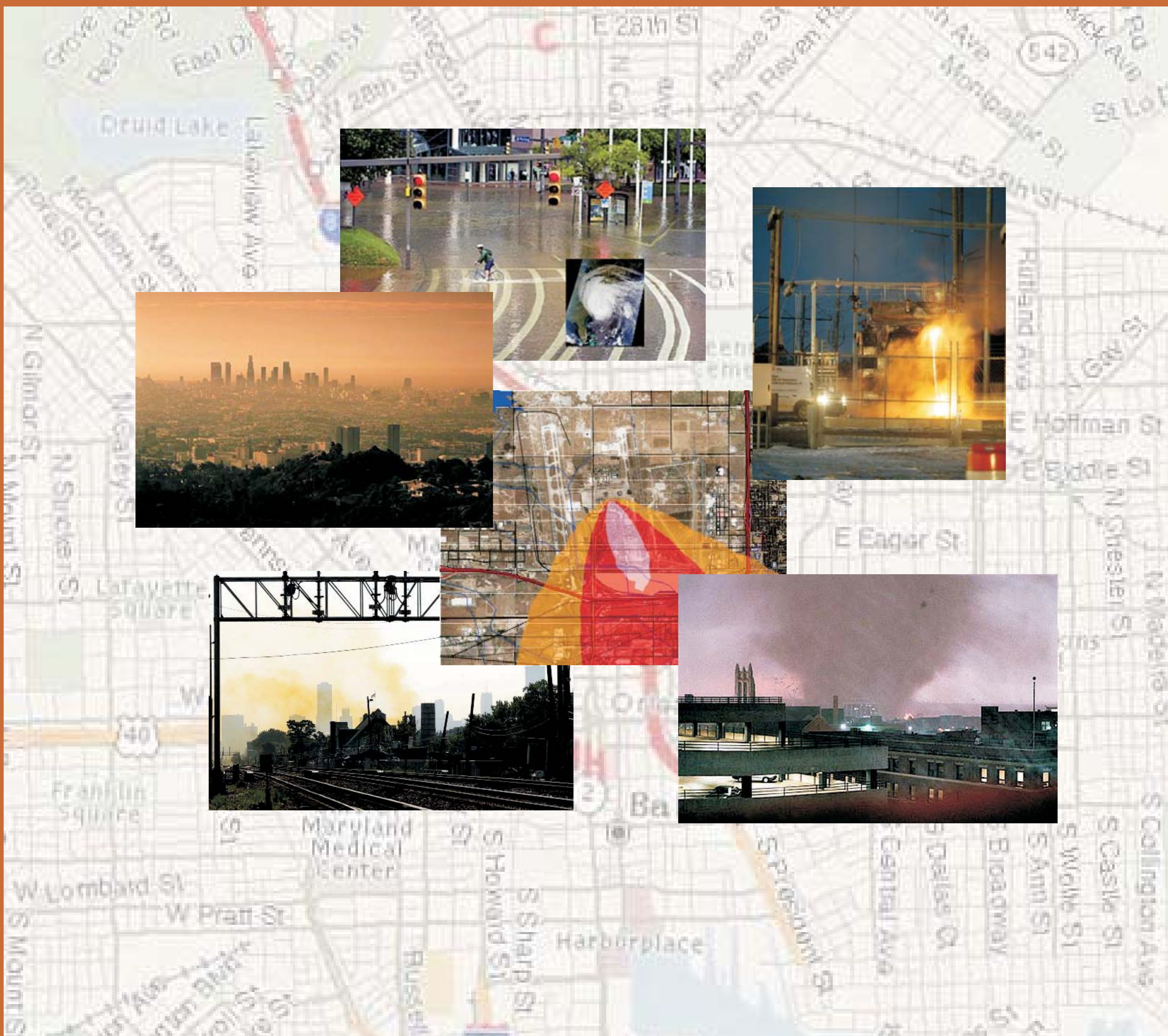
Urban Meteorology

Meeting Weather Needs in the Urban Community



Office of the Federal Coordinator for
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Cover Photos (clockwise):
Top: Hurricane Isabel storm surge, Baltimore Inner Harbor, Top right: Transformer fire after lightning strikes (AP Wide World Photos) Lower Right: F2 tornado, Ft. Worth (Ft. Worth Star-Telegram photo, Carolyn Bauman), Lower left: Toxic fumes (AP Wide World Photos), Top Left: Los Angeles smog (California Air Resources Board), Center: Atmospheric dispersion model graphic (DTRA)

OFFICE OF THE FEDERAL COORDINATOR

FOR

METEOROLOGICAL SERVICES AND SUPPORTING RESEARCH

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Meeting Weather Needs in the Urban Community

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Foreword

Urban meteorology has come to require much more than observing and forecasting the weather of our cities and metropolitan areas. Scientific and technological advances of the past several decades enable us to predict a wider set of environmental parameters at finer spatial scales, for times ranging from the next hour (in nowcasting) to the next several months (for seasonal and climate predictions). As these capabilities have improved, the range of potential uses for the information has increased. Even more important, the potential *value* of this information has risen dramatically—provided we can deliver reliable information, in formats useful to those who can use it, within the time constraints of their decision processes. So understanding who needs the data, what data are truly useful and important to these users, and when they need it are tasks just as important to urban meteorology as producing the data from observations and predictive tools.

The diversity and potential value of the applications means that the mission areas of many Federal agencies may become involved somewhere along the branching paths from observations to applications. Joining them are State and local entities, which are often key decision makers and users of the information, as well as stewards for the ultimate stakeholders: the residents and businesses of our urban communities. The business sector includes partners essential to the production, interpretation, and delivery of meteorological information, as well as users of that information. Partners in the academic community provide expertise in research, public outreach and education, and the innovation and evaluation of products at each step in the process of information creation, delivery, and application. To reap the full potential of urban meteorology for our urban communities and the nation as a whole, all these partners must participate.

The discussion framework that follows presents the concept of urban meteorology, the principal application areas on which we should focus first, and the roles of the principal partners. My intent is not to have the final word on this complex, still evolving field but to initiate and foster a broad dialogue among all interested parties. From that dialogue will come the agreements, the shared values and objectives, and the recognition of common problems through which our combined efforts to improve urban meteorology can be coordinated and made more productive.

//Signed//
Samuel P. Williamson
Federal Coordinator for Meteorological
Services and Supporting Research

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Introduction

In recent years there has been increased national and international attention focused on the need to address urban weather and climate issues. Of the approximately 280 million people living in the United States in 2000, nearly two thirds live in urban areas occupying less than two percent of the U.S. landmass. Weather extremes in the urban area are responsible for thousands of deaths annually, many of which could be avoided by more specific or accurate forecasts, advisories and warnings. To deal with weather and climate hazards to safety and property, urban leaders and managers are demanding more accurate and specific weather and climate information for use in their decision processes. In response to this demand, Urban Meteorology, a specialized, interdisciplinary approach to studying the natural and social environmental elements associated with urban communities, has gained attention and importance in science, technology development, and in applications to a wide spectrum of operational activities.

Weather has special and significant impacts on people living in large urban areas. Heavy rains can cause severe flooding, snow and freezing rain can disrupt transportation systems, and severe storms with accompanying lightning, hail and high winds can cause power failures. High winds can also slow or stop the progress of automobiles, recreational vehicles, rail cars, transit vehicles, and trucks. The urban zone is especially susceptible to landfalling hurricanes because of the large numbers of people at risk (a large percentage of U.S. urban population lives within 50 miles of the Atlantic or Gulf coasts), the high density of manmade structures, and the increased risk of flooding and contamination of potable water supplies.

A compelling case can be made for raising the priority for addressing key issues in urban meteorology. The opportunity to address urban meteorology is a result of three basic factors: (1) technological advances, (2) concern for national security, and (3) concern for public health and safety. With respect to technology, advances in remote sensing and other observing platforms have made urban observations on the subregional scale possible. The evolution of coupled computer models linking the atmosphere, soil, ocean, and biospheric processes along with smaller grid scale has contributed to the ability to assess and predict more accurately the state of the urban environment. The increasing capacity of computer and communications networks facilitates storing and disseminating vast quantities of data quickly. Geographic Information System mapping is a mechanism for capturing and integrating observations and modeling data seamlessly into user-friendly information.

Recent national and international events have heightened attention to acts of terrorism particularly in urban centers with their large populations. Nuclear, biological, or chemical (NBC) releases whether intentional or accidental result in air, water, or soil contamination. These types of contaminants can result in instant death or prolonged illness due to exposure. NBC exposure can also result in genetic and physiological mutations of a vast number of living organisms including humans, plants, and animals. NBC exposure, then, can seriously disrupt a functioning society for a protracted period.

Public health and safety in the urban areas are primary concerns for individual citizens, governments, and businesses. Studies have found a correlation between disease in the urban environment and hydrometeorological processes. Whether these diseases are chronic (rheumatic, coronary, neurological), seasonal (allergies), or psycho-social (violent behavior, slow reaction to stimuli), the large number of people in the urban environment who could be affected by these hydrometeorologically-induced conditions and the repercussions on business and the healthcare system are all cause for concern.

Elements of Urban Meteorology

This discussion framework highlights five primary focus areas within urban meteorology: severe weather, homeland security, air quality, water quality, and climate. Each focus area with attendant impacts is described below.

Severe Weather

Urbanized areas can vastly aggravate the flash flooding associated with hurricanes and other types of severe precipitation events. Changes in surface characteristics in urban

Hurricane Claudette came ashore in Texas on July 15, 2003, peeling off roofs of homes such as this one in Palacios, Texas, knocking out power and flooding low lying areas. (AP Wide World Photos)

areas, lead to rapid runoff of precipitation and flooding. In vegetated areas much of the water is temporarily intercepted by leaves, needles, and trunks. Some of it is evaporated by the plants. The forest litter is a particularly effective storage medium. The radical change of surface from permeable soils and vegetation to impermeable pavements, parking lots, and roofs shortens the time rain or melt-water reaches the water collection areas.

These severe precipitation events impact the built environment as well. Populations in low-income housing (be it trailers, tenement apartments, etc.) are very vulnerable to extreme weather events, as structures are often flimsy and located on land subject to frequent flooding. Hailstorms and winds can also damage property, including the built

Severe Storms
Preparation Costs versus Cost Avoidance

Improvements in forecast skill for severe storms, including hurricanes, tornadoes, and major winter storms, clearly save lives and lessen the risks of injury. The extent to which improvements in storm prediction have also brought economic benefit is harder to assess. For storms that can be forecast with sufficient lead time to protect property (as well as lives), such as hurricanes or major winter storms, the economic *benefits* of preparation (cost avoidance) are typically far more difficult to quantify than are the economic *costs* of preparation.

For example, the costs of preparing for Hurricane Isabel, which made landfall just south of Cape Hatteras, include the evacuation of 300,000 residents in North Carolina and Virginia. A number often cited for the cost of evacuation and other hurricane preparations—although its factual basis is unclear—is $1 million per mile of affected coastline. Airlines canceled 7,000 flights on Thursday, September 18, the day Isabel made landfall, at a *potential* loss estimated at $50 million. However, the ABC News story that quoted this figure did not include an estimate of the potential costs in aircraft damage or schedule upsets (not to mention economic costs of any lives lost or injuries incurred), if those flights had not been canceled. Nor was there an estimate of how many of those lost dollars were regained after the storm passed and passengers rebooked, filling up otherwise empty seats.

By contrast, estimates of the value of cost avoidance are difficult to find, except in anecdotal form. Kristen Lentz, the director of public utilities for Norfolk, Virginia, decided on September 15, three days before Isabel hit the area and took down its electric power grid, to spend public funds to rent generators for the water treatment plant that serves Norfolk, Virginia Beach, and the Norfolk naval bases. Afterward, she described her expense as “the best $100,000 we’ve spent in a long time.” Similarly, Admiral Robert J. Natter, commander of the Norfolk-based Atlantic Fleet, said that sending the Navy’s ships out to sea before Isabel struck cost million of dollars, but he added that the expense would have been far greater if the ships had been battered by the hurricane while still in port. Although the cost of plywood to protect windows from flying debris was cited in many news stories, the economic benefits of three days’ notice to do so were never mentioned.

The difficulties in measuring cost avoidance from preparations for severe weather can lead the unwary to ignore these hidden benefits altogether. A reporter for the *Baltimore Sun*, in a story the day before Isabel struck, noted that a person’s chances of surviving a hurricane are much better now than they were 50 years ago. But he added, “improvements in weather predictions haven’t helped brick and mortar.” Owners of businesses and homes who had time to board up windows, check sump pumps, and clear furnishings and goods from lower floors may have a different view. With respect to preparations for severe weather, it seems too convenient to ignore the old proverb that “an ounce of prevention is worth a pound of cure.”

environment, automobiles, utilities, and other urban infrastructure such as traffic signs and public transportation vehicles.

The impacts of severe winter weather on energy supply, demand, and price are multi-faceted. Weather extremes generally are much more frequent than seasonal extremes. For example, in a given winter, it is not uncommon to have several three-day periods of extremely cold days, even though the average temperature for that winter may be quite near the long-term seasonal average. As a result, the principal impacts on energy demand arise from short-term weather extremes that force energy suppliers to look to the “spot market,” thereby dramatically raising the price. Variability below a threshold (whose value depends on the resiliency of the portion of the energy delivery system in question) can be readily handled by existing system operating protocols. Greater variations, however, demand extreme operating measures and trigger price volatility. Forecasting of these extreme events is therefore more important than detailed forecasting of routine variability.

Meteorological extreme events not only create increased energy demand and price volatility but can also disrupt energy delivery capability and service to the consumer. In some cases, nature imposes an obviously disruptive event. For example, an ice storm can down power lines. Moreover, in the current deregulated, low energy-margin environment, a simple error of a few degrees in the daily temperature forecast can translate into unanticipated energy demands that trigger alerts in the power grid, spot price volatility, or rolling brownouts or blackouts. Because the energy demand for summer cooling is much more dependent on a single energy source—electricity—than is winter heating, severe summer weather often stresses urban energy supply systems more than does winter heating.

After a power blackout across the Northeast in August 2003, pedestrians leaving Manhattan flood New York's 59th Street Bridge to Queens. A prolonged period of summer heat and high humidity, which increased energy demand for air conditioning, was one factor in the massive power grid failure. (AP Wide World Photos)

Severe weather has a significant impact on transportation (whether it is the transport of goods, products, people, etc.). The availability of surface transportation has repercussions not only on the transport of goods and services but also on the ability of the public to evacuate and the emergency responder to respond.

Icing, snow depth exceeding a few inches, and drifting snow can make roadways and bridges impassable. More than 6,000 roadway deaths per year are attributable to weather. High winds accompanied by blowing and drifting snow can slow or stop the progress of automobiles, recreational vehicles, trucks and ships. Below-freezing temperatures or the presence of ice can adversely impact marine transportation. In the U.S. the impact of ice on marine transportation is particularly evident in the Great Lakes and upper Mississippi areas. The commerce that takes place on these waterways can be slowed or stopped by prolonged or repetitive freezing conditions. Icing conditions can even adversely impact the flow of natural gas and oil within pipelines. Extremely cold weather can snap or severely damage cables that support suspension bridges.

Icing and fog reduce visibility and may have an adverse impact on aviation. With appropriate hydrometeorological information beforehand, the aviation community can take appropriate steps to minimize the adverse impacts of winter storms. For example, knowing when and where winter storms will occur could minimize the need to carry needless excess fuel.

The devastation caused by hurricanes, tornadoes, and flooding on the urban environment has been chronicled for decades in the media and scientific journals. However, the impact of the urban environment on severe weather is not so widely known. For example, an urban barrier effect can alter synoptic and mesoscale systems passing over a large metropolitan area. In New York, the city has been shown to decelerate (1) air flows during non-urban heat island periods, (2) slow moving synoptic cold fronts, and (3) sea breeze fronts. These decelerations were linked to a persistent horizontal divergence pattern produce by the city, in which prevailing flow split to form two streams that went around the city. During urban heat island periods, it has been shown that the urban landscape can enhance convection due to either mechanical convection and/or the heat emanating from the urban building configuration.

Urban areas, particularly those with densely aggregated, tall buildings provide wind tunneling which can enhance or produce wind speeds that are not observed in less built-up environments. The contrast in the air temperature as cooler air from a rural area or marine area advects toward the city can result in a cold front near the outskirts of a city. Under certain conditions this type of cold front can impact (mitigate or enhance) a mesoscale or synoptic weather pattern. While it remains to be clarified and demonstrated, local "hot spots" such as the urban landscape, may play a more significant role in convection initiation than previously realized. In essence, the violent weather hazards (such as tornadoes and convective thunderstorms with their associated hail, lightning, and strong winds) and more frequent milder disruptions are often facilitated by conditions that are locally favorable for extreme weather.

Local hailstorms and thunderstorms may be a disaster to crop and gardens within the urban environment, pounding young plants into the ground, shredding leaves, or shattering flowers and seed heads. Hailstorms, thunderstorms, and dust storms, and their associated winds can cause severe damage to urban stands of vegetation, just as they do to a standing crop in agricultural settings. This damage is mechanical in nature. In dust storms, the dust is raised by the wind and can be carried several kilometers away. It causes damage to the plants, particularly small plants, by covering them fully with dust, resulting in changes to metabolic processes (photosynthesis, for example). Hailstorms and thunderstorms cause direct damage to plants.

Most heart diseases are caused by arteriosclerosis and have an important meteorotropic aspect. They can be classified as coronary thrombosis (formation of a blood clot in the heart or coronary artery), myocardial infarction (deficient blood supply in the heart muscles), angina pectoris (paroxysmal thoracic pain). Research strongly suggests a meteorotropic relationship between the passage of weather fronts and the increased occurrence of these diseases. Heart failure has been shown to occur more frequently with the passage of active weather fronts, either cold or warm. Heat waves in urban environments increase the risk of heatstroke, heart attack, and other heat-related death and illness, particularly for susceptible populations (Figure 1).

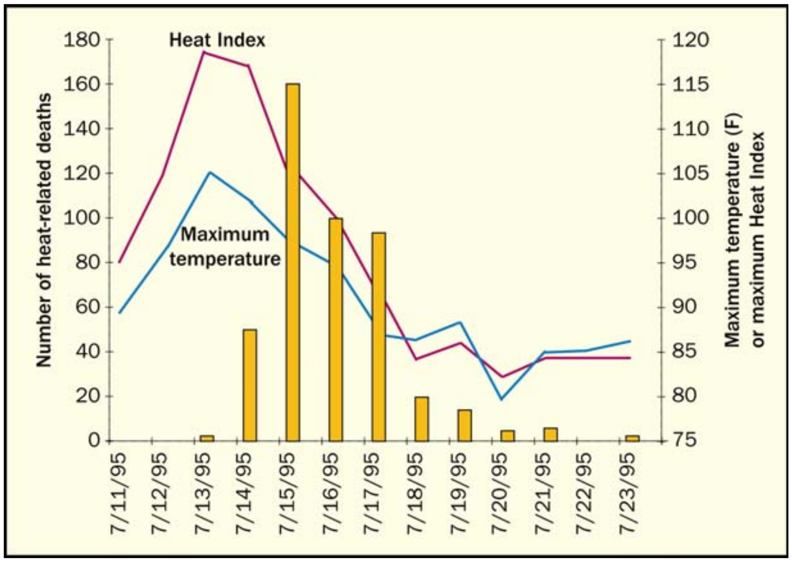


Figure 1. Heat-related deaths (bars), maximum temperature (T_{max}), and heat index (HI) during the Chicago heat wave of July 11–23, 1995. Adapted from National Oceanic and Atmospheric Administration, *National Disaster Survey Report: July 1995 Heat Wave*. U.S. Department of Commerce, December 1995, Figure 9 (pg. 23).

A considerable number of studies have been devoted to the possible direct influence of weather and climate on mental processes. Studies examined the relationship between year-to-year shifts in temperature and violent and property crime rates in the U.S. A positive relation between temperature and serious and deadly assault was observed, even after poverty and population age effects were statistically controlled. Similarly, other aggressive behavior such as spousal abuse and road rage has been examined with similar findings. Violence, a decreased stress tolerance, and ambient temperature are curvilinearly related. Specifically, ambient temperature was directly associated with the frequency of violence through the mid-80s (Fahrenheit). Beyond this point, however, further increases in temperature were associated with a decreasing incidence of violence.

Restlessness of school children is another condition that has been observed as having a meteorotropic influence. It was found that children are more restless during warm events than during cold events. For example, school children were found to be more restless right before a thunderstorm. This unrest was due to the thermal stresses (heat and humidity), which affect the inefficient thermoregulatory system of young children.

Homeland Security

When a technological hazard occurs, the primary vectors for spreading the hazardous materials are air and water. Most pollution releases occur in the atmospheric boundary layer (ABL, that portion of the atmosphere where the earth's surface (land or water) has a direct influence). The stronger the wind shear within the ABL, the stronger the resulting mechanical turbulence. Thermal effects can counterbalance or enhance the effects of wind-induced mechanical turbulence. When the surface temperature is greater than the air temperature, dynamic turbulence results and the buoyancy forces intensify the turbulence due to wind shear. Hazardous gases or aerosols are transported upward, then dispersed laterally by the prevailing wind, forming an atmospheric plume (Figure 2). If the ABL is relatively stable, less dispersion occurs. The urban canopy plays an important role in varying the ABL. The presence of buildings and other structures affects not only flow fields but also the intensity of atmospheric turbulence and ultimately the depth of the ABL.

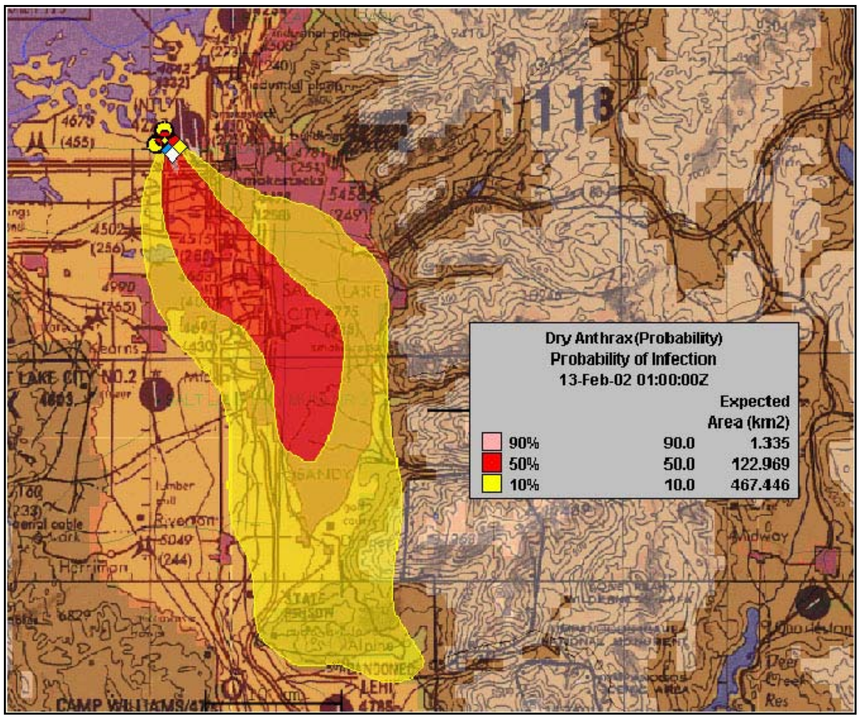


Figure 2. Atmospheric dispersion map, prepared for the Salt Lake City Olympics, showing a planning scenario for transport and dispersion of a plume of anthrax spores in case of a bioterrorism attack. Image courtesy DTRA.

Depletion is the process by which pollutants are removed from the atmosphere. Clouds, precipitation, fog, radioactive decay, and soil deposition on the ground are ways in which pollutants can be removed and are all major factors in surface (water or land) contamination. Knowing the type and timing of precipitation is very important, in responding to hazardous emissions into the atmosphere. Dry deposition occurs during the interaction of the pollutant with the earth's land or aquatic surface. Elements within the surface capture the pollutant. Knowing the uptake character of the surface to specific pollutants, then, is also important. In the case of radioactive hazardous releases, the decay of the pollutant is also a depletion factor. Surface contamination whether by means of depletion or deposition ultimately impacts the quality of the food we eat and the water we drink.

The timing of atmospheric conditions is also important. Whether hazardous material disperses quickly or remains concentrated depends on the movement of weather systems and how quickly a change occurs. For example, if a front moves over a source area, wet deposition could be a primary influence on the extent of ground and water contamination if there is accompanying frontal precipitation. On the other hand, the deposition scenario could be completely different if the hazardous emission occurred after a frontal passage.

Problems of modeling in complex terrain and coastal areas present challenges because of their non-homogeneous nature. Most of the Nation's population lives at or near coastal areas. Many power plants are near the population being served. These plants are potential sources for hazardous releases. They are also potential terrorists' targets. Thus it is important to better understand and characterize coastal areas and other densely populated areas that are near potential release sites. Accurately determining the dispersion of hazardous material in these areas could have a significant impact on a large number of people. Modeling the interaction between indoor and outdoor air is yet another factor where increased emphasis should be applied. The coupling between indoor and outdoor air is important both as a mechanism for reducing indoor concentrations after an indoor release and as a factor affecting the "sheltering-in-place" strategy (in subways or above ground facilities) after an outdoor release.

Air Quality

Ever since cities developed in antiquity, people noticed that urban air was different from rural air. The principal atmospheric difference between urban and rural areas is the drastically altered load of pollutants. Land use, agricultural spraying, traffic density (particularly land and air traffic), distribution of major point sources such as power plants, and heavy industry (e.g., oil refineries and industries that burn coal), play a role in aerosol creation, emission, and deposition. These aerosols are not necessarily inert. For example, iron acts as a catalyst in chemical reactions. Others like lead and vanadium (a component of fuel oil) can be serious health hazards. The presence of ozone can aggravate emphysema and reduce resistance to colds and pneumonia. In addition, CO interferes with the transfer of oxygen from the lungs to body tissues. Pollution also affects the weather and vice versa. SO_2, in the presence of atmospheric moisture can turn into sulfuric acid. Sulfuric acid is hygroscopic. At 60% relative humidity, sulfuric acid begins to grow into droplets interfering with visibility. Decreased visibility can impact transportation safety.

A plume of nitric acid fumes rises from an industrial accident site. Local wind patterns will determine how an atmospheric release of hazardous material spreads into the urban environment. (AP Wide World Photos)

Accidental or intentional release of hazardous materials into the atmosphere and water constitutes a major threat to life and safety. Technological hazards can have local, regional, national, and international ramifications. The large number of hazardous agents complicates preparedness for and response to biological, chemical, and nuclear hazards. In the case of biological agents (such as smallpox, botulism, and anthrax), these can be genetically re-engineered to resist traditional therapies. These altered pathogens can also bypass human and animal immunities obtained through vaccinations. Additionally, there can be a long incubation period and consequent delay in the onset of disease. As a result, secondary transmissions become very difficult to detect and plan for.

Urban areas are not only the recipients of air pollution. Cities can create polluted air, which is dispersed over other areas. For example, the air pollution (the source of which has been attributed to metropolitan Washington, D.C.), which results in acid rain deposition over the Shenandoah National Park. The effects of acid rain are killing prized young brook trout. In addition, the air over the park violates federal standards for ozone and pocks leaves with black spots, thus reducing the biodiversity of the area and making the area more susceptible to invasive species which further reduces the area's biodiversity. The polluted air has also reduced visibility within the park. The park's vistas from the scenic, 105-mile Skyline Drive from Front Royal to Waynesboro are now more frequently a haze. The result of the park's declining biodiversity and scenic views is that the number of people visiting the park has decreased from 2 million visitors annually in 1993 to 1.4 million in 2002. The decline of visitors means less business for the surrounding areas. Urban pollution, then, has its economic drawbacks.

Whether the pollution is natural or anthropogenic, pollution has negative impacts. In addition to the impact on human health and consequently the health care system, polluted air also harms plants (by stunting plant growth), animals (by interfering with physiological processes), building materials (by eroding concrete, rusting metals, etc.), and fabrics. Besides transportation, air quality has a direct economic impact on such industries as agriculture, automobiles, and clothing. The damage caused by air pollution costs the U.S. alone billions of dollars each year. This cost estimate includes money spent for health care, increased maintenance of buildings, and agricultural losses.

When a technological hazard occurs, the primary vectors for spreading the hazardous materials are air and water. It becomes critical to have meteorological and hydrological data that represent the atmospheric and hydrologic conditions at the incident site. It is equally important that models accurately project the pathogen's transport to other areas. Models, therefore, should be equally accurate for diagnostic and prognostic use.

Weather patterns can influence air quality. The presence of a stationary high pressure system or a sustained period of calm air or light winds can mitigate the transport of pollutants. This same weather pattern, however, can contribute to increased pollution over a specific location. In addition, ambient levels of air pollutants tend to rise in winter because of generally increased atmospheric stability, and reduced mixing depths, leading to a poorer dispersive capacity of the atmosphere. Other naturally occurring events can also affect air quality and cloud properties. The Mt. Pinatubo eruption (and resulting silicate dust) occurring a half a world away forced the closure of Clark Air Force Base and thus changed the U.S. strategic posture in the western Pacific.

Water Quality

Many urban areas are located near water bodies. Aside from their aesthetic attractions, streams, lakes, and rivers are a source of water supply. The running water also seems to offer a cheap, planned or unplanned means of sewage disposal. The problem of water quality management in cities has become a major problem of modern society. Poor practices in land use have led to large economic losses. Designs of drainage systems pose major engineering tasks. Poor designs or overtaxed drainage systems can deteriorate water quality and present health concerns.

Urbanized areas can vastly aggravate flooding. Changes in surface characteristics in urban areas lead to rapid runoff of precipitation and flooding. In vegetated areas much of the water is temporarily intercepted by leaves, needles, and trunks. Some of it is evaporated by the plants. The forest litter is a particularly effective storage medium. The radical change of surface from permeable soils and vegetation to impermeable pavements, parking lots, and roofs shortens the time that rain or melt-water reaches the water collection areas. Storm drain systems deliberately designed to carry the water away from residential and business districts reduce the lag times even further. Thus the benefit derived by rapid drying of roads sometimes leads to the high cost of flooding. In addition, heavy water inflow can cause sewer overflow, which also has a negative impact on water quality.

Run-off from rural to urban areas and vice versa presents other challenges, namely excessive silting and eutrophication. Eutrophication is usually produced by the discharge

Water contaminated with heavy metals seeps into a creek near Miami, Oklahoma, from a flooded abandoned mine. Even seasonal precipitation on contaminated soils can cause a problem for urban water supplies. (AP Wide World Photos) of biological wastes into lakes and rivers. Eutrophication produces not only nutrients for the algae cover but, because of the high oxygen demand of these wastes, robs the lakes' fauna of an essential element for their survival. These lakes and rivers can ultimately be a source of drinking water, which is no longer safe to drink. Thus, control of water quality at the inflows, especially adequate dissolved oxygen is a challenge. In addition, the presence of septic systems, salting of snow-covered roads, landfills, brown fields, and the redevelopment of brown fields can adversely impact ground water quality and surface water quality, especially during a heavy water run-off event.

Climate

Climate simulations are predicting an overall warming of the atmosphere due to greenhouse gases. For example, CO_2 allows sunlight to reach the earth and warm its surface, but it prevents some surface heat from escaping out of the atmosphere. This greenhouse effect can result in higher mean atmospheric temperatures near the Earth's surface. If these predictions are correct, changes in temperature can increase the power needed to cool urban building structures (homes, offices, storage facilities, stores, etc.). Similarly, the regional and seasonal temperature fluctuations due to climate oscillations (El Nino, for example) may also increase the power demand for heating and cooling. A warming climate can also affect the available water for drinking, irrigation, and generating power, all of which impact the viability and sustainability of the urban community.

As the risk of flooding increases with climate change, so does the importance of the major drainage systems. New design approaches, which explicitly design roads to act as drains, can radically reduce the duration of flooding. Litter management is critical to the management of urban drainage systems. Often the best investment in drainage is better handling of solid waste to prevent systems from becoming rapidly blocked with debris. Climate change is likely to amplify the challenge of pest control, as new ecological niches appear that may sustain exotic pathogens and disease vectors. For example, flooding may become more frequent in some geographic locations with climate change and can affect health through the spread of water-borne diseases.

Changing climate also changes the vulnerability of coastal areas to flooding. A 1991 report by the Federal Emergency Management Agency estimated that a one foot rise in sea level would increase the size of the 100-year floodplain in the U.S. from 19,500 square miles in 1990 to 23,000 square miles, and increase flood damages (and hence flood insurance rates) by 36-58 percent. Photo courtesy EPA.

Climatological conditions are also important for nuclear, biological, and chemical releases, and Homeland Security response scenario planning. For example, climatological signals such as El Nino, the North Atlantic Oscillation, and the Pacific Decadal Oscillation have a profound effect on atmospheric conditions such as stability, precipitation, and prevailing winds. Thus knowing the strength and timing of these signals is an integral factor in detecting and responding to hazardous material releases.

Many states struggle with energy shortages and price volatility. Climate conditions could exacerbate the challenges, which these states face. For example, during the summer of 2001, a severe drought gripped the Columbia River basin causing the second worst water shortage in that watershed since records have been kept. The resulting reduction in hydroelectric sources contributed significantly to California's energy shortage. Simultaneously, heat waves in California drove demands up sharply leading to enormous increases in "spot market" electricity prices.

Successful forecasts of the 1997-1998 El Nino event and its evident effects on energy demand patterns was one of several factors prompting the development of specialized financial instruments for energy risk management (the weather derivative). As the full weather and climate sensitivities of the revenues and profits of energy providers and consumers become better understood and are more clearly delineated, demand for new products (insurance, catastrophe bonds, etc.) and associated weather services will likely grow.

Climate change can have an impact on water quality. In those areas where there are more frequent heat waves, perhaps of longer duration and more intense storms, greater amounts of storm water runoff will occur. Conversely, if precipitation declines, as some climate scenarios suggest, farmers will increasingly turn to groundwater and wetlands for irrigation, threatening urban water supplies, both in terms of quality and quantity.

Crosscutting Urban Weather and Climate Issues/Components

The following crosscutting components are common to most if not all of the major issues/concerns related to urban weather and climate. Each of the crosscutting issues or factors must be addressed in any actions contemplated to improve weather and climate products or services for urban areas.

Integrated Global Observations

Observations are the lifeblood for developing forecasts, advisories and warnings that cover all of the primary urban weather and climate issues presented above. The present state of weather and climate measuring stations in cities is at best inadequate. Stations are sited in diverse locations over differing surfaces, at various heights and exposure of the individual instruments often violates WMO rules of observing practice.

Research and Technology Tools

Although a substantial amount of research and technology development is in progress more focus needs to be placed on addressing gaps in weather and climate service and support capabilities. In addition, provisions are needed to routinely transfer the results of science research and technology into operational venues throughout government and commercial applications.

Education, Outreach, and Training

Every new or improved product and service for urban weather and climate applications requires some level of education and training to ensure that the information is being delivered in an understandable and user-friendly manner. Outreach helps to involve users in the process from defining requirements or deficiencies to conducting research or development and finally, in delivery of the finished product or service. Using this process helps the entire range of users to understand and apply weather and climate information in a wide spectrum of endeavors: personal, business, and community.

Risk Management

Risks must be considered through continuing assessments of science, technology and application uncertainties, as well as in the costs and benefits associated with each of the urban issues and the proposed actions to mitigate adverse hazards or impacts. Forecast uncertainties must be considered in all decision processes. The educated use of probabilities and confidence levels helps users quantify and consider mitigation for the risks associated with weather and climate forecasts. In addition to the well-accepted mitigation approaches of planning in advance and dealing effectively with weather consequences, the more controversial approach of weather modification may be ripe for careful scientific investigation (see text box).

Weather Modification to Mitigate Weather Effects

At present, risk mitigation activities related to urban weather involve either preparing in advance or responding after the fact. Changing the weather to mitigate risks and improve beneficial effects has been attempted, but without demonstrable success. Previous assessments of weather modification by study committees of the National Research Council (NRC) have concluded that the science underlying attempts to modify the weather is too weak to determine whether such attempts actually produce results. A more optimistic view is taken in a new study, *Critical Issues in Weather Modification Research,* from the NRC. This study points to the significant advances in observing, computational, and statistical technologies during the 30 years since the last NRC study and calls for a coordinated, sustained national program to answer fundamental questions about basic atmospheric processes relevant to weather modification efforts. For example, the report describes how millimeter-wave cloud radar could be used to reveal the physical transformations in regions of clouds seeded with condensation agents such as silver iodide. The publication announcement and the report are available on line at the National Academies Press website, www.nap.edu.

Health Effects

There are varying degrees of public health concerns and impacts in each of the areas of concern in urban meteorology. The health problems associated with the extreme forms of urban weather and climate are often at the level of survival whereas lesser degrees of weather extremes or even benign periods of weather can be insidious or cumulative in their affects on overall public health. A recent example of extreme weather is a record heat wave that scorched Europe in August 2003, claiming an estimated 35,000 lives. In

France alone, 14,802 people died from the searing temperatures--more than 19 times the death toll from the SARS epidemic worldwide. In the worst heat spell in decades, temperatures in France soared to 104 degrees Fahrenheit (40 degrees Celsius) and remained unusually high for two weeks.

Information Dissemination

Communication of weather information has to be an end-to-end process. All the observations and other data that comprise the weather and climate database infrastructure must be readily collected, assembled, quality-checked and made accessible to a wide spectrum of users in all levels of government, industry partners, and to the general public. All subsequent developments such as numerical models, forecasts, advisories, and warnings must be made available for applications that include high-priority, life-protection and life-sustaining weather and climate information to everyone in the urban communities.

Business Continuity Planning

This activity is needed to ensure the survival of an organization or industry when it is exposed to a wide range of natural hazards and environmental or other forms of terrorism. Each of the six primary urban issues must be evaluated in light of survival factors and specific priorities of the business activity and entities involved.

Regional Ecosystem Planning and Management

Urban environments are not ecologically isolated from agricultural areas or natural ecosystems (forests, grasslands, riparian and coastal wetlands, arid lands, etc.). Linkages with urban areas often occur through the weather-related environmental interactions described above. Air and water pollution from urban areas can affect agriculture and natural resources downwind and downstream. Agricultural and urban communities often share the same groundwater and surface water resources. Agricultural practices can affect urban water and food supplies, as well as the recreational areas used by urban dwellers. Urban forests and green spaces slow and reduce stormwater runoff, flooding, and erosion. Urban tree foliage naturally filters particulates and pollutants from the air.

Wildfires in natural areas can threaten the suburban zone around urban centers, just as urban populations seeking recreation provide both the demand for and multiple ecological stresses on natural areas. Regional high winds, such as the Santa Ana winds of southern California, can make wildfires extremely hazardous to urban areas (see text box).

Santa Ana Winds Fan Killer Fires

During October 2003, wildfires exploded across a southern California desiccated by Santa Ana winds, killing at least 15 people and burning more than 500 homes. The two biggest blazes, in eastern San Diego and the San Bernardino suburbs of Los Angeles, forced thousands to flee and closed major highways. Aviation nationwide was disrupted when the evacuation of an FAA flight facility near San Diego limited flights.

In addition to the cross-cutting issues described above, a review of the five major urban issues shows the influence on and from transportation, energy production and use, and biometeorology. For example, in transportation, high winds can impede or stop aviation activities, transit vehicles, automobiles, recreational vehicles, trucks and marine activities. The availability of surface transportation has repercussions not only on the transport of goods and services but also on the ability of the public to evacuate urban areas and for response personnel to reach emergency sites. Icing and fog reduce visibility and (if in sufficient amounts) may close airports or delay flight operations. Extremely cold weather can snap or severely damage cables that support suspension bridges. Elevated temperatures can buckle roadways and train rails. Lightning has an impact on transportation, not only by damage to trees along roadways but also delays due to refueling safety practices and impacts on communication systems. Emissions from vehicles can affect air and water quality. Concentrations of emissions or accidental releases of hazardous materials from vehicles can pose serious health problems and modify weather and climate characteristics for large areas downstream. Having advanced weather information (type, quantity, and temporal and spatial extent) with lead-times that are relevant to the urban areas would provide benefits to urban commerce and in the protection of life and property

Current Capabilities and Limitations in Weather and Climate Services and Products

Capabilities and limitations of current weather/climate services and products to address above issues are found across the Federal agencies, State and local governments, industry and universities. A brief profile of capabilities and limitations includes:

Federal Agencies

U.S. Department of Commerce, National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration's National Weather Service provides basic weather and climate observation networks to serve the nation's needs and international obligations. It collects weather and climate data, conducts initial quality assurance, assimilates the data into databases for access by users, and incorporates data into numerical and other models to develop forecasts, advisories and warnings. Sources of observations include traditional weather stations, weather radars, weather satellites, rawinsonde facilities, cooperative weather stations, a reference climatological network, experimental research equipment, aircraft reports, hydrological networks and more. The greatest limitation is the lack of sufficient observations and more accurate (higher resolution) forecasts to meet time and space requirements for urban weather and climate applications.

NOAA's National Environmental Satellite, Data, and Information Service manages United States civil operational environmental satellite systems, as well as global databases for meteorology, oceanography, solid-earth geophysics, and solar-terrestrial sciences. The activities of the Office of Oceanic and Atmospheric Research support various NOAA meteorological, oceanographic, and space missions including tracking and forecasting volcanic ash and improving observation and forecasting tools for severe weather. The National Ocean Service acquires water levels, currents, winds and other oceanographic data to provide a suite of information products required by marine transportation in coastal areas and in ports.

U.S. Department of Transportation, Federal Aviation Administration

The Federal Aviation Administration administers weather and climate operations and research in support of national aviation activities. The Federal Highway Administration conducts similar activities for the roadways, and the Federal Railroad Administration and Federal Transit Administration support rail and transit systems. More observations and increased forecast accuracy are needed to improve products and services for transportation applications in urban and other areas.

U.S. Department of Homeland Security

The Department of Homeland Security includes the Federal Emergency Management Agency and the United States Coast Guard. These organizations require extensive weather and climate data for emergency preparedness, mitigation, and response and recovery operations related to natural and other disasters, as well as for rescue and lifesaving activities.

U.S. Department of Defense

The Department of Defense (DoD) has responsibilities for reporting weather and producing weather warnings for hazardous weather for their installations, many of which are in or adjacent to urban areas. They also provide specialized worldwide weather, space environment and oceanographic analysis and prediction services in support of military forces. The DoD relies on the databases of the NOAA National Weather Service and other agency databases to provide observations and forecast tools for applications to many of their sites and training operations.

U.S. Department of Energy

The Department of Energy has responsibility for weather and climate support for the transport of nuclear and other hazardous materials across urban as well as other areas across the nation. Very detailed weather information is needed to support their activities.

U.S. Department of the Interior

The Department of the Interior (DOI) has primary responsibility for responding to wildland fires. Such fires often occur adjacent to urban areas and smoke or other airborne particles can affect air and water quality in urban communities. DOI also has responsibilities to monitor air quality in national parks, and collects data related to managing water resources and water quality nationally.

U.S. Environmental Protection Agency

The Environmental Protection Agency (EPA) is responsible for air quality and the regulations and enforcement of air quality standards. Special measuring equipment and networks are needed to assess the dispersion of air contaminants.

National Aeronautics and Space Administration

National Aeronautics and Space Administration requires specialized weather and climate data for space programs and in research programs to improve air safety. Many of their activities are conducted in or near urban areas.

U.S. Department of Agriculture

The Department of Agriculture requires a wide range of high quality weather and climatological data to successfully carry out their missions. Some of the diverse applications that require accurate, timely, and comprehensive data include crop monitoring and weather impact assessment, agricultural yield and productivity modeling, natural resource conservation planning, forest fire potential monitoring, irrigation scheduling, water supply information, reinsurance and compliance programs, crop disaster assistance and emergency relief programs, integrated pest management, crop yield modeling, and agricultural research studies of agricultural applications. Many of their activities take place on urban fringes but also occur within urban areas.

Nuclear Regulatory Commission

The licensing and operation of nuclear facilities require the identification of meteorological and climatological conditions that can affect the safe operation of the facility and that provide input to the assessment of the radiological impacts of any airborne releases from the facility. Detailed observations and forecasts of the dispersion of such releases would be needed to provide advisories and warning to urban or other areas in the path of released materials.

State and Local Governments

State and local governments arrange for specialized weather observations and support for emergency operations in the wake of a storm or technical hazard. These operations include transportation and safety activities such as response to wildfires and hazardous material spills.

Industry and the Private Sector

This sector uses weather and climate information from government or private sources to generate value-added decision support information or services to individuals, corporations or government activities.

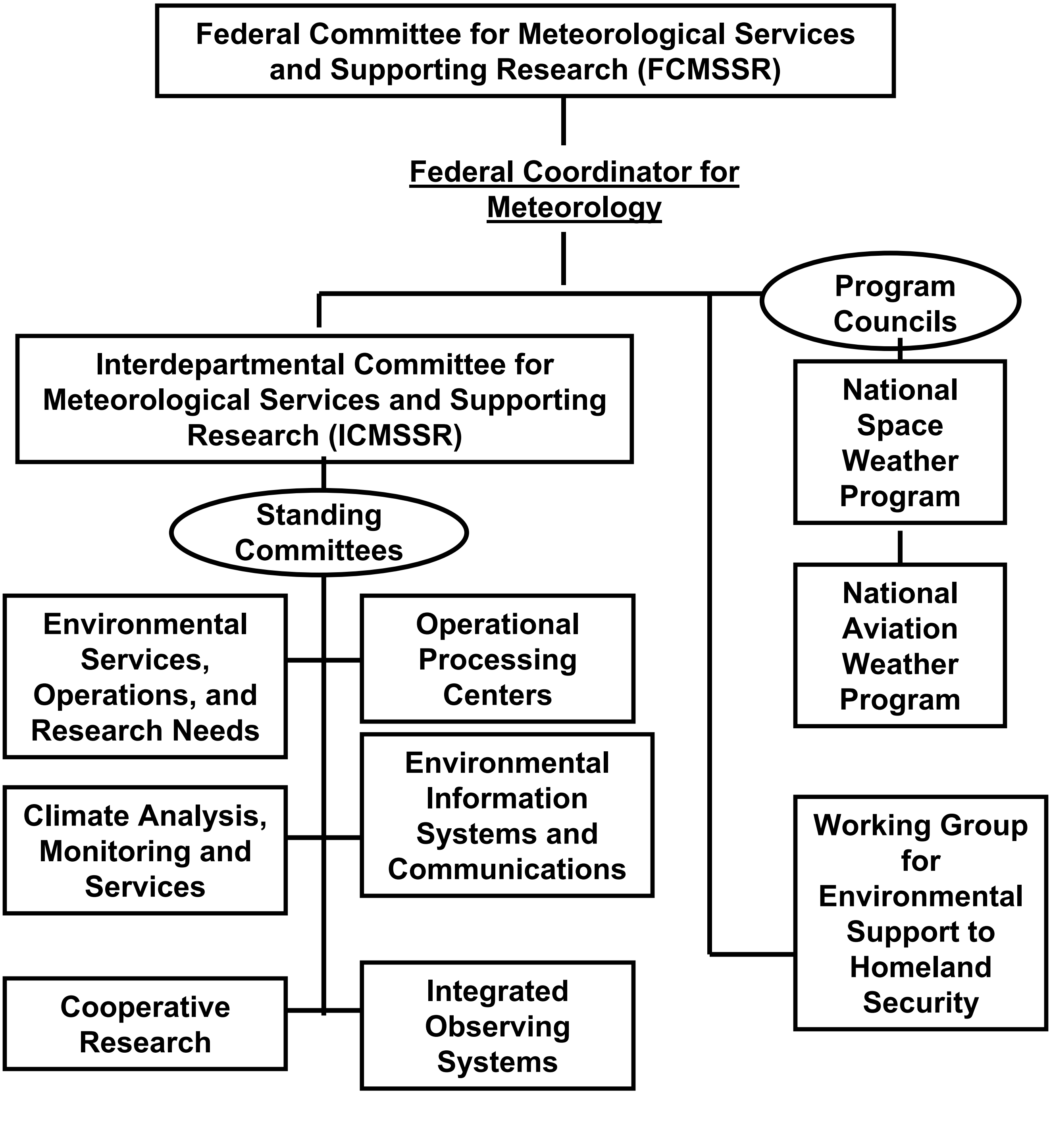
Universities

Universities conduct specialized weather observation and forecasting activities in support of research, development and technology transfer activities.

Why Focus on Urban Meteorology Now?
What Next?

The needs of urban users and the issues expressed in this discussion framework involve measurement, computational and modeling and information delivery systems. It is clear that public decision centers and their industrial counterparts need to take full advantage of the meteorological measurement systems and model products that have emerged during the past several years from activities such as the NWS modernization effort. This will involve substantial investment in local staff training, strategy development, and information facilities. In addition, urban leaders need to assess and respond to unmet community needs pertaining to observational and modeling resources that are available within the current state of the art. Scientists and community leaders together need to jointly establish key needs not met by existing technologies, and develop a science-based strategy to bring such technologies into practice.

The OFCM plans to assist in this effort by sponsoring a Forum in late Fall, 2004 to address urban weather and climate issues. The Forum will provide an opportunity to review requirements and current capabilities, determine unmet needs, discuss priorities, and coordinate development of an R & D plan to address the deficiencies in weather and climate products and services in urban areas.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Federal Coordinator for Meteorology
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National Space Weather Program
Standing Committees
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