SECTION 1

NATURAL DISASTERS AND HIGH IMPACT EVENTS AFFECTING URBAN COMMUNITIES

Introduction

In late summer 2008, a large portion of the United States population was preparing for or enduring the effects of the Atlantic hurricane season as the U.S. coastline experienced tropical cyclones such as Hurricane Gustav, Tropical Storm Hanna, and Hurricane Ike. As these systems approached the coastline and multiple major urban areas, they tested several of the lessons learned from Hurricane Katrina just three years before. Would people evacuate the coastal communities? What would be the impact on gas prices? Where would the storm make landfall? How strong would the storm be at landfall? Would the local, State, and Federal government agencies be prepared? These were just some of the questions on the minds of U.S. citizens and government officials. As the hurricane season continued, the threat of tropical cyclones highlighted the significance of natural disasters and other high impact events on urban communities.

Of the approximately 281 million people living in the U.S. in 2000, more than 68 percent lived in urban areas comprising just two percent of the U.S. landmass [1]. The built environment in these urban areas significantly alters the meteorology of the area, including temperatures, humidity, winds, and precipitation. It also alters air and water quality, what happens to precipitation reaching the ground, and the climate itself. Although the effects of the built environment vary by areal coverage, vertical extent, and types and distribution of structures and pavements, "urban" in this context includes small towns and not just major metropolitan areas. The unique aspects of this environment present special challenges for the meteorological community to meet the increasing demands of the urban population for improved products and services.

In 2004, the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) published a report entitled *Urban Meteorology: Meeting Weather Needs in the Urban Community* [2] which highlighted five primary elements within urban meteorology: severe weather, homeland security, air quality, water quality, and climate. This report and the subsequent September 2004 Forum on Urban Meteorology established a discussion framework to begin identifying needs, priorities, and common problems. The OFCM also initiated coordinated action moving forward in partnership to improve services in the urban environment. Today, the federal meteorological community is pursuing action on a number of fronts to bring these improved services to fruition. This article reviews some specific examples of high impact events in the urban environment, the associated challenges, and coordinated activity underway to improve products and services.

Severe Weather

Severe weather as used in this context is not limited to tornadoes or localized convective storms with winds greater than 50 knots and large hail. Severe weather includes the range of high impact weather events including tornadoes, certainly, but also flooding rains, tropical cyclones, ice storms, snow storms, and extreme heat and cold, for example. Please note that beginning in 2007, the strength of tornadoes is classified using the new Enhanced Fujita (EF) scale (see Table 1), which is referred to in subsequent sections. The following sections describe several severe weather events and specific impacts on urban areas.

<u>Tornadoes</u>

Greensburg, Kansas Tornado – May 4, 2007. The most devastating tornado of 2007 occurred on May 4 when just after 9:30 p.m., the town of Greensburg, Kansas, suffered a direct hit from an EF5 tornado. The huge tornado, over one and one-half miles wide, moved across the center of Greensburg and

Article prepared by Ronla Henry

Figure 1: Greensburg, Kansas, after the May 4, 2007, EF5 tornado. (Photo credit: NOAA)

the mayor later estimated 95 percent of the town of about 1,500 people had been completely destroyed (Figure 1). Ten people were confirmed dead in Greensburg as a result of this first tornado rated as an EF5. The last tornado rated in the highest category of the previous Fujita F-scale had occurred seven years earlier in Oklahoma. Two other tornado-related deaths happened in outlying areas that same evening as more than 20 tornadoes were reported. Although little can be done to reduce property damage in the face of an EF5 tornado, increasing warning accuracy and lead times can help save lives and reduce injuries.

EF Number	3 Second Gust (mph)
0	65-85
1	86-110
2	111-135
3	136-165
4	166-200
5	Over 200

Table 1: The Enhanced Fujita (EF) Scale for estimating tornadic wind speeds based on resulting damage, adapted from the National Weather Service Storm Prediction Center [3].

Memphis and Nashville, Tennessee – February 5-6, 2008. Eighty-two tornadoes struck the mid-South and Tennessee Valley in roughly a 12-hour period from the afternoon of Tuesday, February 5, through the early morning of February 6, 2008. Subsequent damage surveys indicated that, of the 82 tornadoes reported, five were violent EF4 tornadoes, five were rated EF3, and 15 were rated EF2, leaving 56 people dead in four states and making this event the deadliest tornado outbreak since May 31, 1985. All fatalities occurred with tornadoes categorized EF2 or greater.

One of those tornadoes, an EF2, affected southern parts of the Memphis, Tennessee, metropolitan area on February 5, 2008. As the storm moved through the southern Memphis suburbs, it affected Memphis International Airport, the Federal Aviation Administration air traffic control tower, and the NWS Weather Forecast Office (WFO), with personnel in the latter two locations evacuating their buildings during the storm. The tornado caused four fatalities in the Memphis area but the outcome could have been much worse. The tornado struck at the time of day when large numbers of school buses would normally have been on the roads, but Memphis city school officials had dismissed schools early on February 5 because of the storm warnings.

An EF2 tornado also hit Union University in nearby Jackson, Tennessee, on February 5, but there were no fatalities and only minimal injuries at the university. University officials attributed this to advance warning and a good emergency preparedness plan.

Later in the evening of February 5, an EF2 tornado affected portions of the Nashville metropolitan area and at the Sommet Center, officials temporarily halted a National Hockey League game and the fans sheltered in the arena during the storm. There were no fatalities in the Nashville area during this event but the same thunderstorm later produced an EF3 tornado northeast of Nashville, near the rural community of Lafayette, Tennessee, killing 22 people.

Atlanta, Georgia – March 14, 2008. Although conditions were less than optimum for tornadoes or severe thunderstorms, an isolated supercell developed just northwest of the city of Atlanta on the evening of March 14, 2008. This storm intensified as it moved into the city and it produced a tornado that caused damage along a six-mile path, stretching from west of the Georgia World Congress Center to western DeKalb County south of Interstate 20. The storm struck at 9:38 p.m. during a 2008 Southeastern Conference Men's Basketball Tournament game in the Georgia Dome in downtown Atlanta. The tornado passed just north of the dome and had the game not gone into overtime, thousands of fans

Figure 2: Downtown Atlanta, Georgia, after the March 14, 2008, tornado. (Photo credit: NOAA)

would have been in the streets headed to their vehicles or public transportation when the tornado hit, likely significantly increasing the number of deaths and injuries. This tornado was rated EF2, with maximum winds estimated to be 130 MPH. Figure 2 shows some of the damage in downtown Atlanta from this tornado. [4]

These tornado examples highlight the value of an effective warning system, well-designed and executed emergency plans, and the leadership of organizations who understand the severe weather threat and act on it. In addition to improving warning capability through potential new systems such as Multifunctional Phased Array Radar (MPAR) and better high-resolution weather forecasting models, the meteorological community needs to better understand the social sciences aspects of preparedness, warning, and response. These examples highlight the need for continued education and outreach to the public and public officials to improve response to warnings, and the interagency community is moving today to improve these capabilities.

Seattle Area Flooding – December 1-3, 2007

Three successive storms affected the Pacific Northwest on December 1-3, 2007. Fueled by remnants of Pacific Tropical Storms Hagibis and Mitag, the third storm to hit the Seattle area was the strongest. Heavy rainfall and rapidly melting snow produced record flooding in western Oregon and Washington State. The worst flooding occurred about 85 miles south of Seattle near Chehalis, Washington, where 10 feet of water covered a portion of Interstate 5 (Figure 3). Authorities closed a 20-mile stretch of the highway for several days, blocking the major thoroughfare between Seattle, Washington, and Portland, Oregon. According to the Washington State Department of Transportation (WSDOT), the closure cost the state's economy more than $47 million in economic output from the freight system alone. [5]

The Seattle-Tacoma official observing station received 5.57 inches of rain during this three-day period, with 3.77 inches (a record for the day) falling on December 3. NWS WFO Seattle received 4.15 inches of rain that day, setting an all-time record for 24-hour rainfall at that station. Major urban and small stream flooding occurred surprisingly rapidly in King County and the Seattle metropolitan area, an unusual occurrence for these areas. Despite significant road damage in King County, no fatalities were attributed to the flooding.

This case highlights the significant economic impacts of weather events in the urban environment even without widespread, violent destruction of infrastructure. It points to the importance of accurate, relevant, and timely hydrometeorological data and predictions and highlights the importance of weather information for surface transportation. The OFCM hosted mini-workshops on hydrometeorology needs in the fall of 2008 and continues to advance weather support for surface transportation. As in the tornado cases, advanced weather radars and integration of social sciences into the warning process can improve support to the public and protection of life and property.

North American Ice Storm – January, 2007

A series of winter storms plagued much of

North America in January, 2007. The first storm traveled from the Rio Grande Valley on January 11 to New England by January 16, followed immediately by another storm January 16–18 which affected the southern United States from Texas to the Carolinas. The final storm hit the southern plains and Mid-Atlantic States January 19–24.

Figure 3: Flooding of Interstate 5 near Chehalis, Washington, December 2007. (Photo credit: Washington State DOT, by Jim Walker)

These winter storms created a wide swath of damage, affecting several urban areas including St. Louis, Missouri; Dallas-Forth Worth, Texas; San Antonio, Texas; Columbia, South Carolina, and both Raleigh and Charlotte, North Carolina. Heavy snow and ice accumulations on power lines, towers, and trees caused extensive damage across the area, resulting in multiple power outages for hundreds of thousands of residents in these states with some outages lasting up to a week.

The winter weather also significantly disrupted multiple modes of transportation when snow-covered or icy roads caused numerous traffic accidents, rail traffic slowed to a crawl, and ground delays scrambled airline schedules. In Oklahoma, a truck carrying hazardous material slid off of a river bridge. No one was injured, but the truck's hazardous cargo disappeared into the water.

These storms resulted in at least 87 lives lost as well as significant clean-up and repair costs, highlighting the need for improved hydrometeorological predictions, weather information for surface transportation, and effective ways to convey anticipated impacts to the public and public officials.

<u>Improving Products and Services for Severe Weather</u>

The OFCM and the federal meteorological community are working together in a number of ways to improve products and services to better serve the nation's urban population leading up to and during the types of high-impact weather events described above. The Multifunction Phased Array Radar (MPAR) risk reduction effort seeks to explore the potential of phased array radar to more rapidly detect the precursors and onset of tornadic conditions and for improved weather surveillance overall, including heavy precipitation and discriminating rain/ice/snow events. The community is also working together in the area of weather information for surface transportation, moving ahead to bring more and improved information to vehicle operators of all types; highway, railway, waterway, pipeline, and airport managers; maintainers of this infrastructure; and design engineers and policy makers. Related and supporting work includes coordinated tropical cyclone research and development and improving space weather services. Tropical cyclones are clearly high-impact weather events for coastal urban areas and improved intensity forecasting is a high priority. The understanding of space weather effects on communications, navigation, security, health, and the electrical power grid continues to grow through continuing education and outreach efforts of the National Space Weather Program. The community is also more attuned to the social sciences aspects of the forecasting and warning system, building on the work of the OFCM exploration of tropical cyclone warnings in Mobile, Alabama, and Charleston, South Carolina, and the expanded activity in this area in National Science Foundation grants.

Homeland Security

The homeland security element of urban meteorology addresses primarily the vectors of air and water in dispersion of accidental and deliberate releases of chemical, biological, nuclear, and radiological hazards. The urban environment by its nature places large numbers of people in a small area and this area is typically a road, rail, transit, water, pipeline, or air hub, or perhaps all six in the cases of major metropolitan areas. The transport of significant amounts of all variety of hazardous materials into or near urban areas increases the risk of accidental release as does the prevalence of industry often located in or near urban areas. The increased volume of hazardous materials stored, used, produced, or transiting urban areas also brings with it the threat of accidental release caused by weather conditions such as hurricanes, flooding, and tornadoes. Unfortunately, the higher concentration of people also provides a more lucrative target for terrorist activity because of the likelihood of more casualties and greater psychological and political impact. The flow of air and water in the urban environment is critical to responding effectively to either an accidental or deliberate release of hazardous materials.

Accurate diagnostic and predictive transport and diffusion modeling is difficult in the best circumstances and the urban environment adds even more complexity in observing, understanding, predicting, and responding to accidental and deliberate releases of hazardous chemicals, biological agents, and radiological particles. Meteorological conditions such as wind, temperature, cloud cover, and precipitation, combined with the effects of complex terrain dramatically alter the dispersion of these hazards and the resulting effects on the urban populace and infrastructure. Urban terrain includes a wide range of objects from bushes and trees, to houses, bridges, and skyscrapers, all varying in size from a few feet to hundreds of feet to thousands of feet, meaning one or a few observations of meteorological conditions in or near the area will be insufficient for accurate prediction. These features add extreme complexity to urban plume modeling, largely because of the challenge of accurately representing turbulent processes. In addition, the problem is often compounded by a lack of information on the hazard source—what was released, when, and how much. Furthermore, the lack of information on the exchange of indoor and outdoor air for every building in the area adds additional uncertainty in any prediction, particularly for determining effects on the populace.

<u>Improving Products and Services for Homeland Security</u>

Following the September 11, 2001, terrorist attacks, the interagency community under the OFCM's leadership assessed the state of the art among available dispersion models and decided on a core capability. They also established the Interagency Modeling and Atmospheric Assessment Center (IMAAC) to provide a coordinated first response to hazardous releases, and the OFCM led the development of an interagency dispersion model R&D plan to improve capability in light of the extensive limitations of the current generation of models. Although improvements have been made, much work remains to be done. In a June 2008 report, the GAO determined that first responders' ability to detect and model hazardous releases in urban areas is significantly limited. [6] Among their recommendations was a call for accelerated research and development to address plume model deficiencies and improve federal modeling and assessment capabilities, including improvements in meteorological information, plume models, and data sets with which to evaluate plume models.

In addition to improving the models, other actions underway may ultimately contribute to improved capability. Modeling for the urban environment requires complex data assimilation, an area of expertise already identified as critically short. The OFCM is leading an interagency effort to identify other critical skill shortages among the agencies to allow timely action to mitigate this and future shortfalls. In the systems area, MPAR can directly measure the three-dimensional wind field to provide a key input to prediction models and the Joint Urban Testbed project presents the opportunity to improve the overall process but, in particular, improve the availability and quality of meteorological and other observations in major metropolitan areas.

Air and Water Quality

The air and water quality elements of urban meteorology are of widespread and constant concern for the health and economic vitality of the urban area. Unlike the severe weather and homeland security elements which may have very dramatic consequences but tend to be short in duration, air and water quality affects everyone all of the time. Pollutant loading is a concern in both areas, including the spectrum of chemical and particulate pollutants produced locally or carried into the area. These pollutants are generated from transportation, industry, energy production, building heating systems, and even wildland fires where smoke is carried into the area or changes in land cover in burned areas degrade water quality following precipitation and runoff. Predicting the dispersion of pollutants in the urban environment is similar to the plume modeling challenge identified in the homeland security section, but can be additionally complicated by the widespread, various, and persistent sources of pollution compared to the oftentimes point source of an accidental or deliberate release of hazardous chemicals or materials.

Air quality affects the health of the urban populace, particularly the at risk populations of the elderly, infants, and those with respiratory problems. Large metropolitan areas experiencing stagnant meteorological conditions or situated in certain topography often experience particularly severe episodes of poor air quality. Notable recent examples include the 2008 Olympic Games in Beijing, China, and calls for reduced outdoor activity because of wildfires in Northern California. China took unprecedented steps to reduce air pollution during the Games by closing factories and reducing vehicular traffic, leading to the best air quality in a decade and making the mountains north and west of the city visible from the city center. In the United States, wildland fires have been particularly severe in recent years, with records set for acreage burned in wildland fires in 2004, 2005, 2006, and 2007 [7] including the immediate San Diego, California, area in 2007. In June 2008, for example, poor air quality prompted officials to cancel outdoor activities in Northern California due to smoke from wildland fires.

The urban area and its built environment of impermeable pavements, structures, and roofs present an engineering challenge for the design of effective drainage systems, driving the need for climatological information for design and meteorological information for day-to-day management. Overtaxed drainage systems can lead to serious water quality problems and create health hazards when sewage treatment facilities are overwhelmed. Even systems providing adequate drainage can reduce water quality through untreated run-off of chemicals, particulates, and fertilizers from urban roadways, structures, and lawns.

Urban areas often encompass one or more rivers and heavy rains and sudden snow melt across wide areas, including rural areas upstream, can result in urban flooding as described above for the Seattle area. Another example of flooding that also raised concerns over water quality came in June 2008, when portions of the central United States experienced extensive river flooding across much of Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin. Central Iowa and the city of Cedar Rapids were among the hardest hit areas, experiencing floodwaters contaminated with an unhealthy mix of sewage, farm and animal waste runoff, and petroleum products. Residents of Cedar Rapids who returned to their homes to inspect damage and salvage belongings had to wade through the ankle-deep contaminated floodwater, raising concerns about the availability of clean drinking water and skin exposure.

In addition to the negative health effects, various air and water pollutants accelerate corrosion of structures, vehicles, and equipment, adding to the infrastructure maintenance challenges for urban areas. Pollution can also degrade recreational opportunities, not just from a health perspective but from reduced visibility in scenic areas both inside and outside of the urban zone itself.

Water presents the additional problem of the adequacy of supply in addition to the quality of the water available. Drought conditions at various times and locations throughout the country have exacerbated existing conflict and created new conflict over water rights, management, and distribution. Changes in precipitation patterns across urban areas and their supplying watersheds as a result of changing climate can heighten tension as demand grows. The next major section will address climate variability and change in more detail.

Improving Products and Services for Air and Water Quality

Many of the same interagency efforts already described also support improving products and services for air and water quality, including phased array radar, weather information for surface transportation, dispersion modeling, and assessing and addressing hydrometeorological needs. MPAR can directly measure three-dimensional winds in and around the urban area, and improved transportation efficiency through more accurate forecasts and improved application of weather information can reduce the pollutant loading in and downstream from the urban area. As plume modeling improves to support homeland security, those advances will support improved modeling of pollutant dispersion, a better understanding of air and water quality, and potential steps to take to improve air and water quality. Finally, the hydrometeorology mini-workshops in the fall of 2008 began a coordinated approach to identify needs and set priorities to drive improvements in hydrometeorological products and services, not just for the urban environment but across the spectrum of environments and users.

Climate Variability and Change

As the causes and effects of climate variability and change continue to be studied, towns and cities are beginning to prepare for and respond to extreme weather events which may increase in frequency and intensity with changes in climate. According to the U.S. Climate Change Science Program Synthesis and Assessment Product 3.3, *Weather and Climate Extremes in a Changing Climate*, published in June 2008 [8]:

> "In the future, with continued global warming, heat waves and heavy downpours are very likely to further increase in frequency and intensity. Substantial areas of North America are likely to have more frequent droughts of greater severity. Hurricane wind speeds, rainfall intensity, and storm surge levels are likely to increase. The strongest cold season storms are likely to become more frequent, with stronger winds and more extreme wave heights."

Extreme weather and weather-driven events such as heat waves, droughts, wildfires, heavy and persistent rainfall, and floods in urban areas pose risks to urban lives and infrastructure. Severe convective activity such as lightning, damaging winds, and tornadoes routinely threaten and occasionally cause major destruction in urban areas. In coastal areas, rising seas, warming waters, and hurricanes affect the economy, daily lives, and activities not only of urban populations but of the entire nation. The prospect of increased frequency and severity of these events and the new risk to urban areas with no previous experience in such problems has prompted growing concern among public officials. City leaders and other government officials are beginning to take notice and take action.

In New York City, New York, in 2008 the mayor formed a Climate Change Adaptation Task Force and the New York City Panel on Climate Change to develop adaptation strategies to protect the city's infrastructure. [9] The task force brought together city and state agencies, authorities, and private sector entities that operate, maintain, or control critical infrastructure and the Panel organized experts from academia and the legal, engineering, and insurance industries to provide advice to the task force.

As civic leaders at all levels begin to assess the risks associated with climate variability and change and make decisions about planning for adaptation or mitigation, they will need sound advice and the best information possible to support their decisions. The door is open for the federal agencies to begin eliciting specific needs, requirements, and priorities for climate products and services to support decision makers such as city leaders and the New York City Task Force. This decision support will be needed across a number of weather and climate areas, including wildland fires, flooding, severe local storms, water resources and drought, and tropical cyclones.

Changing Patterns of Wildland Fires

Wildfires increasingly infringe on urban areas as the urban boundary expands and blurs at the wildland-urban interface. Changing precipitation and temperature patterns, increasing drought, and accumulated fuel load are raising the risk of extensive fire, especially in the West. Wildland fires burned record acreage in 2004, 2005, 2006, and 2007 [7] and trends show a dramatic increase in fire activity over the last two decades. [10] This increase in activity has placed significant strain on firefighting and fire suppression budgets as well as the fire crews themselves. Climate variability and change can expand, shrink, or shift the areas at greatest risk, and the OFCM's national needs assessment for wildland fire weather showed that 83 percent of respondents rated fire and climate change important.

The interagency wildland fire weather community has completed a national needs assessment and in 2009 will be completing its assessment of current and planned capabilities, identifying gaps in meeting needs, and developing the framework to address the gaps through coordinated interagency activity. The results of this work will support improved wildland fire weather services to the benefit of the urban community and the nation overall. The need for climate information is clear and the potential payoff is high from reliable support to activities such as land use planning and planning and budgeting for firefighting and suppression activities at all levels of government.

Conveying Flood Risk to Leaders and the Public

The frequency and severity of flooding may also be changing and floods will continue to be a threat to urban areas. As illustrated earlier in this article, the recent catastrophic floods in the Midwest have shown the vulnerability of many cities. Flood predictions in these areas were characterized as historic flood events and forecasters for Burlington, Iowa, for example, called for the crest to be a 100- to 200-year flood, second only to the Great Flood of 1993 which was considered a 500-year flood event. However, such characterizations have drawn criticism because the region was struck for a second time since 1993 by a "once in a lifetime" flood. The widespread misunderstanding of 100-year and 500-year floods among the general public pointedly demonstrates the need for improved integration of the social sciences in the forecasting and warning process to deliver products and services that will be more clearly understood and acted upon as intended. This is applicable to both weather and climate products and services and may be even more important for climate because of its more probabilistic and statistical nature.

Localized High-Impact Weather – Implications for Infrastructure

A variable and changing climate can be expected to alter the patterns of severe convective activity such as lightning, damaging winds, and tornadoes that strike urban areas. During the summer of 2008, a powerful and fast-moving severe thunderstorm complex moved through Chicago, Illinois, causing baseball fans to seek shelter in the stadium concourse at Wrigley Field and passengers at O'Hare International Airport to evacuate to lower levels of the terminal. In all, 350 flights were canceled as the fast-moving storms passed through the area, generating effects felt throughout the country's airline and air traffic system. What climate products and services do public officials and the public need in the face of these potential changes? Where is the boundary between climate and a long-term weather forecast and does that matter to the user? Would an airline place enough confidence in a climate prediction to alter its flight schedules? These are just some of the challenging questions yet to be answered.

Water Resources, Water Quality, and Adapting to Drought

Climate variability and change will undoubtedly change the supply and quality of water in some if not many urban areas. Droughts of varying severity, coverage, and duration have real impact on urban areas as water supplies dwindle, water quality declines, fire danger grows in surrounding wildland areas, food shortages drive economic hardships and potentially health problems, energy needs change, and other direct and indirect effects alter the society and the economy. Drought rarely affects a single governmental jurisdiction alone and the likelihood of water-based conflict among local, state, tribal, and national governments and other stakeholders is high. Reliable long term estimates of drought conditions can at least bound the problem and reduce some conflict, but how much uncertainty can be tolerated? What level of confidence is needed in a climate product or service before it will be used as a basis for decisions and agreements with major impacts on large populations? Can intergovernmental agreements and infrastructure projects be flexible enough to change with differing and uncertain time scales of variability?

Changing Tropical Cyclone Threat

Storm surge, damaging winds, flooding, mass evacuations, and in-place sheltering will continue to pose significant challenges for urban emergency managers and city officials. Additional research is needed to understand changes in tropical cyclone activity as a result of climate variability and change, but the potential for increased frequency and severity is a source of concern among these managers and officials. And although coastal urban areas are at highest risk, urban areas well inland also face severe weather and flooding as the remnants of cyclones move across these areas. Predicting the track, intensity, structure, and effects of tropical cyclones remains a challenge and a focus today for coordinated interagency research and development. Tropical cyclones are one example of an area needing improved understanding of the physical processes and greater modeling capacity to be able to meaningfully assess the effects of climate variability and change on the tropical cyclone threat for a given urban area.

Summary

More than two-thirds of the U.S. population resides in an urban area and urban areas present unique challenges for meteorological services and supporting research. This article presented a number of examples of high-impact, weather-related events in urban environments, highlighted some of the associated challenges, and described a number of interagency, coordinated activities underway to address the unique problems of urban meteorology. In 2004, the OFCM in its report, *Urban Meteorology: Meeting Weather Needs in the Urban Community*, identified five elements of primary interest: 1) severe weather; 2) homeland security; 3) air quality; 4) water quality; and 5) climate and this breakout served as the framework for this article.

Challenges in urban meteorology include improving observations and data collection, improving forecasts, integrating social sciences into the forecasting and warning process to deliver products and services that will be more clearly understood and acted upon as intended, and beginning to understand the effects of climate variability and change on the urban environment including beginning to define future climate products and services.

To address these challenges, the OFCM and its interagency partners are working together to improve capability in a number of areas. These include risk reduction for the Multifunction Phased Array Radar, Weather Information for Surface Transportation, tropical cyclone research and development, wildland fire weather needs, assessing hydrometeorology needs and identifying priorities, improving atmospheric dispersion models and establishing the Joint Urban Testbed, and incorporating social science aspects into services to obtain desired responses.

All of these efforts are interconnected, mutually supporting, and aimed at addressing the challenges of the urban environment and high-impact events in these unique areas. The overarching drive is to improve products and services to meet societal demand.

End Notes

1. U.S. Census Bureau, United States Summary 2000: Population and Housing Unit Counts, Part 1, Report No. PHC-3-1, April 2004; Tables 6 and 18.
2. Office of the Federal Coordinator for Meteorological Services and Supporting Research, Urban Meteorology – Meeting Weather Needs in the Urban Community, FCM-R22-2004, January 2004; available online at http://www.ofcm.gov/homepage/text/spc_proj/urban_met/Discussion-Framework.pdf
3. National Weather Service Storm Prediction Center, Enhanced F Scale for Tornado Damage, available online at http://www.spc.noaa.gov/faq/tornado/ef-scale.html
4. National Weather Service Forecast Office Peachtree City, GA, The Atlanta Tornado, March 14, 2008, available online at http://www.srh.noaa.gov/ffc/html/atltor31408.shtml
5. Washington State Department of Transportation Freight Systems Division, Storm-Related Closures of I-5 and I-90: Freight Transportation Economic Impact Assessment Report Winter 2007-2008, Report No. WA-RD 708.1, September 2008.
6. United States Government Accountability Office, First Responders' Ability to Detect and Model Hazardous Releases in Urban Areas Is Signifi-

cantly Limited, Report GAO-08-180, June 2008, http://www.gao.gov/new.items/d08180.pdf.
7. National Interagency Fire Center, Fire Information – Wildland Fire Statistics, Total Wildland Fires and Acres, 1960-2007, available online at http://www.nifc.gov/fire_info/fires_acres.htm.
8. U.S. Climate Change Science Program, Weather and Climate Extremes in a Changing Climate, Synthesis and Assessment Product 3.3, June 2008, p. vii; available online at http://www.climatescience.gov/Library/sap/sap3-3/default.php.
9. City of New York, New York, Mayor Bloomberg Launches Task Force to Adapt Critical Infrastructure to Environmental Effects of Climate Change, PR-308-08, August 12, 2008.
10. National Climatic Data Center, Climate of 2007 Wildfire Season Summary, January 10, 2008; available online at http://www.ncdc.noaa.gov/oa/climate/ research/2007/fire07.html; see specifically http://www.ncdc.noaa.gov/img/climate/research/2007/dec/us-wildfires-1960to2007-pg.gif.