Oral Presentation Session I - Societal Impacts

Crisis Management David Griffin, Griffin Television, LLC, Oklahoma City, OK

Executive decisions, impacts and results during the May 3, 1999 tornadoes will be presented. *(griffin@KWTV.com)*

One for the Record Books, OG&E's Response to the May 3rd Storms Paul Renfrow and Tammy Turnipseed, OG&E, Oklahoma City, OK

OG&E is a company that has a long history of dealing with the damage left behind by storms. On May 3, 1999 a series of tornadoes raked OG&E's service territory including a record setting tornado that hit the Oklahoma City metropolitan area. The result was more than 167,000 customers without power and $14 million in damage to the electric system. In addition to destroyed or damaged electric substations, distribution poles, lines and transformers, the tornadoes severely damaged many of the main transmission lines that supply central Oklahoma with power presenting the potential of area wide power outages.

The storms left many OG&E victims in its wake as well. Many employee's homes were damaged or destroyed and one employee lost his life. But OG&E's response to these storms was one for the record books. Hundreds of OG&E employees threw themselves into the restoration effort. Those efforts ultimately earned the company a national emergency response award from the Edison Electric Institute. (renfrowpl@oge.com)

The 3 May 1999 Oklahoma City Tornado: Deaths From the Historical Perspective Harold E. Brooks**,** NOAA/ National Severe Storms Laboratory, Norman, OK

The 3 May 1999 Oklahoma City tornado killed 36 people directly and at least 5 indirectly. This is the largest fatality total in a single US tornado since 1979. How does this death toll fit into perspective? It occurred against a backdrop of a long-term decrease in rates of death per population. I will discuss the trends in deaths and give some interpretation of the OKC tornado in light of US tornado history. *(brooks@nssl.noaa.gov)*

Tornado-Related Mortality on May 3, 1999 in Oklahoma W. Randolph Daley, Pam Archer, Sue Mallonee, Fred Jordan, Sharon Asher, Centers for Disease Control and Prevention, Oklahoma State Department of Health, Oklahoma State Medical Examiner, Oklahoma City, OK

Background: Between 1994 and 1998, tornadoes resulted in over 200 deaths nationwide. We examined circumstances surrounding tornado-related deaths from the May 3, 1999 tornadoes in Oklahoma.

Methods: We reviewed medical examiner records on deaths related to the May 3 tornadoes and interviewed next-of-kin to determine additional information on the circumstances of death.

Results: A total of 45 tornado-related deaths were reported. Age ranged from 3 weeks to 94 years (mean = 48, median = 46); 25 were female and 20 male. Of the 45 deaths, 42 were from injuries and 3 were from cardiac arrest. Fatal tornado injuries occurred in various locations: 20 in single-family homes, 6 in mobile homes, 4 in apartments, 1 in a public building, 1 in a motor vehicle, 7 outdoors, and 3 undetermined. In single-family homes, 7 deaths occurred in closets, 3 in bathtubs, and 3 elsewhere in a bathroom. No deaths occurred in a basement or underground shelter, though 1 occurred on stairs while entering a basement. Four deaths occurred outdoors when individuals fled their homes and two when motorists sought shelter under bridges.

Conclusion: Most deaths occurred from injuries inside homes. Basements and underground shelters appeared to offer the most protection. *(wcd0@cdc.gov)*

Epidemiology of Tornado Injuries on May 3, 1999 Pam Archer, Sheryll Brown, Elizabeth Kruger, Sue Mallone, Injury Prevention Service-0307, Oklahoma State Department of Health, Oklahoma City, OK

Background: During the evening hours of May 3, 1999, multiple tornadoes occurred in Oklahoma including an F5 tornado. We investigated the epidemiology of tornado injuries throughout the state.

Methods: We reviewed hospital medical records, medical examiner reports, and newspaper articles; injured persons were also surveyed to determine the number, types, and circumstances of injuries.

Results: 597 persons were injured and 45 persons were killed as a result of the tornadoes. 55% were female and mean age 38.5 years (0-98). 29 people were dead at the scene and 613 people were treated in Oklahoma hospitals; 144 were admitted to a hospital and 469 were treated in an emergency room. 69% of persons were injured directly by the tornadoes, 4% preparing for the tornadoes, 7% after the tornadoes, 4% suffered inhalation injuries, and for 17% of people the mechanism of injury was unknown. Geographic locations were known for 400 persons, 73% were in the Oklahoma City metropolitan area, 14% Bridge Creek, and 13% were in other areas of the state. The most common types of injuries were soft tissue injuries (75%), fractures/dislocations (24%), and brain injuries (19%).

Conclusions: The majority of persons killed and injured by the May 3rd tornadoes were located in the Oklahoma City metropolitan area. 73% of persons killed or injured were treated in emergency rooms, 22% were admitted to hospitals, and 5% were dead at the scene. The most common injuries were soft tissue injuries, fractures/dislocations, and brain injuries. *(parcher@health.state.ok.us)*

Use of Vehicles to Flee the 3 May 1999 Tornado: Reasons and Relative Injury Rates Barbara O. Hammer and Thomas W. Schmidlin, Kent State University, Kent, OH

The NWS Service Assessment of the 3 May 1999 tornadoes showed that ample warning lead times and TV coverage "allowed many individuals to escape the path of this tornado (from their homes) via automobile." This action, contrary to safety recommendations, may have saved many lives, although similar actions have lead to deaths in the past (for example, Wichita Falls, 1979). We surveyed residents of 334 homes with F4 or F5 damage in Storm A9 to assess (1) the percentage who fled in vehicles, (2) the relative risk of injury for those who remained in the home and those who fled in vehicles, and (3) to explore the factors influencing the decision to stay in the home or to flee in a vehicle. Results may contribute to understanding the public response to tornado warnings and television coverage and to the understanding of the 'aberrant' behavior of fleeing frame homes in vehicles in the face of longer warning lead times. *(barbhammer@hotmail.com, tschmidl@kent.edu)*

Tulsa's Vision 2020--Creating a Disaster-Resistant Community Ann Patton, Project Impact, Tulsa, OK, Ernst W. Kiesling, Texas Tech University, Lubbock , TX, and Eric Miller, BSW Architects and Vision 2020, Tulsa, Oklahoma

Project Impact is a program of the *Federal Emergency Management Agency (FEMA)* aimed at fostering community partnerships with the mission of creating safer communities and curbing the spiraling economic losses resulting from natural disasters. Tulsa's award-winning *Project Impact* created "Vision 2020" which is aimed at making Tulsa a disaster-resistant community by the year 2020. After gaining widespread recognition for an effective flood mitigation program, Tulsa is now focused on preparing for extreme winds. After enlisting more than 250 diversified partners, Tulsa's *Project Impact* has launched a program of education, demonstration, and planning to mitigate the effects of extreme winds. The essential elements and programs of the award-winning project will be described. *(APatton@ci.tulsa.ok.us)*

How Safe is your School's Tornado Emergency Plan? Andrea Dawn Melvin, Oklahoma Climatological Survey, University of Oklahoma, Norman, OK

Children learn tornado safety in elementary school. They know to go to the lowest level, center-most room, cover their heads with blankets or mattresses, and to avoid windows. Typically, tornadoes occur between 4 PM and 6 PM when children are at home. Using weather reports from local television and radio stations along with the safety procedures learned at school, children survive severe storms. How many of these children would survive at school following the school's emergency plan? Twice a year schools conduct tornado drills. However, in many cases these plans move children to unsafe areas of the building.

The Federal Emergency Management Agency (FEMA) organized a Building Performance Assessment Team (BPAT) to survey the May 3rd tornado damage. The BPAT reviewed the emergency plans of five public schools. Problems found with the school emergency plans included: students remaining in classrooms with interior doors surrounded by glass, students moved to interior hallways with glass windows along the upper edge of the walls, and students moved near substantial looking walls that would not have proved resistant to strong winds or debris.

The BPAT findings need to be communicated to schools. School officials need to know that having an emergency plan does not mean having the safest plan possible. New research, better building codes, and greater forecast lead-times all contribute to successfully implementing the emergency plan. Ignoring improvements in any of these areas and not updating the school's emergency plan jeopardizes the safety of everyone in the school.

Every school must have their tornado emergency plan reviewed for possible weaknesses. The reviews must be conducted by a qualified engineer or architect. Additionally, the Warning Coordination Meteorologist (WCM) of your local National Weather Service Office has been trained to identify safe areas within schools. Don't allow your school to rely on an unsafe or outdated emergency plan. *(admelvin@ou.edu*)

An Assessment of Wind Damage Using Tax Assessor Data Jamie Brown Kruse, Texas Tech University, Lubbock, TX, Kevin Simmons, Oklahoma City University, Oklahoma City, OK, Douglas Smith and Mark Thompson, Texas Tech University, Lubbock, TX

This study uses data from the Oklahoma County Tax Assessor to examine the determinants of dollar losses due to the May 3, 1999 Oklahoma City tornado outbreak. This analysis relates structural characteristics of buildings, their geo-coded locations, and physical damage reports (where applicable) to dollar losses. We generate a storm path and a spatial distribution of damage intensity using this secondary data set. (*VGJLK@ttacs.ttu.edu)*

Tornadoes, Stress and Migration Decisions: Evidence from Oklahoma City Barbara McCain and Jonathan Willner, Meinders School of Business, Oklahoma City University, Oklahoma City, OK

When tornadoes strike a residential area with sufficient force to cause extensive damage, the physical damage can result in emotional and financial distress. Over time, the emotional and financial impact may manifest itself in altered decision making. People effected by the tornado may decide to relocate or remain in their original location. In addition to the emotional and financial considerations, people's perceptions of risks of subsequent tornadoes are likely to influence their relocate or rebuild decision.

This study focuses on perception of future risk, the existence and extent of post traumatic stress syndrome, and decision making post disaster. Empirical results will examine how people made the decision to relocate or remain in their original location following the May 3, 1999 tornado in Oklahoma City, Oklahoma (*bmccain@okcu.edu)*

Oral Presentation Session II - Observations

Enhanced Detection of Tornadoes on 3 May 1999 Using prototype Fine-Resolution WSR-88D Measurements Rodger A. Brown and Vincent T. Wood, NOAA/National Severe Storms Laboratory, Norman, OK

Using simulated WSR-88D Doppler velocity measurements, the authors have demonstrated that enhanced tornadic vortex signatures (TVS) can be produced by decreasing the azimuthal sampling interval from 1.0 deg to 0.5 deg. The authors propose that the conventional 1.0 deg azimuthal sampling interval be cut in half by using half the number of pulses to compute the mean Doppler velocity values (while maintaining acceptable data accuracy).

During the Oklahoma-Kansas tornado outbreak on 3 May 1999, the authors collected prototype WSR-88D data using the WSR-88D Operational Support Facility's KCRI radar in Norman. Archive Level 1 (time-series) data were collected, starting around the time of the first tornado reports and continuing for the next six hours. Using software developed at the National Center for Atmospheric Research, the Archive I data were converted into two separate Archive II (meteorological) data sets, one having 0.5 deg azimuthal sampling and the other having 1.0 deg azimuthal sampling.

As anticipated, the 0.5 deg azimuthal data produced stronger tornadic vortex signatures. Examples of this enhanced detection capability are presented for tornadic vortex signatures that occurred between 30 and 135 km from the radar. *(brown@nssl.noaa.gov)*

Doppler On Wheels Observations of the 3 May 1999 Tornadoes Joshua Wurman, University of Oklahoma, Norman, OK

OU's Doppler On Wheels (DOW) mobile dual-Doppler weather radar network intercepted several tornadoes during the 3 May outbreak. Observations of various stages of tornado evolution were obtained in the tornadoes near Apache, Chickasha, Moore, and Mulhall. Genesis of two tornadoes was captured. Extremely high wind speeds were measured in the Moore and Mulhall tornadoes as well as intriguing sub-tornado structure. *(jwurman@ou.edu)*

Finescale Wind Observations in a Tornado on 3 May 1999 Using the University of Massachusetts 3-mm Wavelength Mobile Doppler Radar Howard B. Bluestein, University of Oklahoma, Norman, OK, and Andrew L. Pazmany, University of Massachusetts at Amherst, Amherst, MA.

On 3 May 1999 low-elevations scans were made with the University of Massachusetts 3-mm wavelength mobile Doppler radar system near Verden, Oklahoma. Spatial resolution of 5-10 m was attained in the eye and in the nearer spiral bands of the tornado. The data presented show F3 wind speeds, which are consistent with damage surveys. The most significant findings are evidence of wavelike structures in radar reflectivity along the edge of the tornado's eye. It is hypothesized that these waves represent shear instabilities. Small-scale couplets in Doppler velocity were also found along the edge of the eyewall; some of these might represent subvortices in the tornado. By the time of the symposium, an analysis of the full horizontal wind field might be available from a short sequence of radar images collected 15-20 seconds apart. (*hbluestein@ou.edu)*

May 3 Tornadic Supercells Viewed from Space During an Overpass of the NASA TRMM Observatory Steven J. Goodman, NASA Marshall Space Flight Center, Huntsville, AL, Dennis Buechler and Kevin Driscoll, University of Alabama Huntsville, Huntsville, AL, Donald W. Burgess, NOAA/NWS/WSR-88D Operational Support Facility, Norman, OK, and Michael A. Magsig, Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma, Norman, OK

At approximately 04:00 UTC on 4 May (23:00 CDT on 3 May) 1999 the NASA Tropical Rainfall Measuring Mission (TRMM) Observatory made an overpass during the Central Oklahoma tornado outbreak. Supercells D4 and G5 were observed by a unique suite of scientific instruments aboard TRMM. The TRMM observatory was launched in November 1997 into a low earth orbit providing global coverage of storms from 35 degrees N latitude to 35 degrees S latitude from an altitude of 350 km. The instruments include the Lightning Imaging Sensor (LIS) which measures total lightning activity (in-cloud as well as cloud-to-ground), the TRMM Microwave Imager (TMI) which measures precipitation and cloud microphysical characteristics, the Precipitation Radar (PR) which is the first meteorological radar flown in low earth orbit, and the Visible/InfraRed Sensor (VIRS) which measures cloud top characteristics such as cloud top temperature in the visible and infrared with high (2 km) spatial resolution. Supercell D4 at Stroud, Oklahoma produced the greatest lightning rates (exceeding 225 flashes per minute) observed worldwide to date by the LIS. The presentation will present detailed satellite and NEXRAD observations of the two supercells during the TRMM overpass. *(Steve.Goodman@msfc.nasa.gov)*

Summary of Mobile Mesonet Observations on 3 May 1999 Paul Markowski, Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma, Norman, OK

Mobile mesonet operations during May-June, 1999 were primarily concentrated on collecting data within the rear-flank downdrafts (RFDs) of supercells. Although RFDs have been believed to be critical for tornado genesis and maintenance for nearly 30 years, direct observations within them are scarce. This presentation will summarize mobile mesonet surface observations of buoyancy, theta-e, and pressure within the RFDs and near-tornado inflow regions of two tornadic supercells that occurred on 3 May 1999.

Three curious phenomena were detected in the 3 May supercells: (1) high theta-e RFD air, (2) high buoyancy RFD air, and (3) lack of baroclinity in the hook echoes. None of these phenomena have been well-resolved by past thermodynamic retrievals, nor are they simulated by three-dimensional cloud models which must unavoidably rely on parameterization of storm microphysics. Comparison with other supercells sampled by the mobile mesonet will be made, and lastly, some analyses of surface pressure fluctuation also will be documented. *(marko@rossby.ou.edu)*

Analysis of Tornado Damage Tracks on the May 3rd Tornado Outbreak Using High-Resolution Satellite Imagery and GIS May Yuan and Melany Dickens-Micozzi, University of Oklahoma, Norman, OK, and Michael Magsig, Cooperative Institute for Mesoscale Meteorological Studies, Norman, OK

A joint effort of the OU Geography Department, the NASA Space Grant program and Space Imaging, Inc., has acquired high-resolution satellite data (5m panchromatic and 25m LISs imagery taken by IRS satellites) before and after the May 3rd tornado outbreak. With the data, we apply remote sensing and GIS methods to analyze tornado track characteristics and compare the tracks with detailed damage surveys conducted by members of the OU Weather Center.

The satellite data show a distinct, well-sampled tornado damage path for the Oklahoma City tornado. Surprisingly, other tornado tracks do not show up as clearly in the data though many other tornadoes produced significant damage. Research is ongoing to determine 1) what is causing the tornado track signature for the Oklahoma City tornado, 2) why is there a difference in signatures for the other tornado tracks, and 3) what are the strengths and limitations of using high-resolution satellite data for future tornado damage surveys. A preliminary hypothesis being tested is that the Oklahoma City tornado produced an unusual amount of damage along its track, particularly through urban areas. This project represents a multidisciplinary study between Geography, Meteorology, NASA Space Grant program, and the Oklahoma private sector (Space Imaging, Inc.). *(myuan@ou.edu)*

A Satellite Perspective of the 3 May 1999 Great Plains Tornado Outbreak and Comments on Lightning Activity Dan Bikos, John Weaver, Bard Zajac, and Brian Motta, Cooperative Institute for Research in the Atmosphere, Colorado State University, Fort Collins, CO

GOES satellite imagery from 3 May 1999 is examined. Synoptic-scale water vapor imagery shows a low-amplitude upper-level trough over the western U.S. deepen dramatically on 3 May, developing a negative tilt as a jet streak digs south-southeastward over California. Water vapor imagery also shows another jet streak propagating rapidly from Baja California to the southern Great Plains. This jet streak intensifies as it propagates into the developing diffluence on the east side of the trough. Thunderstorms initiate as this jet streak moves over western Oklahoma during the late afternoon.

GOES visible imagery shows a north-south cloud boundary over western Oklahoma on May 3 with mostly clear skies to the west and shallow cumulus and stratocumulus exhibiting wave patterns to the east -- suggesting more moist and stable conditions to the east. As the jet streak and associated cirrus propagate over northern Texas, towering cumulus are seen to develop and then dissipate. As the cirrus propagate over western Oklahoma, towering cumulus are seen to develop and persist.

Cloud-to-ground (CG) lightning data indicate that many of the storms on 3 May produced an anomalously large fraction of positive polarity CG lightning. For example, the tornadic storm that destroyed portions of Moore, OK produced predominantly positive CG lighting during its lifecycle. *(bikos@cira.colostate.edu)*

Oral Presentation Session III - Forecasting and Warning

Beyond the Nowcast Range: 24-h Forecast Guidance Concerning Convective Initiation and Mode for the Great Plains Tornado Outbreak of 3 May 1999 Paul Roebber, University of Wisconsin at Milwaukee, Milwaukee, WI, David Schultz, NOAA/National Severe Storms Laboratory, Norman, OK, and Rich Thompson, NOAA/NWS/Storm Prediction Center, Norman, OK

The 3 May 1999 tornadic outbreak did not conform to conceptions of the classical, synoptically evident outbreak (e.g. progressive, developing cyclone, advection of high equivalent potential temperature air in the boundary layer, well-developed mesoscale boundaries in the form of drylines/fronts, strong vertical wind shear). Although forecasters were well aware of the potential for severe weather 24 hours in advance and outlook risks were upgraded through the course of the day, the initiation/timing, form, and location of the convection were not readily anticipated. In particular, one issue was whether isolated supercells or a single squall line would move across Oklahoma, if convection initiated.

We argue that very high resolution regional models such as the PSU/NCAR MM5 can provide key information about these questions in forecast mode. The 0000 UTC 3 May 1999 forecast cycle of the national Centers for Environmental Prediction (NCEP) aviation (AVN) run of the Global Spectral Model (GSM) was used to provide cold-start initial conditions and lateral boundary conditions for the outermost domain of a quadruply nested (54, 18, 6 and 2 km), 27-h integration. We will show how the model forecast, in combination with available observations, could have been used by forecasters to help develop, and later update, expectations concerning the storms that day. *(roebber@csd.uwm.edu*)

The Challenges in Forecasting the 3 May 1999 Event Beyond 12 Hours Dan McCarthy and Jeff Evans, NOAA/NWS/Storm Prediction Center

The Storm Prediction Center is currently tasked with issuing severe weather outlooks from 12 to 60 hours prior to an event. These forecasts are heavily dependent on the short-term model forecasts distributed by the National Center for Environmental Prediction. Given the well-documented problems the various models have in dealing with mesoscale phenomena and boundary layer forecasts, anticipating the occurrence of severe weather events can be quite challenging. Once an area of severe weather potential is identified, the details of the atmosphere are further examined to determine the magnitude and mode of the expected convection. The forecast categories of "Slight", "Moderate", and "High" are then used to convey the coverage and intensity of the expected severe weather.

Though the 3 may 1999 tornado outbreak was one of the most intense in recent memory to have affected Oklahoma and Kansas, the extreme nature of the event was not well anticipated beyond 12 hours. While model forecasts up to 24 hours prior to the event were consistent in indicating a deep longwave trough over the Western U.S., they underforecast the strength of the flow across western Oklahoma and Kansas. In addition, the model quantitative precipitation and vertical motion fields yielded little run to run consistency over the southern Plains, and forecast only weak low level convergence over the affected area. Instability was also underforecast, however, forecast CAPE was more than adequate to support deep convection (3000+ J/kg) if storms could indeed develop. These factors limited confidence in forecasting the development of isolated supercells within the warm sector during the afternoon, prior to 12 hours before the outbreak commenced. This presentation will address in more detail the model guidance available through 7:00 A.M. CDT on the morning of 3 May 1999, with an emphasis on that from the 00z 05/03 ETA run, and its incorporation into the convective outlook process. *(Mccarthy@spc.noaa.gov)*

An Overview of the Decision Making Process During the 3 May 1999 Tornado Outbreak in Oklahoma and Southern Kansas Michael D. Vescio, NOAA/NWS/Storm Prediction Center, Norman, OK

On 3 May 1999 a localized but very severe tornado outbreak occurred across Oklahoma and southern Kansas. In Oklahoma, more than 70 tornadoes were reported, making this the largest tornado outbreak in the state's history. One of the most interesting aspects of this case was the complex process of convective initiation. The initial supercell (which eventually produced the F5 tornado in Moore) developed well east of a nonconvergent dryline within a relative minimum in an otherwise thick cirrus overcast. The fact that convective towers developed in northwestern Texas around 20 UTC and dissipated shortly thereafter did not provide confidence to SPC forecasters that the initial towers that formed in southwest Oklahoma around 2030 UTC would survive to become sustained supercells. In addition, the operational models did not handle convective initiation properly, with the 12 UTC Eta showing a spurious convective cluster over southeast Oklahoma, and the 18 UTC RUC2 indicating no convection at all in Oklahoma through 06Z. These factors led to considerable uncertainty regarding how the event would unfold. The watch decision process is discussed, highlighting the diagnostic and short term model data that were available at the time the initial tornado watch was issued for Oklahoma. (vescio@spc.noaa.gov)

Warning Operations at the National Weather Service Forecast Office During the May 3rd, 1999 Tornado Outbreak David L. Andra, Jr., NOAA/NWSFO, Norman, OK

The tornadoes experienced in the May 3rd outbreak posed a significant challenge to National Weather Service meteorologists charged with providing forecasts and warnings. While the Doppler radar signatures associated with the storms were relatively well defined, the numbers and intensities of the tornadoes affecting population centers were not typical.

Forecasters were able to provide ample lead time in most instances by employing a warning decision-making process which integrated physically based conceptual models of storm type and evolution, Doppler radar data, details of the mesoscale environment, and ground truth. Statistics for the Norman NWS portion of the outbreak reveal an average lead time of 18 minutes for all tornadoes and 48 minutes for significant tornadoes (F2 or greater).

The Advanced Weather Interactive Processing System (AWIPS) and Warning Decision Support System (WDSS) workstations provided the technological platforms for data integration and warning dissemination. At times, up to four meteorologists were making warning decisions for sub-areas or "sectors" of the NWS Norman area of responsibility using AWIPS, while WDSS provided important storm strength and trend information. This intelligent union of human decision making and technology, when combined with media coverage and actions by local emergency managers and citizens greatly minimized loss of life during the evening of May 3rd, 1999. *(david.andra@noaa.gov)*

The Use of Ground-Truth Reports in the Warning Decision Making Process During the May 3rd, 1999, Oklahoma Tornado Outbreak Dennis H. McCarthy, NOAA/NWS, Norman, OK

During the devastating May 3rd tornado outbreak in Oklahoma, reports to the National Weather Service (NWS) from trained spotters and media intercept crews contributed significantly to the NWS warning decision making process. The operations area of the Forecast Office is configured to incorporate real-time reports and media accounts directly with radar, satellite, mesonet, and other data during severe weather events.

On May 3rd , the first reports of large hail from spotters near rapidly developing thunderstorms in southwest Oklahoma came directly to the Forecast Office in Norman via amateur radio. The first reports of rapid rotation at the base of a storm north of Lawton also came to the Forecast Office via amateur radio. This report was combined with radar information for the issuance of the first tornado warning.
As the event evolved, warning forecasters also took advantage of live telecasts of funnel clouds and tornadoes from intercept crews affiliated with the Oklahoma City television stations. Live footage and on-the-scene accounts helped forecasters assess the magnitude of the event and add valuable detail to warnings and follow-up severe weather statements.

In turn, those in the field were given frequent radar narrative updates via amateur radio from the Forecast Office. At a base station equipped with a full-function meteorological workstation, licensed amateur radio operators, in this case additional Forecast Office staff, were able to coordinate with spotters and emergency managers, provide radar updates, and focus spotter attention on the most dangerous storms.

On May 3rd, the "closed loop" of information flowing among forecasters, spotters, emergency managers, law enforcement officials, and the media contributed to accurate, timely, and detailed warnings. With full-time coverage by the media, countless lives were saved and numerous injuries were prevented. (DENNIS.MCCARTHY@noaa.gov)

The KWTV Warning Environment During the May 3, 1999 Tornado Outbreak Gary England, KWTV, Oklahoma City, OK

Preparations for and actions during the May 3, 1999 tornadoes will be presented. The value of National Weather Service and Storm Prediction Center information will also be discussed. *(england@kwtv.com)*

Getting the Message to the Public Dan Threlkeld, KFOR-TV Television, Oklahoma City, OK

On May 3rd, the public had much advanced warning of the impending storms. Tornado Watches and Warnings were issued well in advance of the deadly storms.

The media's role was critical that day. Through the use of continuous coverage of the storms, beginning in S.W. Oklahoma until the time they ended that evening, the public was fully aware of the danger.

Through the use of the live pictures from the ground and the helicopter, viewers were able to assess the deadly storms for themselves and as a result many more took shelter.

In a prepared video, I will show some of the images and sounds that viewers saw on KFOR-TV that evening and highlight some of the things we learned from that night.*(dthrel@ionet.net)*

The Killer tornado Outbreak of 3 May 1999: Applications of OK-FIRST in Rural Communities Kenneth C. Crawford and Dale A. Morris, Oklahoma Climatological Survey, University of Oklahoma, Norman, OK

The OK-FIRST Project was developed, beginning in October 1996, as a formal educational outreach and support program of the Oklahoma Climatological survey. The goal of OK-FIRST was to develop a transportable, agency-driven information-support system to help public safety agencies harness the information age. The desired impact of OK-FIRST was documentable improvements in how public safety agencies (fire, law enforcement, and emergency management) responded to environmental emergencies.

Today, approximately 3 years later, over 90 public safety agencies, in support of their respective missions, have received formal instruction in the use of many new forms of environmental information disseminated via OK-FIRST (e.g., data from the Oklahoma Mesonetwork, volume-scan data from 15 WSR-88Ds, and other data produced by the modernized National Weather Service (NWS). By design, most communities served by OK-FIRST represent rural areas of Oklahoma (e.g., ~50% have populations of 5,000 or less). Numerous success stories have resulted through the actions of public-safety agencies across Oklahoma that have been "modernized" by OK-FIRST. These results have occurred through the transformation of weather data into useful information and its subsequent application to weather-impacted situations.

The most revealing testimonials about the effectiveness and robustness of OK-FIRST occurred on 3 May 1999, a day of unparalleled killer tornadoes that impacted central and northern Oklahoma. Because the meteorological community of Oklahoma (including the NWS and the broadcast media) performed superbly in dealing the well-over 50 tornadoes, the death and injury toll was amazingly limited to 44 fatalities and 700+ injuries.

However, as major media outlets properly focused on the widespread death and destruction across heavily-populated areas of central Oklahoma, the OK-FIRST system passed a major, critical test. For example, over 36,000 files of WSR-88D information were shared with participants on 3 May. More importantly, several life-saving stories from rural Oklahoma "did not make the national headlines" but provide convincing evidence the OK-FIRST played an important role in saving the lives of many Oklahomans on 3 May 1999. Several of these "untold stores" which were produced through front-line decisions that were supported by timely and accurate information will be illustrated and demonstrated during the presentation. *(kcrawford@ou.edu)*

The 3-4 May 1999 Tornado Outbreak: A Test of the National Weather Service Modernization Eric D. Howieson and Charles K. Hodges, NOAA/NWS, Tulsa, OK

The 3-4 May 1999 tornado outbreak across portions of Oklahoma and Kansas will go down in the history books as one of the largest tornado outbreaks in the United States. During the event, 77 tornadoes were reported in Oklahoma of which 15 were located in the county warning area (CWA) of the National Weather Service (NWS) office in Tulsa, Oklahoma. At 0330 UTC on 2 May 1999, the KINX WSR-88D located in Inola, OK suffered a major failure which made the system inoperable. A team of specialists was dispatched from the Operational Support Facility (OSF) in Norman, OK to the site to start repairs as soon as the failure was diagnosed. However, due to the nature of the failure, the radar was not brought back to an operational status until 1930 UTC on 4 May 1999. Therefore, the Tulsa NWS office was forced to work the tornado outbreak without the radar that would have provided the best severe weather coverage.

A major part of the NWS Modernization was the installation of the WSR-88D radar at sites all across the country. The placement of these radars was, in part, based on overlap of adjacent NWS offices CWAs for coverage during radar outages and to provide backup services. Although there were a few difficulties, the 3-4 May 1999 event was handled well as the new Advanced Weather Interactive Processing System (AWIPS) performed up to expectations. This paper goes into details of what worked and didn't work during a large severe weather event for a modernized NWS office. *(Eric.Howieson@noaa.gov*)

Lessons Learned from the Destruction of the 3 May 1999 Oklahoma City Tornado Charles A. Doswell III, NOAA/National Severe Storms Laboratory, Norman, OK

A survey conducted by the Federal Emergency Management Agency in the wake of the devastating tornado of 3 May 19999 in the Oklahoma City metropolitan area highlighted a number of important results. The damage caused by this violent tornado is likely to be representative of what tornadoes interacting with urban metroplexes can do. There are three important lessons. (1) A considerable reduction in damage to communities could result from minor improvements in construction practices. (2) In the eastern 2/3rds of the nation, there is considerable incentive to provide cost-effective tornado shelters for the purpose of reducing casualties. (3) There is a considerable need for improvements in preparation for tornadoes by public-use facilities. *(doswell@nssl.noaa.gov)*

Performance of NSSL Warning Decision Support System during the May 3, 1999 Central Oklahoma Tornado Outbreak Patrick C. Burke, Gregory J. Stumpf, DeWayne Mitchell, Chirstina D. Hannon, Valerie K. McCoy, NOAA/National Severe Storms Laboratory, Norman, OK, and David L. Andra NOAA/NWS, Norman, OK

The National Severe Storms Laboratory's (NSSL) Warning Decision Support System (WDSS) is an experimental system that is currently being tested in about one dozen National Weather Service Forecast Offices (NWSFO) nationwide. A WDSS was in use during severe weather warning operations at the Norman, Oklahoma NWSFO on May 3, 1999, during a destructive tornado outbreak.

We will provide a summary of the performance of the various severe weather detection algorithms for this storm case. Particular emphasis will be placed on the NSSL Mesocyclone Detection Algorithm (MDA), the NSSL Tornado Detection Algorithm (TDA), and the NSSL Bounded Weak Echo Region (BWER) algorithm, as well as the WSR-88D radar overview of the storms. (pburke@nssl.noaa.gov)

Oral Presentation Session IV - Modeling and Analysis

Mesoscale Meteorology Behind Visually Observed Supercell Structures and Morphologies on 3 May 1999 Roger Edwards and Richard L. Thompson, NOAA/NWS/Storm Prediction Center, Norman, OK

Visually evident structures of several of the tornadic supercells from 3 May 1999 were photographically documented throughout much of their life cycles by field observers. These features are compared with concepts of supercell morphology and tornado potential commonly associated with specific storm structures. Supercell evolution as observed from the ground is also compared with some radar-indicated storm characteristics. Finally, evolution and tornado production of several of the 3 May supercells is linked to identifiable ambient meteorological conditions on the mesoscale, e.g., changes in cloud base character as two storms passed over a confluence line into a region of backed surface winds and smaller dew point depressions. *(edwards@spc.noaa.gov)*

Explicit Prediction of the Moore, OK Tornadic Supercell Using Single-Doppler Retrieved Fields Obtained From WSR-88D level-II Data Jason Levit, Richard Carpenter, Alan Shapiro, Keith Brewster, Gene Bassett, and Kelvin Droegemeier, Center for Analysis and prediction of Storms, University of Oklahoma, Norman, OK

As part of an ongoing research effort into the 3 May 1999 tornado outbreak, the CAPS single-Doppler retrieval/assimilation procedure has been used to initialize short-range, high-resolution numerical predictions of the Moore, Oklahoma tornadic supercell from a time-series of WSR-88D single-Doppler radar observations. The retrieval/assimilation procedure includes the Shapiro two-scalar wind retrieval, a variational velocity adjustment, a Gal-Chen type thermodynamic retrieval and a simple moisture specification step. Retrieved "pseudo-observations" are blended with traditional observations (surface, upper-air, and satellite data) within the ARPS Data Analysis System to create model initial fields that explicitly resolve the incipient tornadic supercell.

A variety of storm-scale prediction experiments are underway including 3-km and 1-km predictions using radar retrieved fields, as well as cycling experiments using retrieved data from successive applications of the retrieval package. In addition, the robustness of the prediction results will be evaluated by examining a simple set of ensemble predictions created using the scaled lagged-average forecast technique. The sensitivity of the predictions to the explicit inclusion of the incipient storm via the single-Doppler retrieval procedure will be considered in conjunction with more idealized simulations presented by other researchers at the symposium.

Results from a preliminary 3-km prediction are quite encouraging. Application of the single-Doppler retrieval procedure at 2200 UTC (using five successive radar data volume scans from the Oklahoma City WSR-88D radar) yields model initial fields that resolve the deviant horizontal wind fields and principal storm updrafts associated with both the dominant right-moving cell and the weaker left-moving cell. The numerical prediction initialized from these retrieved fields agrees quite well with the observed storm evolution during its long-lived tornadic phase. In particular, the model-predicted storm develops significant cyclonic rotation and a pronounced hook-like appendage on its southwest flank, and maintains these features for more than two hours. The model predicted storm does, however, move slightly faster than its observed counterpart and weakens too rapidly after 0000 UTC. An experimental 1-km prediction (also initialized at 2200 UTC) further illustrates the model's ability to reproduce the tornadic mesocyclone region. *(jlevit@ou.edu)*

Verification of ARPS 3-km Storm Forecasts of May 3, 1999 David Jahn, Eric Kemp, and Jason Finley, Center for Analysis and Prediction of Storms, University of Oklahoma, Norman, OK

The FAA through MIT/Lincoln Lab funded a one-year study at CAPS/OU to investigate the value of mesoscale numerical weather forecasts to aviation users. In particular for this study, the predictive capability of the Advanced Regional Prediction System (ARPS) was evaluated for the May 3rd tornado event. In so doing, techniques for the verification of highly discrete, small-scale features such as individual storms, were investigated.

Overall, a forecast that correctly handles storm initiation, duration, intensity, and general movement can be very valuable even if the forecasted location is slightly incorrect. Predicting a severe thunderstorm several hours in advance but only a county off is a very skillful forecast, but such spatial errors can lead to unrepresentatively low verification statistics when using traditional scoring techniques such as the Probability of Detection scores (POD) and high False Alarm Rates (FAR). It is essential, therefore, to use modified techniques that allow for some error tolerance and correct for phase-error biases in performance scores.

A "fuzzy" logic validation technique was used to compare and score mesoscale precipitation forecasts as compared with radar reflectivity. First, reflectivity is interpreted as a binary event by which a "yes" observation or forecast was determined by values greater than an arbitrarily set threshold; 40dBZ was used in this study. A "hit" is scored for a gridpoint with a "yes" observation (forecast) when a "yes" forecast (observation) occurs within an arbitrary distance; otherwise it is a "false alarm" ("miss"). A distance of 7.5 km was used. Traditional scores such as POD, FAR, and Critical Success Index (CSI) can then be calculated from the hits, misses, and false alarms, but the results will be more tolerant of slight spatial errors in the forecast.

An additional approach for dealing with forecast phase-errors is through a phase-shifting approach, by which the forecasted fields are optimally shifted such that the overall difference with observations is minimized. In this process, the forecast region is divided into sub-domains, for which the amount of phase-shifting is determined separately. Thus the shifting of a storm complex is not always uniform to accommodate nonhomogeneous phase errors across the domain.

In this study, verification statistics were calculated for the 3-km forecasts of the May 3rd tornado event generated using the Advanced Regional Prediction System (ARPS). Using the "fuzzy" logic approach as well as phase-shifting to alleviate spatial error, the POD for the 1- and 2-hour forecasts are respectively 0.84 and 0.59.
(djahn@ou.edu)

Phase-correction Data Assimilation Applied to the 3 May 1999 Tornado Outbreak Keith A. Brewster, Center for Analysis and Prediction of Storms, University of Oklahoma, Norman, OK

Using a successive correction analysis scheme (ADAS) and an analysis increment-updating data assimilation system developed for ARPS, the 3 May 1999 tornado outbreak is simulated using surface aviation, Oklahoma Mesonet, radar and satellite observations. A mesoscale and storm-scale forecast are produced from the data assimilation system.

The data are first assimilated into a 12-km mesocale forecast. The mesoscale forecast is then used as an initial condition for a storm-scale forecast. The storm-scale forecast is corrected using an automated phase-correction scheme, which uses Doppler radar and surface data to adjust the simulation for position errors in the thunderstorms and mesoscale features near the time of initial storm formation. A forward forecast is run from that point and compared to radar observations and the forecasts produced without benefit of the phase correction step. *(kbrewster@ou.edu)*

The May 3, 1999 South Wichita Tornadic Supercell: A Closer Examination Peter L. Wolf, NOAA/NWS, Wichita, KS

During the early evening hours of May 3, 1999, a severe thunderstorm developed over southern Kansas and evolved into a supercell. The supercell produced an F4-intensity tornado over Haysville and south Wichita that killed six people and injured one hundred fifty people.

Some important features of the supercell seemed to be unfavorable for the development of a large tornado. The supercell was not necessarily isolated from other convection. While the supercell moved at a slower speed than surrounding thunderstorms, it showed no right deviation. In fact, it appeared to move slightly to the left of the mean 0-6 km wind. The storm motion took the mesocyclone directly over areas affected by the heart of the forward flank downdraft (FFD), rather than along the southern periphery of the FFD as may be more commonly observed for tornadic supercells. The reflectivity structure of the supercell was much less impressive than for many of the Oklahoma supercells that developed on May 3. WSR-88D imagery showed the mesocyclone to be near the center of a large area of high reflectivity.

This presentation will focus on factors that appeared to oppose the development of a large tornado from the southern Kansas supercell. A comparison of this case with other past cases will lead to important operational questions regarding our ability to distinguish between supercells that will produce weak, short-lived tornadoes, or no tornadoes at all, and those that will produce violent tornadoes. *(peter.wolf@noaa.gov)*

Mesoscale 4DVAR Data Assimilation for the Great Plains Tornado Outbreak Dusanka Zupanski, Milija Zupanski, David F. Parrish, Geoffrey J. DiMego, and Eric Rogers, NOAA/NCEP/Environmental Meteorological Center, Washington, DC

A Four-Dimensional VARiational (4DVAR) data assimilation system is being developed at NCEP, for the mesoscale eta model. The system is formulated in an approximate mixed resolution mode (coarse adjoint, fine forecast model), as well as in full blown, computationally demanding, fine resolution mode.

The tornado outbreak in the Great Plains is a special challenge to the 4DVAR algorithm, being a mesoscale and stormscale severe weather event. Our goal is to perform 4DVAR data assimilation for this event with the full blown fine resolution algorithm, aimed at 10-30km grid spacing (the choice will depend on the available computer time at the NCEP's IBM SP parallel computer). In addition to NCEP's routine observations, we will assimilate NEXRAD hourly precipitation estimates. An attempt will also be made to include NEXRAD radial velocities.

An alternative, computationally less expensive data assimilation approach will also be challenged in this tornado event. We will upgrade the operational 3DVAR algorithm with the capability to assimilate precipitation data through the use of a linearized precipitation model and its adjoint.

The results of the two approaches will be evaluated and compared, using the extensive database collected for this event. *(dusanka.zupanski@noaa.gov, wd20kd@ncep.noaa.gov)*

A Past and Future Look at the Rapid Update Cycle for the 3 May 1999 Severe Weather Outbreak Stan Benjamin, Tracy Smith, Barry Schwartz, Georg Grell, John Brown, NOAA/FSL, Norman, OK, and Phillip Bothwell and John Hart, NOAA/NWS/Storm Prediction Center, Norman, OK

The Rapid Update Cycle (RUC), running at NCEP and developed at NOAA/FSL, has become a key forecast tool for predicting environments conducive to development of severe convective weather. The performance of the operational RUC from NCEP on 3 May 1999 was mixed, giving some indication of strong moisture convergence where the first storms started in southwestern Oklahoma, but failing to predict much precipitation. In this presentation, we will compare operational RUC forecasts with RUC forecasts made with a few key differences:

1. inclusion of wind profiler data that was missing at NCEP due to a temporary timing problem

2. use of an improved version of the 40km model, including improvements in the Grell convective parameterization, use of MM5 cloud microphysics, boundary-layer and surface physics
3. use of the new 20-km version of the RUC to be made operational at NCEP in summer 2000.

Through these experiments, we will examine what improvements from RUC guidance might be expected for a similar situation in the future with a more complete data assimilation and an advanced version of the RUC model. *(Stan.Benjamin@noaa.gov)*

Some Aspects of Mesoscale Model Forecasts for 3 May 1999 Steven J. Weiss, NOAA/NWS/Storm Prediction Center, Norman, OK, John S. Kain and Michael Baldwin, University of Oklahoma/NOAA/National Severe Storms Laboratory, Norman, OK, John A. Hart, NOAA/NWS/Storm Prediction Center, Norman, OK, and David J. Stensrud, NOAA/ERL/National Severe Storms Laboratory, Norman, OK

The ability of various mesoscale numerical weather prediction models to provide useful guidance in predicting important synoptic and mesoscale features associated with the 3 May 1999 tornado outbreak is examined. Models utilized in this study are operational eta-32 and RUC2 models, an experimental version of the eta incorporating the Kain-Fritsch convective parameterization, the NSSL version of the MM5 model, short-range ensemble forecasts from the NSSL MM5 incorporating six different combinations of boundary layer and convective parameterizations, and the mesoscale version of the Advanced Regional Prediction System (ARPS). We investigate the ability of these models to predict the evolution of the synoptic scale and mesoscale mass and wind fields, as well as thermodynamic and kinematic parameters that are related to convective mode and organization. In addition, the sensitivity of convective precipitation development within the model atmospheres is examined by comparing forecasts from different models, and by varying the physics within the same model. Finally, the challenges associated with introducing a short-range ensemble forecasting system into an operational work environment is discussed. These include the need to: 1) better understand the strengths/weaknesses of different parameterizations as they relate to convective initiation and evolution, and 2) develop ways to transfer this knowledge to forecasters in a practical manner so they can use model output to more accurately assess the level of uncertainty (or confidence) in forecasting thunderstorms on a given day. (weiss@spc.noaa.gov)

Performance of the Storm Cell Identification and Tracking Algorithm During the May 3-4, 1999 Oklahoma Tornado Outbreak W. David Zittel, NOAA/NWS/WSR-88D Operational Support Facility, Norman, OK

The output of the WSR-88D's Storm Cell Identification and Tracking (SCIT) algorithm generated during the May 3-4, 1999 major tornado outbreak in Oklahoma was analyzed over a nine-hour period from 22:15 to 07:15 UTC. Generally, SCIT correctly tracked cell motion from southwest to northeast; however, the average length of time individual cells were tracked was shorter than expected. Although one cell was tracked continuously for nearly three hours, storm cells were tracked on average, for only a little more than 20 minutes. Manual analysis of base reflectivity products showed that eight supercells were responsible for producing 50 tornadoes in Central Oklahoma. In contrast, the SCIT algorithm identified multiple cells both within each supercell and over the lifetime of the supercell. For each supercell, the average length of time any individual cell was associated with a tornadic circulation was between 35 and 40 minutes. *(wzittel@osf.noaa.gov)*

Oral Presentation Session V - Shelter Technology and Wind Engineering

Estimates of the Duration of Damaging Winds in Selected Locations from the May 3, 1999 Tornado Outbreak Rob Howard and Arthur L. Doggett, Texas Tech University, Lubbock, TX

In analyzing the damage documentation data from the May 3, 1999 tornado outbreak, Texas Tech researchers were interested in knowing the duration of damaging winds influencing a given site. To help explore this question, estimates were computed using information about path diameter and forward motion of the vortex. Initial computations show that the duration for the Moore-Del City tornado varies from 60 to 90 seconds. Discussion of the procedure used, site-specific durations, and error analysis will be presented. *(wahow@ttacs.ttu.edu)*

Single-Family Residential Damage and Estimated Wind Speeds Anna Gardner and Kishor C. Mehta, Texas Tech University, Lubbock, TX

On May 3, 1999, a series of tornadoes touched down in central Oklahoma. These tornadoes claimed 45 lives. The high death toll, along with the extensive damage, prompted Texas Tech University's Wind Science and Engineering Research Center to send 3 teams to the Oklahoma City area to investigate structure performance. Residential structure performance was of particular interest due to the severity and amount of damage and the 23 fatalities that occurred in single-family residential suburban communities. The majority of single-family residences were wood-frame construction with brick veneer. The consistency in their construction type, materials, and locality, and large number experiencing all levels of damage provided an opportunity to establish a gradation scale of damage and associate wind speeds. The variables affecting the extent of damage the homes experienced are outlined in this presentation. Discussion of these variables is important in order to view damage from an engineering perspective and permit classification of the damage and the association of wind speed ranges capable of the ensuing damage in the Moore and Del City communities. (zva55@ttacs.ttu.edu, Kishor.Mehta@coe.ttu.edu)

Residential Storm Shelters: The Birth of an Industry Ernst W. Kiesling, Texas Tech University, Lubbock, TX, and K. Simmons, Oklahoma City University, Oklahoma City, OK

The concept of aboveground storm shelters built within a residence has existed for more than two decades. Limited development and utilization continued over the years. Then tornado damage in Texas and Oklahoma during the past three years coupled with incentive grants accelerated growth and established a shelter industry. This paper will describe a series of events that provided impetus to the growth of the industry. The widespread utilization of residential shelters in Oklahoma during 1999 will be discussed. In addition, the paper will discuss the role of *Federal Emergency Management Agency's (FEMA's)* incentive program, with respect to developments in the home building industry as well as the manufacturing industry. *(ekiesling@coe.ttu.edu)*

Taking Shelter: Estimating the Safety Benefits of Tornado Saferooms David Merrell, Center for Economic Studies, U.S. Bureau of the Census & H. John Heinz III School of Public Policy and Management, Carnegie Mellon University, Pittsburgh, PA, Kevin Simmons, Meinders School of Business, Oklahoma City University, Oklahoma City, OK, and Daniel Sutter, University of Oklahoma, Norman, OK

Recently powerful tornadoes have struck populated areas in Alabama, Texas and Oklahoma, raising interest among the public and policy makers in storm shelters and tornado saferooms. More than 14,000 Oklahomans applied to a first of its kind saferoom rebate program sponsored by FEMA following the May 3, 1999 Moore tornado. We estimate the potential safety benefits from tornado shelters. We estimate casualty functions (fatalities, injuries) based on factors like storm intensity, county population density and time of day using historical data from Oklahoma. We then estimate expected tornado casualties for Oklahoma over the next decade using historical tornado frequencies and population growth projections assuming no further market penetration of saferooms. We then calculate the cost per life saved and injury prevented for saferooms. *(dave-merrell@ou.edu)*

Effective, Low Cost Sheltering Options Dan Gallucci, Coastal and Rural Assistance League, Dawsonville, GA

With commendable improvements in forecasting and reporting of severe outbreaks has come more urgency for protection. Seek shelter, TAKE COVER IMMEDIATELY…..but where? Children, families and workers need a safe place to go when advised of an imminent hit.Sooner or later it gets down to protecting flesh.

From the blazing world of gunfire and anti-terrorist blast suppression comes advanced material sheltering alternatives that are unexcelled for debris resistance, uplift, racking, tear apart and crush: all the forces at work destroying buildings and hurting people.

Two programs are currently in progress; one for community sheltering retrofit and the other Saferooms for families, which we originated in 1995. Any hall closet, pantry or powder room reinforced; ARMORED using a combination of standard 2x4 construction and Kevlar advanced material reinforcement from New Necessities. The are available through non-profits Coastal and Rural Assistance League and Habitat for Humanity. CARAL Saferooms typical cost is about $1000 and take 6 hours to construct. Especially easy to retrofit, CARAL Saferooms have been installed in forty (40) states.

In the second program, we are providing guidance to FEMA, schools boards and facilities managers for a very clean, easy and fast retrofit utilizing New Necessities lightweight bulletproof K-Armored panels to 'line' structurally sound areas such as 'duck and cover halls'. Cost is typically $300/a student and crews are in and out in one day. This same K-Armored material was chosen above all others for two of the most secure installations in the world; The President of the United States/United States Secret Service, and Fort Know/United States Mint.

This work won an American Society of Civil Engineers Global Innovation Award for civilian structural reinforcement. We have recently been invited to share our work both at the FEMA National Summit and in the not yet released Mass Sheltering Guide. The International Building Code 2000 have solicited our engineering for the new national Code as well as being on the Building Durability Steering Committee. In Oklahoma, Don Burgess (NSSL) Ann Patton (Tulsa) as well as Oklahoma City Habitat (where our Saferooms were chosen for survivor's new homes), VO Tech and The Lumbermans Association are still supporting of our works. Real news people can use; Easy to build, inexpensive and reliable shelter options that will hold at the limit and with God's help provide for the continuing protection for people at risk, season after season.

Saferooms Take Tulsa by Storm—Builders' Success Stories Josh Fowler, Home Builders Association of Tulsa, Oklahoma, Tulsa, OK, Ernst W. Kiesling, Texas Tech University, Lubbock TX, and Ann Patton, Project Impact, Tulsa, OK

Homebuilders have proven the acceptance and marketability of In-residence shelters. Notable success has been achieved by builders in Florida and Oklahoma where no incentive grants were available. Utilization in speculative housing in Tulsa, including entire developments, will be described. The role of the Tulsa Home Builders Association will be presented along with perspectives concerning some of the barriers to widespread utilization of In-Residence shelters and storm resistant features.

FEMA'S Building Performance Assessment Team Report on the Midwest Tornadoes of May 3, 1999 Clifford Oliver, Federal Emergency Management Agency, Washington DC, and Scott Tezak, Greenhorne & O'Mara, Washington, DC.

On the evening of May 3, 1999, an outbreak of tornadoes tore through parts of Oklahoma and Kansas, in areas that are considered part of "Tornado Alley", leveling entire neighborhoods and killing 49 people. The storms that spawned the tornadoes moved slowly, contributing to the development and redevelopment of individual tornadoes over an extended period of time.

On May 10, 1999, the Federal Emergency Management Agency's (FEMA's) Mitigation Directorate deployed a Building Performance Assessment Team (BPAT) to Oklahoma and Kansas to assess damage caused by the tornadoes. The BPAT was composed of national experts including FEMA Headquarters and Regional Office engineers and staff; a meteorologist; architects; planners; wind engineers; structural engineers; and forensic engineers. The mission of the BPAT was to assess the performance of buildings affected by the tornadoes, investigate losses, and describe the lessons learned. The BPAT prepared a report that discussed observations, conclusions, and recommendations, which are intended to help communities, businesses, and individuals reduce future injuries and the loss of life and property resulting from tornadoes and other high-wind events.

Although designing for tornadoes is not specifically addressed in any current building codes or standards, strict code enforcement requiring homes be built to the criteria in the newest codes and standards (such as ASCE 7-98) would improve the strength of the built environment. The BPAT concluded that buildings constructed to these newer codes and standards would have experienced less damage in areas that were affected by the inflow winds of all tornadoes and concluded that the best means to reduce loss of life and minimize personal injury during any tornadic event is to take refuge in specifically designed tornado shelters. Although improved construction may reduce damage to buildings and provide for safer buildings, an engineered shelter is the best means of providing individuals near absolute protection. (Clifford.Oliver@fema.gov)

Performance of Shelters in the Oklahoma City/Kansas Storms of 3 May 1999 Larry J. Tanner, Texas Tech University, Lubbock TX

Both below ground and aboveground shelters were successfully utilized in the May 3, 1999, storms in Oklahoma and Kansas and were responsible for saving many lives. Post-storm assessment revealed a multiplicity of types and sizes of shelters. The types included conventional outdoor cellars and home basements and, for the first time, aboveground in-residence shelters. Shelter sizes ranged from personal/family size, medium group size, to mass shelters sized to accommodate hundreds of occupants. This investigation revealed numerous design and maintenance shortfalls of the observed shelters. Also revealed were problems and concerns specifically related to larger-sized, public shelters. The publicized success of the aboveground shelters, along with the recommendations of President Clinton, spawned reconstruction to include shelters, primarily aboveground, and the inclusion of safe rooms in public buildings, such as schools. These observations and recommendations are included in FEMA 342, *Building Performance Assessment Report: Midwest tornadoes of May 3, 1999*, published October 1999. Resulting sponsored research includes *FEMA: National Performance Criteria for Tornado Shelters*, published May 28, 1999, and *FEMA: Design and Construction guidance for Tornado and Hurricane Community Shelters*, scheduled to be published fall 2000. *(Larry.Tanner@coe.ttu.edu)*

A Damage Survey of Moore, Oklahoma: What Have We Learned? Tim Marshall, Haag Engineering Company, Dallas, TX

On May 4th, the Institute for Disaster Research at Texas Tech University sent three survey teams to the Oklahoma City area to conduct a damage survey. The teams had five tasks: 1) to map out the damage path and assign F-scale numbers to the damaged residences, 2) to document the performance of housing, 3) to interview witnesses, 4) to document projectiles, and 5) to determine if there were any above or below ground shelters within the damage path and assess their performance. Both aerial and ground surveys of the damage were conducted from Bridge Creek to Midwest City. The damage path was divided between the teams for the survey. My team surveyed the damage from the Bridge Creek area to Moore, Oklahoma. The findings of each of our tasks will be presented. *(TimPMarshall@cs.com)*

The Design of An Above-Ground Storm Shelter For Mulhall-Orlando Public Schools John W. Buckley, Architects in Partnership (AIP), Norman, OK

The May 3rd, 1999 tornado completely destroyed the elementary school in Mulhall, Oklahoma. AIP was retained to rebuild the facility, which was to include a tornado shelter for the general populace. The basis of AIP's architectural practice is the design of public schools in the state of Oklahoma. This presents certain challenges due to the high occurrence of tornadoes in the state. Unfortunately, these challenges have prevented most Oklahoma school districts from providing an adequate level of tornado safety. In recognition of the need, AIP has developed an experience profile with public school above-ground tornado shelters including Frederick Elementary School, completed in 1998; Mulhall Elementary School, currently under construction; and Crescent Public School, currently under design.

The difficulties encountered in the design of a facility such as Mulhall Public School are numerous. For example:

1.Why can't Oklahoma public school storm shelters be built under ground?

2.What variances are required from strict building and fire codes?

3.How can the safety of large numbers of people be assured considering the limited data available on the structural performance of large buildings under the high wind loads generated by F-5 tornadoes?

The presentation is designed to focus on how these and other problems were converted into assets for the students, teachers, and citizens of Mulhall, Oklahoma. (*johnb@aipok.com)*

Engineering Observations of May 3, 1999 Oklahoma Tornadoes Kai Pan and Masoud Zadeh K2 Technologies, Inc. San Jose, CA

On May 3, 1999, a severe tornado outbreak occurred in Oklahoma, Kansas and other Midwest states. It spawned violent tornadoes up to F5 category, which affected a large area including Oklahoma City and its suburbs. Forty-eight people from Oklahoma and Kansas lost their lives. The tornadoes also caused one of the worst insurance losses, in excess of $1.5 billion, from tornado catastrophes in the U.S. history.

Since the tornado struck some highly populated areas, it provided a vivid exhibition of the impact of hazardous natural forces on our built environment. A wide range of structures, from single-family homes to engineered industrial structures, suffered varying degrees of damage. In the early morning of May 6, a post-event investigation team started its three-day visit to some of the hardest-hit locations in the Oklahoma City area. The timely visit provided a unique opportunity to examine the damage patterns of different structural types from an engineering perspective. An aerial photography crew was also dispatched to survey the damage from Chickasha to the northeast of Oklahoma City. About 100 high-resolution aerial photographs were taken, clearly showing the damage along the tornado paths. The high-resolution images enable detailed observations of property damage, which are complementary to field observations.

In this presentation, damage observations are discussed for different construction types, which include residential, commercial, industrial, schools, churches, and lifelines. A large number of residential homes were destroyed or damaged by the tornadoes in some highly populated urban areas. The wind forces of the tornadoes were so strong that even some well-engineered commercial and industrial structures suffered severe damage. *(Kai_Pan@ewb.com).*

Poster Presentations

High Resolution Model Forecasts of the May 3rd Tornado Outbreak Using Varying Background Fields as Initial Conditions Jason J. Levit, Center for Analysis and Prediction of Storms, University of Oklahoma, Norman, OK, Phillip Bothwell, NOAA/NWS/Storm Prediction Center, Norman, OK, Richard Carpenter and Steve Weygandt, Center for Analysis and Prediction of Storms, University of Oklahoma, Norman, OK

The Advanced Regional Prediction system (ARPS) is used in this study to predict the local environment over central Oklahoma during the afternoon of May 3rd, 1999. The purpose of this investigation is twofold. First, we seek to specifically determine the reasons for convective initiation of the several supercell storms that formed in southwest and Central Oklahoma by performing high resolution (3 km) forecasts over the region. Second, we investigate the impact of using different models as background fields for the initial conditions, in an attempt to learn more about the use of varying background fields within an ensemble forecast framework.

The different models used include the MAPS (FSL), Eta (NCEP0), and cycled ARPS forecasts. Early results from experiments using the different background fields indicate strong differences in the forecast fields. For example, cycled ARPS forecasts using a convective parameterization contain an environment already stabilized in some locations, yielding a poor forecast in the regions where strong convection is expected to occur. Tests with the parameterization turned off will be performed to determine this impact.

Finally, using an SDVR (Single Doppler Velocity Retrieval) technique to retrieve storm-scale parameters from the Moore, OK tornadic supercell, high-resolution forecasts will be performed using the varying background fields as well. (jlevit@ou.edu)

Tracking the Oklahoma City Tornado with Radar: Successes and Challenges Donald W. Burgess, NOAA/NWS/WSR-88D Operational Support Facility, and Michael A. Magsig, Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma, Norman, OK

The KTLX central Oklahoma WSR-88D(Doppler) radar displayed strong, well-defined signatures at locations along the track of the violent May 3rd Oklahoma City tornado. The traditional tornado proxy of strong and localized velocity differences compares favorably with damage locations and documented changes in tornado intensity (F-Scale). The radar also displayed a unique maximum in the reflectivity data at tornado locations as the tornado moved through Bridge Creek and the Oklahoma City metropolitan area. The localized reflectivity signature is believed to emanate from large amounts of debris being lofted to high heights by the tornado. While strong tornado signatures were observed with radar for many storms on this evening, the challenge still exists to understand exactly what radar is measuring and how to extend this understanding to medium and long ranges where sampling limitations inhibit clear detection of a storm's tornadic signature. It will be shown that even for a large tornado at close range, the WSR-88D tornado signature is significantly larger than the actual tornado's diameter of maximum wind. *(dburgess@osf.noaa.gov)*

Idealized Numerical Simulations of the May 3 Supercell Thunderstorms Edwin Adlerman, Yvette Richardson, Dan Weber and Lou Wicker, NOAA/National Severe Storms Laboratory, Norman, OK, and Ming Xue, Center for Analysis and Prediction of Storms, University of Oklahoma, Norman, OK

Several idealized numerical simulations were carried out using appropriate representative soundings from the 3 May 19999 environment. The results of these simulations will be discussed, with emphasis on storm structure, mesocyclone behavior, and comparisons with observations. In addition, we will discuss the simulation's sensitivity to the characterization of the initial environment, and its implications for storm-scale NWP. (eadlerman@hoth.gcn.ou.edu)

Preliminary Investigations of Warning Dissemination, Warning Behavior, and Epidemiology in the 03 May 1999 Oklahoma Tornado Outbreak Matthew Biddle, University of Oklahoma and Oklahoma County Emergency Management, Norman, OK

On 3 May 1999, a large outbreak of tornadoes in Western and Central Oklahoma and South-Central Kansas included a long-track violent tornado that struck portions of Oklahoma City and its suburbs to the Southwest and East (hereafter known as the "OKC Tornado"). This storm alone resulted in 40 of the 49 fatalities of the outbreak. Beginning the day after the impact, field surveys were collected from persons residing or working within the damage area of the OKC Tornado path regarding their actions, and the actions of those in their care or company. Similar data were obtained for the Oklahoma fatalities (n=44). The purpose of the field operation was to collect geographical, demographical, behavioral, and attitudinal information from a sample of survivors, and to the fullest extent, for all victims. Morbidity and mortality data were analyzed for significant trends in warning access, source, compliance, and lead-time as well as shelter availability, cultural and architectural variables, hazard perception, and self-assessment of warning systems.

Goals were to catalog significant differences between victim and survivor traits, to identify successful warning operations, respondent actions, and media practices, and to characterize emergent risk factors for death, injury, and damage. Major risk factors for death included living in a wooden house, a house with walls not anchored to the foundation, becoming airborne, and being elderly. Risk factors for survival included traditionally-identified measures such as taking shelter in interior rooms, taking shelter below ground, having access to, and consulting televised warning information. In addition, being alerted to the tornado by a third party via telephone, leaving locations in the path, being aware of the tornado watch, and familiarity with sources of weather information in general, are also identified as significant factors in morbidity and mortality profiles. Also of note are unprecedented percentages of warned public, impact of media coverage, and certain unique and innovative NWS and media actions during the event. Some of these activities are not well characterized nor generally advocated by public safety authorities, yet occurred in numbers that require careful consideration in the future evolution of watch/warning systems and public safety awareness campaigns. (mbiddle@ou.edu)

An Examination of Products Issued During the 3-4 May, 1999 Tornado Outbreak Richard Smith, NOAA/NWS Southern Region Headquarters, Fort Worth, TX

Text projects issued by National Weather Service Forecast Offices (NWS WFO) during the May 3-4, 1999 tornado outbreak are examined. The historic outbreak directly impacted three WFO warning areas – Norman, Wichita and Tulsa. Products, including tornado and severe thunderstorm warnings, severe weather statements and short term forecasts issued during the event are analyzed for their frequency, content and effectiveness. The use of “situation-specific” wording by all three offices in warnings and statements is explored. The use of WarnGen, the AWIPS-based warning generation program is also examined. Given the volume of products issued and the amount of severe weather that occurred, WarnGen played a pivotal role in warning generation and dissemination. Examples of exceptional products are included. (richard.smith@noaa.gov)

Monitoring Severe Weather at Your School Andrea Dawn Melvin, Oklahoma Climatological Survey, University of Oklahoma, Norman, OK

Most schools monitor weather events by watching the TV local news, cable weather updates, or by listening to local radio stations. But schools can increase their weather preparedness by monitoring real-time weather data and products on the Internet.

The Oklahoma Climatological Survey (OCS) has created a series of weather risk web pages that focus on a particular weather hazard such as severe or winter weather. The severe weather page is divided into four panels. Each panel displays interactive maps of weather data using the OCS’s WxScope? Plugin. The four panel display contains a color contour map of Oklahoma Mesonet temperatures/wind vectors, a color contour map of Oklahoma Mesonet dew point temperatures/wind vectors, a color contour map of Oklahoma Mesonet mean sea-level pressure/wind vectors, and a regional mosaic of NEXRAD data. All four panels can be animated by the user. All maps automatically update to ensure display of the most current data.

Schools can monitor their own threat of weather hazards using the risk pages along with a NOAA weather radio. The NOAA weather radio should be equipped with tone alerts and be programmable to specific counties (SAME capable). A teacher or administrator can be assigned the task of monitoring weather conditions or this can be issued as a class assignment. (admelvin@ou.edu)

Characterization of Windborne Projectiles Zhongshan Zhao & Mark S. Martinez Texas Tech University, Lubbock, TX

Projectiles are objects found penetrating/perforating exterior or interior walls, roofs, automobiles, and other surfaces; debris is an object displaced from its original position. The specific gravity, shape, and weight of a debris piece, along with wind speed, are factors determining whether the debris will take flight. Commonly observed windborne debris includes roofing materials, plywood board, gypsum board, lumber, broken tree branches, and small, lightweight household items. A certain amount of momentum is required for the projectile to penetrate/perforate a specific building component or an object. More accurately, the momentum (mass x speed), impact angle, material type, and geometry of the projectile head govern the behavior of the impact. The majority of buildings surveyed in the aftermath of the May 3, 1999, Oklahoma tornadoes were residential buildings of wood-frame construction. Overwhelmingly, the debris generated was of wood material. Projectiles penetrating brick veneer were typically 2"x 6" wood boards. Wood boards of 1" x 6", 2" x 4", and 2" x 6" cross-sections were found penetrating wood roof decks and automobiles. Sill smaller wood projectiles penetrated interior walls. The average weight of documented 2" x 6" and 2" x 4" wood projectiles was 10 and 3 lbs, respectively. Segments of steel gas pipes and lightweight C-section steel pieces also became airborne projectiles. *(ZKNG0@ttacs.ttu.edu)*

WSR-88D VIL Performance During the May 3-4, 1999 Oklahoma Tornado Outbreak Randy Steadham, NOAA/NWS/WSR-88D Operational Support Facility, Norman, OK

The WSR-88D (NEXRAD) computes Vertical Integrated Liquid (VIL) in two different ways. The first technique, gridded VIL, is based on a 4x4 km grid; the second is cell-based. During the May 304, 1999 tornado outbreak, Level II archive data were obtained from the Norman, OK Twin Lakes (KTLX) WSR-88D and evaluated using the WSR-88D Algorithm Testing and Display System (WATADS). May 3-4, 1999 tornadic supercells were reviewed to see performance characteristics of both VIL computations. In some instances, cell-based VIL maxima exhibited much lower values than the corresponding gridded VIL maxima. The reasons for these differences are discussed. (rsteadham@osf.noaa.gov)

FEMA'S Community Shelter Project Scott Tezak Greenhorne & O'Mara, Inc., Washington, DC, and Paul Tertell, Federal Emergency Management Agency, Washington, DC

Tornadoes and hurricanes are among the most destructive forces of nature. More than 1,200 tornadoes are reported nationwide per year. Since 1950, there has been an average of 89 deaths and 1,521 injuries annually, and devastating personal and property losses caused by tornadoes. The most violent tornadoes are capable of tremendous destruction with wind speeds of 250 mph or more. Damage paths can be over 50 miles long and 1 mile wide. The tornadoes that struck Oklahoma and Kansas on May 3, 1999 resulted in 49 deaths and leveled entire neighborhoods. In an average year, ten tropical storms (six of which become hurricanes) develop over the Atlantic Ocean, the Caribbean, or the Gulf of Mexico. Approximately five hurricanes strike the United States coastline every 3 years; two of the storms will be major hurricanes (Category 3 or greater on the Saffir-Simpson Hurricane Scale). The losses to life and property from hurricane-generated winds and floodwaters can be staggering.

FEMA is presently developing a design manual for engineers, architects, building officials, and shelter owners that provides guidance on the design and construction of tornado and hurricane community shelters. This design manual was guided by a steering committee of national experts who donated their time to this effort. At this time, no building code, standard, or design guide provides detailed guidance on the design and construction of shelters for extreme wind events. The group and community shelter designs are intended to serve many different users, both from the public and private sectors, including schools, hospitals and other critical facilities, nursing homes, and community centers. In addition to design guidance, the manual will include: decision-making software; checklists for evaluating existing buildings; real-life case studies, and sample plans for design created using the guidance in this manual. *(stezak@g-and-o.com)*

Vigilance and Resilience After the Storm—OG&E's Recovery Ernst W. Kiesling, Texas Tech University, Lubbock, TX, Ann Patton, Project Impact, Tulsa, OK, and David Frost, Basic Industries Inc., Tulsa, OK

Oklahoma Gas and Electric (OG&E) Company's distribution system for the Oklahoma City area was severely damaged by the May 3, 1999 tornadoes. On June 1 OG&E's 1500 mw facility in Muskogee, Oklahoma was damaged by a tornado. Exemplary creativity and commitment were demonstrated in restoring service to customers, and in continuously providing power to the region. These efforts will be discussed along with lessons learned from the experience; lessons applicable not only to the electric power industry but also to a wide spectrum of businesses. *(ekeisling@col.ttu.edu)*

Comparison of Profiler Observed and Model Forecast Vertical Wind Profiles on May 3rd, 1999 Jim Johnson and Steve Hunter, NOAA/NWS, Dodge City, KS

Numerical model data were obtained for the May 3rd, 1999 tornado outbreak in Oklahoma and Kansas (RUC, Eta, NGM and AVN models). Coincident data were also gathered from the NOAA Profiler Network (NPN). Model forecast vertical wind profiles were compared to actual wind measurements made by NPN wind profilers at Tucumcari, Aztec, and White Sands, New Mexico, and at Jayton, Texas. Some of the models performed adequately with the strength and location of a forecast jet core moving from New Mexico across Texas and into Oklahoma. Nevertheless, they all forecast this jet core to be significantly higher in the troposphere than indicated by observations from the profiler at Tucumcari, which was nearest the actual jet core. The strengthening and descending jet streak resulted in strong vertical shear through a deep layer. The connection between this shear profile and the prolific production of tornadic supercells is not well understood, although it is a known signature of such events. Speculation about this connection is beyond the scope of this talk. Instead, we present evidence that use of the wind profiler measurements in real-time forecasting enhanced the forecaster's ability to anticipate the serious nature of this event, demonstrating the tremendous value added by the NPN over even the best model forecasts. *(Jim.Johnson@noaa.gov)*

Improved Detection of WSR-88D Mesocyclone Signatures During the Oklahoma Tornado Outbreak of 3 May 1999 Vincent T. Wood and Rodger A. Brown, NOAA/National Severe Storms Laboratory, Norman, OK

Using a mesocyclone model and a simulated WSR-88D Doppler radar, our recent studies have shown that a stronger mesocyclone signature is produced using 0.5 deg azimuthal sampling instead of conventional 1.0 deg sampling. Two reasons for producing the stronger signature are (a) the effective beamwidth resulting from 0.5 deg azimuthal sampling is narrower than that for 1.0 deg azimuthal sampling, and (b) with twice the azimuthal density of data points, there is better sampling of the peaks of the mesocyclone signature. Furthermore, the signature can be detected at least 50% farther away from the radar with 0.5 deg azimuthal sampling than with conventional 1.0 deg azimuthal sampling.

To verify the above simulated findings, Archive level I (time-series) data were collected at the WSR-88D Operational Support Facility's KCRI radar site in Norman during the tornado outbreak of 3 May 1999. With time-series data, two Archive level II data tapes were produced – one having 0.5 deg azimuthal data collection and the other having 1.0 deg azimuthal data collection.

Results show that mesocyclone signatures are stronger using 0.5 deg azimuthal sampling compared to the conventional 1.0 deg azimuthal sampling of the WSR-88D. The results will be discussed in detail at the Symposium. *(wood@nssl.noaa.gov)*

Documentation of Verified Tornadoes for May 3, 1999 in the Norman Oklahoma NWSFO County Warning Area Douglas Speheger, NOAA/NWS, Norman, OK

An historic outbreak of around 60 tornadoes struck the state of Oklahoma during the afternoon and evening hours of May 3, 1999. This is the most tornadoes documented in one day within the state. Among these tornadoes was the first F-5 tornado to strike Oklahoma in 17 years, and the first F-5 tornado documented to strike the Oklahoma City metropolitan area.

Data from many sources were contributed to the national Weather Service Forecast Office (NWSFO) in Norman to document these tornadoes, including videos, photographs, reports from state and local officials, written accounts from storm spotters and chasers, as well as reports given in real-time to support warning operations. In addition, meteorologists from the national Weather Service Forecast Office, National Severe Storms laboratory, Storm prediction Center, and the WSR-88D Operational Support Facility conducted ground surveys on May 4-7. Data from these sources were used to document 59 tornadoes within the NWSFO Norman County Warning Area.

The details from each data source and the WSR-88D radar were used to reach the most accurate information possible for each tornado. The estimated locations documented by videos, photographs and reports were triangulated to obtain the most precise location possible where ground surveys were not performed. Times of events from the various sources were compared with other sources to remove as much time bias as possible from each report. The author documents each the times, locations and intensities of each of the 59 tornadoes in the NWSFO Norman County Warning Area. (*Doug.Speheger@noaa.gov)*

Lessons From 3 May 99 – A New Air Force Weather Information Process Joel D. Martin, USAF, Barksdale AFB, Louisiana

Air Force Weather is responsible for managing a weather information process that supports resource protection for all Air Force, Army, National Guard, and Reserve Component units. In August 1996 the Air force began an end-to-end reengineering of the organization, training, equipment, and processes used to develop and deliver weather information, training, equipment, and processes used to develop and deliver weather information. Four regional weather squadrons were created to act as information hubs. The 26th Operational Weather Squadron (26 OWS) was activated on 1 October 1999 at Barksdale Air Force Base, Louisiana as the weather hub for Oklahoma, Kansas, Texas, Missouri, Arkansas, Louisiana, and Mississippi.

26 OWS will exploit lessons learned from the 3 May 99 outbreak in several areas. This scenario is used to examine how 26 OWS information operations will react to future occurrences. The outbreak information flow provides final design criteria for the 26 OWS "weather cockpit" concept. A comprehensive data set is being assembled to build advanced weather simulator training that will give our first-term airmen the look and feel of working in a weather cockpit during the 3 May 99 outbreak. Performance of the Air Force's operational MM5 model is examined relative to the 3 May 99 outbreak to identify opportunities to improve mesoscale analysis and forecast capabilities within the 26 OWS area of responsibility.

The 26 OWS is also using this meeting as an opportunity to introduce our new organization and build partnerships with key players in severe weather information. *(joel.martin@barksdale.af.mil)*

Sensitivity of the ARPS to Various Data Sources for May 3 High-Resolution Forecasts Robert V. Edwards, Fredrick H. Carr, and Michael B. Richman, University of Oklahoma, Norman, OK

It is important to know which data set, from among the many possible available observing systems, provides the most value to a storm-scale forecast. Considerable resources and effort are expended to acquire and include all possible data types and sources during the analysis phase of the forecast process. It would be useful to know if some data sources are particularly important to the forecast, or if some data sets are redundant. The work in this paper evaluates the impact of withholding individual data types from a forecast of severe convective storms.

The May 3rd tornado outbreak in Oklahoma is used for a case study. The ARPS is used to provide a high resolution forecast. The Eta model is used as an initial background field for the 32km outer domain run. Smaller and higher resolution domains are subsequently nested to get the final high-resolution control forecast. This control run is generated with all data types included. Experimental runs are then conducted withholding a single data type. A statistical analysis on the differences between the experimental and control runs is performed to determine the sensitivity of the ARPS to each data type. *(Edwards@comet-tik.gcn.ou.edu)*

Verification of the Tornado Events in the Norman, Oklahoma NWSFO County Warning Area for the May 3, 1999 Severe Weather Outbreak Gregory J. Stumpf, NOAA/National Severe Storms Laboratory, Norman, OK, Doug Speheger NOAA/NWS, Norman, OK, and Donald W. Burgess, NOAA/NWS/WSR-88D Operational Support Facility, Norman, OK

The events of 3 May 1999 in Central Oklahoma represented one of the worst tornado outbreak in nearly 50 years in Oklahoma, along with the first recorded tornado with F-5 damage in metro Oklahoma City (the most significant singular event in Oklahoma weather history since 1947). Almost 60 tornadoes were verified within the Norman Oklahoma National Weather Service Forecast Office (NFWSO) county warning area alone.

We will describe the chronology of events that led to preliminary and near-final conclusions on the location, times, and strengths of the tornado damage paths. The verification process began from real-time verification during the actual warning operations, then damage surveys in the few days following the event, and finally, more-detailed damage analyses using WSR-88D data, storm chaser/spotter logs and video, high-resolution aerial photography, and engineering survey information. The documentation of the 3 May 1999 tornadoes is unique relative to past outbreaks due to the amount of information used to detail numerous short track tornadoes and small breaks between successive tornadoes. Several factors led to such a plethora of detailed information from this event, including lessons learned from previous, yet contemporary outbreaks in Central Oklahoma, the fact that some of the violent tornadoes hit major population areas, and the popularity of the event with the media, public, and government agencies.

A number of individuals have contributed to the damage analysis of the May 3 events, and the list is too large to include here. See the poster at the symposium for details. (*stumpf@nssl.noaa.gov)*

The Application of Advanced Severe Weather Detection Technology For Television: An assessment of the Performance of VIPIR on May 3, 1999 Greg Wilson, Les Lemon, Jeff Piotrowski, Mike Dickerson, and Bob Baron, Baron Services, Huntsville, AL

During the 1990's, local television broadcasts became a crucial component of the detection, dissemination and response process for significant weather. Advances in communication, computer and weather remote sensing technology allowed for the development of real-time, commercial weather products for television that enabled enhanced situation awareness for the broadcast meteorologists and viewers critical for the protection of lives and property. Most local televisions have some form of real-time severe weather broadcast technology with over 100 stations owning their own weather radars located primarily in the Central and Eastern US. In the mid 1990's, VIPIR (Volumetric Imaging and Processing for Integrated Radar) was developed and deployed as a commercial product to provide television stations with the first real-time, four-dimensional, multi-radar display and processing system capable of running its own severe weather detection algorithms with both NEXRAD and local TV radars. This technology represents a quantum jump in obtaining real-time situation awareness of severe weather beyond the current single-radar two-dimensional displays currently in use. This paper presents an assessment of the real-time VIPIR performance for the May 3, 1999 event. Ground truth verification data for the radar algorithms is discussed as well as examples of visual displays used on the air to inform viewers of the severe weather situation. Application of VIPIR processing for five NEXRAD radars is presented in a regional framework with mesoscale display and animation to examine local severe weather events as they occurred. Future enhancements to VIPIR for the spring severe weather season will also be discussed. *(www.baronservices.com)*

Prediction and Analysis of Convective Initiation of the May 3 1999 Oklahoma Tornadoes Donghai Wang, K.K. Droegemeier, Ming Xue, and R. Carpenter, Center for Analysis and Prediction of Storms, University of Oklahoma, Norman, OK

On May 3, 1999, the convective storms were initiated over southwestern Oklahoma at around 21 UTC. The storms then developed into the most intense tornadoes while they moved northeastward across central Oklahoma. In this paper, we will focus on the following topics: (1) The impact of the explicit grid-scale microphysical and large-scale cumulus parameterization schemes on the convective initiation at grid scales of order 10 km, (2) The two-way interactive nesting study. The nested mode will eliminate the deficiency of using explicit microphysics on the coarse grid, since convection will be resolved better by fine grids. (3) A detailed analysis of convective initiation. High-resolution numerical prediction/simulation can provide much higher spatial and temporal resolutions needed for detailed analysis. We will use simulated data and observed surface (OK Mesonet), upper as well as profiler data to investigate the initiation and early development process of the storms, including a detailed analysis of the mesoscale and synoptic environment, the boundary layer evolution of wind, temperature and moisture fields, as well as the vertical wind shear. *(dhwang@ou.edu)*

Improving Data Availability from NOAA's Profiler Network Douglas W. van de Kamp and Margot H. Ackley, NOAA/Forecast Systems Laboratory, Boulder, CO, and John B. Jalickee, NOAA/NWS/Office of Systems Development, Silver Spring, MD

Remarkably few lives were lost during the May 3, 1999 tornado outbreak, due in great part to the early detection of a descending and strengthening jet observed by the NOAA Profiler Network (NPN) as it approached the Oklahoma/Kansas area. The National Weather Services (NWS) Service Assessment report of the Oklahoma/Southern Kansas Tornado Outbreak of May 3, 1999, contains the following recommendation:

"**The NWS should make a decision on how to support the existing profiler network so that the current data suite becomes a reliable, operational data source."**

This paper addresses activities that will improve the data availability and future operational status of the NPN. Over the 3-year period from October 1996 to September 1999, the monthly average availability of Profiler data ranged from 80% to 97% with an overall average of 91.1% (8.9% data loss). The data loss can be categorized by major subsystems as follows:

Profiler outages, 7.0%, comprise fatal failures and replacements of the line replaceable units (LRUs), and power resents at profiler sites.

The Hub/Facilities component, 1.5%, comprises problems related to software, hardware, and power at the Profiler Hub and network communication of the profiler data to NWS Telecommunications Gateway.

The Communications component, 0.4%, comprises the links between the profilers and the Profiler Hub, including a two-way FTS-2000 line and a one-way GOES link.

FSL and NWS are implementing several improvements that are expected to significantly increase availability of the data. These include implementing remote site power reset capability, improving ground/lightning protection, improving communications, upgrading the Profiler data processing systems, improved reliability at the Profiler Hub, and augmenting monitoring and notification of data receipt. These improvements are expected to increase data availability to 93.4%. Unavailability of NWS maintenance staff was found to be a major contributing factor to Profiler downtime. The NWS has proposed hiring additional staff to support NPN maintenance activities, possibly increasing data availability an additional 2.0%, to 95.4%. The ultimate long-term goal is to convert the NPN to fully operational status, including conversion to the operational frequency of 449 MHz. In December 1999, FSL and the NWS presented the recommendations outlined above, to NWS management. *(Dougv@zeus.fsl.noaa.gov)*

Evaluation of SPC Hourly Diagnostic Fields for the May 3rd Outbreak Phillip Bothwell and John Hart, NOAA/NWS/Storm Prediction Center, Norman, OK

In early 1999, the Storm Prediction Center (SPC) began creating a real-time 3-dimensional "analysis" of the atmosphere by combining an hourly objective analysis of surface observations, and RUC model guidance above the surface. Due to the large number of data sources used by the RUC's initialization scheme, this method was developed to be used by SPC forecasters to monitor numerous diagnostic fields in an hourly fashion and anticipate severe thunderstorm potential. These fields included several parameters that are commonly used in severe weather forecasting, but are not available within operational model output. While surface derived fields were available, many of the newly developed fields that take advantage of the hourly upper air fields were not yet readily accessible to SPC forecasters on May 3rd.

Output for this 3-dimensional analysis will be presented, specifically addressing the anticipation of convective development and severe weather potential during the afternoon of may 3rd. Derived diagnostic fields such as surface and sub-cloud moisture flux convergence, CIN, average lower-tropospheric vertical motion, and upper divergence will be shown to examine whether the complete package would have been useful in forecasting where/when thunderstorm development occurred. Also, commonly used parameters such as CAPE, BRN shear, helicity, and mid level storm-relative winds will be shown to examine the potential utility for forecasting storm type and the severe weather threat. *(Bothwell@spc.noaa.gov)*

Possible Initiation of Storm A (3 May 1999) along a Horizontal Convective Roll Roger Edwards and Richard L. Thompson, NOAA/NWS, Storm Prediction Center, and James G. LaDue, NOAA/NWS/WSR-88D Operational Support Facility, Norman, OK

The first supercell of the 3 May 1999 outbreak (Storm A) produced the most devastating tornado of the event; but it formed well away from any fronts, drylines, outflow boundaries or other surface features traditionally associated with genesis of southern plains tornadic supercells. Instead, the storm formed along a pronounced meridional band of concentrated low (<20 dBZ) reflectivity, as viewed from the lowest two elevation angles of the Frederick, OK, WSR-88D. The reflectivity band was associated with only one outstanding surface feature: wind shifts at one mesonet site over which it oscillated. Radar-indicated characteristics of this band, and kinematic and thermodynamic properties of the convective boundary layer (CBL) inferred from modified soundings, suggest this feature was the updraft portion of a large horizontal convective roll (HCR). The possible large HCR appears to be superimposed with the eastern periphery of a field of much smaller HCRs of slightly different horizontal orientation. *(edwards@spc.noaa.gov)*

Hourly Mesoanalyses Done at the Storm Prediction Center on May 3, 1999 Greg Carbin, NOAA/NWS/Storm Prediction Center, Norman, OK

As part of the routine duties of the mesoscale forecaster at the SPC, surface mesoanalyses in the "area of concern" are performed hourly. These hand analyses are usually completed within 30 minutes past the top of each hour and are used to identify important meteorological features that may play a role in convective initiation, or the character of convective storms. This poster will display reanalyzed hourly surface mesoanalysis charts centered on Oklahoma for the period 1600 UTC 3 May 1999 (11 am CDT) through 0000 UTC 4 may 1999 (7 pm CDT). Each chart will display surface pressure every 2 mb, surface temperature (F) every 5 deg., and surface dew point temperature from 60F every 4 deg. Fronts, drylines, thermal ridge axes, and moisture axes will also be highlighted. In addition, the position of initial convective updrafts, and eventual tornadic supercells will be noted on all charts after 2100 UTC. *(Carbin@spc.noaa.gov)*

Field Data and Mobile Mesonet Operations Summary for VORTEX-99 in the Oklahoma Outbreak '99 Patrick Burke, Kevin Manross, Paul Markowski, and Kevin Scharfenberg, University of Oklahoma, Norman, OK

Field operations of the Verification of the Origins of the Rotation in Tornadoes Experiment - 1999 (VORTEX-99) were conducted during the afternoon and evening of 3 May 1999 during the "Oklahoma Outbreak". On this day, three VORTEX-99 Mobile Mesonets (MM) and one auxiliary vehicle, guided with nowcasting support from National Severe Storms Laboratory (NSSL) personnel, observed and photographed 14 separate tornadoes. The team successfully collected environmental data on at least four tornadoes, and provided real-time field observations and storm spotter information to the national Weather Service Office in Norman. The nature of the 3 May 1999 storm chase was very unique. Researchers were operating in a tornado rich environment close to home. VORTEX-99 intercepted more tornadoes on 3 May 1999 than in all of 1998. Each MM vehicle was equipped with data logging systems that continuously measured temperature, humidity, pressure, wind direction and speed, location, and vehicle velocity. The purpose of the MM is to provide very detailed mappings of meteorological variables in the vitally important near-ground region (i.e. inside the "hook") of tornadic and potentially tornadic storms. One of the primary goals of the VORTEX-99 was to directly sample the air in the immediate vicinity of the tornado during its initial and mature stags. In particular, MMs focused on the environmental conditions and meso-scale boundary orientations in the inflow region to the tornado, as well as in the rear flank downdraft (RFD) region. Simultaneous sub-storm scale observations in these regions are largely unknown and are keys to contemporary tornado genesis theories. Significant MM data were collected for virtually the entire life cycles and form numerous near-tornado locations on the "Apache Tornado" (NWS Storm A) and the "Minco Tornado" (NWS Storm B). Here, spatial and temporal summaries of MM's movements and readings, together with independently obtained radar, photographic, or environmental data obtained on 3 May 1999, are presented to graphically illustrate the MM storm relative movements and the overall VORTEX-99 operations from a storm chase perspective. *(pburke@enterprise.nssl.noaa.gov)*

Finding a Needle in a Haystack: Automated Detection of Tornadic Circulations Using the WSR-88D Robert R. Lee, NOAA/NWS/WSR-88D Operational Support Facility, Norman, OK

The goal of this presentation is to describe the performance of the WSR-88D radar and the Tornado Vortex Signature Detection Algorithm during the May 3rd tornado outbreak in Oklahoma. A needle is hard to find when hidden in a haystack because of the haystack's large volume. Similarly, some tornadoes are hard to detect because they are small compared to the large size of the radar beam and the parent thunderstorm. The tornado or its parent circulation has to be larger than the radar beam in order for the radar to detect a tornado. Fortunately, on May 3, 1999, the storms and tornadic circulations were quite large compared to the radar beam and several storms passed very close to the radar antenna. The circulations were relatively easy to detect both manually and using automated routines.

Tornado ground truth reports from May 3rd were compared to algorithm detections using the Tornadic Vortex Signature (TVS) algorithm, developed in the early 1980's. The ground truth reports were also compared to output from an upgraded algorithm, introduced in 1998. The new, upgraded algorithm demonstrated a Skill Score that was 65% higher than the original algorithm.
(rlee@osf.noaa.gov)

Taking Shelter From the Storm: Building a Safe Room Inside Your House Bill Coulbourne, Greenhorne and O'Meara, Inc. Washington, DC, and Dorothy Andrake, Federal Emergency Management Agency, Washington, DC

In October 1998, FEMA developed construction plans for "safe rooms" that could be built in residential structures to protect the occupants from the effects of very severe wind events, such as tornadoes. Included with the plans was guidance for the homeowner on how to assess their risk to a severe wind event. Plans were developed for a variety of materials and basic house plans so homeowners and builders had useful design and construction information contained in one document. FEMA Publication No. 320 is titled *Taking Shelter from the Storm: Building a Safe Room Inside Your House*. The basis for the designs in FEMA 320 was validated by the May 3 tornado outbreak in Oklahoma and Kansas.

The need for this detailed design and construction information was evident after several major tornadoes struck killing many people and demolishing hundreds, even thousands of homes. While there was a sense of urgency on the part of FEMA, state and local governments and builders to provide some type of protection from high winds, it was equally important that the guidance developed was based on sound research and engineering principles because the design wind speed for these events is so high that care and sound engineering judgement needed to be exercised.

The wide public interest in safe rooms created the need for describing how to meet the level of safety in FEMA 320, either for different designs for residential safe rooms or for larger group or community shelters. This immediate need was met with the National Performance Criteria for Tornado Shelters" prepared by FEMA immediately after the May 3 tornado outbreaks. Federal, state and local officials created innovative programs and outreach efforts to help meet the tremendous public demand for safe rooms. *(bcoulbourne@g-and-o.com)*