Final Report

Special Observing, Forecast, and Warning Tools in the Tennessee Valley and their Application to the End-to-End Warning Decision Making Process

A COMET Cooperative Project

COMET Project Title	**Special Observing, Forecast, and Warning Tools in the Tennessee Valley and their Application to the End-to-End Warning Decision-Making Process**
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NWS Office	Birmingham, AL (BMX) and Huntsville, AL (HUN)
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Project Type	Cooperative
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1. PROJECT OBJECTIVES AND ACCOMPLISHMENTS

This was a multi-agency project involving the following primary project personnel within the NSSTC[1]:

1. Dr. Steve Goodman, senior research scientist, NASA/MSFC.
2. Dr. William M. Lapenta, research scientist, NASA/MSFC.
3. Dr. Kevin Knupp, Associate Professor, Department of Atmospheric Science, UAH.
4. Ms. Karen Altino, M.S. student, Department of Atmospheric Science, UAH.
5. Tom Bradshaw, lead forecaster, NWS/BMX; and SOO, NWS/HUN.

The original project objectives, and personnel tied to these objectives are defined in Table 1.

Table 1. Project objectives, and personnel working on each component.

PROJECT OBJECTIVES	
Scientific Goal(s):	1. Advance knowledge on the relation between total lightning and severe storm attributes (wind, hail, rainfall) and tornadogenesis. Goodman, Knupp, Bradshaw, Altino 2. Advance understanding of the role of boundaries on convection initiation (daytime and nocturnal), thunderstorm modification, and tornadogenesis in the Southeast. Knupp, Goodman, Bradshaw, Laws
Operational Forecasting Goal(s):	3. Improve warning decision making for hazardous weather associated with severe convection, such that FAR are reduced. Goodman, Knupp, Bradshaw 4. Improve flash flood warning accuracy and quantitative precipitation estimates, utilizing advanced measurements such as total lightning. Goodman, Knupp, Bradshaw. 5. Improve effectiveness of severe storm detection capability with current operational sensors via value added knowledge from special observations. Goodman, Knupp, Bradshaw 6. Develop improved methods for disseminating NWS products to external user groups. LaPenta, Goodman, Bradshaw
Educational Goal(s):	7. Develop improved understanding of relations between total lighting and storm attributes. Goodman, Knupp, Bradshaw, Altino 8. Develop improved understanding of the impact of boundaries on convective initiation. Knupp, Bradshaw 9. Develop improved interpretation of profiler measurements. Knupp 10. Transfer knowledge to other WFOs. Bradshaw, Goodman, Knupp

[1] NSSTC: National Space Science and Technology Center (http://www.nsstc.org/)

1. Summary overview of accomplishments and activities

The following items were accomplished during this COMET Cooperative Project:

Infrastructure Improvements

a) The NASA Lightning Mapping Array was completed and utilized for forecasting applications and scientific discovery. (http://branch.nsstc.nasa.gov/cgi-bin/LMA.pl)

b) The *Short-term Prediction Research and Transition* (SpoRT) Center was established with special NASA funds. This has solidified collaboration between research and operations within the NSSTC. (See http://weather.msfc.nasa.gov/sport/)

c) The HUN NWS forecast office was officially opened in 2003. This office is located within the NSSTC annex.

d) UAH established the *NSSTC Operational Weather Cluster for Atmospheric Science Training and Research* (NOWCASTR), which introduced a real-time comprehensive weather measurement capability from the NSSTC location. (Refer to the web site http://vortex.nsstc.uah.edu/mips/data/current/surface/.)

e) UAH started planning a significant upgrade of the WSR-74C radar, donated to UAH from the NWS in 2003. This upgrade will be finalized by November 2004, and will include the Sigmet Antenna Mounted Receiver (AMR) with dual polarization capability. (Refer to the web site http://vortex.nsstc.uah.edu/ARMOR/)

Science

f) Advancements in understanding the relationships between total lightning (from the LMA) and tornadic storm properties were made, in analysis of two case studies.

g) A case study (M.S. thesis) examining the relation between lightning and microburst damaging winds was started, and completed November 5, 2004. In this case, a total flash rate of 6 flashes per second was documented.

Forecasting

h) Output from the MM5 mesoscale model (run at the NSSTC with GOES assimilation) has been made available to regional WFO's.

i) LMA data are now available in real time at the Huntsville, Birmingham, and Nashville WFO's. The HUN office has used this valuable information to issue more timely and accurate severe weather warnings.

j) Through the activities of SPoRT, MODIS data from NASA satellites is being imported into the HUN office, for fog and temperature forecasting applications.

k) Dual polarimetric radar data will be available to the NWS/HUN staff by December 2005.

1.1 Scientific Objectives

Objectives 1 and 2 (Table 1) were accomplished, largely due to the development and research/operational utilization of the NASA Lightning Mapping Array (LMA), described in some detail below (Section 1.2), and profiling instrumentation developed by UAH. A summary of these activities is included in the next two subsections.

1.1.1 Advance knowledge on the relation between total lightning and severe storm attributes (wind, hail, rainfall) and tornadogenesis

Several lightning studies that were funded by the COMET and other closely related projects were undertaken. Descriptions are provided in the following paragraphs.

Analysis of the 5-6 May 2003 tornadic storms (Gatlin and Goodman 2004)

On 5-6 May 2003 two tornadic thunderstorms produced several tornadoes in southern Tennessee and northern Alabama. Data obtained with the North Alabama Lightning Mapping Array (LMA) and National Weather Service Doppler radar were used to analyze the electrical, microphysical, and kinematic evolution of the two storms. The Tennessee storm was a classic supercell that produced a short-lived F3, which exhibited a radar "hook" echo several minutes prior to touchdown. Furthermore, a rapid increase in total lightning activity (or lightning "jump") occurred prior to the appearance of a large increase in mesocyclone rotation. The second tornadic storm was a high precipitation supercell that evolved into a quasi-linear squall line. It produced several weak tornadoes during its lifetime and exhibited one large lightning jump before developing into a squall line. A relative maximum in the total lightning activity preceded the occurrence of each tornado, by 15-20 min. Some of these maxima correspond to increases in reflectivity echoes aloft, supporting previous studies which found a relationship between updraft strength and lightning activity. Also, in the minutes prior to the 5 May 2003 tornadoes, increases in the total flash rate were concurrent with increases of cyclonic shear at low levels within the storm. These findings support the hypothesized correlation between the lightning jump and tornadogenesis. This work was presented at the 22nd Conference on Severe Local Storms, and will form the basis of a M.S. Thesis by Patrick Gatlin (Spring 2005).

Analysis of the 10 November 2002 tornado outbreak (Buechler et al 2004)

On the afternoon and evening of 10 November 2002, the Midwest and Deep South were struck by a major outbreak of severe storms that produced about 80 tornadoes. This was the largest outbreak in the United States since November 1992. About 32 of the tornadoes occurred in Tennessee, Mississippi, Alabama and Georgia, including several long-track killers. The North Alabama Lightning Mapping Array (LMA) and other data sources were used to perform a comprehensive analysis of the structure and evolution of the outbreak. Most of the Southern tornadoes occurred in isolated, fast-moving supercell storms that formed in warm, moist air ahead of a major cold front. Storms tended to form in lines parallel to storm cell motion, resulting in many communities being hit multiple times by severe storms on that evening. Supercells in Tennessee produced numerous strong tornadoes with short to medium-length track paths, while the supercells further south produced several very long-track tornadoes. Radar data indicate that the Tennessee storms tended to split frequently, apparently limiting their ability to sustain long-lived tornadoes, while storms further south split at most one time. The differences between these storms appear to be related to the presence of stronger jet stream winds in Tennessee relative to those present in Mississippi, Alabama and Georgia. LMA-derived flash rates associated with most of the supercell storm cores were about 1-2 flashes per second. Rapid increases in lightning rates (or "jumps") occurred prior to tornado touchdown in many instances. Lightning "holes" (lightning-free regions associated with the echo-free vault) occurred in two of the Tennessee supercells. The complexity of the relationship between lightning and storm severity is revealed by the behavior of one Alabama supercell, which produced a peak flash rate of nearly 14 flashes per second, well after the end of its long-track tornado, while interacting and ultimately merging with a daughter supercell on its southwest flank. Close examination of this powerful storm indicates that its prodigious flash rate was the result of strong flash activity over an unusually large area, rather than a concentrated core of extremely high flash rate activity.

18 August 2002 severe storm

A case study of a microburst event on 18 August 2002 was completed by a UAH graduate student (Karen Altino). Analysis of this case has shown that precursor conditions were favorable for severe localized convection in the Huntsville region, including:

a) a boundary produced by rain showers four hours before the event; and
b) very large CAPE values that exceeded 4000 J kg-1 at the HSV ASOS site.

This strong multicell storm exhibited upshear propagation which resulted in a very slow movement. Locally heavy rainfall, exceeding 100 mm, very strong downburst winds, up to 34 m s^{-1}, and hail up to 19 mm diameter were produced over Huntsville. The intense nature of the storm is evidenced by the extremely high total lightning rates that peaked near *6 flashes per second* around the time of damaging winds. Publications related to this event include Altino (2004), Altino et al. (2004), and a forthcoming manuscript (based on the M.S. thesis) to be submitted to Weather and Forecasting.

1.1.2 Advance understanding of the role of boundaries on convection initiation, thunderstorm modification, and tornadogenesis in the Southeast

On 16 February 2001 a tornado was spawned by a rapidly-evolving shallow supercell storm about 20 km northwest of Huntsville. This was the first event during this project involving a close interaction between a pre-existing boundary and the development and intensification of a F0-F1 tornado. On 15 February, cool air produced by showers and stratiform rain generated a weak gust front that moved over Huntsville, and remained there as a quasi-stationary outflow boundary, at a location about 10 km south of the UAH Mobile Integrated Profiling System (MIPS). During the morning hours of 16 February, this boundary moved slowly northward to just NW of Huntsville by early afternoon. After several weak convective cells were initiated along this boundary, a more intense shallow cell formed at the junction of this boundary and a cold front that was surging southward. The supercell storm remained anchored to the boundary and produced a 2 km wide swath of straight-line winds, followed by a F1 tornado the passed over northern Huntsville. Interestingly, this shallow supercell did not produce cloud-to-ground lightning. A preliminary analysis was presented at the 21st Conference on Severe Local Storms (Laws et al. 2002). A more comprehensive analysis will be submitted to Monthly Weather Review in the near future (Knupp et al. 2005).

In a related effort, a preliminary field study on convective initiation was conducted by the NWS, UAH and NASA PI's in July 2002 (after Knupp participated in comprehensive convective initiation experiments over Oklahoma, Texas, and Kansas during the IHOP-2002 field campaign). The most significant finding of this activity was the realization that CI in the low-shear environment of the Southeast involves rather subtle ABL processes that require further study. Similar joint forecasting projects are planned for the future.

1.2 Improvements in operational forecasting

1.2.1 Development of the Short-term Prediction Research and Transition (SpoRT) Center

NASA/MSFC received funding to develop the SpoRT Center in 2001, to accelerate the infusion of NASA earth science observations, data assimilation and modeling research into the Nation's forecast operations and decision-making procedures. The activity conducts both discovery and product-driven research associated with advanced algorithm development, land/atmosphere interactions, satellite data assimilation, convective initiation and evolution, lightning/severe storm kinematics, and quantitative precipitation estimation and forecasting.

A Collaborative Research Area (CRA) at the Huntsville, AL National Weather Service Forecast Office (NWSFO) and physically collocated within a building shared by NASA researchers, students, and forecasters was created to facilitate technology transfer. The CRA provides the opportunity for the community of researchers, students, and forecasters to work side-by-side in the analysis and evaluation of NASA experimental products. The observations from a number of NASA satellite missions and state-of-the-art community-based mesoscale prediction/assimilation systems are used. Specific examples include 1) land surface information from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Terra and Aqua satellites; 2) radiance data and retrieved profiles from the Atmospheric Infrared Sounder (AIRS) on Aqua, total lightning data from the Lightning Imaging Sensor (LIS) aboard the Tropical Rainfall Measurement Mission (TRMM) and the north Alabama Lightning Mapping Array (LMA); and 3) the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model version 5 (MM5) and the next generation Weather Research and Forecast (WRF) System and associated data assimilation systems including the Forecast System Laboratory (FSL) Local Analysis and Prediction System (LAPS) and the MM5 4-dimensional variational (4D-VAR) system. The principal focus of experimental products is on the regional scale with an emphasis on forecast improvements on a time scale of 0-24 hours. This paper describes the process for the transition of experimental products into forecast operations, current products undergoing assessment by forecasters, and plans for the future. The SPoRT Web page

Two new data sources were introduced during 2003 into three WFOs located in the NWS Southern Region (Huntsville, HUN; Birmingham, BMX; and Nashville, OHX). The MODIS on board the NASA low Earth orbiting Terra and Aqua satellites, and total lightning discharge mapping from a ground-based 3-D VHF lightning mapping sensor array are providing early opportunities for forecasters to develop operational experience with measurements similar to those that may be provided by the next generation of Geostationary satellites. The AWIPS forecaster workstation ingests, displays, and integrates these experimental data sets in addition to the standard data products and model output, allowing the forecaster to readily issue the forecasts and warnings. Early on in the development of the joint collaboration between NASA and NWS, it was clear that product assessment would be most effective if the products were available in near real-time to the forecasters with minimum latency within AWIPS.3 Within this operational environment the researchers and forecasters are jointly able to assess the utility of the new experimental products.

Use of MODIS data by the NWS required some additional configuration of enhancement and data lookup tables for display and data output in AWIPS. We have worked extensively on this to provide enhancements and capabilities consistent with standard AWIPS operations and with enhanced features to best display and use MODIS data. Efforts throughout the year have reduced the data latency by 50%. Most MODIS data and products are available in AWIPS within 45 minutes of data collection.

In addition to the MODIS products available from the EOS atmospheric science team through UW, several key in-house products have been developed that provide useful tools for the NWS. First, a 3-channel color composite (500m resolution) is made in real time and provided to the WFOs.

This product is extremely useful for identifying thin cirrus, convergence lines and convective cloud structures, smoke from agricultural fires, land use and surface features. Second, a fog product, similar to that calculated with GOES, is made and displayed in AWIPS with specific enhancement curves to isolate regions of developing fog and low clouds. Third, a combined LST/SST product is produced with an in-house algorithm.

LST product, along with hourly GOES data, will be used to develop a minimum temperature algorithm for use in the AWIPS Interactive Forecast Preparation System (IFPS). The real time products and L1B radiances are cloud-cleared and made available in real time to the in-house SPoRT modeling group for use in data assimilation studies. Since the evolution of mesoscale phenomena in the planetary boundary layer is sensitive to differential land surface forcing, high-resolution MODIS land and sea surface temperatures can be used to initialize models at scales below 10 km with the potential to fill information gaps such as the improved specification of the pre-storm environment. A technique to assimilate MODIS LST data into the land surface component of MM5 was found to have a positive impact on the formation and subsequent evolution of a non-precipitating sea breeze circulation observed along the Florida panhandle on 14 May 2001 (Figure 4). The experiment was conducted on a 4 km grid to exploit the high-resolution MODIS data. Assimilating the satellite data resulted in realistic representation of differential land surface forcing across and parallel to the coastline. Strength and inland penetration of the sea breeze front were validated with surface observations and NEXRAD clear-air returns.6

Training on the use of the new EOS data and products was provided in several forms to the three regional NWS offices thus far receiving the data. Science sharing sessions and presentations were made on several occasions to the various offices on both MODIS data and product utilization. Based on requests from a couple of these offices, VISITview modules are being developed on "MODIS Polar Orbiting Data and Display" and "Night time Fog Detection with MODIS". The development of these modules is also being coordinated with NWS COMET program.

1.2.2 Implementation and Operational Utilization of the LMA

The North Alabama 3-D VHF regional LMA consists of ten VHF receivers deployed across northern Alabama, and a base station located at the National Space Science and Technology Center (NSSTC), which is on the campus of the University of Alabama in Huntsville. The LMA system locates the sources of impulsive VHF radio signals from lightning by accurately measuring the time that the signals arrive at the different receiving stations. Typically hundreds of sources per flash can be reconstructed, which in turn produces accurate 3-dimensional lightning density maps (nominally <50 m error within 150 km range).

Key objectives of our research investigations using LMA data are: a) Identification of intensifying and weakening storms using the time rate-of-change of total flash rate; b) Improve severe storm potential situational awareness; and c) Evaluation of the potential of total flash rate trend to improve severe storm probability of detection (POD) and lead time.

A 3-D gridded total lightning data set within a 460 km x 460 km domain, updated every 2 min, provides full coverage of the Huntsville, AL (HUN) and Nashville, TN county warning areas, as well as partial coverage of the warning areas of five other NWS office. Forecasters can interrogate the data on any of the 17 horizontal levels or examine the cumulative source density map that includes all levels. Forecasters can also readily dither between NEXRAD and LMA maps and loop multiple frames to enhance situational awareness during severe weather episodes. Real-time software and a wireless Ethernet network allow real-time data to be collected, products generated, and maps distributed, which are augmenting the standard WFO products used in the warning decision-making process. The LMA data are distributed via the NWS Southern Region for ingest and display in the regional WFO's AWIPS decision support system, and archived at each WFO for case studies, event playbacks, and assessments with NASA scientists using the NWS Warning Event Simulator. HUN has upgraded severe thunderstorm warnings to verified tornado warnings and avoided a false alarm on a severe storm through the added information on storm growth, intensification, and decay that can be deduced from the magnitude and temporal trend of total flash rates. The LMA products are automatically updated on the forecasters' workstation. In this way, the forecaster can optimally evaluate the added value of total lightning data within the forecast and warning decision-making process.

The LMA has been used for several comprehensive studies described above in Section 1.1.1. Data from the LMA are now used operationally and have added forecaster skill to several severe storm outbreaks over the last two years.

1.2.3 Development of a comprehensive north Alabama tornado climatology.

The objective of this task was to develop a comprehensive temporal, geographical, and synoptic climatology of tornadoes in north Alabama, with emphasis on those events of intensity F2 or greater. Development of the tornado database and the collection of sounding data, was completed during January 2001. While started under this COMET project, this effort was finished under NASA SPoRT collaboration by a HUN forecaster (Kurt Weber). The following represents the final product:

http://www.srh.noaa.gov/hun/tornadodatabase/index.htm

1.2.4 Summer Convective Rainfall in North Alabama Prediction Exercise (SCRAPE) 2000 validation and summary.

The objective of this task was to verify forecasts which were made by NWS meteorologists during SCRAPE 2000, conducted at the Birmingham WFO during the summer of 2000. These findings will be utilized to develop techniques for improving short-term precipitation forecasts at WFO BHM. The SCRAPE forecasts were compiled during Fall 2000, and preliminary verification methodologies were developed in cooperation with Dr. Lapenta at GHCC. During this time period, plans were made for the provision of precipitation data by GHCC to the NWS that will be used to verify the SCRAPE forecasts. In addition, Lapenta (GHCC) and Bradshaw (NWS) jointly submitted an abstract to the 14^{th} AMS Conference on Numerical Weather Prediction.

The Fall 2001 version of SCRAPE was completed on 9/1/2001. A total of 60 experimental short-term convection forecasts were completed and archived. Participants extensively utilized mesoscale model data provided by GHCC partner Dr. Bill Lapenta, including special 12-hour rapid update model runs developed primarily for the exercise. NWS investigator Tom Bradshaw has conducted the first stage of verification with assistance from Lapenta and GHCC associate Scott Dembek.

1.2.5 Validation of model sensible weather elements and derived statistical guidance.

The objective of this task was to develop a mechanism for displaying model error statistics on a real-time basis. The goal of this work was to enable NWS forecasters to better diagnose short and long-term biases in model sensible weather output, leading to an improvement in overall forecast accuracy. This verification system capitalized on the display/dissemination capabilities of the WFO's office intranet, as well as the Internet. Preliminary planning for this task was carried out at NWS BHM in collaboration with Dr. Lapenta of GHCC. The first phase of software development was completed by Greg Machala and Tom Bradshaw of NWS BHM in February 2001. Because Tom Bradshaw departed the BHM office shortly thereafter, this effort was extended (under SPoRT funding) with a supplemental numerical QPF assessment of the MM5 in May 2003 with forecasters at HUN. Quantitative verification results (Equitable Threat Score and Bias) showed the MM5 out-performed the operational Eta during extreme precipitation events. The forecasters' perception during the decision making process (i.e., while on shift) of MM5 performance was consistent with the quantitative verification statistics. The results of this project can be found in Lapenta et al. (2004)

1.2.6 MM5 model real-time ingest

A procedure for ingesting GHCC MM5 model output into WFO BHM AWIPS system for real time use was successfully implemented in 2001. GHCC partners Bill Lapenta and Scott Dembek developed a process for converting MM5 output to NetCDF format, and provided technical advice to NWS IT Officer Greg Machala (and later to Jason Burk) for processing this data in the AWIPS environment. Other follow-up collaborative work has provided additional MM5 fields and model runs to the local AWIPS suite.

1.2.7 Preliminary modeling case study

NWS investigators Tom Bradshaw and Ron Murphy, along with GHCC partner Bill Lapenta completed a preliminary analysis of the significant snowfall event which affected north Alabama on 20 March 2001. Bill Lapenta produced a retrospective MM5 model run for this event. This output revealed several physical processes which likely played a role in the evolution of the heavy snow. Results were presented at a central Alabama NWA chapter meeting held in December 2001.

2. SUMMARY OF UNIVERSITY/ NWS EXCHANGES

2.1 Data sharing

WFO BHM provided GHCC investigator Dr. Knupp with ASOS data for two separate weather events during February, 2001. Additional information regarding several severe weather episodes was provided to the GHCC participants by members of NWS BHM during the Fall/Winter 2000-2001 period.

Special soundings were acquired from Redstone Arsenal in November 2001 to assess severe weather potential. These soundings were immediately sent to the BHM WFO, and NWS personnel then forwarded the soundings to SPC. Similar activities will be done when possible under future research programs.

UAH members developed procedures for archival of 1 min ASOS data from local sites, HSV and DCU. We are pursued access to numerous AWOS sites within several southern Tennessee counties. The goal is to expand real time or near real-time access to surface data. The COMET principal investigators and other NWS personnel initiated plans to collect all available surface data in the region, and eventually enhance it with additional surface instrumentation. This effort has made slow progress, but is ongoing.

In a related effort, UAH developed a comprehensive surface station adjacent to the National Space Science and Technology Center. This surface station has research-grade instrumentation for measurement of surface weather (T, RH and p and 2 m, wind and T at 10 m), SuomiNet GPS, winds aloft with a 915 MHz profiler, cloud cover and aerosol properties with a lidar ceilometer, and thermodynamic profiling with a 12-channel microwave profiling radiometer. Refer to the web site (http://vortex.nsstc.uah.edu/mips/data/current/surface/). In the near future, profiler data will be reformatted to netCDF and piped into the NWS office via the hub at the NWS Southern Region Headquarters, using the existing SPoRT infrastructure.

Finally, UAH has made plans to supply data from an upgraded WSR-74C radar at the Huntsville airport (donated to UAH from the NWS in 2003) to the HUN office. This radar has just been upgraded to a dual polarimetric capability using latest technology (including the RVP-8 signal processor that will be used in the WSR-88D radar upgrade) from Sigmet, Inc. This effort will further bolster collaboration among UAH, NASA and the NWS well into the future. A web site under construction (accessible from http://vortex.nsstc.uah.edu/ARMOR) will document this activity.

2.2 Workshops and Education

Workshop

A workshop on Short-Term Prediction workshop was conducted on 8-9 April 2001. Invited talks were given by NWS, NASA, NOAA lab, and university researchers. Numerous NWS personnel from the region attended.

Teaching by NWS personnel

Mr. Jason Burk has taught a computer applications course in the UAH Atmospheric Science Department two times, Summer 2003, and Fall 2004. The current course, *Applications of Computers in Meteorology*, has been extremely well received by the graduate students.

Seminars

Seminars will become an increasingly common mode of interaction among UAH, NASA and the NWS. UAH hosts a brown bag seminar every Wednesday during the academic year.

Informal Seminars on significant weather events

These will become more frequent in the future, as an adequate staff level has now been attained in the HUN office.

3. PRESENTATIONS AND PUBLICATIONS

The following conference and journal papers are at least peripherally involved with this COMET project. The publications marked with an asterisk have received primary support from COMET.

Published:

*Altino, K.M., K.R. Knupp, and S. J. Goodman, 2004: Correlation of Lightning Flash Rates with a Microburst Event. 22nd Conference on Severe Local Storms, Hyannis, MA, AMS.

*Altino, K.M., 2004: Correlation of lightning characteristics and flash rates with a microburst event: A case study of 18 August 2002. M.S. Thesis, University of Alabama in Huntsville, 77 pp.

Barnes, P., T. Bradshaw, W. M. Lapenta, J. Burks, C. Darden, G. Jedlovec, and S. Goodman, Infusing NASA technology into the NWS local forecast environment: The WFO Huntsville Experience, National Weather Association Annual Meeting, Oct. 18-23, 2003.

*Bradshaw, J.T., R. E. Kilduff, R. E. McNeil, K. J. Pence, P.Hart and W.M. Lapenta, 2001: Experiences from SCRAPE2000 - Summer Convective Rainfall in Alabama Prediction Experiment. *Preprints, 18th Weather Analysis and Forecasting Conference.* Amer. Meteor. Soc., Boston, MA.

*Bradshaw, J.T., W.M. Lapenta, R.E. Kilduff, R.E. McNeil, K.J.Pence, and P. Hart, 2001: Experiences from SCRAPE 2000 - Summer Convective Rainfall in Alabama Prediction Experiment. *Preprints, 14th Conf. on Numerical Weather Prediction*, Ft. Lauderdale, FL, Amer. Meteor. Soc.

Buechler, D. E., E.W. McCaul, S.J. Goodman, R. Blakeslee, J.C. Bailey, and P. Gatlin, The Severe Weather Outbreak of 10 November 2002: Lightning and Radar Analysis of Storms in the Deep South, 22nd Conference on Severe Local Storms, October 2004, Hyannis, MA.

Gatlin, P.N, and S.J. Goodman, 2004: Signatures in Lightning Activity during Tennessee Valley Severe Storms of 5-6 May 2003. 22nd Conference on Severe Local Storms, Hyannis, MA, AMS.

Darden, C., J. Burks, T. Bradshaw, D. Boccippio, S. J. Goodman, R. Blakeslee, E. McCaul, D. Buechler, J. Hall, and J. Bailey, The Integration of Total Lightning Information into National Weather Service Operations, AGU Fall Meeting, 2003.

Goodman, S. J., R. J. Blakeslee, H. J. Christian, W. J. Koshak, J. Bailey, J. Hall, E. W. McCaul, Jr., D. Buechler, C. Darden, J. Burks, T. Bradshaw, and P. Gatlin, The North Alabama Lightning Mapping Array: Recent Severe Storm Observations and Future Prospects, In Press, Atmospheric Research, 2004.

Jedlovec, G. J., S. L. Haines, R. J. Suggs, T. Bradshaw, C. Darden, and J. Burks, Use of EOS Data in AWIPS for Weather Forecasting, 20th Conference on Weather Analysis and Forecasting, January 2004, Seattle, WA.

Koshak, W. J., R. J. Solakiewicz, R. J. Blakeslee, S. J. Goodman, H. J. Christian, J. Hall, J. Bailey, E. P. Krider, M. G. Bateman, D. Boccippio, D. Mach, E. W. McCaul, Jr., M. F. Stewart, D. Buechler, and W. A. Petersen, North Alabama Lightning Mapping Array (LMA): VHF Source Retrieval Algorithm and Error Analyses, J. Atmos. Ocean. Tech., 21, 543-558, 2004.

Lapenta, W. M., R. Wohlman, T. Bradshaw, J. Burks, G. J. Jedlovec, S. J. Goodman, C. Darden, and P. J. Meyer, Transition from Research to Operations: Assessing Value of Experimental Forecast Products within the NWSFO Environment, 20th Conference on Weather Analysis and Forecasting, January 2004, Seattle, WA.

*Laws, Kevin B., K.R. Knupp and J Walters, 2002: Rapid supercell storm and tornado development along a boundary. Preprints, 21st Conference on Severe Local Storms, San Antonio, TX, AMS.

McCaul, E.W., J. Bailey, S. Goodman, J. Hall, D. Buechler, and T. Bradshaw, 2002: Preliminary results from the north Alabama lightning mapping array. 21st Conference on Severe Local Storms, San Antonio, AMS.

Planned, or in preparation:

*Altino, K.M., K.R. Knupp, and S. J. Goodman, 2004: Correlation of Lightning Flash Rates with a Microburst Event. To be submitted to *Weather and Forecasting*.

*Knupp, K.R., K.B. Laws, and J. Walters, 2004: Rapid Development of a Mini-Supercell Tornadic Storm along a Quasi-Stationary Boundary. In preparation, to be submitted to Weather and Forecasting.

4. SUMMARY OF BENEFITS AND PROBLEMS ENCOUNTERED

4.1 Benefits to UAH and NASA

WFO BHM and other NWS offices in the Southeast continue to benefit from access to the real-time MM5 model output provided by Dr. Lapenta at GHCC. (Refer to http://weather.msfc.nasa.gov/sport/sport_modeling.html). With extensive help from Dr. Lapenta, these data are now ingested into the BHM AWIPS system, thereby enhancing their operational use. Bradshaw has highlighted to GHCC and the NWS staff potential deficiencies with the model's performance during recent precipitation events. In response, Lapenta has provided information which has increased forecasters' understanding of the MM5's initialization, which in turn affects the performance of the model's QPF during winter events. This should lead to more intelligent use of the mesoscale model output during future significant precipitation events.

Other benefits of the COMET collaboration have included a heightened interest in research at the WFO's in HUN and BHM, owing to the involvement of several forecasters and interns in the planned CY2001 COMET activities. A useful side benefit of the collaboration has been the improvement of the BHM severe weather verification program. The proper evaluation of the north Alabama LMA will depend on a thorough acquisition of severe weather reports by WFO BHM. As part of the planning of the task described above, the process for gathering severe weather reports at BHM has been revamped. This will improve the forecasters' ability to evaluate their warning decision making, and will also likely lead to an improvement in the office's future warning statistics. UAH will continue to participate in damage surveys within the core of the STORMnet (i.e., within 50 km of HSV).

Sharing of real-time data from research instrumentation was described in a preceding section. The NSSTC Operational Weather Cluster for Atmospheric Science Training and Research (NOWCASTR) was unveiled in June 2004, and will be expanded in future years. It provides real time data that will be of considerable value to operational forecasting. Refer to the NOWCASTR web site: http://vortex.nsstc.uah.edu/mips/data/current/surface/. In the future we anticipate real-time access to soundings of temperature and humidity from the UAH microwave profiling radiometer

We have also leveraged research from another project (Identification and Delineation Experiment – ABIDE) funded by the NSF. Such leveraging will continue in the future.

4.2 Problems

Although significant progress was made, several problems were encountered that reduced the efficiency of collaborative research:

a) Mr. Tom Bradshaw assumed the position of SOO at the HUN office. While this was a positive step in principal, the spin-up of the HUN office, combined with a minimal staff, consumed much of Mr. Bradshaw's time.

b) Dr. Kevin Knupp continues to receive minimal support from UAH (4.5 months per year). This has limited place limitations on his ability to interact frequently with HUN staff.

The first of these two problems has been addressed by increasing the staffing levels at the HUN office (one additional lead forecaster and one intern). A solution to the second problem is being pursued with UAH administrators.

5. FUTURE PROSPECTS

The degree of collaboration among UAH, NWS and NASA within the NSSTC improved immensely over the 4 year period of this project. We believe this was money well spent, as it was leveraged considerably by other funded research within UAH and NASA. Moreover, NASA initiated the SPoRT center during this period. The future for continued collaboration appears very bright, with the following items still on our list:

a) Additional expansion of SPoRT activities.

b) Development of operational products from the NOWCASTR.

c) Integration of ARMOR data into the NWS environment.

d) Expansion of surface mesonet coverage in the HUN CWA region, and the state of Alabama.

e) Close collaboration in Homeland Security research.

f) Continued collaboration in educational collaboration through workshops, courses, and formal/informal seminars.