent comparative dataset. These studies will help lay the practical foundation for future comparative local data assimilation studies. While this is clearly not going to be the equivalent of a formal OSSE, we did carefully test the long-standing question of whether additional local surface data (in particular) either improves or degrades mesoscale model prognostic performance. The resounding answer from this effort is that local data, when properly processed in an assimilation system, does indeed improve model performance. NOAA FSL provided the support of the Real Time Verification System. The results are available on the FSL RTVS website for the Coastal Storms Initiative funded period at:
http://www-ad.fsl.noaa.gov/fvb/rtvs/csi/

The ground truth for this effort was the LAPS diabatically adjusted data analysis, while the WRF model produced hourly forecasts, verification was done at three hourly intervals to match the temporal frequency of the ETA model. These real-time model forecasts were compared against the hourly LAPS data assimilation for that hour. The primary model variables to be measured and compared will be the model wind speed and direction and relative humidity, with mesoscale precipitation, thunderstorm initiation, and temperature as secondary variables to be verified. Most of the data assimilation and modeling work was done by Dr. Welsh with assistance from the UNF researchers and NOAA FSL, but continues at WFO JAX with the new SOO Peter Wolf and ITO Art Wildman.

Results Related to Dissemination of Findings

1.7 Prepare "White Paper" for the project.

Julia Downes, the lead graduate student funded by this project, has completed the white paper related to the alternative wireless data communications protocols that could be used. She has also completed her Master's Degree requirements and a published paper

related to the state-of-the-art in "impromptu" or "ad-hoc" wireless network protocol alternatives.

The final versions of these papers are published on the website and were presented at the National Weather Association and American Meteorological Society Annual Meetings in 2003 and 2004 respectively. Julia's thesis was also based on her work with this project and is available from the University of North Florida library.

1.8 Build and maintain a Website for the project to aid in disseminating the results.

The project website, initially designed and maintained by Julia Downes, was operational (ucar.cocse.unf.edu) until late 2004 when it was decided to revamp the entire laboratory website and server. This process took much longer than anticipated and conflicted in priority with other ongoing work with the iFlorida RWIS project effort and deadlines.

The new Advanced Weather Information Systems Laboratory which grew out of this effort and the funding of the iFlorida project (a National RWIS prototype led by UNF) is aimed primarily at operational forecasters and other researchers at this point, however, we are working on developing content which will eventually also be of interest to the general public. The website for this project is now found at: http://www.awislab.org/comet

1.9 Organize/present two Workshops for forecasters/ researchers.

The first workshop was designed to get input from forecasters and researchers about the design and operation of the system—not just to present results. The first workshop was conducted in August, 2002. A second workshop was conducted in April 2005 at the University of North Florida with representatives of most Florida forecast offices, several state agencies, and the research community.

1.10 Conduct quarterly Seminars to update local forecasters on the progress of the project and to get input on the design of the system.

This activity, aimed primarily at the NWS Jacksonville office staff, has actually occurred much more frequently than planned, albeit informally. Regular (almost monthly) project meetings have provided many opportunities for interaction and have obviated the need to have formal quarterly meetings. This activity has waned over the last year as the project was essentially completed. Final results of the project will be presented to the WFO JAX staff in August 2005.

1.11 Present project results at appropriate conferences and publish results in journals.

The results of this effort have been presented to the meteorological community in the form of presentations at both the AMS and NWA annual meetings in 2003 and 2004. In addition, a formal peer reviewed paper is "in press" now. See reference list below in Section 3.

SECTION 2: SUMMARY OF RESEARCH AND EDUCATIONAL EXCHANGES

2.1 The University research team presented a seminar on the project to the North Florida Weather Association (NFWA) members at their Fall '01 quarterly meeting which was hosted at UNF. Forecasters from the Navy, Air Force, and local TV stations were present as well as several students that are not being supported by the project. The meeting gave local forecasters an opportunity to learn about the project and tour our lab facilities. Also, as a result of this presentation, the members of the NFWA decided to work towards amending their charter to include a student membership status, at a reduced cost, and to look for funds to support a small annual scholarship for a student at UNF that was doing meteorological-related research. The NFWA membership did, in fact, vote to include a student membership status at their spring meeting.

2.2 The students attending the first meeting were interested enough to also attend the NFWA spring meeting hosted by the Florida National Guard Weather Flight and their training facilities at Camp Blanding, about 60 miles Southwest of Jacksonville and the summer meeting held at the University of Florida's Lightning Research Center.

2.3 Pat Welsh, then the SOO at NWS Jacksonville, held two seminars at UNF. One for students of Dr. John Alexander's senior Electrical Engineering "capstone" course in interface design, talking about instruments and how some common meteorological instruments operate and their interface design in order to transform the native signal into either analog or digital data streams. The COMET project was introduced and its implications for mesoscale weather data discussed with the students. Existing mesoscale weather initiatives of the National Weather Service in modeling the atmosphere at high resolution were also introduced. Dr. Welsh also gave a College of Arts and Sciences sponsored faculty seminar that was directly focused on the development of a Florida statewide Mesonet, and the history of local mesoscale modeling between the Florida NWS offices and Florida State University and NASA, with both the current status and future plans for modeling in Florida discussed.

2.4 Julia Downes successfully presented her project-related thesis prospectus in January 2004 to her graduate committee and an audience of other faculty and students. Several students, both directly and indirectly involved in the project, have toured the NWS Jacksonville office to learn about the current state-of-the-art in forecasting, data assimilation, and atmospheric modeling. This relationship has continued to date, and as an outgrowth of the Coastal Storms Initiative, one of the students involved in this project is currently funded to assist with the porting of the SWAN (Delft University, NE) model to the WFO JAX CSI cluster computer.

SECTION 3: PRESENTATIONS AND PUBLICATIONS

3.1 The first formal presentation of this work was to the OFCM Interdepartmental Hurricane Conference in March 2001 in Orlando Florida. It continued from the original COMET Partners Project between UNF and WFO JAX which was reported via NWS Southern Region Headquarters Tech Attachment which can be found at:

http://www.srh.noaa.gov/topics/attach/html/ssd00-31.htm

3.2 Other websites referencing this work are as follows:

http://www.srh.noaa.gov/topics/attach/pdf/ssd03-18.pdf
http://www.srh.noaa.gov/topics/attach/pdf/ssd04-10.pdf
http://www.srh.noaa.gov/topics/attach/pdf/ssd04-02.pdf
http://www.nwas.org/meetings/03program.html
http://etd.lib.fsu.edu/theses/available/etd-11122004-131729/unrestricted/bogenschutz.pdf

3.3 A presentation was made by both Dr. Lambert and Dr. Welsh at the Southern Region SOO Conference that was held in Jacksonville Beach on April 15-19, 2002. Dr. Lambert made a presentation at the IEEE Computer Elements Workshop in Vail, Colorado on June 24, 2002. Dr. Welsh made a presentation at the Mesonet 2002 Conference in Oklahoma City, Oklahoma on June 25, 2002.

3.4 Ms. Julia Downes' Masters Thesis in Computer Science was based on this research project, and Julia's results were presented at both the AMS and NWA annual meetings and also NOAATech 2004:

Downes, J., Ahuja S., Lambert J.D., and Welsh P., 2003: Comparing Wireless Network Protocols for Environmental Sensor Networks (ESNs). 28th Annual Meeting of the National Weather Association, 18-23 October 2003, Jacksonville, FL.

Welsh, P. T., Downes, J. and Lambert J., 2003: Wireless Environmental Sensor Networks NOAATech 2004. 21-23 October 2003.
http://www.noaatech2004.noaa.gov/awards.html
http://www.tvworldwide.com/events/noaa/031021/agenda_031023.cfm (video archive)

Wireless Data Networking for Environmental Sensor Networks (ESNS). Julia Downes (Univ. of North Florida), Patrick Welsh (WFO Jacksonville), and J. David Lambert (Univ. of North Florida). 20th Conf. on Weather Analysis and Forecasting/16th Conf. on Numerical Weather Prediction, 84th Annual Meeting of the AMS, 11-15 Jan 2004, Seattle, WA.

Downes, J., S. Ahuja, D. Lambert, and J. Alexander, 2005. "Wireless Ad-Hoc Environmental Sensor Networks: Protocols and Setups". **Annual Review of Communications, Volume 58. International Engineering Consortium.** (peer-reviewed, in press, publication available in Fall 2005).

3.5 Additional References that incorporate results from this project:

Welsh. P. T.,Wildman, A., Shaw, B. Smart, J., McGinley, J., Mahoney, J., Kay, M. 2004: Implementing and evaluating the Weather Research and Forecast (WRF) Model at NWS WFO Jacksonville, Florida. Symposium on the 50th Anniversary of Operational Numerical Weather Prediction, AMS, June 2004, Washington D.C. available at:
http://www-ad.fsl.noaa.gov/fvb/publications/articles/Welsh_NWP50_WFO_WRFfinal.pdf

Welsh, P. T. 2003: NOAA's Coastal Storms Initiative (CSI) in Northeast Florida, and the NWS Local WRF Modeling Project NOAATech 2004, 21-23 October 2003. Washington D.C.
http://www.tvworldwide.com/events/noaa/031021/agenda_031023.cfm (video archive)

3.6 Third-Party Verification Studies

Further studies were eventually conducted that included third-party verification of the data assimilation and modeling portion of this research, which was fully funded under the NOAA Coastal Storms Initiative.

These reports were also reported at the 84th AMS Meeting by our collaborators at Florida State University and resulted in a second Masters Degree for Pete Bogenschutz. Pete applied the methodology of feature recognition to Convective Rain Areas (CRAs) developed by Ebert and McBride (2000) and for Contour Error Mapping developed by Case et al. (2000,2004).

Summer Season Verification of the First NWS Operational WRF Model Forecasts from the NOAA Coastal Storms Initiative Project in Northeast Florida. P. Bogenschutz and P. Ruscher (Florida State Univ.), P. Welsh (WFO Jacksonville), J. Mahoney, J. A. McGinley, M. Kay, B. Shaw, J. Smart (NOAA/FSL), and J. Savadel and J. McQueen (NWSH/OS&T). 20th Conf. on Weather Analysis and Forecasting/16th Conf. on Numerical Weather Prediction, 84th Annual AMS Meeting, 11-15 Jan 2004, Seattle, WA.

Implementing the Weather Research and Forecast (WRF) Model with Local Data Assimilation in a National Weather Service Weather Forecast Office (WFO). Patrick T. Welsh and A. Wildman (WFO Jacksonville), B. Shaw and John Smart (NOAA/FSL), Paul Ruscher(Florida State Univ.), John McGinley (NOAA/FSL), Bernard N. Meisner (SRH/SSD), and P. Bogenschutz (Florida State Univ.) 20th Conf. on Weather Analysis and Forecasting/16th Conf. on Numerical Weather Prediction, 84th Annual AMS Meeting, 11-15 Jan 2004, Seattle, WA.

SECTION 4: SUMMARY OF BENEFITS AND PROBLEMS ENCOUNTERED

4.1 Whereas the current project work was primarily focused on the computer science and engineering aspects of developing a mesoscale weather station network, it is very important to point out that this project has always been thought of as the first phase in a long-term meteorological research partnership between the NWS-Jacksonville Office and the UNF. As such, this project has accomplished the goal of firmly establishing a long-term partnership. As a result of monthly project meetings between the UNF and NWS researchers, there have been two major, and very tangible, benefits from our partnership.

First, the project has enabled us to work on designing a long-term plan for our research, including how and where we might obtain additional funding from other agencies to continue and expand our work. We now have a clear idea of how we plan to use this new technology for scientific studies of our local mesoscale weather phenomenon (including data

assimilation studies [section 3.3 above]), case studies, and verification of severe weather events.
The current project was underway when fortuitous funding of the NOAA Coastal Storms Initiative (NOAA CSI) delayed some of our assimilation planning. This delay allowed a much more comprehensive data assimilation and verification effort than would have been possible with the funding from this project alone. The completion of the assimilation analysis and modeling portion of the project was continued under a no-cost extension until after the model hardware and assimilation software development for NWS Jacksonville Linux cluster was funded by the NOAA CSI. The ability to participate in the CSI project on WRF modeling was finalized, and LAPS data assimilation was initiated. Early on, problems with both the LAPS assimilation and the model prognostic fields were discovered, and with the help of the JAX forecasters and FSL participants, their sources were discovered and corrected. An extensive verification program with NOAA FSL RTVS and modern feature–based methods was conducted (see section 3.6). This is now accomplished, and reported in the literature, providing a new benchmark for Mesoscale Modeling in the WFO.

Secondly, the project led to a successful proposal to the Florida Department of Transportation (FDOT) to install meteorological stations along the three North Florida Interstate Highways as a Research Facility for the development of a Florida Road Weather Information System (RWIS) and further development of the Northeast Florida Mesonet System. Additionally, as a result of this project and Ms. Downes interaction with Motorola protocol developers, technical staff at the Florida Communication Research Lab at the Motorola Labs in Plantation, Florida offered to provide technical assistance and mentoring related to our evaluation of the proposed IEEE 802.15.4 network protocol (Motorola, Inc. is one of the primary sponsors of the new protocol). Also, as a result of this project, Microlinear, Inc. provided funds to support development of specialized spread spectrum radios that are designed especially for this purpose. This research continues to date, with promise of a suite of applications to Environmental Sensor Networks of many differing circumstances, from acre-sized intensive monitoring areas to landscape scale state-wide Mesonets. This protocol work has also been adapted by the University of California at Berkeley for their sensor networking.

The project proposal budget listed monetary contributions by the NWS for the purchase of equipment. Budget approval cycle delays at NOAA slowed down our ability to purchase some of the equipment and parts required during the summer season when the students were most available to work on the project. However, this problem merely delayed the effort until the students were again available rather than ending the research. A recommendation for future grants would be that the NOAA NWS funds be transferred in the April timeframe to allow University students summer support and the concomitant concentration on these efforts.

4.2 NWS developments have been equally promising. The COMET project has been serving as the catalyst to get forecasters in Florida discussing the linking of existing data sources into a statewide mesoscale network. NWS JAX personnel worked with the meteorologist from the state Emergency Operations Center (EOC) and many Florida agencies to develop a methodology to ingest local Florida data into the Advanced Weather Information Processing

System (AWIPS) and received approval from NWS headquarters to do so in 2001. This scripting effort was led by NWS JAX forecaster Pablo Santos (now the SOO at Miami) working with the Forecast Systems Laboratory (FSL) and the first data source is now routinely ingested at all the Florida NWS offices via FSL MADIS. A second small project was initiated with Dawn Wells at Edward Waters College (a historically minority serving institution in Jacksonville) to look at verification statistics by two different methods. GIS support for her senior project was provided by the UNF AGS Laboratory's systems at no cost as part of the partnership. These efforts have led directly to the larger Florida RWIS and Florida Mesonet projects.

4.3 The NOAA Coastal Storms Initiative (CSI) approval and funding occurred with the end of the FY2002 budget cycle. This nationwide initiative started with a Northeast Florida pilot project which had a local modeling component, and the subsequent changes in hardware for local modeling proposed for the NWS office in Jacksonville positively impacted planning for data assimilation and verification. While this greatly delayed the final completion of the COMET project, the additional funding both dramatically increased the scope of the research effort *in toto*, and provided substantial funding for third party verification as described above in section 3.6.