ESTABLISHING INTEGRATED WEATHER, CLIMATE, WATER AND RELATED ENVIRONMENTAL SERVICES FOR MEGACITIES AND LARGE URBAN COMPLEXES – INITIAL GUIDANCE

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Executive Summary

Urbanization, a global phenomenon, is changing the face of human habitation of Earth in the 21st Century. During the first decade we reached the point where 50% of the global population were urban dwellers. Urbanization will further accelerate, especially in developing countries, resulting in a rapid increase in city size and the number of megacities and large urban complexes, many of these along coastal areas. The urban dweller has become especially vulnerable to the impacts of weather and climate extreme events and their environmental consequences. These events often result in domino effects in the densely populated, complex urban environment in which system and services have become interdependent. There has never been a bigger need for user-focused urban weather, climate, water and related environmental services in support of safe, healthy and resilient cities.

People are central to the city and it’s functioning. They require new services that make the best use of science and technology. Each city has a unique set of hazards and risks it faces and this will require tailored priorities when designing these services. Cities also provide unique opportunities to capitalize on the co-benefits that can be achieved by optimizing energy use, improving air quality and minimizing greenhouse gas (GHG) emissions that drive global climate change, through the integrated use of urban weather, climate, water and related environmental services. However, to deliver these services and realize their benefits will require strong and wide-reaching institutional cooperation.

The needs and requirements in each city will be informed by holistic impact and hazard identification to map a city’s specific vulnerabilities and identify the services that would be most beneficial. Coastal cities have different concerns to land-locked cities; similarly requirements of an urban area in the tropics differ from a city that is often impacted by severe winter weather. Data sharing arrangements between city institutions is a fundamental building block for authorities to reach conclusions on the priority services and further to design and establish urban observational networks that capture the phenomena of interest at the spatial and temporal resolution required.

High resolution coupled environmental prediction models that include realistic city specific process, boundary conditions and fluxes of energy and physical properties will be enhanced and developed for the provision of urban services. New urban-focused observational systems are needed to drive these models and to provide high quality forecasts used in these new services. The use of new, targeted and customized dialogue using modern communication techniques with users is required to ensure that services, advice and warnings result in appropriate action and in return inform how best to improve the services. New skill and capacity will be required to make best use of technologies to produce and deliver new services in the challenging and evolving city environment.
National Meteorological and Hydrological Services (NMHSs) are encouraged to establish sound working relationships with municipal authorities and jointly identify and agree on the priorities for joint services and the resources required for sustained service delivery and improvement. Considering the global importance of urbanization, the growing number of mega-cities and large urban complexes, WMO Members would do well to include addressing this phenomenon as a high-level priority and consider how best to also include the unique climate service requirements of the urban environment in the Global Framework for Climate Services (GFCS). WMO Members should showcase their urban experiences, share their experiences and establish best practices as to how to best serve the urban dweller who now is rapidly becoming a majority stakeholder in weather, climate, water and related environmental services.
1. Context

With more than half the world’s population living in urban areas, and the expectation that this proportion and the absolute numbers will increase through this century (UN 2011), it is essential that we establish the capability to provide the necessary environmental information for cities to function safely and well. These cities range from conurbations (e.g. Pearl River Delta) to megacities (e.g. Tokyo, Sao Paulo), to large cities (e.g. London) all the way to small urban areas. Each share common characteristics, notably a high density of population which makes them more sensitive to weather/air quality/climate variations inducing/enhancing health impacts (e.g. epidemic breakouts, respiratory chronic diseases in vulnerable groups, etc.) and affecting socioeconomic activities (transportation, tourism, construction, school access, etc.).

As a large number of activities within the city and nearby are impacted by weather and climate, many, wide ranging agencies have responsibility to provide appropriate services to address these effects. The performance of these agencies can be enhanced with better weather and climate information, resulting in improved quality of life of the citizens and the country as a whole. This may be through better preparation for extreme temperatures, enhanced targeting of responses to flooding, appropriate contingency planning for major sporting/musical/economic events, reducing people’s exposure to air pollution and generally allowing improved day-to-day planning. Given that the critical economic and political infrastructure for a country lies usually in cities, the benefits extend beyond the boundaries of the city itself.

National/regional weather services working with the wide range of public and private agencies that need weather, climate, water and other environmental information can together develop the required services. Urban environmental services can provide information and advice for the municipalities to implement rational planning and development that will increase efficiency and reduce economic losses in the energy, transportation, and health sectors. Increasing efficiency of these services will also work towards mitigating emissions (including greenhouse gases) and lead to more healthy, prosperous and sustainable cities.

As the components of urban systems are tightly intertwined, having good predictions that are tailored for the different systems, spatially explicit at the appropriate scale and refreshed at appropriate time scale allows for the systems to be operated effectively. This is especially important when extreme events are occurring. For example, heat waves cause often enhanced energy demands, changes in consumer patterns and have consequences on health. Similarly, intense precipitation storms may be associated with lightning strikes and flooding, with impacts to transport networks, energy usage and accidents requiring emergency response from the police, fire department and health related groups. These two examples illustrate a cascade or domino set of effects. If the various groups that need to respond rapidly and most effectively are going to optimise their response, small area forecasts are needed that identify which part of the city region are most likely to be exposed to the hazards. Combining the forecast with detailed information about the city,
the people and the infrastructure, allows these resources to be used most appropriately. Services using new communication methods and available technologies will ensure that short term responses can rapidly assimilate data to be used in enhanced forecasts and to communicate tailored products to end users. These services can also provide tools to support long term planning to ensure that cities develop appropriately in the future. As cities are the largest sources of GHGs and impact the surroundings in numerous other ways, ensuring more sustainable living in cities will benefit not only the majority of the global population but also the global environment.

2. Users and Services

People, be it urban or rural dwellers, need weather, climate, water and related environmental services. The focus of this document is on megacities and large urban complexes, therefore it is important to focus on what distinctive aspects of user needs relate to these and to those who live in them. By definition, megacities are very large with high density of population. Such a large entity is heavily dependent on the underlying infrastructure including all transport systems (road, rail, pedestrian, bicycle, etc.), water and power supply, sanitation and drainage systems, and communication networks. The complexity of that infrastructure together with the implied vulnerabilities increases in a non-linear fashion with size. Doubling the size of a city may quadruple the complexity and therefore vulnerability.

On the other hand, cities also have many positive attributes. They have economies of scales that can be tapped to enhance more efficient service delivery. They provide a vibrant backdrop to innovation, cultural interaction and economic progress which exert their influence on the future mode of service delivery. They are hubs for transport, manufacturing and the latest innovation in communication and information technology. A recent study has pointed out a so-called ‘superlinear scaling’ observed in cities: as a city’s population doubles there is on average a 15% increase in wages and patents produced per capita while at the same time requiring 15% less infrastructure per capita to provide the same services. Cities therefore inherently promote efficiencies and could, if managed well, provide part of the answer to many of the dilemmas being faced by humankind. In considering the role of Meteorological Services (MS) in serving a megacity, it is essential to gain knowledge of the infrastructures, an understanding of their complexity, and awareness of their vulnerabilities to ensure that the meteorological services are properly targeted at the most essential elements for each user group. While some vulnerabilities may be common to all megacities, many will be specific to each particular one and will be related to its geographical, climatological and cultural characteristics.

In designing weather, climate and environmental services for a megacity, the MS should work very closely with the city government and all relevant agencies, both those in the public and private sectors. Through this engagement, the MS should aim to develop a broad understanding of the key challenges in maintaining a resilient city, while the city government should develop an appreciation of the wide range of weather, climate and environmental services that can be provided
by the MS in support of management of the city. Building this strong relationship between the MS and the city government is therefore a key enabler in the optimum provision of weather, climate, water and environmental services to the megacity or large urban complex.

Ideally, Meteorological Services should aim to provide weather, climate and environmental services in a seamless fashion across all temporal and spatial scales, ranging from long-range climate change projections to nowcasting products and services.

Meteorological records collected, archived and made available through a MS represent a key resource in designing and developing a megacity. These records should be fully understood and used in planning and developing the physical infrastructure of the city, to promote safety, sustainability and resilience and for the well being and health of the inhabitants. Climate services will also be necessary to identify changes to the climate of the region and the urban area, often a consequence of the very existence of the megacity. The urban heat island effect is the most obvious of these, but there may also be changes for instance to precipitation and wind patterns, and to the hydrological characteristics of the region. Climate services can also contribute to the appropriate choice of plant species for use in parks and other green belt areas, contributing to the recreational amenity and well being of the citizens.

Provision of daily forecast information, both in general form to the public and in more tailored form to the city management and agencies, represents the most obvious contribution which Meteorological Services can make to any city, but these are all the more important in the case of megacities. Normal day to day weather variation between, for example, wet and dry weather will have a major impact on the traffic volumes and on journey times, and this effect will be amplified in a large metropolis. On the economic side, tailored weather forecast information for the many and varied tasks related to the routine maintenance and upkeep of the city can contribute greatly to minimizing costs and maximizing the benefits of this work.

It is at times of severe or high impact weather, at times when the critical infrastructure of a megacity can be put at risk, that weather services can make their greatest contribution through the provision of timely and accurate warnings. For warnings to be useful, Meteorological Services and city government officials and agencies need to establish detailed procedures and protocols for dealing with a range of severe weather scenarios. Weather warnings should span the range from early warnings (up to a week in advance) which will enable city officials to mobilize resources and ensure readiness right through to warnings at very short ranges such as those which track severe convective systems.

Where possible, early-warning systems should link all hazard-based systems. Sustainability and efficiency can be enhanced if systems and operational activities are established and maintained within a multipurpose framework that considers all hazards and end users’ needs. Multi-Hazard Early Warning Systems (MHEWS) are expected to be activated more often than a
single-hazard warning system and, thus, should provide better functionality and reliability also for dangerous high-intensity events (such as tsunamis) that occur infrequently. Multihazard systems help the public to better understand the range of risks, they also reinforce desired preparedness actions and warning response behaviours. The Shanghai MHEWS, for example, is designed to cope with the threats from tropical cyclones, storm surges, rainstorms, heat and cold waves, thunderstorms, and air pollution as well as their cascading effects, such as floods, health impacts, accidents, and infrastructure damage (see Fig. 1).

![Figure 1 - Part of the new Shanghai Meteorological Service multihazard warning center](Photo credit: authors)

From the user point of view, the two core concepts upon which a MHEWS is established are (World Bank, 2013):

- Establishing laws, regulations, and standardized operating procedures and mechanisms for a multiagency response—which clearly identify roles and responsibilities
- Providing operating procedures for early detection, briefing, and warning dissemination on the basis of good observations and forecasts.

A MHEWS should ideally incorporate all risks and vulnerabilities that are both natural and man-made. Many disasters are multi-dimensional. For example, an industrial fire may lead to widespread atmospheric contamination and also to power outage, with subsequent loss of heating or cooling for the entire city or parts of it. The warning system should be able to encompass all the potential consequences that may flow from a single extreme event.
Hazard Domino Effect (Snow storm)

Natural Events
Weather factor is the first collapsed plat of domino.

Snow Storm
Traffic chaos (road and subways)

Social Events
Energy Supply in Emergency
Transportation of coal and food influenced

High tension power grid Colapsed With Demand Electricity transmission to Shanghai

Figure 2 - Examples of domino effect impacting a megacity/urban complex
Given that a multihazard system usually focuses on managing the potential cascade of disasters stemming from an initial hydrometeorological hazard, the primary, secondary, and sometimes tertiary impacts require well-ordered coordination and cooperation to support highly sensitive users as well as the general public. This multiagency coordination and multiphase response requires standard operating procedures (SOPs). Using Shanghai as an example, this has led there to the concept of the five earlys: (a) early monitoring and warning, (b) early briefing (for special users and agencies well in advance of public warnings), (c) early warning, (d) early dissemination, and (e) early handling. (World Bank, 2013)

Another example is the so-called “CLAP” approach that the Shanghai Meteorological Service has developed. This involves creating focus areas that consider:

a) Critical location: e.g., a facility such as a major power plant
b) Line: a certain category of operation, e.g., traffic control
c) Area: a geographic vulnerability
d) People-centred: the highly sensitive groups impacted by certain weather conditions, such as the elderly or very young

A major responsibility of a MS is to provide timely and accurate forecasts and warnings of hydrometeorological events and hazards. However, in order for governments, economic sectors and the public to take appropriate action, they need to understand how the hydrometeorological hazard may impact their lives, livelihoods, property and their economic activity. Defining disaster risk and forecasting hydrometeorological impacts is generally beyond the remit of meteorologists and hydrologists, however, an understanding of these impacts can be developed through engagement with disaster management officials and other relevant experts. Since the risks and impacts associated with extreme weather events are dynamic, it may be argued that NMHSs who develop this capability and understanding through these engagements are best equipped to forecast their impact. (World Bank, 2013)

In order to effectively forecast the impact of severe weather events and assist society to mitigate these impacts, Meteorological Services and city governments need to improve services at the grass-root level and promote awareness of activities that the individuals can undertake to protect themselves, along with developing an understanding of resources or actions that groups can draw upon/undertake to provide mutual support. See Box 1 for the case for Mexico City.
### Box 1 - Example of Mexico City: Current legal framework, institutions and their responsibilities and potential opportunities in the future

<table>
<thead>
<tr>
<th>Legal Framework</th>
<th>Civil protection is supported by different levels of Mexican legislation:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Constitution level: article 123 covers security and health of worker in facilities</td>
</tr>
<tr>
<td></td>
<td>• Law level: General Act for Civil Protection (2000) defines the general terms of each state law on civil protection and the regulation of each state on Civil Protection.</td>
</tr>
</tbody>
</table>

| Institutions that manage the environmental and meteorological risks | CENAPRED (National Centre for Disaster Prevention): in charge of risk management and disaster prevention in Mexico. The federal agency reduces population exposure to meteorological, geological and chemical hazards such as volcanic eruptions, flooding, tropical storms, earthquakes, and chemical releases, among others. National Meteorological Service (SMN): provides meteorological information at national and local level, including, e.g., on hurricanes and depressions, events that can affect economic activities and cause human life loss. The climatological database is managed by SMN. They share information in newsletters or special advisories through fax, modem, phone or internet to specific users such as Interior Ministry, National Defense, Navy, Environmental Secretary, oil companies, electricity companies, Tourism Secretary, state governments, mass media, airports, hospitals, insurers, general public and the National Service of Civil Protection. SMN has begun collecting information from other meteorological networks from other institutions, such as electricity companies, agricultural stations (INIFAP), the navy, and university networks. Environmental Secretary (SMA): Manages Mexico City’s Air Quality Monitoring System - AQMS (Sistema de Monitoreo Atmosférico - SIMAT). This network issues alerts about critical pollution levels and prevent exposure to harmful pollutants. Contingency actions are in place for when measured pollutants levels are above critical thresholds. Meteorological forecasts are used to support the possible termination of contingency actions. Megalopolis Environmental Commission (CAM): Covers six states in central Mexico. The commission implements policies, handles air quality monitoring, emissions standards and smog-check issues in this region. |

| Opportunity Areas | Meteorological information is crucial to reduce economic and human lives losses and a set of services can provide a guide to reduce exposure, enhance preparedness and awareness of weather and environmental events. SMN currently retrieves surface and aboveground meteorological data for use in models using GFS and data assimilation. Model information is provided to CENAPRED to evaluate weather events but (as opportunity area) could be used for volcanic ash, wildfires smoke, sand and dust storms (SDS), pollen, spores and pollution dispersion. A collaborative team among CENAPRED, SMN and universities could be established and managed by CAM in order to produce a new set of products, services and indices for risk reduction by using forecast information, for short and seasonal terms. Interaction with the Atmospheric Science Centre at Universidad National Autonoma de Mexico (UNAM) is an important factor due to the nature of research and products provided by it. (e.g., meteorological forecast, pollen forecast, air quality forecast, volcanic ash dispersion forecast). More interaction between Health Ministry and air quality monitoring agency can induce a better understanding between dose response relations that are specific for the city/country. |
3. Underlying concepts

A broad set of concepts defines the development of an Integrated Urban Weather, Climate, Water and Related Environmental Service. For the purposes of this document and ease of reference, this is abbreviated here IUWCWES. These concepts relate to the conditions faced by urban populations and the impacts of environmental conditions on the mega-city and urban society, the need for a legal framework and clearly defined government agency interactions to enable creation and maintenance of such a system, and the advances of science and technology required to develop and implement such a system. These concepts are elaborated on below.

a) People and their environment

Cities and urban dwellers are consistently exposed to natural and human caused hazards related to the local environment through many events and interactions, such as severe weather, transmission of diseases, health issues impacted by pollution, and other factors. Responses to these events and interactions are dependent on vulnerabilities, exposure, resilience and risk reduction readiness. A mega-city integrated meteorological services project can enhance the ability to respond to these hazards and thereby reduce the impacts and improve the lives and health of the people in a city / urban environment. For example, urban air quality impacts on the health of city inhabitants can be reduced through appropriate warnings and information that allow people to take actions to avoid or reduce exposure. Moreover, benefits can be accrued from an integrated weather service system by industries and other social structures through optimal use of integrated information for planning and day-to-day and longer term decision making (e.g., by the energy industry).

An integrated approach that takes into account the full earth-city-people system is required to meet the needs of individuals as well as communities for improved services. Implementation of enhanced integrated weather services can be expected to lead to a better city and better life for the people inhabiting the city. Development of such a system will take advantage of the more advanced understanding of the interactions between human activities and the environment that has been accumulated in recent decades, and will help to further develop that knowledge through experiences and examinations of applications and outcomes of the system.

Finally, understanding implications and impacts of the city environment (e.g., heat islands, pollution levels) on the longer term climate in the local and extended region will allow better decision making and planning that will help make cities more resilient to climate change and enable future generations of the city population to prosper.

b) Agency and government interactions and connections

The ability to develop the required suite of services is critically dependent on support and collaboration among agencies and municipalities, including the weather service agency, local governments, and service facilities and organizations (e.g., social service organizations, emergency
managers). To ensure success, the legal and legislative framework for such a collaborative infrastructure must be established early in the planning, to visibly specify roles and responsibilities. Clear delineation of the connections among the various partners in developing these services is another essential ingredient to ensure seamless development and application of integrated services. Establishment of criteria and processes for accountability will ensure longer-term continuation of the service and contribute to improvements and enhancements to the system. Harmonization in collaboration with external expertise and guidelines (e.g., international organizations such as WMO) will increase the breadth of impact of the service, facilitate collaboration with other countries embarking on similar efforts, and aid in securing longer-term support for the effort.

c) Science and technology

Development of an IUWCWES system requires scientific and technological development in many areas. Some examples include (a) development of understanding and knowledge regarding enhanced observational needs to meet the requirements of integrated services in mega-city and other urban environments, and identification of observational source locations in complex environments; (b) development of concepts, scientific capabilities and technology for seamless services; (c) development of the science and technology required for provision of service applications to society; (d) development of smart delivery approaches, including the application of new technology to create an “intelligent and wise” city; (e) development of methods for efficiently making use of large, complex databases (i.e., "Big Data"); and (f) development and implementation of user-relevant approaches for evaluating the quality and benefits of products and services. Accomplishing these activities will require an acceleration of the transition of research capabilities and knowledge to operational systems. The scientific effort is also heavily reliant on extensive sharing of capabilities and knowledge among city organizations that are undertaking comprehensive services system development.

4. Components of integrated urban services

To develop an IUWCWES, action is required on a number of fronts (Fig. 3). In the following section these components are outlined. With time these sections will be expanded further (online) with examples of best practice and lessons learnt by various cities around world. This will also be an important contribution to the capacity building.
Initiation of an Integrated Urban Weather, Climate, Water and Related Environmental Service (IUWCWES)

As every urban area has its own socio-economic, environmental and political setting, it is critical that the first step in initiating an IUWCWES is to identify the hazards (natural and human) that the city is likely to be exposed to and the agencies that need to be involved in the establishment of an IUWCWES. Fundamental to the success of such a system is the collaboration across agencies, involving public and private partnerships (Examples in Box 2 and 3).

Figure 3 - Components of to the development an Integrated Urban Weather, Climate, Water and Related Environmental Service (IUWCWES)
Shanghai Meteorological Service of the China Meteorological Administration (SMS/CMA) aims to change from traditional weather forecasts to weather disaster risk forecasts, to a multi-hazard risk analysis and reduction support approach. To realize this, the focus has been on the risk to site-specific areas from high-impact weather, based on the nature of the weather or weather related hazard as well as the vulnerability and exposure of sites. Thus the resilience of the city infrastructure as well as its capacity for risk management is enhanced (Fig B2.1).

On 1 October 2006, The Shanghai People’s Congress passed the “Shanghai Implementation Regulation of the Meteorological Law of the PRC”. It clarifies the mandate of SMS in disaster risk reduction (DRR). Weather departments are required to provide special services through multi-agency cooperation to, and receive support and feedback from, government departments such as Agriculture, Fisheries, Flood Control, Traffic and Transportation, Fire Control, Police, Environmental Protection, Civil Administration, Public Health, Tourism, Harbour and Maritime management.

Action plans for weather disasters such as heavy fog, freezing rain and snowstorm, heat waves, strong winds and lightning were issued by the General Office of Shanghai Municipal Government (SMG).

The agencies responsible for issuing warnings are members of the Shanghai Emergency Management Response Committee, who actively participate in the MHEWS planning process. The Committee consists of more than 50 members from various government agencies and departments related to the issues of flooding, severe weather, fire, traffic accidents, chemical accidents, nuclear power accidents, public health, earthquakes, and marine emergencies. SMS is a member of the Committee. The primary role of SMS is for ‘Early Warning Generation and Dissemination’. Early warning includes original disaster warnings and secondary level disaster warnings which require cooperation with other departments, such as flood warnings resulting from typhoons.

Figure B2.1 - Linkages between exposure and vulnerability to weather and climate events influence the impacts and probability of disasters (disaster risk). (Source: SMS modified from IPCC 2012)
In February 2013, the Shanghai Emergency Warning Center (SEWC) was established (Fig. B2.2) to make the emergency responses more efficient by bringing all stakeholders and relevant agencies under one roof.

The joint response mechanism to DPM among government agencies has been established; with 36 different joint response mechanisms among 25 governmental departments of the city (Fig B2.3).

An example of joint response warnings and standard response actions: collaboration with Shanghai Flood Prevention Department, Shanghai Water Affairs Bureau. The flood prevention department and SMS have established a joint warning dissemination mechanism for emergency response, thus the flood prevention warning is disseminated in accordance with the 4-level weather warning system through the dissemination platform of SMS.

Figure B2.2 - Role of SEWC in the Shanghai emergency management system (Source: SMS)

Figure B2.3 - Multi-agency cooperation between SMS and relevant agencies (Source: SMS)
Box 3 - Example of collaboration: London

The London Climate Change Partnership (http://climatelondon.org.uk/) brings together groups and expertise in the fields of environment, finance, health and social care, development, housing, government, utility, communications, transport and retail sectors. Their shared interest is to ensure London is a well-adapted and resilient city to extreme weather and future climate change. The partners shape the LCCP work programme, share knowledge, carry out research, develop solutions and influence policy in London.

b) Databases and data sharing

Essential to the IUWCWES is the integration and sharing of data. With higher resolution modelling and observations in a complex and dynamic urban environment, knowledge of all the components in relation to each other is critical. Thus fundamental is a detailed geographic information system (GIS) that allows data to be shared. Such a framework is essential to end-users, allowing data to be provided in the format that will help make their decision-making most efficient. It will also help the IUWCWES to most effectively understand the needs of the end-user.

Existing local information needs to be collected and organized to identify and fill gaps in order to build comprehensive databases for the development of forecast products and services. Such databases need to contain information on: topography, roughness heights, land cover, land use, building heights and vegetation cover, flood levels, population density, vulnerable people, transportation network, hospital admissions, mortality/morbidity, illnesses, emission inventories (including carbon), etc. The development of reliable emission inventories has multiple advantages, including rational urban planning and emission mitigation, and are a key input for air quality forecasting models. They can also provide for the basis for determining anthropogenic heat sources and entry points.

Obviously, (a) database(s) is/are also needed to facilitate data sharing between users that are meteorologists but also end-users. Such databases need to be capable of incorporating new technologies as they become deployed and/or available (e.g., Overseem et al. 2013). Given the complex nature of the urban surface, high-resolution 3-D data is also needed. However, care is needed in the interpretation and assessment of the applicability of the data for particular applications. Thus the ability to easily combine the meteorological data with the supporting GIS (e.g. building height in the vicinity of a site) and other data (e.g., georeferenced heat emissions) will help ensure that the data can be used appropriately. The capability to rapidly assess what areas and conditions measurements are representative of, so the appropriate data are assimilated and better quality model output is provided to the end user so that they can enact the appropriate response is critical. For example, to respond to a chemical, nuclear or biological (CNB) dispersal event, using the correct wind or turbulence data is critical for first responders.
End-users often do not use the best data that are available because the format that NMHS provide the data in is not easily used by others (e.g., Grimmond 2013). Integrated systems must provide the data rapidly in appropriate formats used not only across the meteorological and hydrological communities, but also the broad spectrum of end-user communities

c) Observations

Urban areas have typically been relatively poorly served with respect to observations by NMHSs as the urban environment creates challenges for siting instruments following standard guidelines (WMO 2008, 2012a,b). Although WMO has published guidance for siting some instruments in urban areas (WMO 2012c), typically most sources of canopy layer meteorological data within an urban areas are not operated by NHMS (e.g., Grimmond 2013, Muller et al. 2013a,b). Also, typically, a number of other agencies collect observations in urban areas (see examples in Box 1 and Table 1) that are critical for the development of an IUWCWES.

However, often there are insufficient observations and/or they are not representative of the appropriate area of interest. Thus to develop an IUWCWES the observational network would need in most cases to be enhanced (e.g. Table 2). In addition, attention needs to be directed to the footprint of the various observational systems to identify gaps relative to the urban characteristics.

The complexity of the urban surface means that understanding the scales of processes is critical. Although in every city there will be a wide range of end-user needs and some may have specialized requirements, most applications will benefit from a common type of set of measurements. This typically includes measurements that cover the meso-scale. Observations are needed of the physical and chemical characteristics both horizontally and vertically. Today, it is the vertical information that is most likely to be missing (Grimmond et al. 2010, NRC 2010, 2012). The data can be assimilated to provide improved forecasts which can then be used to improve other end-user products.

At the local scale (e.g., neighbourhoods) and micro-scale (e.g., street canyons, parks), where people live and decisions are made and where end-users need the most specific information, conditions are also the most variable. New technologies will allow crowd sourcing of information (e.g., Met Office WOW sites, Oversteem et al. 2013), but such data collection needs to be closely linked to the surface 3-dimensional characteristics (e.g., GIS data base with building and vegetation outlines and heights) so the information can be used appropriately for applications and modelling.

Strategic selection of monitoring stations and their density is needed, based on the range of applications and the nature of the variability of the city and its setting. To develop a forecast system including weather and air quality, stations should cover all kinds of land uses (e.g., highly dense urban, residential, industrial, suburban), catchments, downwind and upwind areas so that it could be representative of an urban cluster /megacity (Bieringer et al. 2013). Enhancing the density of monitoring sites would be an improvement but is highly dependent on availability of resources. Thus
it is important to know what the available stations are representative of, with a combination of criteria to set priorities for enhanced observational ability. Observational facilities should include ground based (surface instruments, radars, etc.), in-situ and satellite monitoring for both surface and vertical profiling. The criteria pollutants which are directly relevant to health and agriculture should be a priority (PM$_{10}$, PM$_{2.5}$, O$_3$, NO$_2$, CO, HCs). In terms of climate, species like BC, OC, GHGs, and for weather radiation, UV, T, P, H, RF, WS, WD are priorities. Remote sensing is likely to play an important role in permitting measurements in places that are difficult to access (e.g., Lidar oriented in different directions and with different wavelengths can measure a number of aspects of the atmosphere that cannot be measured using traditional sensors, e.g., Wood et al. 2013). New technologies are likely to be developed and trialled in urban areas.

In the context of developing the IUWCWES observational network, the recommendations from the WMO GURME Workshop on Urban Meteorological Design can be taken into consideration, including questions that need to be addressed (Dabberdt et al. 2013):

- Do current observations meet the requirements of urban applications?
- Where are they lacking?
- What is the highest priority in terms of observations?
- How can observations be improved to meet modelling and operational demands?
- How should an existing observing system be updated and designed to meet the emerging requirements for weather and climate research and applications in urban environments?
- Which sensors, procedures, and processes are needed?
- Which measurement strategies will provide the best benefit for cost?
- What are the requirements across the spectrum of data gathering, collection assimilation, archival, and dissemination processes? How can we address them?

In addition to the deployment of the instrumentation and the linkage to surface characteristics, appropriate guidelines and standards need to be followed for quality control/quality assurance. In some cases approaches need to be developed to ensure the nature of urban area is appropriately captured.

The WMO Integrated Global Observing System (WIGOS) is a framework for coordination and evolution of WMO observing systems and WMO contributions to co-sponsored observing systems; a framework for enabling the integration, interoperability, optimized evolution and best practice operation of WMO observing systems. Observations towards urban services may be developed and implemented within the WIGOS System.

The WMO Information System (WIS) has become operational in January 2012. WIS includes Global Information System Centres (GISCs) to coordinate the global exchange of information and Data Collection or Production Centres (DCPCs). The WIS system may be useful for exchange of data for the modelling activities in urban services.
Table 1 - Some examples of urban networks

<table>
<thead>
<tr>
<th>Location, Operated by, Website, Services provided</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>New Delhi/ Pune</strong>, Ministry of Earth Sciences, Govt. of India, <a href="http://safar.tropmet.res.in/pune">http://safar.tropmet.res.in/pune</a></td>
<td>Air Quality &amp; weather - Now, Air Quality &amp; weather forecast, UV Index –Skin Advisory, Air Quality Index (AQI)– Health Advisory ,City Pollution Maps</td>
</tr>
<tr>
<td><strong>Shanghai</strong>, Shanghai Meteorological Services</td>
<td>Weather Forecast &amp; warnings, multi hazard, special reports</td>
</tr>
<tr>
<td><strong>Mexico City</strong>, Environmental Secretary (SMA)</td>
<td>The Integral Atmospheric Monitoring System (SIMAT) network measures meteorological, UV radiation, deposition species and criteria air pollutants and provides AQI, AQ forecast, UV index and AQ alerts.</td>
</tr>
<tr>
<td><strong>UK defra</strong> : Department for Environment Food &amp; Rural Affairs <a href="http://uk-air.defra.gov.uk/">http://uk-air.defra.gov.uk/</a></td>
<td>City wise Pollution Forecast, Latest measurement</td>
</tr>
</tbody>
</table>

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Table 2 - Required observation capabilities to enhance early warnings *(Dabberdt et al. 2013)*

<table>
<thead>
<tr>
<th>Observation</th>
<th>Target Needs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>Heavy rain, Hail Detection, Freezing rain detection</td>
</tr>
<tr>
<td>Wind</td>
<td>High Winds, Wind Shear, Vertical Gradient</td>
</tr>
<tr>
<td>Visibility</td>
<td>Heavy Fog, Haze</td>
</tr>
<tr>
<td>Fire</td>
<td>Fire Source, Smoke Source</td>
</tr>
<tr>
<td>Green House Gas/ Pollution</td>
<td>Chemical Releases, O₃,CH₄,NΟ₂,ΝΟₓ,SO₂,CO,CO₂, Particulate Matter (PM₁, PM₂.₅, PM₁₀)</td>
</tr>
</tbody>
</table>
d) Modelling and prediction

Numerical Weather Prediction (NWP) plays an important role in modern meteorological forecast and service. It is useful to establish a multi-scale NWP framework to forecast from nowcasting to medium-range. Besides extrapolation-based nowcasting systems, a rapid update system for assimilating data, such as radar, is recommended (e.g., for thunderstorm initiation and evolution). For medium-range forecast, an ensemble system is a useful tool for the provision of not only the probabilistic forecast but also for the forecast uncertainty information.

High temporal and spatial resolution are especially important to NWP in cities. A temporal resolution of 1-hour or less and a spatial resolution of 3-km or less are recommended. Physical process parameterization schemes should be carefully selected and tuned. High density of local observations is needed in order to obtain the initial field matching with the high model resolutions. Refined and current land-use categories databases are also needed.

A rapid update cycled (RUC) system is necessary to provide model outputs with high temporal and spatial resolution. At least a 3-hour updated frequency is required. The RUC system should have the ability to assimilate more nonconventional data, including AWS, radar, GPS and satellite data.

It is important to develop an ensemble system to provide information such as probability, extreme, uncertainty, maximum likelihood, etc. The impact forecast and decision-making support service also depend on the ensemble system. The generation of ensemble members should consider both the initial condition error and the model error. More user-oriented ensemble products can be produced to meet specific needs. An application flow should be established to analyze the forecast uncertainty and maximum likelihood by using the ensemble information, tracing the extreme ensemble member and verifying with the observations.

Advanced data assimilation schemes such as 4DVAR, EnKF, or Hybrid Variational-Ensemble are encouraged to be implemented. Using observations with high temporal and spatial resolution is essential for a megacity. Besides conventional data, the observations should include AWS, radar, GPS, satellite, etc., for both surface and vertical profile. The direct assimilating of pollutant data (PM_{10}, PM_{2.5}, O_3, etc.) into the model is important especially for chemical weather prediction.

To generate actionable information for addressing climate risk and opportunities, the providers must rely on predictions of climate, which is commonly defined as the weather averaged over a long period. Climate prediction for a megacity can be done by studying large scale and long term processes, such as ocean temperature and currents, changes in land cover, and slow changing variables in the atmosphere. Ocean and land surface changes can produce fluctuations that are potentially predictable, which makes it possible to predict the climate at seasonal and inter-annual time scales. To provide targeted climate prediction products, prediction models for temperature and rainfall as well as high impact climate events (i.e. heat waves, onset and offset of
Meiyu in Shanghai) are needed to be developed. Furthermore, the uncertainly of climate predictions must be taken into consideration in order to meet the decision maker’s needs.

**Climate change** is a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It may be a change in average weather conditions, or in the distribution of weather around the average conditions (i.e., more or fewer extreme weather events). Climate change is caused by factors that include oceanic processes (such as oceanic circulation), biotic processes, variations in solar radiation received by Earth, plate tectonics and volcanic eruptions, and human-induced alterations of the natural world. Greenhouse gas emissions are one of the most important human induced factors. Increased greenhouse gas concentrations are expected to increase Earth’s average temperature, influence the patterns and amounts of precipitation, reduce ice and snow cover, as well as permafrost, raise sea level, and increase the acidity of the oceans. These changes will influence food supply, water resources, infrastructure, ecosystems, health, etc. Scientists use computer models of the climate system to better understand these issues and project future climate changes and their impacts. To meet the special needs of a megacity, regional downscaling models (dynamic or statistical) are needed to produce refined climate change products.

e) **Applications**

Weather related forecasts are needed to support a wide variety of application services. These include, but are not limited to the following examples.

**Weather** forecasts are used for instance to support diverse aspects of **energy** services, including logistic deployment of repair teams to areas with expected weather related **power** outages, helping to locate and manage wind power production, to support solar power production, forecasts of heat and cold waves to modulate energy production, and for use in optimizing energy efficiency of buildings on a daily basis.

**Air quality** predictions have broad applications that include actions to reduce exposure to the public (through alerts etc.), evaluation of emission reduction strategies, and assistance in guiding urban development and manufacturing (locating industrial facilities, power plants, etc.).

**Health** forecast services make use of AQ predictions for some chronic and acute outcomes. Acute warnings are communicated to the public via air quality indices. Prediction of pollen and spores, and air borne vectors are used to inform/prevent infectious disease exposure. Weather related components are used to forecast insect and flu outbreaks, impacts to heat/cold waves.

AQ predictions of **dispersion** of volcanic ash, smoke, chemical/bio/nuclear releases, including trajectory analysis of plume location, are needed to aid aviation, for emergency responses, fire containment, etc. These services require high temporal and spatial resolution and the additional need for emissions estimation, which is often outside the met services responsibilities.
Weather and air quality also impact forestry and agriculture production. Exposure to ozone reduces yields and aerosols can reduce photosynthetic surface fluxes. Temperature and rainfall predictions (seasonal) influence decisions on crop selection and seed varieties.

**Water** related applications include forecasts of urban flooding and coastal inundation, high waves and storm surges associated with severe storms, and forecasts of the potential for drought conditions, needed for water resource management.

The **transport** sector is vulnerable to a variety of weather and environmental conditions. Shipping, aviation, rail, public and private transport are impacted by snow, rain, high winds, waves, lightning, fog and haze. Forecasts of these weather and environmental conditions as well as the conditions of the roadways are needed for safe, effective and efficient transport of people and goods.

f) **Communications and outreach**

The path from generating raw data to decisions that provide social and economic benefits is complex and needs scientific understanding and linkages with socioeconomic aspects at each step. The observed air quality and weather data, issued forecast or nowcast and alerts should be provided to the public and other stakeholders (e.g., various government organizations, educational institutes etc.) in a manner through which everyone can see the benefits generated through the service and make optimum use. Hence, an essential part of IUWCWES is to design a user-friendly system product.

As an example air quality is addressed more closely here. According to WHO, in 2012 around 7 million people died prematurely due to air pollution. Despite most countries having National Ambient Air Quality Standards (NAAQS), the awareness of high level of air pollution and/or the frequency of exceedence of NAAQS is insufficient for citizens to assess urban air quality. They need the levels and potential health risks of air pollution presented in an understandable format; such as the Air Quality index (AQI) \(^{(USEPA, \ 2003, \ 2008)}\) (Table 3), Health Index or UV Index (UVI). Such indices should be sufficiently flexible to account for different levels of population exposure, variable meteorological and climatic conditions occurring in an area as well as the sensitivity of flora and fauna. For example, the potential risk associated with skin damaging UV radiation can be indicated by UVI. AQI and UVI provide information in terms of colour, and codes which can be easily understood and hence can be considered as public information tools that help to protect public health on a daily basis from the adverse impact of air pollution and harmful solar radiation. There must be health and skin advisory associated with each category or colour code of AQI and UVI for different groups of people including healthy and sensitive, which helps the general public to take preventive measures and minimize the need for drug treatment, hospitalization, lose of productivity and working days, and even helps in intensive care unit (ICU) management.
Main objective of the Air Quality Index (AQI): to inform and caution the public about the risk of exposure to daily pollution levels.

AQI scale: designed to aid understanding of impact of the surrounding air quality to health. Thus improve decision making to limit short-term exposure to air pollution and adjust activity levels during increased levels of air pollution, especially for people who are sensitive to air pollution.

AQI ranges from 1 to 500 (or so) with higher number indicative of greater health risks. The function used to convert from air pollutant concentration to AQI varies by pollutant and by country. AQI ranges are given a descriptor and colour code. Standardized public health advisories are associated with each AQI range.

Driving AQI and Data requirements: Public health impacts of air pollution can be classified as acute and chronic health outcomes, due to exposures to particulate and gaseous air pollutants. These may be different in different countries (e.g. environmental conditions, immunity levels). Hence, defining break points for AQI requires long term data sets on air quality as well as assessed data on mortality, hospital admissions, and other clinically significant health indicators. Environmental Health studies include health effects caused by chemicals via epidemiology, toxicology, and exposure science.

As part of the System of Air Quality Forecasting & Research (SAFAR) a series of products have been developed that get updated each hour so the variability and most recent air quality and weather conditions in the region are known. The established alert network generates E-mail and SMS alerts for extreme weather conditions or air pollution event. The products:

i. Air Quality - Now
ii. Air Quality - Tomorrow
iii. Weather - Now
iv. Weather - Tomorrow
v. UV Index –Skin Advisory
vi. Air Quality Index (AQI) – Health Advisory
vii. City Pollution Maps at 1 km x 1 km resolution

provide information on current and 1-2 days in advance air quality and weather, harmful radiation and emission scenarios across the city area in a very simple and user friendly format. This helps to reduce future losses by helping policy makers and the general public in their decision making. Air Quality Now, Weather Now and information of current UV radiation (UV Index (UVI)) helps to reduce the impact of deteriorated air quality and harmful UV radiation on human health, human skin, agricultural crops etc. Whereas the Air Quality and Weather forecast, associated alerts and city pollution maps provides input for action plans so as to minimize future impacts which directly or indirectly leads to socioeconomic development in the region.
In developing an IUWCWES, inclusion of the **dissemination of information** is important otherwise the maximum benefits will not be obtained (an example in Box 4). In emergency situations, the key is to transmit the information as rapidly as possible as lead-time is a crucial component to being able act and take preventive measures. Thus, there is the need to develop various user-friendly dissemination platforms that are accessible by anyone without space and time barriers. Effective dissemination tools include dynamic professional web portal, Digital Display Board System (DDS), Integrated Voice Response Service (IVRS), communication through the traditional media like press release, media conferencing, TV, radio, generating SMS alerts, E-Mail alerts etc. Information can also be disseminated through leaflets, publications, and by organizing workshops, conferences, symposiums etc. Training or awareness programmes organized to inform
various stakeholders about how they can use the IUWCS products and how they should respond will help to spread awareness rapidly. Consideration needs to be given to the appropriate languages for the products to be available in. Data sharing and active collaboration with the local governmental agencies like local corporations or disaster management units will result in better utilization of the service as it will help governmental and intergovernmental bodies to take preventive measures and develop sustainable policies to reduce future damage caused by extreme air pollution or weather events. These two way interactions can play a crucial role in improving the service products as per users need and help to evaluate the system. Crowd sourcing also allows for two way communications as the general public can provide higher spatial resolution which can be enhance the IUWCWES products which are in turn publicly available.

The establishment of an IUWCWES with its system products will not only help to improve awareness and mitigation planning but help in achieving “better city, better environment, better life” and “faster, more inclusive and sustainable growth” which the providers should be committed to by rendering valuable input regarding services on weather, climate, air quality, and UV radiation. It will also help to reduce total cost of environmental damage.

g) Evaluation

Evaluation of the system and its components is a critical aspect of the IUWCWES system development and is needed to document the benefits of the system for developers, users, and managers. In particular the evaluation should consider each stage and component of the system to understand its contributions to the benefit chain, and to determine if improvements can be made to increase those benefits. More specifically, independent evaluation of a large sample of forecasts and warnings is needed to ensure that the results are credible, and to provide a breadth of understanding of the capabilities of the system. Measures used to evaluate the forecasts and warnings need to be relevant for the users of the system (i.e., user-relevant metrics are required) in order to assess the true quality and benefits of the forecasts; standard “broadly-applied “metrics, such as root mean squared error, cannot meet this need. In addition, extensive efforts are needed to evaluate the actual use of the warnings and other information communicated to end-users in order to examine the usefulness of the system for end users, including the general public and more sophisticated users (e.g., energy companies). In-depth case studies of the use of the warning and information systems are also useful and will provide information that can be beneficial in understanding specific situations and users; however, they do not replace the need for more extensive studies.

Economic evaluation of benefits due to the advisories, alerts and products are important in order to estimate the savings made on the investment of this type of system.
f) Research and Development

Research on basic physical and chemical processes and development of numerical models and tools are an integral and central component of a reliable and accurate forecast products and service systems. As those involved in operational delivery are not necessarily responsible for research and development, strong and long-term partnerships should be established between researchers and operational groups (internal and external).

Numerical models most suitable for an integrated urban weather, air quality and climate forecasting operational system are the limited area models with coupled dynamic and chemistry modules (so called Coupled Dynamic and Chemistry Transport Models, CDCTMs). CDCTMs have been developed mostly over the past 15 years following rapid advances in computing resources plus extensive basic science research (Grell et al. 2000, Wang and Prinn 2000, Mari et al. 2000, Zhang et al. 2003, Grell et al. 2005, Fast et al. 2006, Arteta et al. 2006, Marécal et al. 2006, Barth et al. 2007a, Longo et al. 2013). Current state-of-the-art of the CDCTMs encompass interactive chemical and physics process, such as aerosols-clouds-radiation, coupled to a non-hydrostatic and fully compressible dynamic core including monotonic transport for scalars, allowing feedbacks between the chemical composition and physical properties of the atmosphere. However, simulations using fine resolutions, large domains and detailed chemistry over long time duration for both the aerosol and gas/aqueous phase are still too computationally demanding due to the huge model complexity. Therefore, CDCTMs weather and climate applications still must compromise between the spatial resolution, the domain size, the simulation length and the degree of complexity for the chemical and aerosol mechanisms. A typical model run on the weather scale for an urban domain use a reduced number of chemical species and reactions because of its fine horizontal and vertical resolutions, while climate runs generally use coarse horizontal and vertical resolutions with reasonably detailed chemical mechanisms (Barth et al., 2007b). There are initiatives to expand the related services of large forecast centers.

For example the MACC-II - Monitoring Atmospheric Composition and Climate - Interim Implementation – project is the current pre-operational Atmosphere Service, which provides data records on atmospheric composition for recent years, data for monitoring present conditions and forecasts of the distribution of key constituents for a few days ahead. MACC-II combines state-of-the-art atmospheric modelling with Earth observation data to provide information services covering European air quality, global atmospheric composition, climate forcing, the ozone layer and UV and solar energy, and emissions and surface fluxes. (atmosphere.copernicus.eu)

The representation of the urban land surface has undergone extensive developments but no scheme is capable of dealing with all the surface exchanges (Grimmond et al. 2011, 2012). To complicate this further, as the resolution of models becomes greater, combined with the large size of urban buildings in many large cities, the limits of current understanding are being challenged. Key questions include:
Should buildings be directly resolved?
What can be simplified to make the computations tractable in realistic modelling time?
At what scale can the current land surface schemes and model physics be applied?

Research needs also relate to secondary organic aerosols and its interaction with clouds and radiation, data assimilation including chemical and aerosol species, dynamic cores with multi-tracer transport efficiency capability and the general effects of aerosols on weather/climate evolution. All of these areas are concerned with an efficient use of models on massively parallel computer systems.

Operational centres that base their products and services on CDCTMs not only need to follow closely the evolution of the research and development of these coupled models, but interactively engage with these activities. Research on basic physical and chemical processes and development of numerical models and tools are an integral and central component of a providing reliable and accurate forecast products and services. Nevertheless, operational people are usually not responsible for these research and development activities, so strong and long-term partnerships should be established between researchers and operational groups (internal and external). These partnerships should promote the development of methods of evaluation to measure improvements in forecast skills and benefits. Workshops focused on bringing research and operations together such as the International Workshop on Air Quality Forecasting Research (IWAQFR) series are needed to improve forecast skill and services.

i) Capacity Development

“Know-how” is an important aspect to the success of any agency or operational group. It can be produced by day-to-day experience. To produce valuable products and better services know-how, training and experience sharing among peers are needed. Countries/cities/NMHSs/agencies can reach high levels in operation and management of IUWCWES and/or MHEWS by training in the different aspects of the systems. A programme between educational centres (e.g. universities), national agencies or international agencies can be developed in order to fulfill every requirement in each stage of the development and/or operation of an IUWCWES.

For the actual personnel in agencies related to the IUWCWES, a set of skill specific training programmes can be developed using local and/or international expertise. Sharing experiences by conferences, symposia and workshops is one of the best ways to have interaction among people from different countries and expertise areas that share a common goal. For specific topics like severe weather forecasts, climate change interaction, hurricanes, air quality, study tours, staff exchange and/or expert meetings are recommended. A training aspect is a key factor for a successful operating IUWCWES and these activities can build upon the WMO GAW Urban Research Meteorology and Environment (GURME) project. The WMO established GURME as a
means to enhance the capabilities of NMHSs to handle meteorological and related aspects of urban pollution. GURME is designed to do this through co-ordination and focussing of present activities, as well as initiation of new ones. More details about GURME can be found at the GURME web site, http://mce2.org/wmogurme/

5. Resource Requirements

The following is concerned with what additional resources are needed over and above a current operational meteorological service.

a) Human resources

A good urban weather/climate service means not only accurate forecast on weather/climate-relevant events, but also on the high impact weather and climate events’ effect on the multiple-aspects of the city’s operation and residents’ health and safety. In order to provide better urban weather/climate services, in addition to meteorological experts (weather forecaster, climatologist, applied meteorologist, etc.), multi-disciplinary expertise, including urban related expertise, and technical, professional and supporting staff are needed. Additional skills in social sciences, including communication, and additional skills in IT skills, including GIS, can also play an important role on the urban weather/climate service. Based on this principle, multi-disciplinary urban related expertise is of great need, table 4 lists several related disciplinary expertise.

Table 4 - Examples of additional expertise that will beneficial to support an IUWCWES

<table>
<thead>
<tr>
<th>Related discipline</th>
<th>Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment protection</td>
<td>Handling procedures of pollution events, public protection against pollution, etc.</td>
</tr>
<tr>
<td>Public health</td>
<td>Expertise on acute/chronic disease, communicable diseases, food safety, heat wave, etc.</td>
</tr>
<tr>
<td>Geologic hazard</td>
<td>Mud flow, landslide, (for the megacity located in mountains)</td>
</tr>
<tr>
<td>Flood control</td>
<td>Handling of urban city inundation, inland water resource management, etc.</td>
</tr>
<tr>
<td>Oceanography</td>
<td>Tide, wave, tsunami, seawater encroachment, sediment accumulation, etc.</td>
</tr>
<tr>
<td>Transportation</td>
<td>Control of city transportation, highway management, harbour management</td>
</tr>
<tr>
<td>Social science</td>
<td>Communication, media, leading public opinion, jurisprudence, etc.</td>
</tr>
<tr>
<td>IT</td>
<td>GIS, detection equipment maintenance, software development, etc.</td>
</tr>
</tbody>
</table>

b) System resources

For urban services, scientific- and user-driven observations are necessary to provide enough data for accurate forecasts and services. Furthermore, observation sites are critical for the representativeness of the urban meteorology. Different instrument, equipment and monitoring systems have different kinds of site requirements. It is important for the city government or local management department to provide convenient access to the observational sites.
It would be desirable for the local government to invest in weather service facilities including buildings, computers, detection equipment, and communication network. This naturally depends on the economic situation.

Model systems are required for the provision of an urban service. The model systems usually would include data assimilation and coupled atmospheric models (with multi-time scale and multi-spatial scale) and applied models (i.e., hydrological, chemical, biometeorological, etc.).

A communication and coordination office should be established so that the multi-agency joint action can be coordinated. All relevant agencies should participate in the IUWCWES work. Legislation will help to stipulate responsibilities, and agreements between the meteorological service and other agencies will simplify the cooperation procedures. Importantly, the communication office should have authority and good relationships with all agencies.

c) Technical expertise

WMO Programmes and regional specialized centres are in the position to give important support to the development of the services. This includes the fields of observation and monitoring, modelling, disaster prevention and reduction, and public weather services.

Technical support can also be provided by NMHSs already experienced in the specific area of service, especially by those that are already running MHEWS or IUWCWES projects. Other institutes and academia are likely to be able to provide relevant and useful input, too.

d) Financial resources

The new characteristics of urban services and disaster management with technological improvements means that a long-term investment mechanism is required to meet the dynamic needs of urban safety. Both facilities and software development need ongoing financial support. Central and local governments should participate in the investment into IUWCWES. In addition, paid services for special users, especially for businesses, can provide another channel of financial support to the service provider to allow for sustainable development.

It is important to note that the new urban services offer greater efficiencies and cost savings from the benefits related to a healthier and less vulnerable city.

e) Improving Efficiency and Effectiveness by restructuring service resources

Service resources play a significant role in the whole process, therefore, improving efficiency and effectiveness by restructuring service resources is essential. The service resources include for instance departments and agencies of meteorology, water affairs, aviation, traffic, agriculture, tourism, and construction. An updated mechanism of service planning and organization, service delivery should be established, enhancing efficiency and effectiveness.
6. **Recommendations**

1) Encourage NMHSs to assess their current status and service gaps, and to identify and prioritize new urban services with their municipalities/cities.
2) Establish pilot projects in appropriate areas where possible.
3) Establish an international coordination office.
4) Enhance international cooperation between appropriate organizations.
5) Make urbanization and city related services a priority in WMO.
6) Ensure Urban Framework for Climate Services (UFCS) becomes one of the essential parts of GFCS.
7) Encourage WMO Members to showcase their urban services (for others to learn from).
8) Showcase these activities in appropriate events.
9) Create an urban (megacity)services website (e.g., showcases above).
10) Build partnerships for resource mobilization.
7. References


UN (2011): World Urbanization Prospects, the 2011 Revision, United Nations, Department of Economic and Social Affairs,


World Bank (2013): Reducing the Impact of Hydrometeorological Hazards – National Meteorological and Hydrological Services and Emergency Response


### 8. Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AQ</td>
<td>Air Quality</td>
</tr>
<tr>
<td>AQI</td>
<td>Air Quality Index</td>
</tr>
<tr>
<td>BC</td>
<td>Black Carbon</td>
</tr>
<tr>
<td>CAM</td>
<td>Megalopolis Environmental Commission – Comisión Ambiental Megametropolitana</td>
</tr>
<tr>
<td>CENAPRED</td>
<td>National Center for Disaster Prevention (Mexico), Centro Nacional de Prevención de Desastres</td>
</tr>
<tr>
<td>CNB</td>
<td>Chemical, nuclear and biological</td>
</tr>
<tr>
<td>CLAP</td>
<td>Critical locations, Line, Area and People-centered</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon monoxide</td>
</tr>
<tr>
<td>CSO</td>
<td>Civil Society Organization</td>
</tr>
<tr>
<td>DPM</td>
<td>Disaster Prevention and Mitigation</td>
</tr>
<tr>
<td>DRR</td>
<td>Disaster Risk Reduction</td>
</tr>
<tr>
<td>EXPO</td>
<td>World Exhibition or Exposition</td>
</tr>
<tr>
<td>GFCS</td>
<td>Global Framework for Climate Services</td>
</tr>
<tr>
<td>GFS</td>
<td>Global Forecast System</td>
</tr>
<tr>
<td>GHG</td>
<td>Green House Gas</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>GURME</td>
<td>GAW Urban Research Meteorology and Environment</td>
</tr>
<tr>
<td>H</td>
<td>Humidity</td>
</tr>
<tr>
<td>HCs</td>
<td>Hydrocarbon Compounds</td>
</tr>
<tr>
<td>ICT</td>
<td>Information and Communications Technologies</td>
</tr>
<tr>
<td>ICU</td>
<td>Intensive Care Unit</td>
</tr>
<tr>
<td>INIFAP</td>
<td>National Institute of forestry and agriculture research - Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias</td>
</tr>
<tr>
<td>IUWCWES</td>
<td>Integrated Urban Weather, Climate, Water and Related Environmental Services</td>
</tr>
<tr>
<td>LCCP</td>
<td>London Climate Change Partnership</td>
</tr>
<tr>
<td>MHEWS</td>
<td>Multi-Hazard Early Warning System</td>
</tr>
<tr>
<td>NMHS</td>
<td>National Meteorological and Hydrological Service</td>
</tr>
<tr>
<td>NO₂</td>
<td>Nitrogen dioxide</td>
</tr>
<tr>
<td>NRC</td>
<td>National Research Council</td>
</tr>
<tr>
<td>O₃</td>
<td>Ozone</td>
</tr>
<tr>
<td>OC</td>
<td>Organic Carbon</td>
</tr>
<tr>
<td>P</td>
<td>Pressure</td>
</tr>
<tr>
<td>PM, PM₂.₅, PM₁₀</td>
<td>Particulate Matter, PM size 2.5 µm or less, PM size 10 µm or less</td>
</tr>
<tr>
<td>PRC</td>
<td>People's Republic of China</td>
</tr>
<tr>
<td>PWS</td>
<td>Public Weather Service</td>
</tr>
<tr>
<td>RF</td>
<td>Rainfall (integrated precipitation)</td>
</tr>
<tr>
<td>SDS</td>
<td>Sand and Dust Storms</td>
</tr>
<tr>
<td>SEWC</td>
<td>Shanghai Emergency Warning Center</td>
</tr>
<tr>
<td>SIMAT</td>
<td>Integral Atmospheric Monitoring System (Mexico) Sistema Integral de Monitoreo Atmosferico</td>
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<td>SMA-DF</td>
<td>Federal District Environment Secretary- Secretaria del medio Ambiente del Gobierno del Distrito Federal</td>
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<td>Acronym</td>
<td>Full Form</td>
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<tr>
<td>SMG</td>
<td>Shanghai Municipal Government</td>
</tr>
<tr>
<td>SMN</td>
<td>National Meteorological Service (Mexico) Servicio Meteorologico Nacional</td>
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<td>UFCS</td>
<td>Urban Framework for Climate Services</td>
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<td>Universidad Nacional Autónoma de México – National Autonomous University of Mexico</td>
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<td>UV</td>
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<td>WMO Integrated Global Observing System</td>
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<td>WMO Information System</td>
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