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## Urban Climate and Necessity for Adaptation in Cities

### An Information Statement of the American Meteorological Society

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#### Motivation

According to the United Nations Fund for Population Activities (UNFPA), the world is undergoing the largest wave of urban growth in history. More than half the world's population now lives in towns and cities, and by 2030 this number will swell to about five billion. By 2050, it is predicted that 70 percent of the world's population will live in megacities, according to the Institute for Economics & Peace. Today, there are 33 megacities (i.e., populations greater than 10 million) with 14 more cities expected to reach that mark by 2050. As the speed and scale of urbanization increases, cities and the people who live there become particularly vulnerable to weather hazards, climate variability, and climate change. Large urban areas have complex governance systems with separate departments responsible for the administration of services (e.g., urban planning, water network management, energy, housing, emergency services planning) that must effectively communicate a response to an undesirable event that is most appropriate for the common and unique opportunities and challenges they face. This organizational complexity increases the risks and vulnerability of cities and renders it difficult to develop comprehensive response, mitigation, and adaptation tactics and strategies and to plan for future risks. Urban meteorological and local climatic issues are of increasing concern at the international level. Two of the challenges that are the focus of the World Meteorological Organization World Weather Research Program are "high impact weather," including its impacts in cities, and "urbanization."

This AMS information statement aims to raise awareness of weather and climate hazards on the urbanized environment and population to improve potential future policy implications about city management and planning. As an information statement, it is intended to provide a trustworthy, objective, and scientifically up-to-date explanation of scientific issues of concern to the public at large.

#### Urban climate and extreme weather impacts in cities

Cities, especially megalopolises, can have their own urban climate and can modify the local and regional weather in a significant way. The urban heat island effect, poor air quality, and the splitting/enhancement of thunderstorms are examples of weather/climate-related threats that can seriously impact people and infrastructure. In addition, there are non-urban regional weather/climate-related threats such as wildfires and flash flooding that can severely impact urban inhabitants and infrastructure even though they originate from outside the city limits. See the AMS statements on [Drought](#) (including wildfires) and [Flash Flooding](#).

##### *The urban heat island (UHI)*

The urban heat island effect (UHIE) is the result of densely packed buildings; dark, impervious pavement and rooftops; a relative paucity of green space for shading and evapotranspiration; high thermal mass; and waste heat from air conditioning systems. Its impacts in terms of extreme heat are exacerbated by warming due to climate change. Absorption of solar radiation

and the release of waste heat from HVAC systems during daytime hours in cities creates a dome of warmer air that can obstruct air flow, trap pollutants, and transport polluted air downwind of the urban environment. At night, even as the surface cools under clear skies and calm winds, the air temperature remains relatively warm due to the heat absorbed during daytime by urban materials, and the air near the surface can be laden with pollutants, especially particulate matter, accumulated during the day. Daytime temperatures in urban areas can then be up to 7°F higher than temperatures in outlying areas, and nighttime temperatures can stay much warmer in city environments than in the rural countryside—up to about 4°–22°F higher for U.S. cities.

### *Thunderstorms*

Cities, even the largest megalopolises, are not well represented in operational models used for weather prediction. As a result, evaluating the interaction between severe storms and urban environments is rendered more difficult. Storms can split when encountering the urban thermal dome, or they can intensify as they pass over the thermal dome. In the latter case, the thermal dome generates convergence of air and lifting of the warmer heat island air, resulting in greater instability and spawning the development of thunderstorms. Weakening nighttime thunderstorms can be reinvigorated by the urban heat island. In general, cities are known to generate clouds or thicken existing clouds as air is lifted upon encountering the thermal dome, leading to a distinctly urban condition known as the urban rainfall effect. When high-intensity precipitation events occur, the imperviousness of large surface areas in cities makes them more vulnerable to flooding when the stormwater discharge capacity becomes overwhelmed.

### *Air and water quality*

Urban air quality is a result of both local emissions and pollution transport into and out of the city, and it is significantly affected by local conditions, including the weather and climate generated by the city itself. In the presence of a stagnant high pressure system, conditions can worsen over a period of days as pollutants accumulate and photochemistry (chemical reactions stimulated by solar radiation) increases the number of pollutant species by converting primary pollutants to secondary and tertiary species. With little ventilation, these environments are responsible for deleterious respiratory health issues, which disproportionately affect underserved/marginalized communities. Horizontal transport of the urban plume under light to moderate wind conditions can have a serious impact on affected downstream communities (e.g., Houston pollution plume), often raising pollution concentrations to alarming levels even in the absence of local emissions. While a precipitation event brings the pollution episode to an end through wet deposition, pollutants scavenged by the precipitation and carried into storm drains can affect water quality in rivers and streams.

## **Adaptation of cities to climate change**

In most countries, cities are obliged to have climate change mitigation<sup>1</sup> strategies to reduce the emission of greenhouse gases. However, due to the particular sensitivity and vulnerability of urban populations and infrastructure to extreme weather and climate events, adaptation<sup>2</sup>

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<sup>1</sup> Mitigation—limiting climate change—involves reducing the flow of heat-trapping greenhouse gases into the atmosphere, either by reducing [sources of these gases](#) (e.g., the burning of fossil fuels for electricity, heat, or transport) or enhancing the “[sinks](#)” that accumulate and store these gases (such as the oceans, forests, and soil). [The goal of mitigation](#) is to avoid significant [human interference with Earth’s climate](#), “stabilize greenhouse gas levels in a timeframe sufficient to allow ecosystems to adapt naturally to climate change, ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner” (from the [2014 report on Mitigation of Climate Change](#) from the United Nations Intergovernmental Panel on Climate Change, page 4).

<sup>2</sup> Adaptation—adapting to life in a changing climate—involves adjusting to actual or expected future climate. The goal is to reduce our risks from the harmful effects of climate change (like sea level rise, more intense extreme weather events, or food

strategies are also crucial. Consideration of mitigation and adaptation together can lead to improved outcomes, particularly for those with greatest vulnerability. For example, relying on air-conditioning systems increases greenhouse gas (GHG) emissions and also releases the heat from buildings to the outside environment. This can amplify the urban heat island effect by approximately 2°–4°F and disproportionately affect people that do not have access to cool spaces.

Interdisciplinarity and co-construction are essential to achieve the goals of mitigation and adaptation. City stakeholders and other urban partners need information and methodologies adapted to their territories and local issues. Development of local meteorological observation networks (e.g., for the UHI) can be a way to expand the database that decision-makers need to improve their understanding of the relationship between weather and climate drivers and intracity vulnerabilities and the efficacy of alternative responses. AMS encourages transdisciplinary actions between scientists, private companies, and the public sector not only within the weather, water, climate enterprise but also across the architecture, geography, sociology, economy, transportation, law, and governance sectors. Such transdisciplinary cooperation is necessary for mitigation planning as well as to advance the development of future adaptation policies aiming to improve the quality of life of all citizens, protect the urban environment, and build smarter and more efficient infrastructure.

## **Urban science and equity, inclusion, and justice**

Research and applications in urban meteorology can help to improve the quality of life and resiliency of all people, but social disparity and poor urban infrastructure exacerbate the problem for the most vulnerable urban citizens.

The urban climate science and services community can coordinate with other fields of science, especially the social sciences, to provide a holistic understanding of the myriad challenges of unequitable city living and biases of policy implementation and capacity building. For example, to limit health impacts during heat waves, identification of hot spots in cities is necessary but not sufficient. Urban cooling actions and planning (e.g., urban greening) should not inadvertently contribute to increased vulnerabilities in other neighborhoods. Adaptation actions should focus on vulnerable populations and strongly consider diversity, equity, and inclusion in their decision-making processes. Importantly, the most vulnerable communities are often the least understood and their needs underrepresented in urban development processes, so special efforts must be made to engage these populations and meet their needs. While urban expansion can have detrimental effects like the urban heat island effect, careful planning and sustainable development practices can help maximize the environmental benefits while minimizing negative impacts. These include the following:

1. **Efficient land use:** Urban expansion often leads to more efficient land use as it concentrates development in a smaller area. This can help preserve natural habitats and open spaces outside of urban boundaries.
2. **Public transportation:** Expanded urban areas often lead to improved public transportation systems, which can reduce individual car usage and decrease greenhouse gas emissions.
3. **Green infrastructure:** With urban expansion comes the opportunity to integrate green infrastructure such as parks, green spaces, and urban forests. These features help

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insecurity). It also includes making the most of any potential beneficial opportunities associated with climate change (e.g., longer growing seasons or increased yields in some regions).

mitigate the urban heat island effect by providing shade, reducing surface temperatures, and absorbing carbon dioxide.

4. **Economic opportunities:** Urban expansion can create economic opportunities through job creation, increased economic activity, and improved access to services and amenities.
5. **Technological innovation:** Cities are hubs of innovation, and urban expansion can drive technological advancements aimed at mitigating environmental impacts, such as energy-efficient buildings, smart grids, and sustainable transportation solutions.
6. **Social cohesion:** Urban expansion can foster social cohesion by bringing diverse communities together and providing opportunities for cultural exchange and interaction.
7. **Resource efficiency:** Concentrating population and resources in urban areas can promote resource efficiency through economies of scale in infrastructure provision, waste management, and energy distribution.

As it relates to weather, water, and climate, AMS recommends the following actions for city governments:

- Integrate ongoing research and explore new avenues to create strategies for mitigating and adapting to weather and climate-related hazards in urban areas, aiming to reduce their impact and manage associated risks effectively.
- Establish dense urban meteorological and air quality monitoring networks and ensure that the collected data are easily accessible to the public through open access channels.
- Foster a collaborative, interdisciplinary approach to address weather- and climate-related challenges across various sectors, with a focus on mitigating their impacts on vulnerable communities within urban environments.
- Utilize all available resources to combat the urban heat island effect, incorporating conservation efforts, technological innovations, and emerging practices. Additionally, consider implementing incentives to encourage investment in improving the overall quality of urban living for all residents.