Agenda
Northeast Regional Operational Workshop
Albany, New York
Tuesday, November 2, 2004

8:00 am
Welcoming remarks
Eugene P. Auciello, Meteorologist In Charge, NOAA/NWS Albany, New York
Warren R. Snyder, Science & Operations Officer, NOAA/NWS Albany, New York

Session A. Modeling
Session Chair – Thomas A. Wasula

8:10 am
Remarks by Session Chair

8:15 am
An Update on the Stony Brook University Ensemble Forecast System
Brian A. Colle
Institute for Terrestrial and Planetary Atmospheres
Stony Brook University, State University of New York, Stony Brook, New York

8:40 am
Utilization of the Stony Brook University Mesoscale Ensemble System at WFO's and RFC's
Jeffrey S. Tongue
NOAA/NWS, Weather Forecast Office, Upton, New York

9:05 am
Verification of the Stony Brook Ensemble Forecast System
Matthew Jones
Institute for Terrestrial and Planetary Atmospheres,
Stony Brook University, State University of New York,
Stony Brook, New York

9:30 am
High-Resolution Simulations of the 25 December 2002 Banded Snowstorm using Eta, MM5, and WRF
David R. Novak
NOAA/NWS Eastern Region Headquarters, Bohemia, New York

9:55 am
Break

10:20 am
Systematic and Random Errors in Operational Forecasts by the UK Met Office Global Model
Tim Hewson
UK Met Office, Exeter, England

10:45 am
The Good, the Bad, and the Ugly: Numerical Prediction for Hurricane Juan (2003)
Ron McTaggart-Cowan and Lance F. Bosart
Department of Earth and Atmospheric Sciences, University at Albany, State University of New York, Albany, New York

11:10 am
Customization of a Mesoscale Numerical Weather Prediction System for Transportation Applications
Anthony P. Praino
IBM Thomas J. Watson Research Center, Yorktown Heights, New York

11:35 am
Lunch

Session B. Severe Convection/Warm Season
Session Chair – George J. Maglaras

1:00 pm
Remarks by Session Chair

1:05 pm
The Long-Lived MCV of 11-13 June 2003 during BAMEX
Thomas J. Galarneau Jr.
Department of Earth and Atmospheric Sciences, University at Albany, State University of New York, Albany, New York

1:30 pm
The Structure and Climatology of Boundary Layer Winds in the Southeast United States and its Relationship to Nocturnal Tornado Episodes
Alicia C. Wasula
Department of Earth and Atmospheric Sciences, University at Albany, State University of New York, Albany, New York

1:55 pm
A Statistical and Synoptic Climatological Analysis of United States Heat Waves
Scott C. Runyon
Department of Earth and Atmospheric Sciences, University at Albany, State University of New York, Albany, New York

2:20 pm
Break

2:45 pm
Warm Season Climatology of Convective Evolution Over the Coastal Northeast United States
Michael Charles
Institute for Terrestrial and Planetary Atmospheres, Stony Brook University, State University of New York, Stony Brook, New York

3:10 pm
The August 9, 2001 Lake Breeze Severe Weather Event Across New York and Western New England
Thomas A. Wasula
NOAA/NWS, Weather Forecast Office, Albany, New York

Session C. Operations
Session Chair – Warren R. Snyder

3:35 pm
Getting Ready for Winter: An NCEP Update
Louis W. Uccellini
NOAA/National Centers for Environmental Prediction, Camp Springs, Maryland

4:10 pm
AWIPS Radar and Warning Strategies Using Multiple Workspaces
Josh Korotky
NOAA/NWS, Weather Forecast Office, Pittsburgh, Pennsylvania

4:35 pm
Operational Urban Mesonet-Driven Model for Homeland Defense Applications
Mark C. Beaubien
Yankee Environmental Systems, Turners Falls, Massachusetts

Session D. Hydrology/Tropical Events
Session Chair – Steve DiRienzo

5:00 pm
Remarks by Session Chair

5:05 pm
Frantic About Frances, 9 September 2004
Richard H. Grumm
NOAA/NWS, Weather Forecast Office, State College, Pennsylvania

5:30 pm
An Overview of the Tropical Cyclone-Induced Flooding in Central New York and Northeast Pennsylvania in 2004
Michael S. Evans
NOAA/NWS, Weather Forecast Office, Binghamton, New York

Agenda
Northeast Regional Operational Workshop
Albany, New York
Wednesday, November 3, 2004

Session D. Hydrology/Tropical Events (continued)
Session Chair – Steve N. DiRienzo

8:00 am
28 August 2004 Flash Flood in Addison County Vermont
Gregory Hanson
NOAA/NWS, Weather Forecast Office, Burlington, Vermont

8:25 am
Warm Season Extreme Quantitative Precipitation Forecasting for the Burlington, Vermont Region
Eyad Atallah
NOAA/NWS, Weather Forecast Office, Burlington, Vermont

8:50 am
The Importance of Real-Time Data During an Operational River Flood Event
Ron Horwood
NOAA/NWS, Weather Forecast Office, Taunton, Massachusetts

9:15 am
Break

Session E. CSTAR Projects
Session Chair – Kenneth D. LaPenta

9:30 am
Cool-Season Regime Transition and Its Impact on Precipitation in the Northeast
Heather Archambault
Department of Earth and Atmospheric Sciences, University at Albany, State University of New York, Albany, New York

9:55 am
Cyclogenesis and Upper-Level Jet Streaks and their Influence on the Low-Level Jet
Keith Wagner
Department of Earth and Atmospheric Sciences, University at Albany, State University of New York, Albany, New York

10:20 am
The May 11, 2003 Severe Weather Null Case Across the Northeastern and Mid-Atlantic States
Michael L. Jurewicz
NOAA/NWS, Weather Forecast Office, Binghamton, New York

10:55 am
Cool Season 500 hPa Cutoff Cyclones; Precipitation Distribution and a Case Study
Anthony Fracasso
Department of Earth and Atmospheric Sciences, University at Albany, State University of New York, Albany, New York

11:20 am
Forecasting Eastern United States Winter Storms:
Are We Getting Better and Why ?
Jeff S. Waldstreicher
NOAA/NWS Eastern Region Headquarters, Bohemia, New York

11:45 am
An Examination of Mesoscale Factors which Influence the Precipitation Distribution of Landfalling Tropical Cyclones
Alan F. Srock
Department of Earth and Atmospheric Sciences, University at Albany, State University of New York, Albany, New York

12:10 pm
Lunch

Session E. Winter Weather/Cool Season
Session Chair – Jeff Waldstriecher

1:15 pm
A Simple Physically Based Snowfall Algorithm
Daniel K Cobb Jr.
NOAA/NWS, Weather Forecast Office, Caribou, Maine

1:40 pm
The Effects of Climate Variability on Buffalo, New York Winters
Robert Hamilton
NOAA/NWS, Weather Forecast Office, Buffalo, New York

2:05 pm
A Long-Lived Intense Continental-Scale Front:
28 February-4 March 1972
Lance F. Bosart
Department of Earth and Atmospheric Sciences, University at Albany, State University of New York, Albany, New York

2:30 pm

Break

Session F. Hudson Valley Ambient Meteorology Study (HVAMS) Projects
Session Chair – Ingrid A. Amberger

3:00 pm
Remarks by Session Chair

3:10 pm
Convective Boundary Layer Structure in the Hudson Valley
Jeffrey M. Freedman
Atmospheric Information Services, Albany, New York

3:25 pm
Rain Shadows in the Hudson Valley
Jeffrey M. Freedman
Atmospheric Information Services, Albany, New York

3:40 pm
The Hudson Valley Ambient Meteorology Study ("HVAMS")
An Investigation of the Diurnal Evolution of Local Circulations
Jeffrey M. Freedman
Atmospheric Information Services, Albany, New York

3:55 pm
Evening and Nocturnal Winds in the Hudson Valley
David R. Fitzjarrald
Atmospheric Sciences Research Center, University at Albany, State University of New York, Albany, New York

4:20 pm
Spatial and Seasonal Changes in Watershed Response to Rainfall Events in the Catskill – Hudson Valley Region
Matthew J. Czikowsky
Atmospheric Sciences Research Center, University at Albany, State University of New York, Albany, New York

4:45 pm
Closing Remarks
Warren R. Snyder

4:55 pm
Adjourn

NROW 7 will be held November 1-3, 2005

Acknowledgments

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An Update on the Stony Brook University Ensemble Forecast System

Brian A. Colle and Matthew Jones
Institute for Terrestrial and Planetary Atmospheres
Stony Brook University, State University of New York, Stony Brook, New York

Jeffrey S. Tongue
NOAA/NWS Forecast Office, Upton, New York

Since the spring of 2003, Stony Brook University (SBU) has been running an 18-member MM5 ensemble down to 12-km grid spacing over the Northeast United States for the 0000 UTC cycle using the Penn State University-NCAR Mesoscale Model (MM5). This work, which is partially supported by COMET, is in collaboration with NOAA/National Weather Service (NWS), Weather Forecast Offices (WFOs) at Upton, NY, Mt. Holly, NJ, and Taunton, MA, as well as the NWS Northeast River Forecast Center and the NWS Eastern Region.

The ensemble has included 12 different physics-based members (three boundary layer and four convective parameterization schemes – 12 combinations) using the National Centers for Environmental Prediction (NCEP) Eta grids for initial and boundary conditions. The additional six (6) members are different model initializations from the 2100 UTC NCEP’s short-range ensemble forecast system Eta breds at the 0000 UTC Global Forecast System. One can view the ensemble member output and statistics at http://fractus.msrc.sunysb.edu/mm5rte.

This talk motivates the use of this ensemble system with a few case examples, such as the heavy precipitation associated with Jeanne (September 2004) over southern New England. Some changes to the ensemble system are also discussed in light of some verification results. For example, the MRF PBL members were 3-4 ^{o}K too warm at the surface around the Gulf Stream, which led to MM5 forecast problems with the December 2003 nor-easters. As a result, several bug fixes and the TOGA-COARE surface flux algorithm were put into the SBU MRF version in January 2004. This has reduced the warm bias over water by over 50%. In order to correct for model biases, model output statistics (MOS) has been constructed for each ensemble member for the warm season. Some preliminary results from this MOS effort will be shown.

The Weather and Research Forecasting (WRF) model was introduced to the 0000 UTC ensemble in the summer of 2004. The WRF is run down to 12-km grid spacing over the Northeast U.S. using similar physics to the MM5 control member (Grell convective parameterization, MRF PBL, and simple ice microphysics). This talk will present some WRF examples as well as plans to diversify the ensemble with additional WRF members.

Utilization of the Stony Brook University Mesoscale Ensemble System at WFO's and RFC's

Jeffrey S. Tongue
NOAA/NWS, Weather Forecast Office, Upton, New York

Robert Shedd
NOAA/NWS, Weather Forecast Office, Taunton, Massachusetts

A Cooperative Program for Operational Meteorology, Education and Training (COMET) collaborative effort between the National Weather Service (NWS) and Stony Brook University (SBU) is examining the value of a short term mesoscale ensemble forecast system for operational use at NWS offices. Offices involved in the COMET funded effort include the NWS Weather Forecast Offices at Upton, NY, Mount Holly, NJ and Taunton, MA, as well as, the Northeast River Forecast Center (NERFC) and Eastern Region Headquarters. The system uses the Penn State/NCAR mesoscale model (MM5) run with various physics and initial condition options. The results/output from the model are posted on the internet at http://fractus.msrc.sunysb.edu/mm5rte and ingested into AWIPS for operational use and evaluation.

The precipitation fields from the MM5 runs routinely show a high degree of variability. While forecasters can quickly jump to the ensemble mean for a solution, examination of individual runs allows the forecaster to understand and incorporate the variability involved in their forecast process. For example, at the NERFC, they utilize the precipitation and surface temperature grids from each of the MM5 ensemble members to generate short term hydrologic ensemble at several forecast locations. These are converted into basin average precipitation and temperature. Using the ensemble streamflow prediction processes with the NWS River Forecast System, each of the precipitation and temperature time series generate a hydrologic forecast ensemble member. Statistical analysis procedures are used to generate probabilistic hydrologic forecast products for the next two days. These graphical products, which display a possible range of river stage in the future, are made available on a demonstration basis on the NERFC web site. Currently, this demonstration includes forecasts at four locations, but it is planned to increase this number in the near future.

This presentation will discuss and demonstrate how the NWS is using the SBU ensemble forecast system operationally and how operational NWS forecasters are learning to incorporate the information from it into their local portion of the National Digital Forecast Database.

Verification of the Stony Brook Ensemble Forecast System

Matthew Jones and Brian A. Colle
Institute for Terrestrial and Planetary Atmospheres,
Stony Brook University, State University of New York,
Stony Brook, New York

Jeffrey S. Tongue
NOAA/NWS Weather Forecast Office, Upton, New York

The Stony Brook University Short-Range Ensemble Forecast (SBU SREF) system has been running operationally since May 2003 at 36- and 12-km grid spacing over the Eastern and Northeast United States for the 0000 UTC cycle using the MM5 (http://fractus.msrc.sunysb.edu/mm5rte).

Verification has been completed for the 18-member SBU SREF system for both the warm (April-September, 2003) and cool (October 2003-March, 2004) seasons. Ensemble-mean forecasts have smaller errors for sea-level pressure and 10-meter wind direction than the individual members for all forecast hours when averaged over either the warm or cool season. However, for 2-m temperature and 10-m wind speed, the ensemble mean is only the best member on average during the day. At night many members have a warm and high windspeed bias at the surface; therefore, the ensemble mean retains a significant bias. Similarly, during the day the significant 2-m moist bias in the Eta PBL hurts the ensemble mean.

The average model skill at the surface varies more with changes in model physics than with initial condition perturbations during both warm and cool seasons, which highlights the need to include model physics variations in the ensemble system. In fact, the physics ensemble-mean shows greater skill on average than the initial condition ensemble-mean for most surface parameters during both seasons. In addition, the 12-km ensemble-mean skill is comparable to that of higher resolution 4-km forecasts, even those initialized 12-h later (1200 UTC).

The SBU SREF system has some ability to predict skill of the ensemble-mean and represent forecast uncertainty by a correlation between ensemble spread and errors of the ensemble-mean. The usability of ensemble spread varies significantly between surface parameters due to persistent biases in the component members of the ensemble. This usability varies from little or no representation of forecast uncertainty (e.g. 2-meter temperature) to good representation of forecast uncertainty (e.g. 10-meter wind direction).

The SBU ensemble-mean also outperforms each individual member for 24-hour precipitation (24P) as measured by an equitable threat score

(ETS) for the warm and cool seasons. The ensemble-mean 24P overpredicts precipitation at low thresholds, while it underpredicts at higher thresholds (> 20 mm) due to the smoothing of the ensemble-mean field. Since a large subset of members has a similar 24P bias, the most-probable category (MPC) field is not more skillful than the ensemble- mean. Probabilistic precipitation produced by the SBU SREF system is more skillful than climatology, and forecast probabilities have good reliability for most precipitation thresholds.

A bias calibration with a 14-day training window reduces ensemble error by 10-40% for strongly biased surface parameters, thus motivating incorporation of calibrated temperature, humidity, and wind speed fields into the real-time data stream for the NWS.

High-Resolution Simulations of the 25 December 2002 Banded Snowstorm using Eta, MM5, and WRF

David R. Novak
NOAA/NWS Eastern Region Headquarters, Bohemia, New York

Brian A. Colle
Institute for Terrestrial and Planetary Atmospheres
Stony Brook University, State University of New York, Stony Brook, New York

Daniel Keyser
Department of Earth and Atmospheric Sciences, University at Albany, State University of New York, Albany, New York

The 25 December 2002 (Christmas Day) snowstorm was a historic snowfall event for central and eastern New York State, with storm total snowfall accumulations exceeding 75 cm (29.5 in.) in many locations. These extreme snowfall accumulations were due largely to the formation of an intense mesoscale snowband, found in the comma-head region of a rapidly deepening cyclone along the northeast U.S. coast. This study will explore the capabilities of high-resolution models to simulate the development of banded precipitation in this case. Comparisons between the operational NCEP Eta model, fifth-generation Pennsylvania State University–NCAR Mesoscale Model (MM5), and the Weather and Research Forecasting model (WRF) will be presented.

The operational Eta, MM5, and WRF models were run at 12 km horizontal resolution and were initialized at 0000 UTC 25 December 2002 – approximately 19 h before band development. All three models accurately predicted rapid cyclogenesis with forecast surface cyclone tracks within 50 km of the observed track; however, the models underpredicted the cyclone intensification, exhibiting cyclone central pressure errors as great as 12, 10 and 3 mb for the Eta, MM5, and WRF models, respectively. Despite various strengths of the surface cyclone, all three models exhibited band development in central New York within 2 h of the observed time. Although the timing of band development was relatively accurate, band formation was as much as 100 km too far southeast and band dissipation occurred 2–3 h prematurely in all three model forecasts.

Rapid Update Cycle analyses showed that the observed band developed northwest of the surface cyclone as the midlevel low formed in association with secondary cyclogenesis along the coast. Strong frontogenesis developed within the deformation zone just north of the deepening midlevel low, which is consistent with climatological studies of banded precipitation in northeast U.S. cyclones. All three model runs captured this evolution, and exhibited midlevel frontogenesis maxima on the order of 10 °C 100 km^{-1} h^{-1}, oriented parallel to the simulated band. Assessment of the moist symmetric stability in all three model forecasts showed slantwise neutrality above the frontogenesis maximum, with saturation equivalent potential vorticity values less than 0.25 Potential Vorticity Units. A narrow, sloping ascent maximum exceeding 0.5 m s^{-1} was found on the equatorward side of the frontogenesis maximum. Although one might expect the forecast band to be directly beneath the maximum ascent, all three models forecast the band 20–40 km further northwest. It is hypothesized that factors such as precipitation drift and precipitation lofting may account for at least part of this displacement in the model forecasts and presumably in the real atmosphere.

This case shows that high-resolution models are capable of simulating the physical processes governing the evolution of mesoscale bands. Further research is planned to explore the common band position and timing errors noted in the model runs, microphysical aspects of the observed and simulated band, as well as the general predictability of mesoscale banded precipitation.

Systematic and Random Errors in Operational Forecasts by the UK Met Office Global Model

Tim Hewson
UK Met Office, Exeter, England

A primary focal point of forecaster activity is the identification of likely errors – systematic or random – in numerical model output, and correcting or adjusting for these in issued forecast guidance. This requires at the outset an understanding of each model's error characteristics, and this talk will address this, specifically for the Met Office's operational forecast model, first looking at bulk statistics, and then focusing on systematic biases - in particular those that relate to hazardous weather in the NE of the North American continent. As regards skill in predicting surface pressure and upper level height fields in the Northern Hemisphere extratropics the Met Office global model is currently second only to ECMWF, with the American GFS model in third place. Multi-model error plots will be briefly presented, with indications also of some regional and seasonal differences (one key seasonal difference is that during the summer months the GFS model is elevated to second place). Overall there is a strong argument for giving high weight to Met Office model forecasts, especially as availability of the usually superior ECMWF runs can be relatively limited in North America.

Systematic biases in Met Office model forecasts occur in different parameters, and on different temporal and spatial scales. These need to be allowed for, and include: net global precipitation exceeds observed precipitation by about 30% handling of cyclonic systems, number of modest cyclones and frontal waves reduces with forecast lead time, the greatest discrepancies occurring near land-water boundaries such as around the Great Lakes and near the Eastern Seaboard, the handling of extra-tropical transitions, wherein the bogussing method used can lead to large errors if there is marked system acceleration surface winds over the NE US, which are systematically too light the diurnal cycle in convection, which is handled poorly the inland penetration of winter-time marine convection, which is lacking, and which means lake effect events will generally be missed the soil moisture analysis, which is reset to climatology every Wednesday; this can adversely impact moist convection, cloudiness and temperatures after periods of anomalous rainfall an inability to clear fog in light wind conditions, which can lead to depressed surface temperatures at certain times of the year orographic precipitation and the rain-shadow effect, both of which reduced when a new model formulation with highly smoothed orography was introduced.

Such errors will be discussed in more detail, making reference to any research activities currently aimed at addressing them.

The Good, the Bad, and the Ugly: Numerical Prediction for Hurricane Juan (2003)

Ron McTaggart-Cowan and Lance F. Bosart
Department of Earth and Atmospheric Sciences, University at Albany, State University of New York

John Gyakum
McGill University, Montreal, Quebec, Canada

The range of accuracy of the numerical weather prediction (NWP) guidance for the landfall of Hurricane Juan (2003), from nearly perfect to nearly useless, motivates a study of the NWP forecast errors on 28-29 September 2003 in the eastern North Atlantic.

Although the forecasts issued over the period were of very high quality, this is primarily because of the diligence of the forecasters, and not related to the reliability of the numerical predictions provided to them by the North American operational centers and the research community. A bifurcation in the forecast fields from various centers and institutes occurred beginning with the 0000 UTC run of 28 September, and continuing until landfall just after 0000 UTC on 29 September. The GFS (NCEP), Eta (NCEP), GEM (Canadian Meteorological Centre; CMC), and MC2 (McGill) forecast models all showed an extremely weak (minimum SLP above 1000 hPa) remnant vortex moving north-northwestward into the Gulf of Maine and merging with a diabatically-developed surface low offshore. The GFS uses a vortex-relocation scheme, the Eta a vortex bogus, and the GEM and MC2 are run on CMC analyses that contain no enhanced vortex. The UK Met Office operational, the GFDL, and the NOGAPS (US Navy) forecast models all ran a small-scale hurricane-like vortex directly into Nova Scotia and verified very well for this case. The UKMO model uses synthetic observations to enhance structures in poorly-forecasted areas during the analysis cycle and both the GFDL and NOGAPS model use advanced idealized vortex bogusing in their initial conditions.

The quality of the McGill MC2 forecast is found to be significantly enhanced using a bogusing technique similar to that used in the initialization of the successful forecast models. A verification of the improved forecast is presented along with a discussion of the need for operational quality control of the background fields in the analysis cycle and for proper representation of strong, small-scale tropical vortices.

Customization of a Mesoscale Numerical Weather Prediction System for Transportation Applications

Lloyd A. Treinish and Anthony P. Praino
IBM Thomas J. Watson Research Center, Yorktown Heights, New York

A wide variety of operations in the transportation industry are weather sensitive to local conditions in the short-term (3 to 36 hours). Typically, they are reactive due to unavailability of appropriate predicted data at this temporal and spatial scale. Hence, the optimization that is applied to these processes to enable proactive efforts utilize either historical weather data as a predictor of trends or the results of synoptic-scale weather models. While near-real-time assessment of observations of current weather conditions may have the appropriate geographic locality, by its very nature is only directly suitable for reactive response. Alternatively, mesoscale numerical weather models operating at higher resolution in space and time with more detailed physics may offer greater precision and accuracy within a limited geographic region for problems with short-term weather sensitivity.

Such forecasts can be used for competitive advantage or to improve operational efficiency and safety. In particular, they appear to be well suited toward improving economic and safety factors of concern to state and local highway administrations. They are also relevant to other state and local agencies responsible for emergency management due to the effects of severe weather. Among others, such factors relate to routine and emergency planning for snow (e.g., removal, crew and equipment deployment, selection of deicing material), road repair, maintenance and construction, repair of downed power lines and trees due to severe winds, evacuation from and other precautions for areas of potential flooding, etc.

To address these issues, we build upon our earlier work, the implementation of an operational testbed, dubbed "Deep Thunder". This prototype provides nested 24-hour forecasts for the New York City metropolitan area to 1 km resolution, which are updated twice daily. The work began with building a capability sufficient for operational use. In particular, the goal is to provide weather forecasts at a level of precision and fast enough to address specific business problems. Hence, the focus has been on high-performance computing, visualization, and automation while designing, evaluating and optimizing an integrated system that includes receiving and processing data, modeling, and post-processing analysis and dissemination. Part of the rationale for this focus is practicality. Given the time-critical nature of weather-sensitive business decisions, if the weather prediction can not be completed fast enough, then it has no value.

Such predictive simulations need to be completed at least an order of magnitude faster than real-time. But rapid computation is insufficient if the results can not be easily and quickly utilized. Thus, a variety of fixed and highly interactive flexible visualizations have also been implemented. They range from techniques to enable more effective analysis to strategies focused on the applications of the forecasts.

The concept behind Deep Thunder in this context is clearly to be complementary to what the National Weather Service (NWS) does and to leverage their investment in making data, both observations and models, available. It is therefore also complementary to the deployment of Road Weather Information System (RWIS) stations by state highway administrations to monitor real-time weather conditions along roads. The idea, however, is to have highly focused modeling by geography with a greater level of precision and detail than what is ordinarily available. Therefore, we will review our particular architectural approach and implementation as well as the justification and implications for various design choices. Then we will outline how this approach enabled customization for problems associated with transportation applications as well as discuss the specific customizations. Finally, we will present some results concerning the effectiveness of such modeling capabilities for these applications.

The Long-Lived MCV of 11-13 June 2003 during BAMEX

Thomas J. Galarneau, Jr. and Lance F. Bosart
Department of Earth and Atmospheric Sciences, University at Albany,
State University of New York, Albany, New York

An unusually strong subtropical jet (STJ) prevailed during the period 5-14 June 2003, in conjunction with the field phase of the Bow Echo and Mesoscale Convective Vortex Experiment (BAMEX). A noteworthy aspect of this period was the variety of organized convective systems over the southern and central Plains and Mississippi Valley. These convective systems appear to be spawned by transient disturbances embedded within the STJ. Many of these convective disturbances generated Mesoscale Convective Vorticies (MCVs), some of which were long-lived.

A particularly long-lived MCV formed over Oklahoma near 0600 UTC 11 June at the northern end of a squall line that was triggered by a transient disturbance embedded within the STJ. This MCV could be tracked northeastward to Lake Erie by 0000 UTC 13 June. The purpose of this presentation is to document the life cycle and structural evolution of this MCV. This MCV was noteworthy for: (a) upshear tilt, (b) growing upscale, (c) reorganizing convection, and (d) acquiring frontal structure.

The Structure and Climatology of Boundary Layer Winds in the Southeast United States and its Relationship to Nocturnal Tornado Episodes

Alicia C. Wasula and Lance F. Bosart
Department of Earth and Atmospheric Sciences, University at Albany, State University of New York, Albany, New York

Russell S. Schneider, Steven J. Weiss, Robert H. Johns,
NOAA/NWS Storm Prediction Center, Norman Oklahoma

Geoffrey S. Manikin,
NOAA/NWS Hydrometeorological Prediction Center, National Centers for Environmental Prediction, Camp Springs, Maryland

Patrick Welsh
NOAA/NWS Weather Forecast Office, Jacksonville, Florida

This talk will report on the results of a comprehensive study of cool season tornadoes in the southeast United States. Previous research has shown that there is a relatively high frequency of tornadoes in the overnight to early-morning hours during the cool season in the Southeast, particularly in areas close to the Gulf of Mexico. In fact, most strong and violent tornadoes (F2 or greater) in Florida occur during the cool season, associated with extratropical cyclones. The cause of this nighttime maximum during the winter months is not well understood, and one focus of this research will be on gaining a better understanding of the causes of this phenomenon.

Previous research in the development of severe weather scenarios along the Gulf coast has also documented the importance of return flow warm, moist tropical air inland from the Gulf, which may commence several days after the passage of a cold front into the Gulf. The warm Loop Current in the Gulf also can increase fluxes of heat and moisture into this return flow air, which can lead to rapid air mass destabilization. It has also been shown, however, that forecasting the trajectories of return flow air is difficult, and that operational numerical prediction models are not able to accurately forecast the modification of the boundary layer (partially due to lack of data over the Gulf), which can be important in determining the severe weather potential over the Southeast.

Composite results of this study suggest that nocturnal cool-season tornado episodes in the Southeast are associated with a stronger mid-level trough and upper-level jet than their daytime counterparts, as well as stronger flow and more moisture in the low-levels (i.e., 850 hPa and below). This talk will report on the results of current research, in which we use boundary layer wind/temperature data (including surface, radiosonde, and pilot balloon) to examine the climatological structure of the boundary layer in the Southeast, as well as the boundary layer structure prior to and during tornado episodes. The diurnal variation of the low-level winds near the Gulf coast will be examined to determine if there is evidence of more backed surface winds than further inland (particularly during the overnight hours), which would increase the low-level directional shear and contribute to a more favorable environment for supercell development near the immediate Gulf Coast. Additionally, use of pilot balloon and radiosonde data will be made to examine the low-level (0-3 km) wind shear profiles in the vicinity of nocturnal tornado episodes.

A Statistical and Synoptic Climatological Analysis of United States Heat Waves

Scott C. Runyon and Lance F. Bosart
Department of Earth and Atmospheric Sciences, University at Albany, State University of New York, Albany, New York

Although heat wave fatalities comprise a large portion of national weather-related deaths annually, they remain a relatively understudied weather phenomenon within the meteorological research community. With the goal of improving forecasts of these high-impact weather events, this study presents a synoptic climatology of regional heat waves in the United States. A detailed statistical analysis showing the frequency, duration, and intensity of heat waves will also be presented.

A persistent high temperature anomaly was considered to be a heat wave if, for at least three consecutive days, high temperatures at a station exceeded the climatological 97.5 percentile temperature (approximating a two standard deviation anomaly). Heat waves were defined as regional when they occurred simultaneously at two or more cities within a National Climatic Data Center (NCDC) standard region. Percentiles were used in place of standard deviation anomalies because it was found that high temperatures in most cities are not normally distributed. Heat waves were identified using a dataset of daily high temperatures over a 54-year period from January 1948 to December 2001 retrieved from NCDC Daily Surface Dataset. In order to identify temporal trends in heat wave frequency, annual and decadal time series of both high temperature events and any days exceeding the 84 percentile (approximating a one standard deviation anomaly) and 97.5 percentile will be shown.

Statistical analysis shows that, for most cities, high temperatures more than two standard deviations below normal are more frequent than daily highs greater than two standard deviations above normal. Preliminary research also indicates that heat waves are most frequent in southern and southeastern regions of the country, with the fewest heat waves occurring across the Inter-mountain West. Composite analyses in progress will help to explain region-to-region differences in the synoptic character of heat waves.

Warm Season Climatology of Convective Evolution Over the Coastal Northeast United States

Michael Charles and Brian A. Colle
Institute for Terrestrial and Planetary Atmospheres, Stony Brook University, Stony Brook, New York

Jeffrey S. Tongue
NOAA/NWS, Weather Forecast Office, Upton, New York

The rapid evolution of convective systems approaching the coastal metropolitan region of New York City (NYC) is a significant forecast problem. The purpose of this study is to show the distribution and evolution of summertime convection over the coastal Northeast U.S. in order to improve the forecasting of severe weather. This study constructs a cloud to ground lightning climatology over the Northeast, a composite of the synoptic-scale flow, and a few case examples.

A five-year (2000-2004) climatology of cloud to ground lightning data was compiled for June and August over the Northeastern U.S. During some years (2000 and 2004) there was a minimum in lightning strikes along the coast in June as compared to interior locations, which suggests that the relatively cool and more stable marine boundary layer (MBL) weakened the convection. However, some years did not show much marine impact in June (2002 and 2003); therefore, there may be other factors that helped to maintain convection near the coast, such as baroclinic forcing and instability aloft.

To begin separating these factors, lightning cases were defined as those days that New Jersey, southeast New York or Connecticut received >10 lightning strikes. These were then divided into two types of convection: frontally forced (≤100 km ahead of a cold front or ≤200 km ahead of a warm front) and non-frontally-forced. For the non-frontally-forced cases, a distinct gradient in strikes exists near the coast in June and August, suggesting that non-frontally-forced convection frequently weakens as it interacts with the MBL. In contrast, the frontally-forced cases have little decrease in lightning toward the coast.

To relate the results with upper-level flow, NCEP/NCAR reanalyses of 700mb monthly mean heights from June and August were analyzed. The climatological average flow regime for June is nearly zonal aloft over the Northeast. This occurred in June 2000, 2001 and 2004, and was associated with a significant coastal gradient in lightning. However, when there was an anomalous trough over northern New England (June 2002) or an upstream trough centered over the Great Lakes (June 2003), which were associated with several frontal events, there was a significant amount of coastal lightning.

A few case examples will be presented to illustrate the different types of convection. Future work will involve examining convective mode (organized/long-lived convection vs. disorganized/short-lived convection) as a possible factor in lightning distribution, as well as mesoscale model simulations of events.

The August 9, 2001 Lake Breeze Severe Weather Event Across New York and Western New England

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Lake breeze initiated thunderstorms are quite common across western and central New York. Occasionally, the lake breeze boundaries migrate eastward from off Lakes Ontario and Erie across the Mohawk Valley, Catskills and Adirondacks into extreme eastern New York and western New England. Severe thunderstorms producing damaging winds in excess of 50 knots (58 mph), large hail (greater than 1.9 cm) or even tornadoes may occur from a lake breeze boundary.

An unusually strong lake breeze boundary moved across western and central New York into the Albany forecast area during the mid to late afternoon on 9 August 2001. New York and New England were located in the warm sector of a very hot and humid air mass. Afternoon temperatures exceeded 35°C over portions of western and central New York. Surface dewpoints were well in excess of 20°C over most of the region. A cold front was slowly pushing eastward through the western Great Lakes region in the afternoon. Sounding analyses from 1200 UTC 9 AUG and 0000 UTC 10 AUG at KBUF and KALB indicated a large amount of instability over the region with surface based convective available energy (SBCAPE) values exceeding 2500 J kg^{-1}. Wind profiles showed 0-6 km shear values of about 30 knots with primarily west/northwesterly flow between 700 hPa and 500 hPa from the 1200 UTC sounding at KALB. The flow backed to the southwest in the mid-levels by the mid to late afternoon with a 250 hPa 60 knot jet streak moving over upstate New York. A cluster of severe thunderstorms fired east of Lake Ontario along the lake breeze boundary after 2000 UTC and caused extensive wind damage in the Mohawk Valley, Adirondacks, the Lake George Saratoga region and Southern Vermont between 2200 UTC AUG 9 and 0100 UTC AUG 10. Numerous trees and power poles were knocked down, as well as a few hail reports up to 5.0 cm occurred.

This talk will examine the synoptic and mesoscale environment that caused the lake breeze initiated severe weather over New York and western New England. Data used in this analysis will include surface and upper air observations, satellite imagery, and KENX WSR-88D data. Also, 40-km RUC and 80-km ETA initialized model data will be shown in the presentation.

Getting Ready for Winter: An NCEP Update

Louis W. Uccellini
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In this presentation, recent forecast advances at NCEP that span the spectrum from seasonal climate prediction, to 6-10 forecasts, to ensembled based 1-3 day forecasts will be presented with a focus on the application of forecasting winter weather. The talk will highlight: 1) the recent implementation of land-ocean-atmosphere coupled dynamic "Climate Forecast System"; 2) the recent improvements in 6-10 day and day 8-14 forecasts based on CDC's "reforecast technique"; 3) a creation of a Winter Weather Desk that works with the newly emerging Short Range Ensemble Forecast (SREF) system and uses a "collaborative" forecast process to foster a productive interaction between HPC and the NWS local forecast offices in support of the NWS winter watches and warnings produced by the WFOs throughout the country. Updates on the NCEP computer suite, building status and other issues will also be provided.

AWIPS Radar and Warning Strategies Using Multiple Workspaces

Josh Korotky
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Effective warning operations require a strategy for visualizing, organizing, and using large volumes of data (e.g., radar, observations, satellite imagery, numerical model output, etc.), while simultaneously creating and disseminating time critical warnings and statements. Multiple workspaces (each with a uniquely configured Display 2 Dimensional (D2D) can be set up to display information for a variety of severe weather hazards concurrently, including separate displays for generating warnings (WarnGen) and products (Watch Warning Advisory (WWA)).

Warning environments can become rapidly complex. Maintaining high situation awareness (SA) requires an ability to 1) display all relevant information on all relevant scales simultaneously, 2) screen and prioritize relative threats and storms, 3) manage numerous tasks and applications easily (e.g., Advanced Weather Interactive Processing System (AWIPS) Procedures, radar summary tables, radar One Time Requests, the System for Convective Analysis [SCAN], Flash Flood Monitoring and Prediction software [FFMP], and 4) issue/disseminate warnings and other products without disturbing other critical data displays.

This presentation illustrates AWIPS radar detection and warning strategies using multiple workspaces. Operational Templates demonstrate how individual workspaces can be configured to monitor 1) radar signatures of severe weather and flash floods, 2) radar evidence of imminent tornadoes and damaging wind, 3) satellite imagery, observations, mesoscale analysis, model forecast graphics, and 4) generate and disseminate warnings and other products. Multiple workspace strategies allow considerably more data to be displayed, with much less data display manipulation (e.g., swapping of D2D panes and loading new data into D2D panes).

In addition to multiple workspaces, this presentation will demonstrate how to effectively manage numerous D2D tasks unique to each workspace. Effective task management eliminates the need to search for windows that disappear behind the main D2D window. A combination of multiple workspaces and efficient task management allows more time to concentrate on severe weather detection and warning operations.

Operational Urban Mesonet-Driven Model for Homeland Defense Applications

Mark C. Beaubien
Yankee Environmental Systems, Turners Falls, Massachusetts

While urban mesonets have been setup in recent years, linking data toplume dispersion models in real time for operational purposes has only recently been attempted. This talk covers work done for the Democratic National Convention in Boston during the summer of 2004. Ten rooftop-mounted meteorological stations provided realtime wind speed and direction to a central receiver, linked to the Defense Threat Reduction Agency's Hazard Prediction and Assessment Model (HPAC).

HPAC was originally developed as a tool for force protection in the military but is now being used by emergency responders to for civilian evacuations after a domestic attack. An independent real time wind map was also provided. Model-data interaction and 'lessons learned' will be discussed. Core technology used in Boston was a spin off funded by NOAA's Small Business Innovation Research program.

Frantic About Frances, 9 September 2004

Richard H. Grumm, Joseph Vallini, and Michael Dangelo
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The remnants of hurricane Frances brought heavy rains to the Mid-Atlantic and Ohio Valley on 8-9 September 2004. The heaviest rainfall over Pennsylvania was from the center of the State westward toward Ohio. Heavy rains affected Ohio, New York, and many States to the south. Though the storm was no longer a hurricane as it moved across western Pennsylvania, its deep low pressure center and broad cyclonic circulation made it a powerful storm.

Hurricane Frances spent much of late August and early September lumbering westward toward Florida. It peaked as a category four storm but weakened considerably before making landfall in Florida. The storm crossed the Florida Peninsula, entering the Gulf of Mexico north of Tampa. The storm than reentered the United States in the Florida panhandle and worked its way northward. The inflow bands associated with this large cyclonic circulation produced tornadoes in its path while it was a hurricane and a tropical storm. In all likelihood, the storm produced the single largest tornado outbreak in history for the state of South Carolina. The storm lumbered into Pennsylvania on the evening of 8 September 2004 and entered western New York during the morning hours of 9 September 2004.

The most significant threat from “Frances” was the potential for heavy rainfall. Due to its weakened nature, it was not considered a problem for wind and severe weather, though the potential for severe weather and tornadoes is always a potential threat from tropical storms as the move through the region as experienced with Hurricane Fran in September of 1996. Fran made landfall in North Carolina around 830 PM 5 September 1996. Fran brought heavy rains and some severe weather on the evening hours of Friday 6 September 1996 into early Saturday.

Other recent hurricanes to bring wind and or rain to Pennsylvania include hurricane Floyd on 16 September 1999 and Isabelle 18 September 2003. Isabelle brought strong winds and heavy rains to portions of Pennsylvania.

Frances was the second tropical system to put the region under the gun for heavy rainfall. Earlier, in August, Hurricane Charley was thought to have the potential to produce heavy rains in Pennsylvania and along the Mid-Atlantic coastal regions. Unlike lumbering Frances, Charley zipped out of the Gulf of Mexico south of Tampa, Florida late in the afternoon of 13 August 2004, crossed the Florida Peninsula, passing near Orlando and then raced up the East Coast. The storm was off the Delmarva Peninsula bye the evening of 14 August 2004. In addition to its rapid movement, Charley was a compact storm relative to Frances.

The storms had one significant thing in common; both were forecast to move much slower than observed by the NCEP stepped terrain (ETA) model. In both events, the ensemble prediction systems (EPS) and the Global Forecast System (GFS) out performed the ETA in the forecasts of the storms movement. The slow forecasts in the ETA likely contributed to the perceived threat for heavy rainfall with Charley which never materialized in Pennsylvania or the Mid-Atlantic region.

This paper will document the heavy rains associated with hurricane Frances in Pennsylvania. The goal is to show where the rain fell and how the storm was predicted by the NCEP forecast models. This storm provides and interesting contrast to the poorly forecast rainfall with hurricane Charley.

An Overview of the Tropical Cyclone-Induced Flooding in Central New York and Northeast Pennsylvania in 2004

Michael S. Evans
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An overview of four tropical weather systems that produced substantial flooding in central New York and/or northeast Pennsylvania in 2004 is presented. The magnitude and location of the flooding associated with each storm is summarized. In addition, the precipitation distribution patterns associated with each storm are compared and contrasted, and are related to the large-scale flow pattern and to surface cyclone and frontal system locations and tracks.

Recent collaborative research done at the National Weather Service in Taunton, Ma, and the State University of New York at Albany has focused on identifying flow patterns and topographic features that modulate patterns of heavy rainfall associated with tropical cyclones. The observations from this study are compared to observations from that research, to test whether or not the aforementioned research can be applied to central New York and northeast Pennsylvania. In addition, the observations from this study are compared to findings from other research on convective flash flooding not necessarily related to tropical cyclones. Specifically, relationships between heavy precipitation, and features such as upper-tropospheric jet entrance regions, lower-tropospheric wind maxima, equivalent potential temperature advection, instability, and topography are examined for each storm. Ultimately this research can provide insight about environments associated with tropical cyclone-induced flooding in central New York and northeast Pennsylvania, which will improve forecasts and warnings.

28 August 2004 Flash Flood in Addison County Vermont

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Summer Flash floods in Vermont are arguably the most substantial weather threat to lives and property in the Burlington county warning and forecast area. Heavy rains from thunderstorms over the steep slopes of the Green mountains can bring fast run off and flash flooding. Almost all of the presidentially declared disasters in Vermont are a result of flooding.

On Saturday 28 August 2004, a nearly stationary thunderstorm produced as much as seven inches of rain between 2100 UTC and 2400 UTC in eastern Addison County Vermont along the west slopes of the Green Mountains. Flash flooding resulted in the towns of Bristol and New Haven. Little Otter Creek and the New Haven river flooded; however, much of the damage occurred in overland flow of runoff before it entered any stream channels.

At 500 hPa, the northeastern United States was under a long wave ridge with a shortwave trough moving through the ridge. At the surface, a stationary front was located in the Saint Lawrence Valley into southern Quebec, while a trough of low pressure, an old outflow boundary, was orientated east-west across central Vermont, and acted as the surface based focus for thunderstorm development and continuation.

Deep tropospheric moisture and instability was present at the surface, dew points were in the lower 70s °F, and precipitable water values were 1.5 to 1.75 inches with the higher values over the southern Lake Champlain valley. Surface based Convective Available Potential Energy (CAPE) values were 400 to 800 J kg^{-1} with the higher values centered in the Champlain valley. The thunderstorms developed and were sustained in the area of the highest gradient of CAPE and not in the CAPE maximum.

The surface boundary provided low level convergence of warm moist air to initiate convection. The Vertical Azimuth Display (VAD) Wind Profile display from the Weather Surveillance Radar-1988 Doppler (WSR-88D) located in Colchester, Vermont (KCXX) located north of the surface boundary showed northerly winds in the boundary layer. Through the mid levels however, the flow was westerly, and was representative of the flow over Addison County. The 500 hPa steering flow from the west was parallel to the surface boundary, and acted to keep convection regeneration on the surface boundary. The westerly flow was perpendicular to the western slopes of Vermont’s Green Mountains. In this area, in 5 miles the terrain rises from around 300 feet mean sea level (MSL) in the Otter Creek Valley to 2000 feet MSL in the

Hogback Mountains and South Mountain. The upslope component likely aided in initiating and sustaining the convection.

The synoptic setting for this event resembled the classical synoptic and mesoscale model of meso-high heavy rain events, with a surface boundary south of the main boundary, winds aloft parallel to the surface boundary, and a weak 500 hPa short wave moving through the large scale ridge.

An overview of the flash flood event, including surface, upper air, model, radar data, and FFMP output will be presented Radar trends and differences in rainfall estimates between neighboring WSR-88Ds will be shown. The utility of FFMP output will be discussed, in light of the limitations shown in the WSR-88D precipitation processing.

Warm Season Extreme Quantitative Precipitation Forecasting for the Burlington, Vermont Region

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The problem of quantitative precipitation forecasting (QPF) continues to be a challenge. Large-scale numerical guidance is helpful, but improvements in QPFs have lagged those of the 500 hPa height forecasts. Substantial warm-season precipitation events include those that are associated with former tropical cyclones, mesoscale convective systems, or relatively weak baroclinic zones associated with elevated convection. Examples of recent heavy precipitation cases resulting in devastating flooding and a Presidential declaration of Disaster are the 12 June 2002, flooding in northeast VT and the 27 June 1998, flooding in the Green Mountains of Vermont. This study focuses on predicting extreme warm-season precipitation amounts for the complex topography in the Burlington, Vermont (BTV) region.

Regional scale events were identified from rainfall data including BTV and other surrounding stations. The unified precipitation data set (UPD), a gridded data set available from Climate Diagnostics Center (CDC) that includes cooperative observing stations precipitation amounts, was used. Cooperative observers report 24-h totals at 1200 UTC; the Burlington station data was chosen to correspond with the method of reporting of the cooperative stations. The UPD was used to eliminate events attributed to isolated small-scale convection over Burlington, leaving regional scale precipitation events (greater areal extent) in the Burlington area for study.

The daily maximum precipitation at any grid point in the region bounded by 43.50-45.00 deg N latitude and 74.25-72.00 deg W longitude for June, July, and August for the 50-year period from 1948 to 1998 were considered. The mean and standard deviation of the precipitation were calculated, and categories for the cases were identified from the statistics. Extreme cases were represented by 1200 UTC 24-h totals exceeding 2 standard deviations above the mean or greater than 37 mm (1.45 in). Heavy cases were those between 1 and 2 standard deviations above the mean, or 24-37 mm (0.95-1.45 in). Moderate cases were those between 0.5 and 1 standard deviations above the mean, or 18-24 mm (0.70-0.95 in). To insure independence among the events, a separation of at least 7 days between cases was imposed.

During the 50-year period, using the stipulation of a 7-day separation, we found 53 extreme cases, 94 heavy cases, and 61 moderate cases. Extreme events, which are rare, were preferentially eliminated from the more common heavy events. In addition, dates before 1963 were eliminated owing to the poor quality of the available NCEP reanalysis. To create composites comparable to the extreme cases, the same numbers (53) of heavy and moderate cases were used and were chosen at random.

The National Centers for Environmental Prediction (NCEP) reanalysis and 30 year climatologies were used to construct composites of each intensity category. A composite field, anomaly from climatology, and statistical significance were plotted for standard meteorological variables. Fields investigated include sea level pressure, 500 hPa heights, 1000-500 hPa thickness, precipitable water, Showalter and Coupling Indices, and dynamic tropopause height and wind.

Preliminary composites from the extreme, heavy, and moderate categories and selected cases will be presented. The categories will be compared to each other and climatology. The selected cases will illustrate the variability of the areal precipitation distribution. Through the identification of large-scale anomalous circulation precursors to warm season precipitation events in and near the Burlington, VT forecast region, it is expected that forecasters will be able to recognize the intensity of an event in advance and improve forecast and warning lead times.

The Importance of Real-Time Data During an Operational River Flood Event

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From 13-14 April 2004, a storm system dumped 2 to 5 inches of rain across a large portion of southern New England as well as over most of Long Island in southeastern New York State. The heaviest rainfall occurred across eastern Long Island, southern Connecticut and Rhode Island.

The National Weather Service’s (NWS) Northeast River Forecast Center (NERFC) provides river forecast guidance to Weather Forecast Offices (WFO) across New England and New York State to aid them in the issuance of river forecasts and warnings. To provide accurate river forecast guidance, the NERFC depends on timely and accurate hydrometeorological information including observed and forecast rainfall amounts, observed snow water equivalents, observed and forecast temperatures, observed river stages and observed reservoir elevations. This data is input into the National Weather Service River Forecast System (NWSRFS), which produces forecasts of river levels out 2 to 3 days into the future.

This presentation will show how a break in the accurate chain of data resulted in significant challenges trying to forecast flood levels that occurred along the Pawtuxet River in Rhode Island during this particular event. Specifically, inaccurate data from Scituate reservoir gave forecasters the impression that a large portion of the runoff into the Pawtuxet River watershed was being controlled, when in fact, significant amounts of water were exiting the Scituate reservoir directly into the upper reaches of the Pawtuxet River, adding to river flow and stage downstream at the NERFC forecast point at Cranston, Rhode Island.

Cool-Season Regime Transition and Its Impact on Precipitation in the Northeast

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Past research has pointed to a relationship between cyclogenesis and rearrangement of the large-scale flow, and synoptic conventional wisdom suggests that high-impact weather events are associated with large-scale regime transition. Motivated by these considerations, and as part of the CSTAR Program at the University at Albany, we investigate cool-season regime changes impacting the northeastern United States from a synoptic climatological perspective.

Daily indices representing the North Atlantic Oscillation (NAO) and the Pacific–North American (PNA) pattern, generated from the National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) reanalysis dataset, were used to define weather regimes objectively. Upon examining the temporal variability of the indices, regime transition was defined to be a teleconnection phase change (i.e., a change from negative to positive phase or positive to negative phase) of more than two standard deviations over a seven-day period. Climatological precipitation anomalies over the Northeast during regime transitions were then calculated from the NCEP Unified Precipitation Dataset.

Regime transitions from positive to negative NAO are shown to correspond to enhanced precipitation in the Northeast, especially in December, January, and February, while regime transitions from negative to positive PNA are linked to enhanced precipitation in November, March, and April.

Relationships between regime transition and precipitation will be interpreted using composites of characteristic thermal and dynamical forcing during regime transitions. Synoptic precursors will also be identified in order to improve forecast skill of precipitation in the Northeast during large-scale flow reconfigurations.

Cyclogenesis and Upper-Level Jet Streaks and their Influence on the Low-Level Jet

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The low-level jet (LLJ) has long been tied to increased nocturnal thunderstorm activity across the Great Plains of the United States. The classic explanation of the Plains LLJ is that it is driven by a combination of diurnally varying differential heating over sloping terrain and diurnally varying boundary layer frictional coupling and decoupling. These physical processes combine to maximize the strength of the LLJ at night and into the early morning hours. However, Uccellini (1980), in a reexamination of some LLJ cases from Bonner (1966), along with cases from Izumi (1964), Hoecker (1963), and Newton (1956), found that in some of those cases the LLJ appeared to be coupled dynamically to upper-tropospheric features. In this study, we reexamine Uccellini's findings by means of composite maps produced from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) gridded reanalysis data, which were unavailable at the time of his study.

Fifteen cases of the Great Plains LLJ studied by Uccellini were reanalyzed using the NCEP/NCAR gridded data sets. Of these 15 cases, only three were found to have the classic diurnal pattern for LLJ formation consisting of a strong ridge over the front range of the Rockies with weak upper-level flow. The other 12 cases show a progressive trough over the Rockies with upper-level jet streaks propagating eastward over the LLJ. In these 12 cases, there is a general pattern of leeside cyclogenesis north of the LLJ.

To illustrate the effects that upper-level jet streaks and leeside cyclogenesis have on the LLJ, a case from 23 April 1961, was reanalyzed using the NCEP/NCAR gridded datasets. This case features an intensifying low-level cyclone north of the LLJ and an eastward propagating upper-level jet streak, which allows the pressure gradient across the Plains to increase. In response, the intensity and position of the LLJ do not vary diurnally. Instead, the LLJ maintains its strength and propagates eastward, suggesting that it is coupled dynamically to upper-tropospheric features. Possible applications of these findings to Northeast LLJs will be discussed.

The May 11, 2003 Severe Weather Null Case Across the Northeastern and Mid-Atlantic States

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An approaching cold front was expected to produce an outbreak of severe thunderstorms and tornadoes across the Northeastern and Mid-Atlantic states from New York to Virginia during the afternoon and early evening of May 11, 2003. The initial Tornado Watch issuance by the National Weather Service (NWS) Storm Prediction Center (SPC) described the potential event as a “particularly dangerous situation” due to an unusually potent combination of instability, strong low-level shear, and forcing. Despite these expectations, occurrences of severe weather were limited to two weak tornadoes, several funnel clouds, and a few reports of strong winds and hail in New York and northern Pennsylvania.

There was a significant history of severe thunderstorms and tornadoes across the central United States for several days prior to May 11 (May 7-10). Synoptic and mesoscale settings over the Midwest on May 10 are compared to those of May 11, over the eastern United States in order to identify notable similarities and differences. The degree of low-level shear was similar on both days, indicating that the wind shear profiles on the 11^{th} were supportive of severe, organized linear convective systems and/or supercells. However, the strong shear on May 10^{th}, was well balanced by substantial convective available potential energy (CAPE), while the CAPE on the 11^{th} was much less, due in part to the presence of a strong mid-tropospheric capping inversion. In addition, evidence is shown that a deep layer of large-scale forcing for ascent occurred with the storms over the Midwest on May 10^{th}, while the forcing for upward motion was restricted to the lower-troposphere on the 11^{th}. Meanwhile, strong subsidence was indicated over the mid-troposphere on the 11^{th}, associated with the cap. Several possible reasons for the development of this cap are outlined. Thermal and moisture parameters within the boundary layers of the warm sector environments on May 10^{th} and 11^{th} are also contrasted.

Numerical model performance over the eastern states on May 11, is assessed. Middle and upper-tropospheric jet streak features were misplaced by the models, leading to an incorrect forecast of where the strongest jet induced vertical motions would develop. The misplacement of the jet induced subsidence likely led to errors in the strength and placement of the cap, while forecast errors regarding the jet induced ascent resulted in problems assessing associated factors such as the amount of destabilization and forcing for convection.

Lastly, radar imagery from New York State and Pennsylvania on May 11, is investigated. This data showed that a few thunderstorms over central New York and northeast Pennsylvania developed significant low-level rotation, however there was little associated severe weather. It is hypothesized that one reason for the lack of severe weather was that weak updrafts associated with the storms could not support strong reflectivity cores aloft. Another possible factor was that the warm sector associated with this event was very narrow. As a result, the rotating storms that developed within the warm sector quickly moved east of the warm sector into a region where the lower-troposphere was relatively stable. The low-level stability may have been sufficient to keep strong winds from reaching the surface, and may have inhibited tornadogenesis.

Cool Season 500 hPa Cutoff Cyclones; Precipitation Distribution and a Case Study

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Cutoff cyclones pose a challenge to forecasters, especially in the northeastern United States. A climatology of cool season (October–May) cutoff cyclones has been produced for the period 1948–1998 using the gridded reanalysis datasets available from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR). The NCEP Unified Precipitation Dataset (UPD), a once-daily (1200–1200 UTC) gridded precipitation dataset available on a 0.25 deg grid, also has been used to construct monthly precipitation maps for all cases where a cutoff cyclone was present in the northeast US and vicinity. The purpose of this presentation is to use these datasets to diagnose and understand the distribution of precipitation associated with the passage of cutoff cyclones in the Northeast by means of composite and case studies, and to determine whether there are characteristic precipitation signals associated with particular cutoff cyclone tracks.

The average daily precipitation amounts were compared to climatology, showing a variation from about 30% to over 60% from October to May of the climatological precipitation throughout the Northeast associated with cutoff cyclones. A 19-year (1980–1998) subset of the dataset was used to subjectively choose cutoffs that followed one of four favored tracks near the Northeast (Mid-Atlantic, Southwest, Clipper, and Hudson Bay). Average daily precipitation maps for all cutoffs within a track for the entire cool season (except May) were then produced. Also, storm-relative maps were constructed for each track using storms that fell within or close to the US border, showing the previous 24 h average cumulative precipitation. Mid-Atlantic and Southwest type cutoffs produce the most precipitation, while Clipper and Hudson Bay type cutoffs are typically much drier. Southwest cutoffs focus their precipitation far to the east of the cutoff track, while the other three types focus their precipitation closer to the track.

A case study of a cutoff cyclone from late May 2003, initially representative of a Southwest cutoff, was conducted. The cutoff tracked across the Great Lakes, became nearly stationary, and then looped cyclonically around and passed through Pennsylvania, New York State, and then northern New England. Although heavy rains were forecast for most of the Northeast, some locations received well under 25 mm, while other areas received closer to 100 mm over a period of about one week. The structure and evolution of this cutoff cyclone and its associated precipitation shield were examined. A key finding is that vorticity maxima rotating around the periphery of the cutoff seem to be the best indicator of where significant precipitation will fall, especially when the cutoff is nearly stationary and quasi-barotropic.

Forecasting Eastern United States Winter Storms: Are We Getting Better and Why ?

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An analysis of winter storm warning verification statistics for National Weather Service (NWS) Offices across the Eastern United States for the winter seasons of 1993-94 through 2003-04 will be presented. This analysis showed that in addition to steady improvements in the probability of detection (POD) and false alarm ratios (FAR), a substantial 48% increase in average lead time of winter storm warnings has occurred during the last several winters (from around 12.5 hours during the latter 1990s to 18.5 hours during 2003-04).

To assess the reasons for these improved verification scores, a number of factors that impact the forecast and warning performance of NWS offices for winter storms will be explored, including: collaborative applied research and implementation into operations; training activities; computer system advances and software development; improvements in numerical weather prediction systems; changes in operational procedures; efforts to increase collaboration within the forecast process; and climate impacts (e.g., event frequencies and large scale weather regimes). Interactions between these various factors will also be examined.

To further examine the impact of collaborative research activities on winter storm warning performance, results of an analysis of the verification scores for the Northeast U.S. offices involved in the State University of New York (SUNY)-Albany Collaborative Science, Technology, and Applied Research Program (CSTAR-I) research project will also be presented.

An Examination of Mesoscale Factors which Influence the Precipitation Distribution of Landfalling Tropical Cyclones

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Landfalling tropical cyclones (TCs) provide a challenging forecast problem, especially regarding major threats like storm surge, high winds, and heavy rainfall. Storm surge and strong winds are fairly predictable in relation to the storm center, and weaken rapidly with increasing distance from the core of the circulation. However, the precipitation structure associated with a landfalling TC does not fit any specific model, and is more likely to have maxima far removed from the main circulation. Mesoscale phenomena such as coastal fronts, orographic enhancement, and cold air damming can have a marked influence on the aerial precipitation coverage. Coastal fronts tend to concentrate precipitation along and to the cold side of the boundary, orographic enhancement adds a lifting mechanism for enhanced precipitation with upslope flow, and cold air damming can both change the orientation or position of a boundary and increase the upslope component of the flow.

Atlantic Tropical Storms Marco (1990) and Jerry (1995) were chosen because coastal fronts, cold air damming, and orographic enhancement significantly alter each precipitation distribution far away from the storm center. Both Marco and Jerry produced rainfall maxima over 230 mm, though neither storm ever reached hurricane intensity. The high precipitation totals distant from the storm center can be attributed to the interaction of synoptic scale and mesoscale features. NCEP's Unified Precipitation Dataset (UPD), synoptic upper air analyses from NCEP/NCAR's Global Reanalysis, NHC Best Track data, and hourly high-resolution surface data from the USAF's DATSAV3, NCEP's ADP, and ICOADS will be used to explain how the coast's physical features modify the total precipitation distribution.

A Simple Physically Based Snowfall Algorithm

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The era of highly detailed digital forecasts and increased client expectation has increased demand for detailed and skillful *quantitative snowfall forecasts* (QSF). The challenge of accurate QSF given improved NWP *quantitative precipitation forecasts* (QPF) lies in the ability to accurately assess the snow ratio and its evolution throughout a snow event.

Snow crystal density is primarily a function of temperature and humidity. Highly spatial or low density crystals such as dendrites are favored at temperatures between -12 and -18 Celsius. This temperature zone is commonly referred to as the *snow production zone* (SPZ). Low density crystals are further favored in supersaturated environments as would be expected in at least moderately ascending air. In a basic sense the observed crystal density or snow ratio is at any given time the result of a natural integration of the temperature and humidity along the trajectory of the falling crystal. Observed snowfall is then the integration of the product of snow ratio and precipitation rate over time.

The snowfall algorithm, developed by the author, mimics nature by using a top-down approach to calculate snow ratios at given times using NWP data sets. Layer contributions to snow ratio are a function of temperature, vertical motion, and relative humidity. In brief, the average temperature of each humid layer (RH>75%) is equated to a snow ratio. The snow ratio is then weighted by the layer's percent contribution to the total column upward motion. Finally, the snow ratio contribution of each layer is summed up to yield a sub-cloud base snow ratio.

The highest snow ratios, 25:1, will occur when the bulk of the vertical motion lies within the SPZ. Smaller snow ratios occur when the vertical motion maxima does not coincide with the SPZ, or when the vertical motion maxima stretches vertically from the SPZ encompassing both warmer or colder temperatures.

The snowfall algorithm can be used with both Bufkit and as a Smart Tool in the NWS's *Graphical Forecast Editor* (GFE). Bufkit data has the advantage of having the highest vertical resolution possible and consequently the best estimate at a given point of snow ratio and potential snowfall. It also allows a forecaster to evaluate the snow ratio through visual inspection of the sounding. The GFE Smart Tool has the advantage of producing aerial distributions of snow ratio and snowfall. The best forecast would be made using the two together.

This presentation will briefly review snow microphysics as it relates to snow ratio and the methodology of the algorithm. Application of example output from both the Bufkit and Smart Tool versions will be demonstrated using a case which occurred over northern Maine on January 22, 2004. Finally, efforts towards a comprehensive verification of the algorithm for the upcoming winter season will be introduced.

The Effects of Climate Variability on Buffalo, New York Winters

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Over the past twenty five years there has been a dramatic increase in the research and understanding about the effects of long term global weather (e.g. climate) phenomena on sensible everyday weather. This is especially the case with El Nino Southern Oscillation (ENSO). While ENSO refers to a climate process based in the Equatorial regions of the Pacific Ocean, it has far reaching effects around the entire globe. These effects have been well documented and disseminated to an increasingly astute, geopolitical public, but there is a need to understand these effects on a local level.

Research by the Climate Prediction Center has shown that El Nino, the warm phase of ENSO, has substantial impacts on the sensible winter weather across the Northern Plains of the United States. Temperatures in this particular region average well above normal during the winter months, and studies have shown that the positive temperature departures extend across much of the Great Lakes Region as well. There are also very noticeable anomalies shown during the cool, La Nina phase of ENSO.

While moderate to strong correlations with ENSO can explain many of the temperature and precipitation anomalies on a local level, there are other climate phenomena such as the North Atlantic Oscillation (NAO) that have similarly important weather controlling effects. The NAO is the oscillation in mean sea level pressure between the subtropical high over the Azores and the polar low in the vicinity of Iceland. A corresponding index relates to the difference in pressure and 500 mb heights between the two areas and can be either positive or negative, depending upon the departure from normal for both variables. Unlike ENSO which remains in one phase for 6 months to 3 years at a time, the NAO index varies from year to year, month to month and even week to week.

Temperatures across the Great Lakes Region, including the Western New York area, average above normal during positive phases of the NAO with below normal temperatures and above normal snowfall found during the corresponding negative NAO events. While these findings are important in themselves, this study will show that substantial anomalies occur during specific combinations of ENSO and the NAO.

Temperature departures for the winter months (November-March) since 1950 were averaged then grouped with ENSO and NAO phases. The results show that positive temperature anomalies more than double during a ‘phased’ El Nino and positive NAO episode compared to averages found when only looking at El Nino events. Similarly, a 50% greater positive temperature anomaly was found during a ‘phased’ La Nina and positive NAO event. In contrast, the combined effect of a neutral ENSO and negative NAO provide stronger signals for colder winters. These stronger signals are seen within the temperature departures although some similar evidence can also be found.

The study will ultimately show that integrating several climate variability modes with temperature and snowfall departures can be quite useful on the local level. Recognizing the effects of these combined variability modes (ENSO and NAO) can be very valuable for local utilities that routinely plan several months in advance for natural gas and heating oil supplies. Local municipalities can also benefit from the data for snow removal budgeting, and depending on the location of the study, recreational businesses such as ski resorts can improve their planning as well. In the broadest sense, value is gained by understanding that long range forecasting depends on several climate processes rather than just one.

A Long-Lived Intense Continental-Scale Front: 28 February-4 March 1972

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The most intense large-scale front the author can ever remember seeing (going back to the 1950s) occurred from 28 February through 4 March 1972. The front had its origins over the northern Rockies and the High Plains. It then expanded eastward to New England and southward to the Gulf of Mexico. Frontal temperature contrasts exceeded 50°C over 500 km.

The purpose of the talk will be to: 1) illustrate the importance of diurnally varying differential diabatic heating on frontogenesis, and 2) show the structure of front-terrain interactions. Also of interest is that despite the long-lived nature of the front and the associated intense thermal contrast that no significant cyclogenesis event occurred.

Convective Boundary Layer Structure in the Hudson Valley

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The structure and dynamics of the convective boundary layer (CBL) are well understood, but the presence of topography alters certain features. Here, we present case studies and a composite of unusual convective boundary layer structures observed during the intensive field campaign (IFC) of the Hudson Valley Ambient Meteorology Study ("HVAMS"). The HVAMS IFC deployment occurred during the fall of 2003, and featured a dense network of high quality high temporal resolution surface stations and remote sensing platforms, including periodic and continuous measurements of vertical profiles of winds, temperature, and humidity.

To identify conditions favorable for development and maintenance of the double inversion, observations taken from a variety of remote sensing and observational platforms were made during the HVAMS IFC. These include CBL structure flights on the instrumented University of Wyoming King Air aircraft, vertical profiles of temperature, humidity, and winds from the Tethered Atmospheric Observing System (TAOS), Albany National Weather Service rawinsonde data, a NOAA Environmental Technology Lab wind profiler, a sodar, and the Mobile Integrated Profiling System (MIPS) from the University of Alabama at Huntsville.

Despite vigorous convective mixing, significant directional wind shear is frequently noted above $0.5z_i$, and appreciable vertical scalar gradients are observed. In the extreme, cross-valley horizontal advection and along-valley channeling leads to an afternoon double inversion within the CBL. These differential advection effects have not previously been extensively documented nor are they accounted for in mesoscale forecasting or air quality models.

The persistence of the multiple BL structure depends on the intensity of surface buoyancy flux, which tends to destroy the midlevel inversion, and horizontal thermal advection that tends to enhance it. The combined influence of valley channeling, fog, and overlying forcing (i.e. advection of warmer air and elevated mixed layers from off the Catskill Plateau) is key in the formation and maintenance of multiple mixed layers within and above the Hudson Valley. Valley channeling serves to maintain low-level ambient conditions (temperature and humidity); fog occurrence diverts energy that would normally initially be used to drive mixed layer growth to dissipating the fog; and finally, warm air advection aloft helps to strengthen the established fossil inversion, allowing for the development and persistence of the multiple mixed layers.

Rain Shadows in the Hudson Valley

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The classic topographically—induced precipitation shadow is often associated with the large mountain ranges of the western United States. Here, we present three cases of such rain shadows in and around the Hudson Valley of New York State, where the valley walls range from 200 – 1000+ m. These events occurred during the intensive field campaign (IFC; September – October 2003) of the Hudson Valley Ambient Meteorology Study ("HVAMS"). The HVAMS IFC deployment featured a dense network of high quality high temporal resolution surface stations and remote sensing platforms, including periodic and continuous measurements of vertical profiles of winds, temperature, and humidity. As such, previously anecdotal evidence of downsloping—induced precipitation shadows in the Hudson Valley can now be quantitatively documented. We will show that these rain shadow zones are directly related to the overlying wind field and underlying topography, as well as the vertical temperature/humidity profiles. Finally, we show how the long-term (less dense) observation network does not necessarily depict these rain shadows.

Especially influential topography is the Catskill Escarpment, a part of the Catskills, an eroded plateau west of the Hudson Valley. Between Kingston and Catskill (about 35 km), the Escarpment forms the west wall of the valley (the "Wall of Manitou") with elevations in excess of 1000 m; north of Catskill, it turns to the northwest (just to the south of Catskill Creek), where it forms the Blackhead range, again with elevations in excess of 1000 m.

Three heavy rainfall events occurred during the IFC: 23 September, 26-27 October, and 29 October. Each was characterized by rainfall in at some locations within the HVAMS environs in excess of 50 mm; during the 26-27 October event, rainfall exceeded 100 mm in a few locations. All events also featured distinct precipitation shadows in one or more areas of the valley, with rainfall amounts 20 – 60+ mm lower than observed in the surrounding higher terrain. The orientation of the Escarpment with the prevailing winds above is a key factor in determining the extent and magnitude of the rain shadows.

The Hudson Valley Ambient Meteorology Study ("HVAMS") An Investigation of the Diurnal Evolution of Local Circulations

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Beginning in Autumn 2003 and continuing through the summer of 2006, a team composed of researchers from the Atmospheric Sciences Research Center (University at Albany), the University of Santa Maria, RS, Brazil, Atmospheric Information Services (Albany, NY), and graduate and undergraduate students from the University at Albany Department of Earth and Atmospheric Sciences are examining how the mesoclimate in New York's Hudson River Valley (the "Valley") is modified by the topography, land-use heterogeneity, and diurnal changes in atmospheric stability. The project has important practical implications in terms of understanding the meteorological input to pollutant dispersion and transport models, operational meteorology, air mass modification, and mesoscale numerical modeling.
This is a basic research project funded by the National Science Foundation (NSF, Physical Meteorology Section) that aims to address the following questions:

- How do valley topography and land-use patterns modify the observed local climate under range of different weather patterns?
- How much does surface temperature and humidity vary over the Hudson Valley landscape?
- What causes changes in wind direction & intensity (wind shear) with height?
- How do winds, temperature and humidity evolve over a sequence of fair weather days
- How does the valley channel winds in the daytime and at night?

In addition to focusing on the above issues, the HVAMS network was also designed to acquire data during significant transient phenomena.

During and after the HVAMS Intensive Field Campaign (IFC—15 September – 31 October 2003) these have so far included heavy precipitation (three occurrences during the IFC) and high wind events during October 2003 and April 2004.

The IFC featured the deployment of 9 Integrated Surface Flux Facility (ISFF) stations and the Tethered Atmospheric Observation System (TAOS) from NCAR; the Mobile Integrated Sounding Unit (MIPS) from the University of Alabama at Huntsville; the University of Wyoming King Air instrumented aircraft; NOAA's ETL wind profiler at Schenectady Airport; a sodar near the Hudson River ten miles south of Albany at Schodack Island State Park; and additional rawinsonde launches at the NWS WFO Albany. In addition to these IFC observations, long-term deployments (1 – 2 years) of five weather stations at various sites within the Valley and a 20 m flux tower located at a farm in Red Hook (northern Dutchess County) continue to acquire high resolution meteorological and trace gas data.

Evening and Nocturnal Winds in the Hudson Valley

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Channeling in the Hudson Valley on fair weather days often leads to a convective boundary layer with a deep along-valley flow that shears to cross-valley flow in the upper mixed layer and above. On days with little synoptic disturbance, lower atmospheric mixing continues in the convective boundary layer for a time following the end of solar heating and sets the stage for development of the nocturnal boundary layer. The subsequent growth of the stable surface and boundary layers often depends strongly on local topography and land cover. After the early evening transition the wind at 150-300 m often exhibits the wind direction that was previously above the daytime mixed layer at 850 mb.

During the Hudson Valley Ambient Meteorology Study (HVAMS), 26 flights of the instrumented Wyoming King Air were completed, with most flight tracks confined to a 100-km stretch of the Hudson River just south of Albany NY. Because of flight altitude restrictions, measurements of the stable boundary layer were made during a series of early-morning and early evening 'close approaches' by the Wyoming King Air research aircraft to small regional airports. As the night progressed, a low-level (80-150 m altitude above river level) nocturnal jet was observed to flow along the Hudson valley axis on fair weather nights. We present several cases observed during the intensive observation period (September-October 2003). Special effort is made to coordinate observations from an 18-station surface station network, two sodars, two wind profilers and tethered balloon-borne instruments. The HVAMS surface network (nine flux-measuring weather stations, 5 standard weather stations and operational weather stations) is used to identify how nocturnal mixing episodes that may result from the jet presence. Spatial differences in minimum temperature are related to the nocturnal mixing episode frequency.

Spatial and Seasonal Changes in Watershed Response to Rainfall Events in the Catskill – Hudson Valley Region

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A series of rainfall events occurred in the Catskill Mountain – Hudson Valley region in September and October 2003, during the intensive field campaign (IFC) of the Hudson Valley Ambient Meteorology Study (HVAMS). Precipitation in the region during some events was not evenly distributed spatially due to the presence of rain shadows. Consequently, the watersheds of the region did not receive uniform amounts of precipitation, and may be expected to respond differently. Significant regional variations in such responses may have implications for forecasts of event streamflow peaks and the subsequent streamflow recessions.

We examine watershed response for watersheds inside and outside of the regional precipitation shadow in terms of streamflow peak, streamflow recession (the decline in streamflow following the streamflow peak), and diurnal streamflow fluctuations in the dry periods between rainfall events. Secondly, these precipitation events occurred during the autumnal transition period from the growing to the dormant season. The decreased evapotranspiration during this transition period should also change the observed watershed response, and are examined.

We present cases during the HVAMS IFC during which nine NCAR-PAM surface weather stations and five Hobo surface weather stations (Onset Computer Corp.) were deployed throughout the Catskill - Hudson Valley region to provide detailed regional spatial differences in precipitation for each event. Fifteen-minute USGS streamflow data were used in the analysis.