Guidance on Integrated Urban Hydrometeorological, Climate and Environmental Services

Volume I: Concept and Methodology

2019 edition

WEATHER CLIMATE WATER

WORLD
METEOROLOGICAL
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WMO-No. 1234

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EDITORIAL NOTE

METEOTERM, the WMO terminology database, may be consulted at http://public.wmo.int/en/resources/meteoterm.

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EXECUTIVE SUMMARY

This *Guidance on Integrated Urban Hydrometeorological, Climate and Environment Services (Volume I: Concept and Methodology*) serves to assist WMO Members in the development and implementation of the urban services that address the needs of the cities stakeholders in their countries.

Migration to cities creates densely populated environments and associated infrastructure. This results in increasing vulnerabilities and exposure to natural and anthropogenic hazards. In 2015, under Transforming our World: the 2030 Agenda for Sustainable Development, the United Nations identified "sustainable cities and communities" as one of its 17 Sustainable Development Goals.

This Guidance serves to assist in the achievement of this goal. Advances in high resolution (space and time) observation and prediction are permitting the development of Integrated Urban Hydrometeorological, Climate and Environmental Services to meet the needs and requirements of cities. Although such services are early in development and sometimes are lacking full capability, in many cases they already cover issues from provision of multi hazard early warnings (for example, for severe weather, flooding, air quality and health) to advices on urban design, planning and zoning that require commensurate microclimate information on the city block scale. Urban services are usually within the mandate of city governments but require some information from regional and national scales. The provision and application of hydrometeorological, climate and environment urban services are within the capability and capacity of many National Meteorological and Hydrological Services (NMHSs). Owing to co dependencies, delivery of effective and efficient urban services requires integration, cooperation and collaboration among different scientific disciplines, urban professions, various levels of government, the public and the private sector.

The concept and methodology presented in this report is based on the outcomes of two Member surveys and the expertise of the members of the inter-programme working group. The content of the report went through extensive consultations with a broader expert community and their input is reflected in this final report. Results from two surveys indicated that several Members have started implementation of Integrated Urban Services. Urban service requirements are city specific and are driven by many local factors such as the natural and human made environment, the science, the applications, the infrastructure, the organizational structure, the mandates and the socioeconomic situation. Indeed, the surveys identified that Members have existing capabilities to deliver urban services, but that there is often a lack of mutual awareness. There is also a lack of interaction and of understanding of the requirements and capabilities of service providers and service users. The challenges of local versus national mandates and of roles and responsibilities can be solved only through collaboration. Multidisciplinary and multiagency approaches are therefore needed. The surveys also indicated different levels of maturity with respect to implementation of Integrated Urban Services.

This document includes recommendations on the establishment and provision of the Integrated Urban Services by WMO Members.

1. INTRODUCTION

Accelerating growth of urban populations has become a driving force of human development, especially in developing countries. Crowded cities are centres of creativity and economic progress; however, polluted air, extreme weather conditions, flooding and other hazards create substantial challenges in the urban environment. The United Nations Conference on Housing and Sustainable Urban Development in October 2016 adopted the New Urban Agenda (United Nations, 2017), which brings into focus urban resilience, climate and environment sustainability, and disaster risk management (Box 1).

Box 1. United Nations New Urban Agenda

Quito Declaration on Sustainable Cities and Human Settlement for All (partial)

1. We, Heads of State and Government, Ministers and High Representatives, have gathered at the United Nations Conference on Housing and Sustainable Urban Development (Habitat III) from 17 to 20 October 2016 in Quito, with the participation of subnational and local governments, parliamentarians, civil society, indigenous peoples and local communities, the private sector, professionals and practitioners, the scientific and academic community, and other relevant stakeholders, to adopt a New Urban Agenda.
2. By 2050, the world's urban population is expected to nearly double, making urbanization one of the twenty-first century's most transformative trends. Populations, economic activities, social and cultural interactions, as well as environmental and humanitarian impacts, are increasingly concentrated in cities, and this poses massive sustainability challenges in terms of housing, infrastructure, basic services, food security, health, education, decent jobs, safety and natural resources, among others.

…

5. By readdressing the way cities and human settlements are planned, designed, financed, developed, governed and managed, the New Urban Agenda will help to end poverty and hunger in all its forms and dimensions; reduce inequalities; promote sustained, inclusive and sustainable economic growth; achieve gender equality and the empowerment of all women and girls in order to fully harness their vital contribution to sustainable development; improve human health and well-being; foster resilience; and protect the environment.

Source: United Nations (2017)

Increasingly dense, complex and interdependent urban fabrics are rendering cities vulnerable. A single extreme event can lead to a widespread breakdown of a city's infrastructure, often through cascading downstream or "domino" effects. Natural hazards in a high-density urban environment can have a significant downstream cascading impact on existing infrastructure and services, requiring short-term mitigation and longer-term planning and policy responses (see Figure 1).

A WMO cross-cutting urban focus initiative supports implementation of the New Urban Agenda and the Sustainable Development Goals (SDGs; https://www.un.org/sustainabledevelopment/sustainable-development-goals/) (for example, SDG 11 on sustainable cities and communities). It does this through the novel concept and approach of Integrated Urban Hydrometeorological, Climate and Environmental Services (hereafter referred to as Integrated Urban Services) for sustainable development and multi-hazard early warning systems for cities. WMO also supports the Sendai Framework for Disaster Risk Reduction 2015–2030, which aims to substantially reduce the impacts of disaster in terms of mortality, economic loss and damage, and disruption of basic services, and to contribute to the mitigation of technological and security risks.

WMO recognizes that rapid urbanization necessitates new types of services (Box 2), which could be achieved through the use of Members' operational practices, science and technology. However, the challenges that Members may face in enabling these services also need to be considered. Integrated Urban Services should assist cities to cope with the challenges of

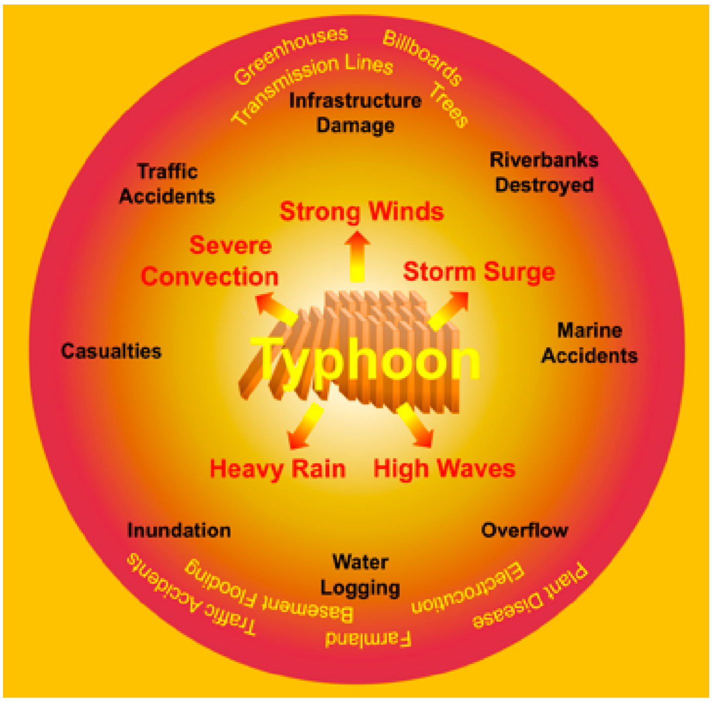

Figure 1. Example of the domino effect

Source: WMO

making good use of: dense observation networks, high-resolution forecasts across different timescales, multi-hazard early warning systems, improved understanding of how to deliver and communicate the information, improved understanding of public perception to Integrated Urban Services information and warning response, climate watch systems, and climate services for risk management and adaptation strategies, within a framework that promotes SDG 11 on thriving sustainable and resilient cities (Box 3).

Box 2. Urban Services

“Urban Services”, in the traditional sense and in the context of city management (by mayors and other city agencies), refers to transportation, housing, water management, waste management, snow clearance and so forth.

In this report, “Integrated Urban Services” refers to the provision of WMO Member weather, climate, hydrology and air quality infrastructure (data, observations and predictions) that may be used to support traditional (and new) urban services. These services may be provided directly through Member operations or indirectly through stakeholders or partners in public and private agencies.

Services include weather forecasts, due thunderstorms, typhoons, costal inundation, flooding, air quality and health-related stress, as well as climate services for building codes, zoning, planning and design.

Integrated Urban Services are inherently high resolution and are provided at roughly the spatial scale of the urban footprint and smaller. However, they are highly dependent on the application, requirements, and local and regional factors. The urban domain is defined by local governments and may include nearby cities, the areas and road in between cities, rural watersheds and locations of industries, in order to capture their impacts. Urban planners may include surrounding areas, as planning in major metropolitan areas will affect housing, transportation and recreation in those areas.

Box 3. Integrated Services

At the most basic level, provision of "Integrated Services" means that the end user receives an appropriate product that takes into consideration two or more of meteorology, climate, hydrology and air quality. These services have generally been delivered individually through different programmes or agencies. Some, if not all, of the critical urban applications are inherently integrated due to co-dependencies. For effective services and efficient delivery, the core issues to resolve are mandate and collaboration.

Integration can mean several things, for example: organizational integration, providing a single access point for services or data, merging monitoring networks, coupled modelling, creating products from distinct systems or providing expertise at the service level. High-resolution local area meteorological modelling is one foundational element for suburban scale services (for example, at the city-block scale), but large-scale phenomena (for example, typhoons or synoptic storms) also affect cities.

WMO has provided assistance to Members for the increasing demands of urban areas to improve resilience to environmental, weather, climate and water-related hazards, increased frequency and severity of weather, water and climate extremes and impacts brought about by climate variability and change, through the following:

(a) Resolution 68 of the seventeenth session of the World Meteorological Congress (WMO, 2015*a*): "Establishing a WMO cross-cutting urban focus"
(b) Decision 15 of the sixty-eighth session of the Executive Council (WMO, 2016): "Implementation of WMO cross-cutting urban focus" and its Annex ("WMO cross-cutting urban focus: outline for implementation framework 2016-2019")
(c) Decision 41 at the sixty-ninth session of the Executive Council (WMO, 2017*b*): "Guidelines for the development of an integrated operational platform to meet urban service delivery needs"
(d) Integrating air quality and urban issues into the WMO Strategic and Operating Plan 2020-2023

In response to Decision 41, WMO created a cross-sector multiprogramme international expert task team for the development of this *Guidance on Integrated Urban Hydrometeorological, Climate and Environmental Services*.

To capture the cross-cutting aspect of the Guidance, contributions were solicited and provided from all WMO Technical Commissions and programmes. The relevant commissions and programmes, particularly the Commission for Hydrology and the Global Climate Programme, identified experts representing the expansion in scope of the previous guidance(WMO, 2014*a*) to include hydrological and climate services. Experts were appointed to an expert task team and a writing team, and included participants from Members, academia, the private sector, urban councils and the Secretariat. To achieve a fully comprehensive review that included a wide breadth of stakeholders and users, this Guidance was the topic of a special session at the Cities & Climate Change Science Conference in 2018 (https://citiesipcc.org/), where participants were invited to review it. Urban focal points within WMO were contacted for their contributions, as well as expert teams, scientific advisory groups and working groups (see the Annex for a list of contributors).

The purpose of this Guidance is to document the concept and methodology of the development and initiation of Integrated Urban Services that meet the special local needs of cities as expressed by stakeholders, and to assist countries and cities in fostering and making the best use of such services.

WMO Members are the intended audience of this Guidance. As it is a cross-cutting initiative, mandates and responsibilities will extend beyond National Meteorological and Hydrological Services (NMHSs), and will be relevant to other concerned agencies at different levels of government, universities, agencies and the private sector. In many cases, these four sectors are not within the mandate of the same agency. The provision of traditional urban services (for example, transportation, planning and zoning) often fall under the mandate of the city government. It should be noted that the scope of the Integrated Urban Services follows that outlined in the *Role and Operation of National Meteorological and Hydrological Services* (WMO, n.d.) and that the private sector and others may also provide services for businesses. Hence, agreements and collaboration are two critical aspects of the Integrated Urban Services concept and its implementation.

In addition, there are significant differences in requirements among Members for weather, climate, hydrological and environmental services. There are existing Integrated Urban Services at different levels of maturity. For example, climate services for severe weather (for example, snow loads, wind loads or return periods of extreme winds) are already used to establish construction codes. At the innovation stage, high-resolution (1 km) numerical weather and climate prediction simulations are being used to generate 10 (or more) year climatologies for urban design and planning at the city-block scale.

Implementation can be significantly different in each instance, depending on the requirements, the capabilities and the resources available. Implementation can be done at the technical level, where different models are coupled (for example, weather and air pollution models or weather and hydrological models), at the product level (for example, where data from different sectors are combined into a single product) or at the service level (for example, where various experts may provide advice to the user).

As Integrated Urban Services are in their infancy and novel in concept, this Guidance is presented in multiple volumes. This first volume articulates the concept and methodology based on state-of-the-art examples of existing Integrated Urban Services and research achievements. The second and third volumes will provide examples, case studies and implementation guidelines. As Integrated Urban Services are emerging, the Guidance will be a living document and will be updated as needed.

Volume I of the Guidance discusses the needs (objectives, requirements and scope) of Integrated Urban Services (Chapter 2), creating the concept and model of integrated solutions for service delivery (Chapter 3), the various components of such a system (Chapter 4), the way forward, research and implementation issues (Chapter 5) and recommendations (Chapter 6). Boxes are used to illustrate the concepts presented in the text and to give some examples.

Part 2 contains four annexes: the Demonstration City Survey (Annex A), the National Meteorological and Hydrological Service Survey (Annex B), Annotated References (Annex C) and Alphabetical References (Annex D).

2. NEEDS FOR INTEGRATED URBAN SERVICES

2.1 Objectives, requirements and examples

Cities are interpreted here as local and subnational authorities with responsibilities for an urban area. They are increasingly organizing and identifying themselves as a force in addressing the challenges of urbanization, climate change, shifting economic and demographic trends and other development issues (for example, through the International Council for Local Environmental Initiatives (ICLEI; http://www.iclei.org). The past two decades have seen the formation of major networks, led or sponsored by high-profile leaders, for example, ICLEI, C40 Cities (http://www.c40.org) and 100 Resilient Cities (http://www.100resilientcities.org).

Through these networks, local and subnational governments are setting goals and calling upon governments, academia and private sector communities to support their initiatives, including the science and innovations required to achieve them. The following objectives are of relevance to this Guidance:

(a) "A resilient city is prepared to absorb and recover from any shock or stress while maintaining its essential functions,[1] structures, and identity as well as adapting and thriving in the face of continual change" (ICLEI, 2018).
(b) "A Smart City has embedded 'smartness' into its operations, and is guided by the overarching goal of becoming more sustainable and resilient. It analyzes, monitors and optimizes its urban systems, be they physical (e.g. energy, water, waste, transportation and polluting emissions) or social (e.g. social and economic inclusion, governance, citizen participation)" (ICLEI, 2018).
(c) "An EcoMobile city fulfils its objective of creating a more livable and accessible city by utilizing sustainable urban mobility principles to achieve significant reductions in greenhouse gas emissions and energy consumption, improvements to air quality, and increased mobility opportunities for all citizens" (ICLEI, 2018).
(d) "A view of resilience that includes not just the shocks—earthquakes, fires, floods, etc.— but also the stresses that weaken the fabric of a city on a day to day or cyclical basis. […] Building urban resilience requires looking at a city holistically: understanding the systems that make up the city and the interdependencies and risks they may face" (Earth Economics, 2018).

Many cities worldwide subscribe to these objectives, regardless of their size and state of socioeconomic development. Their calls for action are driven by the fundamental needs of ensuring the safety of the population and building resilience to extreme weather. They are also increasingly driven by societal expectations of a quality living standard (including long-term city development) and ambitions, supported at the political level, to give cities an economic edge through their image and, in doing so, be competitive with peers in their ability to attract businesses to the cities (for example, see Figures 2 and 3).

Figure 2. Urban development strategic directions towards a liveable high-density city exemplified by Hong Kong 2030+ planning.

Source: Hong Kong 2030+: Towards a Planning Vision and Strategy Transcending 2030 (2016)

[1] http://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/what-is-a-disaster/what-is-vulnerability/

Box 4. Nature-based solutions

Nature-based solutions are the best solutions for cities

Blue and green solutions – an ecosystems approach for urban design (blue refers to adding water elements, and green to adding trees and parks) – need weather, climate, hydrological and air quality information for their design and management at the suburban scale. Sharing basic knowledge on urban processes, models and existing solutions with user community is fundamental for successful implementation of the Integrated Urban Services. Therefore, capacity-building is a basic step for the adoption of the Integrated Urban Services concepts by different professionals (for example, architects, engineers, urbanists and policymakers) concerned about the resilience of cities. Understanding of the tools available from the scientific community is also crucial and must be included as part of academic curricula for urban designers. Databases and existing models should be organized in such a way that they can be easily accessible and useful to professionals. Knowledge of the repositories of data and models on existing examples of applications is needed and should be organized to promote direct access to such tools.

Urban services and city design

Water: forecast of water resources availability (in terms of flow and precipitation) is fundamental in managing the functioning of blue solutions and to activate them during dangerous occurrences. Knowledge of the amount and location of water, its pathways and urban floodplains is needed for integrated flood management (WMO/Global Water Partnership Associated Programme on Flood Management, 2006; World Wildlife Fund, 2017).

Heat: it is important to foster green design over a city to activate secure pathways for fragile populations, to furnish warnings (including climate watch advisories) and to design a proper texture of the city itself (for example, where to place hospitals, schools or commercial centres).

Ecology: ecological pathways within cities are not simply a biological issue – for example, interactions between the air flow and the urban environment affect the transport of biological materials such as pollens, spores and small insects.

City texture and materials: during the design phase, weather and climate information is of fundamental importance to properly design and plan future city structures (open spaces and living spaces). The increased quantity of permeable surfaces has to be considered to improve water retention and therefore decrease runoff and flood peaks.

At the city level, the provision of the Integrated Urban Services will take the form of services that provide support and information, potentially including regulations, to citizens, businesses,

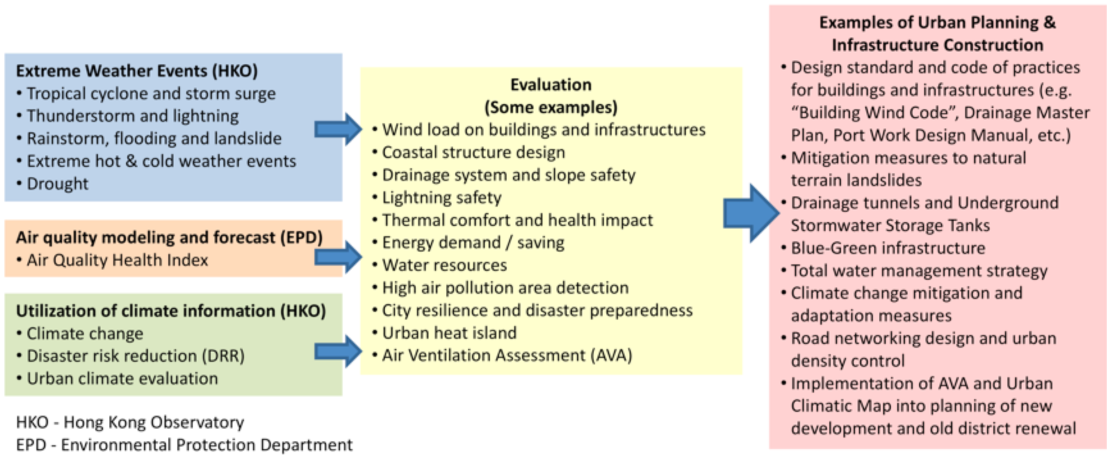

Figure 3. Integrated Urban Services and their impact on urban design and planning – Hong Kong example

Sources: Tsz-Cheung Lee, Hong Kong Observatory; Chao Ren, Chinese University of Hong Kong institutions and responsible authorities on an ongoing basis. Evolution in terms of urban management services requires new approaches because the knowledge and ability to deliver cut across many entities, scientific disciplines and timescales. For example, a heatwave that follows a moderate, yet prolonged, dry spell may require a city to deal simultaneously with enhanced energy demands, an increased load on the health-care system, water quality and supply issues and even wildfires at the urban interface. The magnitude of the impact on city operations will depend on how much lead time there was to anticipate the situation, the available information on the pre-existing drought conditions, understanding of the ramifications to other services and the design of urban systems. The ability to integrate all the information throughout the management of the situation would increase the capacity to cope.

NMHSs produce fundamental data, products and services that are used with or without their knowledge to provide city-level urban services. Many NMHSs have specialized products and warnings that feed into emergency response structures at the national level. In some instances, these extend to more complex multi-hazard early warning systems where NMHSs deliver integrated services within urban settings (see Box 5) . For greater efficiency and efficacy, the agencies involved in the development and delivery of the urban services in Member countries should consider generalizing and specializing their infrastructure (for example, observations, models and products) for urban meteorological, climate, water and environmental management applications. Integrated Urban Services require new and innovative approaches to fully capture the dependencies in the urban system.

Box 5. Shanghai (China) example of a decision-making process

Mandate and responsibility

The Shanghai People's Congress issued the Shanghai Implementation Regulation of the Meteorological Law of the PRC on 1 October 2006. Measures for the Defense of Meteorological Disasters in Shanghai, issued by the Shanghai Municipal Government on 1 March 2017, clarified the mandate of the Shanghai Meteorological Service in disaster risk reduction and weather/climate/environment services. Weather departments are required to provide services through multiagency cooperation, and to receive support and feedback from different sectors (for example, water, traffic and transportation, environment and emergency response).

Organization

As a decision-making organization, Shanghai Emergency Management Response Committee has more than 50 members from various government departments and is in charge of the Shanghai Meteorological Service based Shanghai Emergency Warning Center for early warning and the Shanghai Emergency Response Center for early handling, which brings all stakeholders and relevant agencies under one roof (see Figure 4).

Decision-making and actions

Thirty-six different joint response mechanisms (including cooperation agreements and flood prevention warnings) among government agencies for disaster prevention and mitigation have been established (see Figure 5). Action plans for weather disasters such as heavy fog, freezing rain, snowstorms, heatwaves, strong winds, rainstorms and lightning were issued by the General Office of Shanghai Municipal Government, and each agency has its own responsibilities. Upon receiving an early warning message, actions are taken according to these mechanisms and action plans.

2.2 **Scope**

First-order needs of cities are well documented by the United Nations (2017). They are influenced by geographical (for example, coastal, river, mountainous, polar and desert) and geophysical (for example, fault line, volcano, duststorm, fire danger and space weather) factors, climate conditions and the existing environment of the city itself. Whether NMHSs are already involved

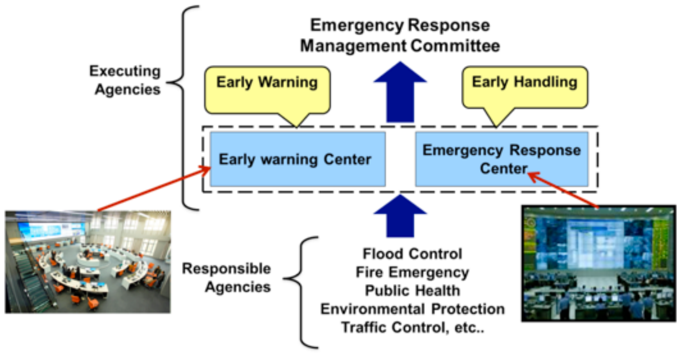

Figure 4. Role of the Shanghai Emergency Response Center in the Shanghai Emergency Management System

Source: Shanghai Meteorological Service

in their provision of urban services or not, many Members are well accustomed to weather, climate, hydrological and environment-sensitive products that can inform services in urban areas. These include monitoring and prediction for:

(a) Severe weather (for example, typhoons and extratropical storms)
(b) Droughts and water resources management, to meet the needs for supply, quality, food and security
(c) Heatwaves and cold waves, including heat stress and extreme cold prediction
(d) Sandstorms, duststorms, wildfires
(e) Flash floods and landslides
(f) River and lake flooding (due to river and lake overflow, storm surges or swell)
(g) Sea-level rise due to climate change
(h) Coastal inundation
(i) Air and water pollution
(j) Chemical and other harmful matter dispersion events
(k) Harmful ultraviolet (UV) radiation
(l) Pollen and other aerobiological allergens
(m) Changes in soils (for example, shrinkage and swelling of clay soils)

Integrated Urban Services should include societal impact predictions, such as:

Figure 5. Multiagency cooperation among Shanghai Meteorological Service and relevant agencies

Source: Shanghai Meteorological Service

(a) Disruptions due to sandstorms, duststorms, volcanic ash, wildfires
(b) Disruptions to key functions such as transportation, telecommunications and energy distribution, due to intense winds, rain, freezing rain, snow, ice, fog, hail, flooding and lightning
(c) Availability, planning and support for renewable energy (for example, solar power and wind energy)
(d) Impacts of typhoons/hurricanes and major storms
(e) Impacts on humans and ecology

Members may need guidance on how to interface the hydrometeorological information with urban systems, as specifics remain to be defined. WMO plans (to educate and train meteorologists in Integrated Urban Services methods (https://public.wmo.int/en/resources/meteoworld/urban-meteorology-environment-and-climate-services to help extend existing services to a range of urban users. Synthesis articles (for example, Grimmond et al., 2010; Mills et al., 2010; National Academy of Sciences, 2012) summarize requirements of local governments, private sector and other city-level stakeholders that represent user needs. No individual organization can unilaterally define the user needs. They must arise from an iterative and consultative process among experts and practitioners.

The needs for integrated services are also not expressed specifically. Integration has proven to be an effective practice in multi-hazard early warning systems, and has demonstrated that the holistic approach should be included in cities' definitions of resilience. Scientifically, the evolution of modelling systems towards comprehensive Earth systems and the extension of forecasting capacity towards sub-seasonal and seasonal timescales, and to the smaller nowcasting and urban scales, provide other levels of integration at the level of modelling.

Services to support longer-term decisions are also being developed: urban design and planning towards resilience in the context of climate change; societal expectations for liveability, health, workability and sustainability; and urban actions to reduce greenhouse gas emissions.

The needs for Integrated Urban Services are wide ranging and require the capabilities that go beyond the remit of NMHSs. However, with operational expertise and understanding of the dynamic physical dependencies within complex Earth systems, NMHSs are equipped to contribute significantly. A hydrological example is the source–pathway–receptor concept used in integrated flood management, where water resource and land-use management is integrated for disaster risk reduction (WMO/Global Water Partnership Associated Programme on Flood Management, 2017) (see Figure 6).

Public understanding of warning messages is critical to successful mitigation. Integrated Urban Services should result in consistent cross-sector messages. However, experience has shown that understanding of warning messages, risk profiles, human response and effective risk communication is a challenge and requires attention.

3. CREATING INTEGRATED URBAN SERVICES

3.1 Concept

The concept of Integrated Urban Services and organization of activities is currently unformalized. Some NMHSs have established systems that can provide partial Integrated Urban Services, subject to mandate, capability and capacity. This Guidance proposes practised approaches to develop and deliver Integrated Urban Services. The concept builds on existing prototypes and operational examples of such systems by conceptualizing good practices.

Figure 7 demonstrates the components of an Integrated Urban Service. The process may be instigated when a need has been highlighted, often following an event that has had significant economic and/or societal impact, such as a heatwave, storm or flood event, or when there is an opportunity for partners to come together with a shared vision of needs (for example, the Olympics or through sociopolitical will). Components of an Integrated Urban Service

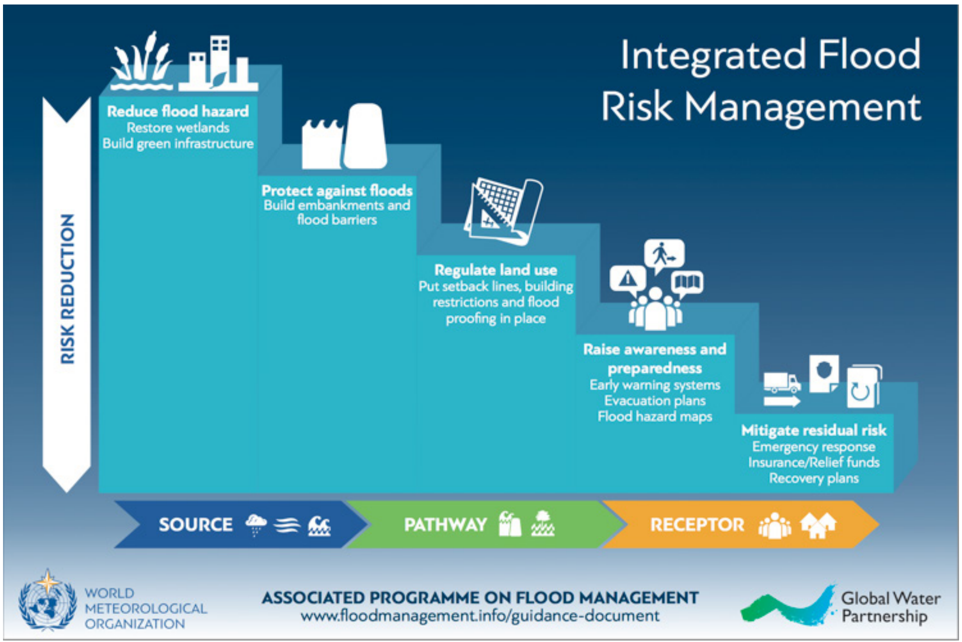

Figure 6. Source–pathway–receptor concept for integrated flood risk management: risk management of the domino effect

Source: WMO/Global Water Partnership Associated Programme on Flood Management (2017)

will be based on identification of the issues and the creation of an appropriate partnership. Understanding the needs of users and capabilities of the delivery partners requires early engagement with a range of existing and potential stakeholders who use (or may use) knowledge, infrastructure and expertise of NMHSs and other provider agencies to make decisions that affect urban-scale policy and actions at short, medium and long timescales. The partnerships that are developed are based on mutual understanding of how best to create and deliver weather, climate, hydrological and environmental services.

The capabilities of NMHSs that include observations, data exchange systems, monitoring and modelling valuable for generation of useful information (post-processing) and that can be utilized by the relevant partners are central to the system. The final step of the service delivery (which also represents the first step in the next development cycle) is a scientific and societal impact evaluation and assessment of the Integrated Urban Services system. This step is required to understand the impact of the services on the city's capacity, if the user needs are met, and helps to identify areas where research and development are required. The resources and skills in academia, research institutes, private sectors and other agencies will all be needed to meet the challenges of implementation of Integrated Urban Services. At each stage of the collaborative process, there is an ongoing training, education, and research and development process. The process is not complete until the partnership is examined to ensure that the Integrated Urban Services is sufficiently resourced for the task at hand.

To function effectively the groups involved in the development of the Integrated Urban Services need to combine and share their information within a given infrastructure. Furthermore, the resulting performance can be substantially enhanced if systems and operational activities are established and maintained within a multi-purpose framework. Best practices from multi-hazard early warning systems established that better functionality and reliability are achieved through frequent activation of systems. Likewise, it is expected that the synergies developed as a result of seamless integrated prediction models (WMO, 2015*c*) will yield the same or more gains for the same costs due to efficiencies of the support of wide-ranging urban environmental management.

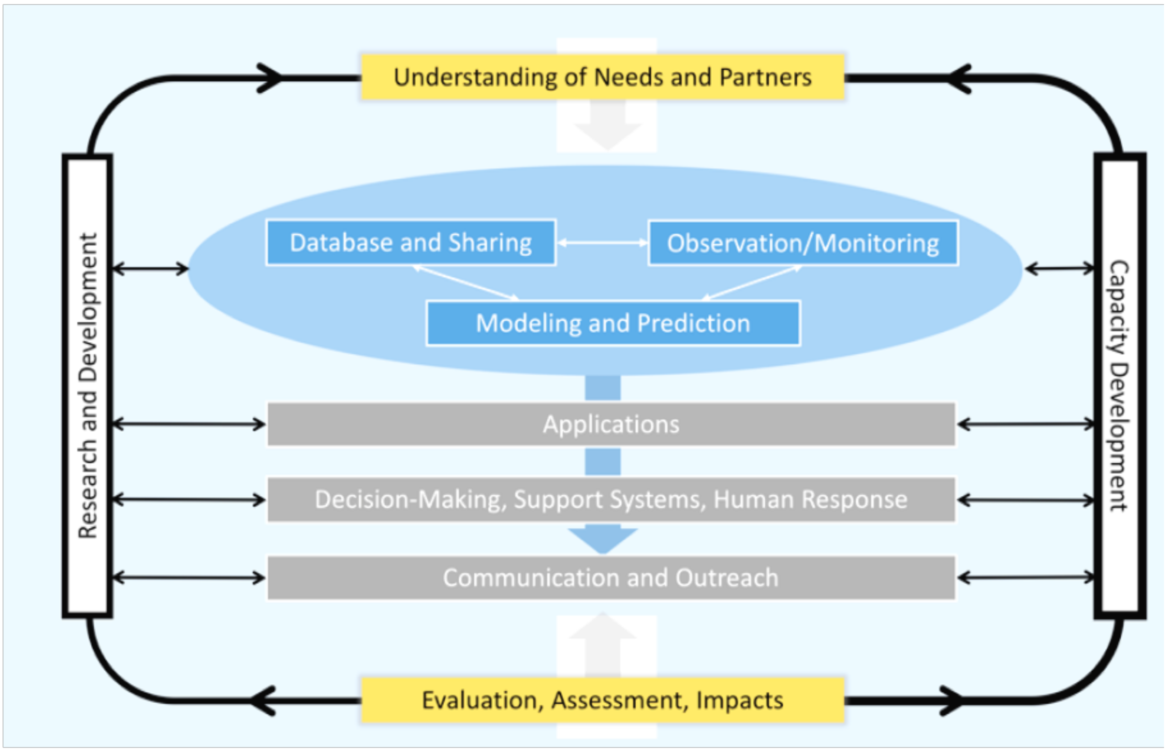

Figure 7. Schematic of the components of an Integrated Urban Services system

3.2 Role of National Meteorological and Hydrological Services

> To implement an Integrated Urban Service, it is important to understand the urban issues, identify relevant stakeholders, develop partnerships and build cross-cutting collaborations. This process requires the development of institutional and infrastructure capacities within NMHSs and/or together with city authorities and other potential providers and users of the information related to urban services.

As recognized in the WMO Convention, NMHSs are a fundamental part of national infrastructure, and play an important role in supporting vital functions of governments (WMO, 2015*d*). NMHSs conduct activities directed at improving understanding of the weather, climate, hydrological and environmental cycle, undertake monitoring of these phenomena, and provide forecasts and services to a range of users to respond to relevant needs. The four sectors (weather, climate, water and air quality) that are considered here may not currently be under the same agency or included in the mandate of NMHSs. One of the key aspects of Integrated Urban Services is to establish mandates and collaborations either through legislation or through cooperative agreements among involved agencies.

NMHSs have a central role in the development and delivery of the Integrated Urban Services due to the following:

(a) NMHS operational systems and service delivery mechanisms are reaching scales where information can interface with the types of applications required by cities. However, important developments are needed to support such applications utilizing adequate scientific basis (for example, urban areas need to be better represented in observations and models).
(b) NMHSs collect observations that are critical to Integrated Urban Services, yet they need to be complemented by observations made by the other agencies and from "unconventional" sources (for example, crowdsourcing) from within the urban environment. Utilization of the new sources of data would require advance assimilation and integration techniques.
(c) NMHSs can best harness the potential and results of specialized research now and in the future.

(d) NMHSs already recognize themselves as key players in bringing the gap between research and operations with potential to foster the development of Integrated Urban Services.

However, NMHSs need to evolve to better utilize their potential for the development and delivery of Integrated Urban Services:

(a) NMHSs need to be prepared to broaden their service offerings, recognizing that there is a shift in the service paradigm resulting from the needs for Integrated Urban Services beyond extremes and emergency situations to include subtler changes in stressors, as well as their cumulated/compounded impacts over different timescales.
(b) NMHSs need to understand the end recipients of the service offering, to ensure they are effectively addressed, and that provided services lead to appropriate behaviours and actions.
(c) NMHSs need to recognize the important role that Integrated Urban Services play in addressing the societal needs and their own roles and responsibilities in provision of such services.

The services currently provided by NMHSs are frequently underused for a variety of reasons, including lack of knowledge or capacity, or poor fit with applications.

It should be stressed that other agencies, particularly those concerned with city design, management and planning, have significant roles and responsibilities in the overall specification, scope, definition, implementation, delivery and utilization of Integrated Urban Services.

3.3 Instigating an integrated system

There is a wide diversity of urban weather and climate, physical, economic and social geographies, governance structures and capacities in cities. They are subject to different environmental constraints, needs and priorities. This means that the Integrated Urban Services that emerge will be specific to city conditions.

Therefore, Members need to identify the specific environmental conditions that affect their cities at different space/timescales, though some of the issues can be common for multiple Members. Some Members already address a variety of urban-related problems such as high-impact weather, air quality, climate extremes, climate change impacts and flooding. Several NMHSs contribute to, or partner with, decision-making agencies on an operational basis. Although instigation of an Integrated Urban Service may come about from a specific post-disaster event, it is the opportunity to develop more broadly considered Integrated Urban Services that can address other urban issues.

3.4 Raising awareness of stakeholders

Before developing new services, NMHSs together with partner organizations should undertake a reflective and comprehensive meta-analysis of the Integrated Urban Services they currently provide, and the stakeholder needs that they satisfy. These services may not be explicitly identified as an urban service and may not be used by urban decision-makers. This analysis should consider the agencies that use this information or those that could potentially benefit from it.

The goal is to develop a partnership network tuned to the identified urban issues – these will likely be time and scale dependent. Responses to different needs, such as a flash-flood event versus a tidal flooding event versus sea-level rise, will require different partners.

The critical item is to identify the key links in the information flow where decisions are facilitated and made (Figure 7, middle grey box).

3.5 Developing links with stakeholders based on expertise

After examination of the existing services as described in section 3.4, NMHSs and their partner organizations need to verify if their services satisfy the user requirements and address the specific concerns of the cities. It is important to engage and listen to city stakeholders, to identify how NMHSs and their partners can enhance their services and use their expertise to address specific issues. Case studies can be used to demonstrate the value of existing or extended services with city stakeholders.

3.6 Building partnerships

This section focuses on the ways to establish the connections and working relationships between HMHSs, other institutions involved in developments of certain elements of Integrated Unban Services and users of the information. Particular elements of the Integrated Urban Services may be provided by universities, national research institutes, volunteer networks and the private sector.

The nature of the partnership relationship is likely to vary based on the legal framework in which the exchanges occur. For example, a memorandum of understanding (MoU) can be signed between the partner organizations (see Box 6). Such MoU's should clarify the roles and responsibilities of partner organizations, could include a common language for communication, address data requirements and establish timelines (see Chapter 4).

Some countries have established or are building a National Framework for Climate Services (WMO/Global Framework for Climate Services, 2018), to coordinate, facilitate and strengthen collaboration among national institutions to improve the production, availability, delivery and application of science-based climate prediction and services to different stakeholders and users. National Frameworks for Climate Services are being initiated, led and spearheaded by NMHSs, which are the only official government-recognized providers of weather, water and climate services in most countries. NMHSs engage all relevant national stakeholders to enable improvements and sustainable delivery of climate services. This is done through permanent and sustained dialogue that helps to identify and prioritize the needs for climate information and products tailored to the decision-making and contexts of different users in a country. Such arrangements represent a potential basis for an Integrated Urban Services partnership.

Box 6. Legal framework and example of partners in Mexico City

Legal framework

In Mexico, civil protection is supported by different levels of legislation: (a) at the constitution level, Article 123 covers security and health of worker in facilities and (b) at the law level, the 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.

Through a presidential decree, the Comisión Nacional del Agua (CONAGUA) is responsible for the national plan and mandate for flood management (CONAGUA, 2013).

Responsible institutions

Centro Nacional de Prevención de Desastre (CENAPRED) is in charge of risk management and disaster prevention. This federal agency reduces population exposure to meteorological, hydrological, geological and chemical hazards such as volcanic eruptions, flooding, tropical storms, earthquakes and chemical releases.

Servicio Meteorológico Nacional (SMN) provides meteorological information and manages the climatological database at national and local levels, including on hurricanes and depressions, and events that can affect economic activities and cause human life loss. It shares information in newsletters or special advisories through communication channels such as fax, modem, phone or Internet to specific users such as the 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. It has begun collecting information from other meteorological networks from other institutions, such as electricity companies, agricultural stations, the Navy and university networks.

Secretaría del Medio Ambiente manages Mexico City's Air Quality Monitoring System (Sistema de Monitoreo Atmosférico). This network issues air quality and meteorological forecasts to alert the public about critical pollution levels and prevent exposure to harmful pollutants. Contingency actions are in place for when measured pollutants levels are above critical thresholds.

Comisión Ambiental de la Megalópolis (CAMe) covers Mexico City and five states (Puebla, Tlaxcala, Morelos, Hidalgo and Mexico) in central Mexico. This commission plans and executes policies, and handles air quality monitoring, emissions standards and smog-check issues in this region.

Opportunity

SMN observation and model information is provided to CENAPRED to evaluate weather events, but (as an opportunity area) could also be used for volcanic ash, wildfires smoke, sandstorms, duststorms, pollen, spores and pollution dispersion. A collaborative team among CENAPRED, SMN and universities could be established and managed by CAMe 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 Nacional Autonóma de México is an important factor due to the nature of research and products that it provides (for example, meteorological, pollen, air quality and volcanic ash dispersion forecasts).

More interaction between the Health Ministry and the air quality monitoring agency can induce a better understanding between dose response relations that are specific for the city/country.

4. COMPONENTS OF INTEGRATED URBAN SERVICES

4.1 Initiation

The general structure of an Integrated Urban Service typically includes the following (see Figure 7):

(a) Observation and monitoring
(b) Data, databases and data sharing
(c) Modelling and prediction capability
(d) Tailored urban service applications
(e) Decision support systems that inform decision-making and include human behaviour/ response considerations
(f) Products, service delivery, communications and outreach
(g) Evaluation, assessment and societal impacts
(j) Research and development
(i) Capacity development

Figure 8 indicates the actions required for the development of an Integrated Urban Service. In a general sense, Integrated Urban Services are built on existing systems, infrastructures and mechanisms. They improve and integrate the following main elements (and subsystems):

(a) Weather (especially nowcasting of high-impact weather at the urban and sub-urban scales, in all conditions, and taking into account the urban influences).
(b) Climate (urban climate, climate extremes, sector-specific climate indices, climate projections, climate risk management and adaptation). Note that the existing Climate Services Information System is designed for producing, and operationally delivering, authoritative climate information and products at global, regional and national scales, through appropriate operational mechanisms, data exchange, technical standards, authentication, communication and products.
(c) Hydrology and water-related hazards (flash floods, heavy precipitation, river water stages, inundation areas, storm tides, sea-level rise and urban hydrology).
(d) Air quality (urban air quality and other larger-scale hazards such as duststorms, wildfires and smog).

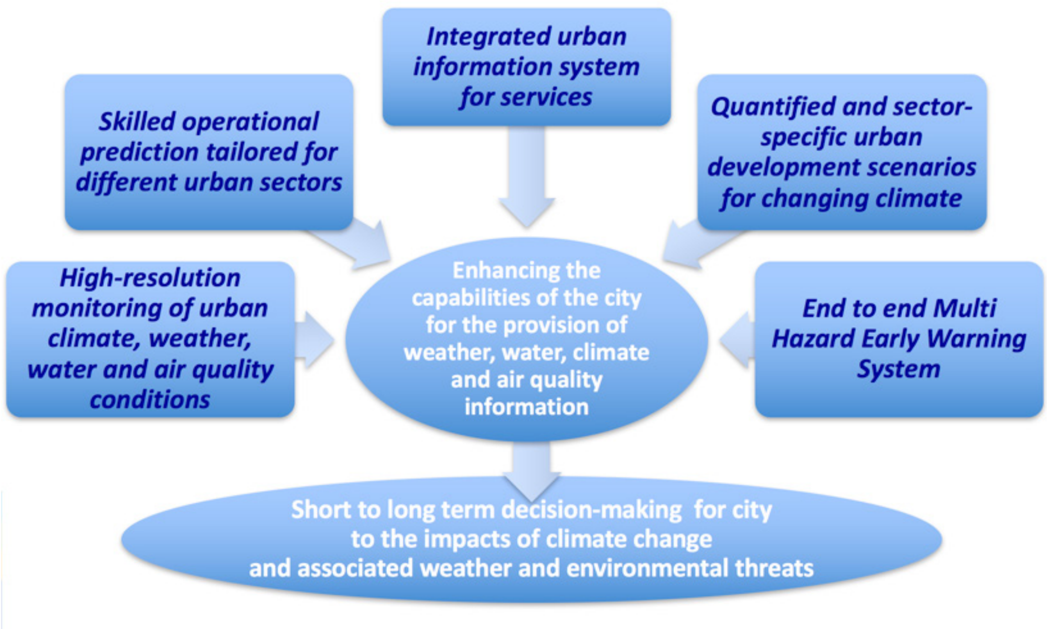

Figure 8. Actions for the development of an Integrated Urban Service

Source: WMO

Figure 9. Seoul example of a multidisciplinary approach for provision of an Integrated Urban Service

Source: Korea Meteorological Administration (WISE, 2015)

As every urban area has its own geographical, socioeconomic, climatological, environmental and political setting, a critical next step in building an Integrated Urban Service is to identify the hazards (natural and human) and other risk factors at urban and larger scales to which the city is likely to be exposed and the agencies that need to be involved. The definition of an urban area depends on location and could be connected with: density (people or buildings), physical topography (bounded by rivers or mountains), political or administrative boundaries (city states or through agreements), hazard sources (watersheds), design or planning criteria (metropolitan region such as Jing-Jin-Ji in China) or by other factors. The needs and objectives of the services will be specific for that city and varied within the urban area. As an example, the requirements for Integrated Urban Services in Seoul, Republic of Korea, include urban ecology, agriculture/forest meteorology, flash floods, road weather and hazardous dispersion and point-specific prediction (see Figure 9).They are designed to "fit for purpose" (for example, required mosquito prediction service is included in the urban ecology block of the urban services as shown in Figure 9). The urban set-up can also amplify or mitigate hazards that need to be considered. For example, impervious surfaces can amplify flooding at the regional scale, dense tall buildings can trap air pollution and greenspace can mitigate large-scale heatwaves.

An Integrated Urban Service must consider seamless provision of services across all timescales: from the historical past, current state monitoring, nowcasting (multi-hazard early warnings that are very short term, for example, thunderstorms, flash floods and dispersion), short-term and medium-range forecasting for larger-scale phenomena (typhoons and extratropical storms), to long-term (sub-seasonal to seasonal and climate change) timescales at urban and sub-urban spatial scales for climate risk management, adaptation to climate change, mitigation strategy assessments and urban planning.

The Integrated Urban Service should not be static. The service itself and its elements must be evaluated on a routine basis, and being compared with the evolving requirements, developments in state-of-the-art technologies, service tools and praxis. Thus, the research, development and implementation process should be iterative. Inevitably, evolution of Integrated Urban Services will require investment in the science and people for sustainability.

A multidisciplinary approach must be adopted from the outset, to facilitate appreciation and understanding of each partner's perspective. For example, knowledge of the impacts of air quality on urban vegetation may be included in urban planning legal documents. However, this is an innovation requiring social and legal research to be put into practice by the city administration.

4.2 Observations

Different types of urban observations are required by Integrated Urban Services. In this section, the focus is on hydrometeorological and air quality observations. Other types of datasets and databases are considered in section 4.3.

Urban areas have typically been relatively poorly served with respect to observations by NMHSs because the urban environment creates challenges for siting meteorological instruments (for example, raingauges) following standard guidelines. Operational numerical weather prediction models and assimilation systems are not always suitable for using such observation data, as urban environments and processes are not yet sufficiently represented in numerical weather prediction models. Historically, meteorological networks were designed for synoptic-scale weather forecasting and aviation applications. Hence, they are mostly located in fields and airports, away from the urban environment. This is also true for air quality networks, but not for most streams and rivers, which have gauges. In addition, the current network is too sparse to detect the spatial variability of urban climates.

There are four types of requirements for urban observations:

(a) Real-time data provision
(b) Data provision in the form appropriated for assimilation and establishing initial conditions for numerical weather forecasting
(c) Data appropriateness for evaluation and verification of climatology models
(d) Data appropriateness for evaluation and verification of services (including information on human perception and response)

When establishing an urban station, the WMO guidelines (WMO, 2014*b*) for siting are often inappropriate, hence the observations to support the Integrated Urban Services should retain a flexible approach. This often means different solutions for individual atmospheric properties and may mean that not all observations at a "site" are made at the same place. The updated WMO urban siting requirements (WMO, 2014*b* (edition updated in 2017)) may not fully reflect the requirements of the current/next generation of urban models capable of resolving street canyons and buildings.

The Rolling Review of Requirements process (http://www.wmo.int/pages/prog/www/OSY/GOS-RRR.html) is an ongoing WMO process to update observation requirements of the Global Observing System. Fourteen application areas are defined, including weather, climate, hydrology and air quality. While there is an aspect of atmospheric composition information for urban and populated areas, the Integrated Urban Services may require more concise articulation of observational requirements in existing application areas.

The key issues related to urban observations is their representativeness (for example, is an urban wind measurement – and its sampling, processing and location – intended to represent the mean canopy flow or to also include the effect of a building?) and purpose of the observation (for example, for assimilation, initialization or verification). These depend on the application and the capabilities and requirements of the urban model (for example, does the model assimilate only mean winds or does it require canyon winds?) (WMO, 2006).

Mobile sources (for example, mobile phones or cars) are emerging as sources of meteorological data (for example, for pressure, temperature and precipitation measurements). They also provide useful information and a communications channel for issuance and validation of warnings and regarding responses to the warnings (for example, increased social media usage). Mobile phones will be an increasingly important source of data in urban environments due to their high density, and WMO guidance is required on this topic.

4.2.1 *Types and purposes of measurements*

Measurements and measurement locations should be representative of the character of the urban fabric under consideration (for example, high or low building density, urban canyons, green urban areas, central business districts and suburban areas).

Observations of the physical and chemical characteristics are needed with high temporal and spatial resolution, including the vertical dimension, for the surface and the urban boundary layer, depending on the service requirement.

An observation system must be designed considering the requirements of the urban applications and services, resources and capacity of an NMHS and its partners. Complete watersheds, upstream areas and areas outside the high-density urban area may need enhanced observations as well. The choice of a right mix of observations, scale and frequency of the sampling is a challenge and the components of the mixture will evolve over time.

4.2.2 *Measurement methodology*

The quality and the representativeness of the urban observations may change over time due to changing environment of urban stations and changing characteristics of the instruments themselves (for example, re-calibration or replacement). In this respect it is important to regularly update the station metadata(on instruments and surrounding).

The *Guide to Meteorological Instruments and Methods of Observation* (WMO, 2014*b*) should be followed for instrumentation deployment and to make the link to site characteristics. The *Guide to Hydrological Practices* (WMO, 2009) and *Manual on Stream Gauging* (WMO, 2010) provide guidance on hydrological measurements. For health-related measurements, *Guidelines on Biometeorological and Air Quality Forecasts* (WMO, 2004) are available. It is recognized that the integrating nature of urban services requires reflections in the mentioned guiding documents.

Multiple networks including ceilometers, Doppler lidars, microwave radiometers, small radars (Figure 10), wind profilers and Doppler sodars (often only deployable at airports due to noise) exist for continuous real-time monitoring of precipitation and the dynamic and thermodynamic structure of the urban boundary layer. Employing such networks efficiently at urban measurement sites and the development of highly resolving three-dimensional scanning water vapour lidars and automated unmanned aerial vehicles provide high potential for improving short-term forecasts and high-impact predictions. The measurement uncertainty needs to be known for these remote-sensed and for surface data.

Satellites can monitor the physical urban surface processes. Such data can be utilized to assess societal vulnerabilities to near-term climate changes (see Figure 11, which shows the correlation between surface temperature and land use supporting the concept of nature-based solutions). High-resolution multisensor systems and new processing techniques have improved the accuracy of satellite thermal monitoring, allowing data assimilation into urban climate models. New space-borne thermal radiometers and hyperspectral infrared imagers have recently been and/or will be launched in the coming years. Advances in vertical profiling measurements are also expected (for example, Meteorological Operation Second Generation and Meteosat Third Generation).

4.2.3 *Collaboration for integrated observations*

In addition to increasing availability of small mobile sensors (for example, within mobile phones or within vehicles) and small air quality sensors, and improved understanding of their quality and use, there is a large range of other data sources that contain important information on the indoor and outdoor three-dimensional urban space. These data include detailed information about the urban fabric typically found in geographic information system (GIS) databases. They provide information about building and vegetation, and their locations and heights. Other relevant data

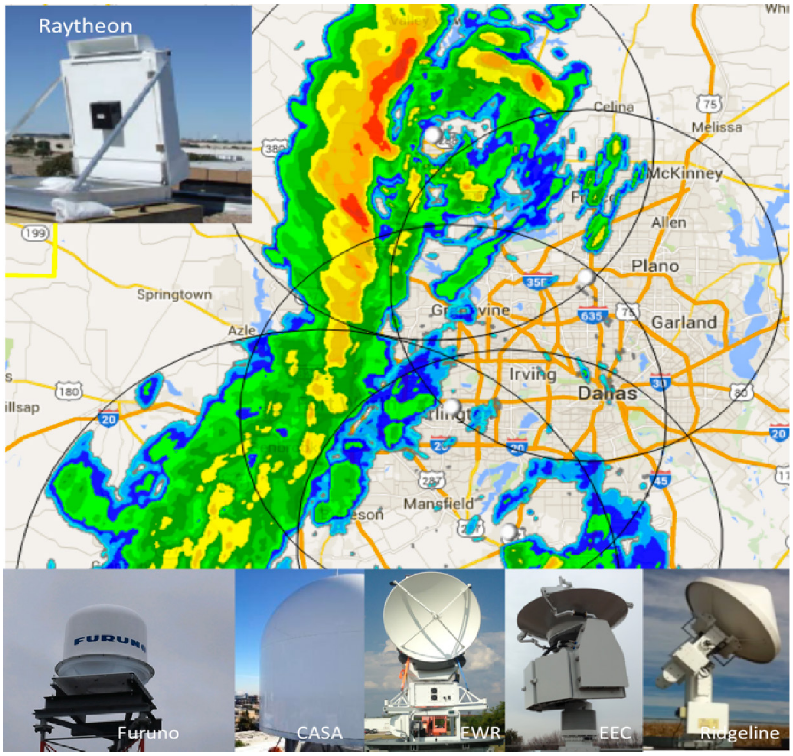

Figure 10. Urban radar network. Networks of small radars (bottom images; black circles show location and range in top image) are deployed in the Dallas–Fort Worth area to solve the Earth curvature low-level detection problem. These radars are expected to be replaced by low-cost, low-maintenance, low-infrastructure X-band phased arrays radars (upper left and lower left image).

Source: Brenda Philips, University of Massachusetts

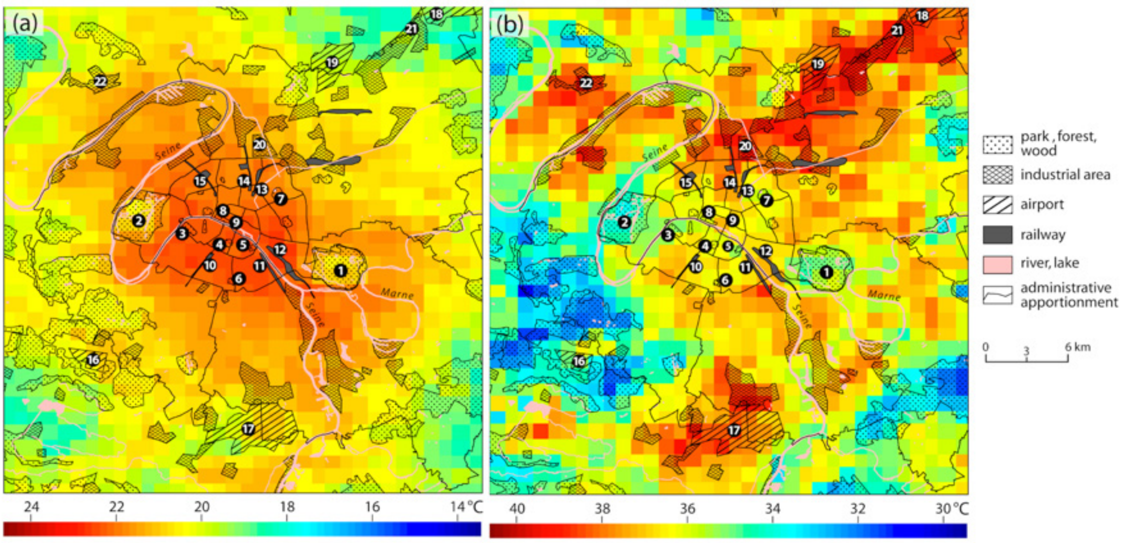

Figure 11. Satellite remote-sensing of land surface temperature. Land surface temperature composite images of the Paris region during the August 2003 heatwave (1 km resolution – National Oceanic and Atmospheric Administration Advanced Very High Resolution Radiometer) and land cover/use overlay: (a) night (01–03 Universal Time Coordinated (UTC)) and (b) day (12–15 UTC). Numbers refer to: park land (1–8), dry land (9), transportation hubs and industries (10–22).

Source: Dousset et al. (2011)

related to energy use are critical for understanding anthropogenic heat fluxes (and the feedback to energy demand), public health assessments (exposure and vulnerable population) and so forth.

Providers of geophysical information and city administrations are encouraged to share their data and jointly exploit them to improve the services through the appropriate collaborative mechanisms. Data collected by private companies (for example, Google) and big data concepts are emerging data sources that will play a role in the future services.

In addition to "traditional" observational data, there is another genre of data relevant to Integrated Urban Services. This includes broad categories such as environmental, geomorphological, socioeconomic, and human population and activity (see Box 7 and Figure 12 for an example). These are essential to provide context and support for urban analyses and model applications addressing issues, including policy requirements, urban planning and assessments, emergency response and human behaviour. They are also needed for service evaluation (see section 4.8).

Box 7. Example of an Integrated Urban Service GIS data source

The World Urban Database and Access Portal Tool (WUDAPT), an initiative of the International Association of Urban Climate, is a system to support intra-urban climate assessments, surface energy budget, meso- to urban-scale weather, and chemical and air quality forecasting applications. Its scope is to facilitate worldwide urban-scale state-of-science, fit-for-purpose model applications with different levels of accuracy, precision and resolution of the urban parameters as required. The example in Figure 12 provided by this tool shows the wide variety and scale of the urban surface in Guangzhou, China.

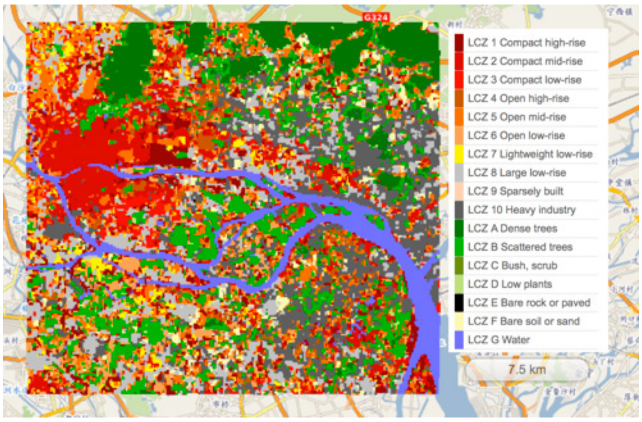

Figure 12. Example of a land climate zone classification map from the WUDAPT website (http://www.wudapt.org/) for the inner core of Guangzhou, China

Source: WUDAPT web site, with permission of Dr Ching, University of North Carolina

The categories of other data may be:

(a) Primary-type data from disparate sources such as: (a) administrative data (census, energy use or emission data) from a variety of platforms and (b) remote-sensing data from satellite, mobile and stationary platforms, in addition to in situ surface and profiling data that capture hydrometeorological and air quality information
(b) Regenerated (processed) data created from primary data including analyses, modelling outputs of weather, air quality and risk advisories
(c) Information on damage (for example, tornado damage surveys or flooded areas) and measures taken based on the Integrated Urban Services outcome (for example, traffic bans, areas where warnings were issued and warning level)
(d) Inputs for modelling and analyses

Standardized protocols are required for all these data sources to assure data quality.

4.3 Databases and data sharing

Datasets from urban observations are collected by different agencies, with different systems and sensors, for different requirements, to provide evidence-based services. Exchange of data among partners is encouraged, to enable Integrated Urban Services, and also as a means and opportunity to communicate, interact and exchange knowledge and understand the user needs (see Box 8).

Box 8. Examples of data and data products

Australia (Commonwealth Scientific and Industrial Research Organisation): the Australian Air Quality Forecasting System predicts daily levels of photochemical smog, atmospheric particles (including windblown dust and smoke) and 22 other pollutants (https://www.cmar.csiro.au/airquality/aaqfsanim.html).

Hong Kong, China (Hong Kong Observatory): surface meteorological observations, upper air soundings, remote-sensing, sand and dust weather information, weather forecasts covering multiple timescales (for example, nowcasting to climate projections), warnings of hazardous weather, climate data and summaries, and the Community Weather Information Network (http://www.hko.gov.hk/contente.htm).

New Delhi/Pune, India (Ministry of Earth Sciences, Government of India): air quality and weather – now, air quality and weather forecast, UV index – skin advisory, air quality index (AQI) – health advisory and city pollution maps) (http://safar.tropmet.res.in).

Seoul, Republic of Korea (Korea Meteorological Administration): current weather and digital, mid-term weather forecast (http://web.kma.go.kr/eng/weather/forecast/current_korea.jsp).

Mexico City, Mexico (Environmental Secretariat): the Integral Atmospheric Monitoring System network measures meteorological parameters, UV radiation, deposition species and criteria air pollutants, and provides AQI, air quality forecast, UV index and air quality alerts (http://ghdx.healthdata.org/record/mexico-mexico-city-automatic-air-quality-monitoring-network-database).

United Kingdom of Great Britain and Northern Ireland (Department for Environment Food & Rural Affairs): city-wide pollution forecasts and latest measurements (http://uk-air.defra.gov.uk/).

United Kingdom (Met Office): weather forecasts – 5 d, maps, timelines and temperature ranges; text forecasts – temperatures, temperature maps, rainfall, surface pressures, cloud and rain, wind gusts, UV, cloud cover and pollen counts; observations – last 24 h, maps, regional extremes and timelines; weather – temperatures, rainfall, wind, wind dust, satellite infrared, satellite visible, infrared satellite and rain, lightning and extremes; climate – average tables, average graphs, location comparisons and average maps (http://www.metoffice.gov.uk/).

United Kingdom (Environmental Research Group, King's College London): air quality/air pollution – nowcasts and forecasts (http://www.londonair.org.uk/LondonAir/Default.aspx).

United States of America (Environmental Protection Agency): AQI forecasts, current AQI, data and maps by monitor location (http://airnow.gov/).

There are many challenges to making observations open for operational use, to foster ongoing and future Integrated Urban Services developments and to make them easily accessible, owing to format differences, metadata definitions, storage in different databases and usage policies by the different network owners. Nonetheless, WMO has existing guidelines for operational data, metadata, storage and efficient sharing of these data and also a process (Rolling Review of Requirements) to update them. The following is a summary of some key characteristics for databases:

(a) All datasets from the different measuring networks of the different (technical) observing system operators should be stored in one (virtual) central database (regional data/data of this area).
(b) This database must be easily accessible and redundant (with the mirror servers in several locations to prevent data loss in the case of physical damage to one of the locations).
(c) The different data formats must be converted into known WMO supported data formats (dataset description necessary and also encoding/decoding software).
(d) This database should be freely accessible to all users (open data) with data sharing and usage policies (for example, WMO, 2017*b*).
(e) Metadata, which combine and link information on individual datasets, should be available to users for various sources, ideally in the *WIGOS Metadata Standard* (WMO, 2017*c*) and other international standards.
(f) All stations (with assigned identifiers) of NMHSs and third-party data networks should be stored with their metadata in OSCAR/Surface (https://oscar.wmo.int/surface/#/)
(g) All information about the station environment (orography, building heights, green spaces and so forth) must be recorded on an ongoing basis. Mobile data and spotter reports may represent a gap in implementation of the harmonized data formats.
(h) Measurement network operators (network owners) are responsible for maintaining the metadata on a regular basis. The metadata should be freely available to all data users.
(i) Recording of the data in the databases should be fully automatic and quality controlled in real time. The results of this quality control should be saved/stored as quality flags in the database. The quality information (metadata) should always be made available when using observational data (output from databases). New data sources with unknown or partially known quality should be treated with special care.

For hydrological data, in addition to the WMO *Guide to Hydrological Practices* (WMO, 2009), the *World Hydrological Cycle Observing System Guidelines* (WMO, 2015*e*) and the *Guidelines for Hydrological Data Rescue* (WMO, 2014*c*), the WaterML standard information model (http://www.wmo.int/pages/prog/hwrp/chy/data-access-exchange.php) provides information on data management and exchange standards. For the atmospheric composition data, the guidance from the respective World Data Centers on the metadata and data exchange should be considered (see for example https://www.gaw-wdca.org/Submit-Data).

4.4 Modelling and prediction

In the framework of Integrated Urban Services, models aim to represent urban processes, the urban area and its salient elements (atmosphere, water flow and quality, buildings, infrastructure, population and so forth). Models can be numerical (for example, a chemistry–atmosphere forecast model), physical (for example, wind tunnels and climate chambers), statistical (for example, interpretation of observations) or conceptual (for example, a diagnosis map for urban planners).

Models must be able to predict and assess the state and evolution of urban environment to aid decision-makers and users. The service levels will be defined by the capabilities of the models available to the implementers of the Integrated Urban Services.

Regional seamless Earth modelling systems that include feedback and interactions among atmosphere, ocean and land at very high resolution (possibly downscaling to hundreds of metres or even less to detail urban influences) are valuable tools and crucial to address multiple Integrated Urban Service requirements. Integration at this level requires collaboration among diverse and highly technical disciplines. While full integration of meteorology, climate, hydrology, oceanography and atmospheric chemistry may be a logical step and a long-term strategic goal, there are significant challenges in its implementation. The disciplines addressing different elements of the Earth System use different languages, have different prediction and modelling paradigms, have different objectives and link with different end users in different ways. Forming partnerships among relevant model developers and experts in these disciplines is critically important.

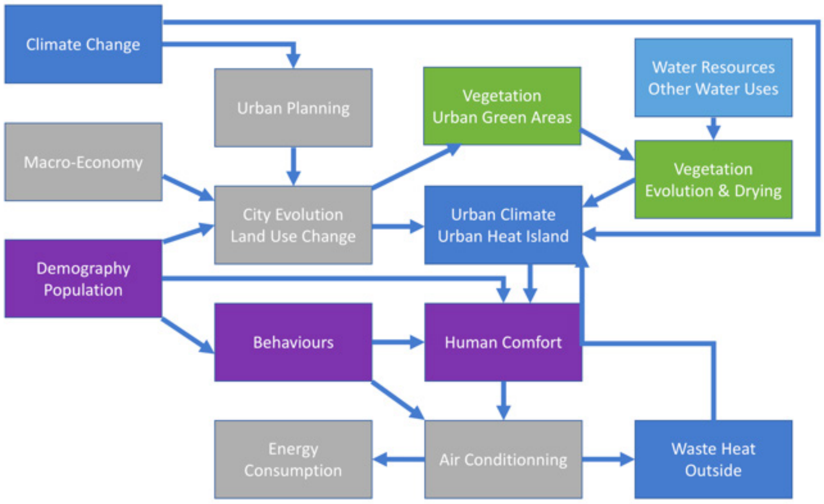

Figure 13. Urban vegetation, water, human comfort (behaviour) and use of air conditioning (waste heat is expelled to the atmosphere) are linked through heat and temperature (urban heat island)

Source: Valèry Masson, Météo-France

The operational deployment of numerical models supporting Integrated Urban Services must be carefully managed considering the maturity of the additional elements. Extending exiting operational NWP models to higher-resolution NWP or to coupled numerical environmental prediction models is a complex undertaking, and management rules are generally not in place. Normal practice in meteorology and air quality is to accept an upgrade if there are good scientific grounds, the overall performance is improved and there is no significant degradation of an important variable. In hydrology, performance for each separate river basin model is one criterion for operational deployment. However, Earth System modelling is very complex, and appropriate success metrics must be identified.

In cities, the processes at play can be either physical, biogeochemical or socioeconomic, and need to be represented in Earth system models for the intended service. For example, for heatwave alerts or urban planning, the physical and social processes that influence the urban heat island need to be represented. Outside temperature/heat causes interior building temperatures to rise; this results in increased air-conditioning use and the waste (anthropogenic) heat is released back into the environment, which then warms up the air. Figure 13 shows an example (in Paris) of linking socioeconomic modelling and hydrobiological behaviour.

Figure 14 shows an example of the main linkages across spatial (urban/megacities to regional to global) and temporal (nowcasting/forecasting, seasonal and climate) scales from the MEGAPOLI project (http://megapoli.dmi.dk).

Ocean–atmosphere–wave interactions, ocean–wave–riverine interactions and land use have to be accounted for in modelling environmental hazards in urban areas near to the coast in order to predict and determine exposure and vulnerability. Figure 15 shows an example of coupling meteorological, lake circulation, wave, flood and air quality modelling.

Urban vegetation (street trees, parks, low vegetation, green roofs and so forth) is important to urban planning (for example, by modifying the urban heat island) and emergency management (for example, in urban flood management). However, urban vegetation is currently lacking in most urban canopy modules (meteorological and hydrological) (Harada and Imamura, 2005).

To meet the high-resolution needs of urban designers, urban climate models should include urban climate projections through downscaling techniques. Knowledge/prediction of future development of urban areas is crucial for estimating the impact of adaptation and mitigation measures for a specific urban system.

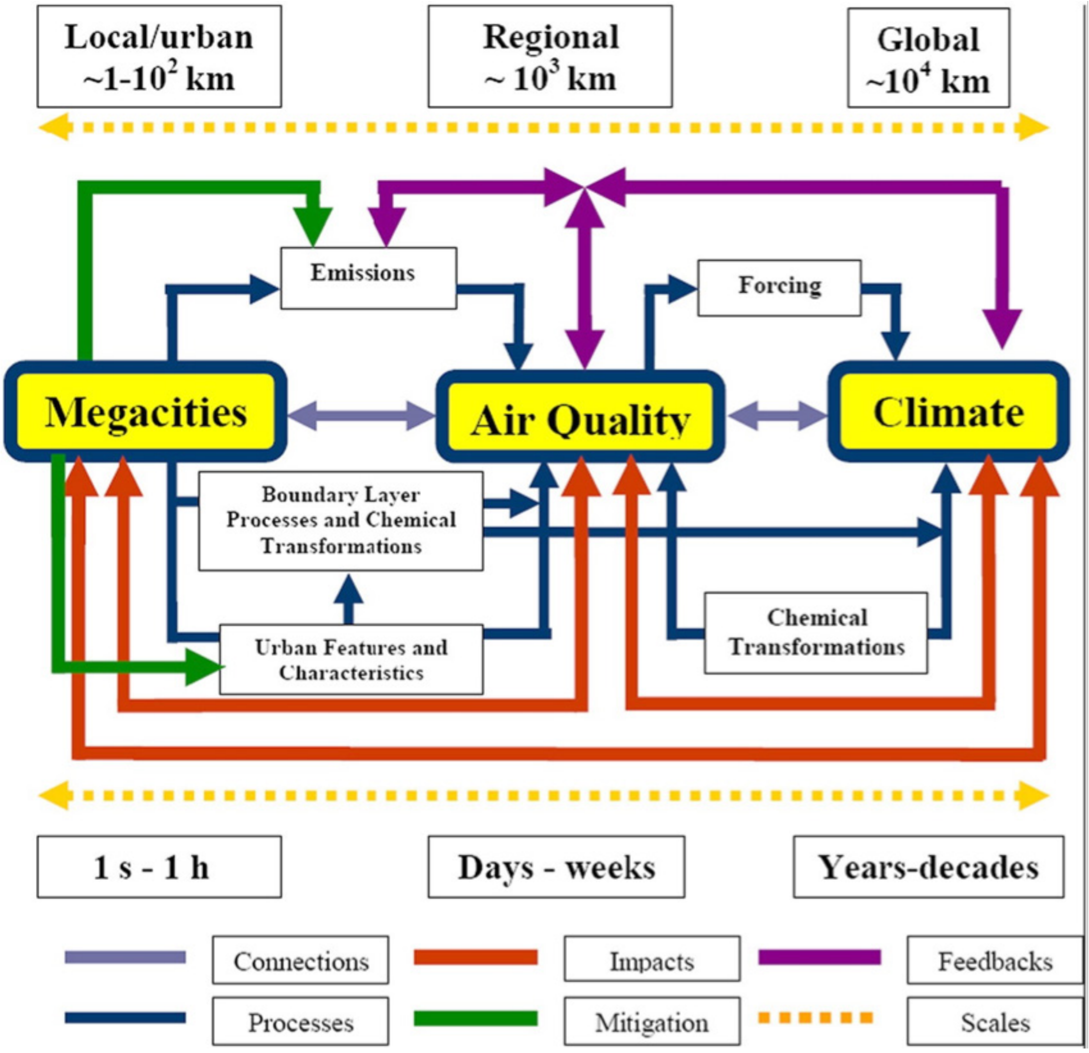

Figure 14. Ecosystem, health and weather impact pathways, and mitigation routes that need to be included in Integrated Urban Services. The relevant temporal and spatial scales are indicated (the MEGAPOLI project).

Source: Baklanov et al., 2010

The Integrated Urban Services systems need to consider: fine-scale urban data (section 4.2), urban observations for assimilation and model initialization, urban canopy models, urban vegetation, land use and land cover (to assess exposure, vulnerability and also soil permeability, which might affect the hazard in terms of lag time), ensemble prediction, quantification of uncertainties and processes requiring multidisciplinary approaches.

Integration of urban services can be done at technical, product or service levels, or all three. The necessity to integrate at technical (several models into one tool) or service levels (Integrated Urban Services tool using data produced by models in other services/institutions) depends on the objective of the Integrated Urban Services and of the urban interactions to be addressed. If there is no significant interaction between two processes, two-way coupling of the models may not be necessary.

4.5 Applications

4.5.1 *Diversity*

There is a wide variety of urban services such as: urban-specific disaster risk reduction, better city operations, human health, sustainable city and economic development, decision support and planning at scales from months to seasons, managing weather/climate risks, adaptation to changing climate and urbanization at a neighbourhood scale (~1 km). Related applications have to include various sectors or stakeholders, such as energy, water supply and sanitation for water resource assessment, flood forecasting, environment, health, agriculture and food security, ecology, transport and tourism, to determine the full range of requirements.

4.5.2 *Universality and dissimilarity*

Some application services encompass aspects are common (universal) in all urban areas (for example, urban heat island, tidal inundation, weather/climate/air quality and human health). Others are special concerns and specific (dissimilarity) to different cities (for example, heat or cold stress depending on latitude, mudslides in a mountainous city and water supply in an arid city).

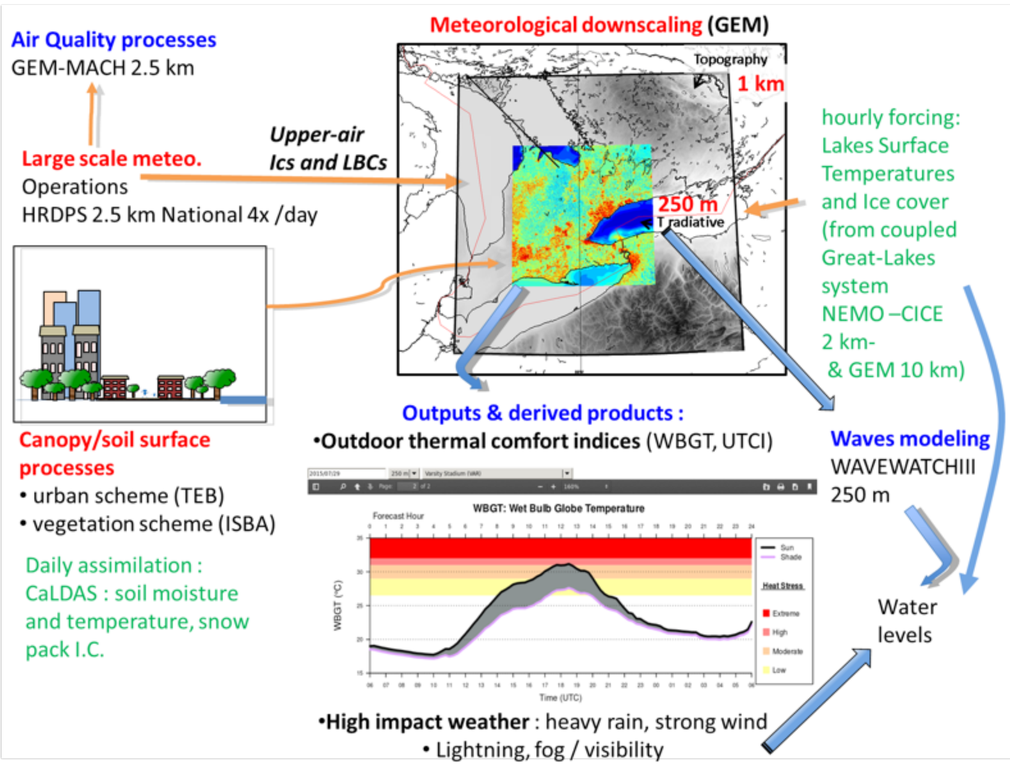

Figure 15. Example of nested and coupled urban-scale modelling. State-of-the-art Integrated Urban Services models consider meteorology (250 m resolution), air quality (2.5 km), lake wave (250 m) and lake circulation (2 km) deterministic and ensemble approaches. Water levels are used to couple to a flood forecasting model. CaLDAS = CAnadian Land Data Assimilation System; CICE = Sea ICE model; GEM = Global Multiscale Model; GEM-MACH = Global Multiscale Model Air quality and Chemistry ;HRDPS = High-Resolution Deterministic Prediction System; I.C. = Initial Condition; Ics = Initial Conditions; ISBA = Interactions between the Biosphere and Atmosphere ; LBC = Lateral Boundary Conditions; NEMO = Nucleus for European Modelling of the Ocean; TEB = Town Energy Balance; UTCI = Universal Thermal and Climate Index ; WBGT = Wet-Bulb Globe Temperature.

Source: Sylvie Leroyer and Stéphane Bélair, Environment and Climate Change Canada

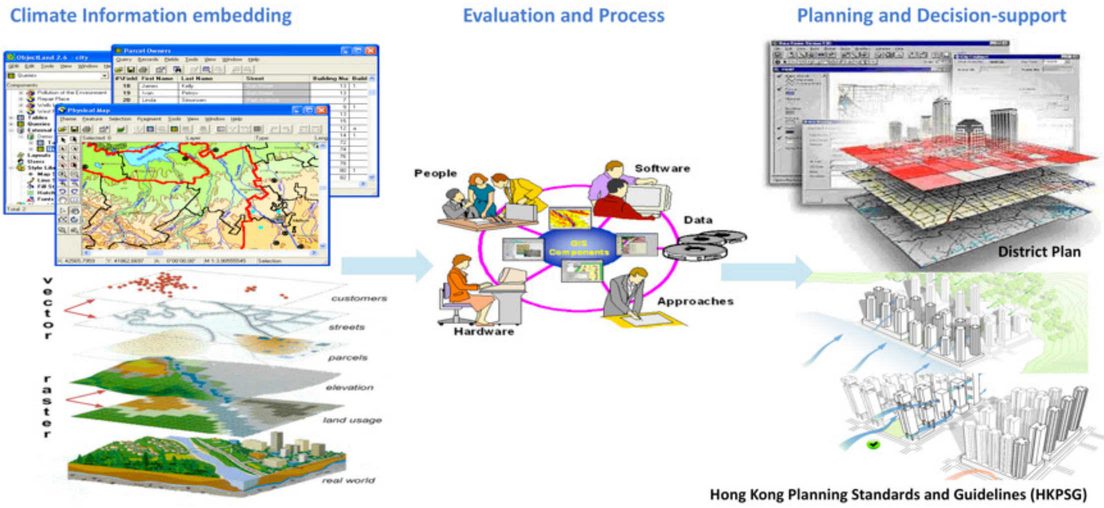

Figure 16. Climate and the urban environment planning – high-resolution Integrated Urban Services information is needed for urban design and planning at the city-block scale

Source: Chao Ren, Chinese University of Hong Kong

Development of tailored, impact-based forecasting and products for different services depends on the required temporal and spatial scales, which range from nowcasting (minutes and metres) to urban design planning scales (decades and longer from building to whole-city scales).

Urban applications are diverse and require real-time data for severe weather or flood nowcasting, online or offline data analysis using historical information, or specialized models (for example, air quality or hydrological and hydrodynamic models). Figure 16 shows a concept of how climate information is used for planning and decision support.

4.6 Decision-making, decision support and human behaviour

Decision support systems are needed to support disaster risk reduction early warning systems. These are tools that are used to efficiently present relevant, often uncertain and conflicting, information, to technical experts (for example, severe weather or flood forecasters) for assessment to support warning decision-making that may also take into consideration societal impacts, consequences and action statements (for example, the issuance of severe weather warnings for typhoon tracks have uncertainty or river level predictions are nearing flood thresholds).

The predictions are presented together with the observations, historical information of performance and assessment of impact (including human behaviour) in order to issue the appropriate message and location of the expected impact for the target audience. Past recent events have a significant influence on human behaviour and need to be considered. Overwarning of previous events ("crying wolf") results in lack of trust and can have a detrimental effect on actions to current warnings.

In most countries, the civil protection agency (the authority in charge of response operations) responds during times of crisis to locally elected authorities (for example, mayors). Integrated Urban Service products from the decision support system can therefore help in the communication of risk, as these authorities might not have the necessary background to fully understand the phenomena, and might take inappropriate decisions that would aggravate the impact of the disaster (for example, evacuating people to unsafe areas). For hydrology, Dewetra (https://public.wmo.int/en/media/news/wmo-and-italian-national-civil-protection-department-agreement) is a forecasting and warning support tool for operations that is endorsed by WMO and available to Members.

Over time, through interaction, collaboration and development, civil protection requirements may propagate back into the decision support system or even deeper into the Integrated Urban Services system, and could include additional requirements for observations, siting, data collection, modelling and post-processing/applications.

4.7 Service delivery communications and outreach

4.7.1 *Multidisciplinarity*

The path from raw data to generating products, providing services and delivering them to stakeholders is complex and diverse. For instance, in emergency situations, the information/ warnings should be disseminated as quickly as possible, as lead time is a crucial component in taking preventive measures. For urban design and planning, climate information need not be provided in real time.

Integrated Urban Services and their products should be co-designed in close collaboration with users. An overly detailed or rich presentation of information can be counterproductive, exceeding capabilities of the user to analyse/comprehend it.

Information on the spread and uncertainty of results also has to be compiled and properly communicated. Production of such information depends on the capabilities of the models/ observations to represent uncertainties, and on the Integrated Urban Services stakeholders to use them.

4.7.2 *Communication strategy*

A communication strategy needs to be developed that will identify proper mechanisms for disseminating the information to relevant stakeholders in an appropriate form/format, through relevant mechanisms depending on the type of information and the target audience. *The WMO Strategy for Service Delivery and its Implementation Plan* (WMO, 2014*d*) and the *WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services* (WMO, 2015*f*) can be used as starting points.

An integrated products/services delivery platform, providing access to all identified users (depending on their type and needs) might have to be established for information dissemination (see Figure 17). For example, the Global Framework for Climate Services has established National Climate Outlook Forums and National Climate Forums to share climate services products (including uncertainty) with users including explanations on the products access interpretation of risk and articulating the ways of creating a culture of collaboration and opportunity for inter-agency coordination (http://www.wmo.int/gfcs/).

The main principle in communicating information is that it should be provided in a usable manner so that all users, especially the target stakeholders, will get maximum benefit and make optimum use of the service (see Figure 18). The users and stakeholders should be trained/ informed through awareness programmes about the use of the Integrated Urban Services products, how they should respond and to further spread awareness. Dissemination media and tools include dynamic web portals, a digital display board system and an integrated voice response service, as well as communication through traditional media such as television, radio, email alerts, press releases, media conferencing and short message service alerts. Information can also be disseminated through leaflets and publications, and by organizing workshops, conferences, symposia and so on. Information disseminated through social media (for example, Facebook and Twitter) should be properly controlled by responsible experts, as any misinformation may create confusion and even panic in the public.

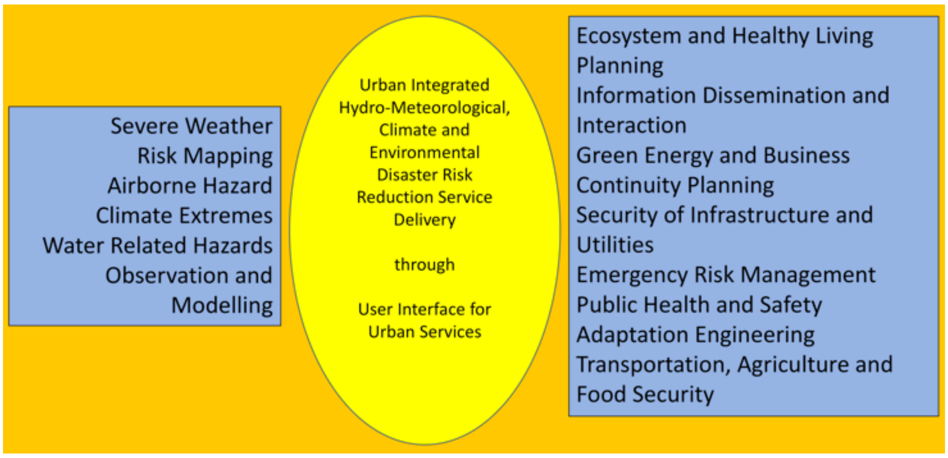

Figure 17. User interfaces to Integrated Urban Services. Users must be able to access Integrated Urban Services products for a variety of purposes, requiring different interfaces and platforms.

Source: WMO

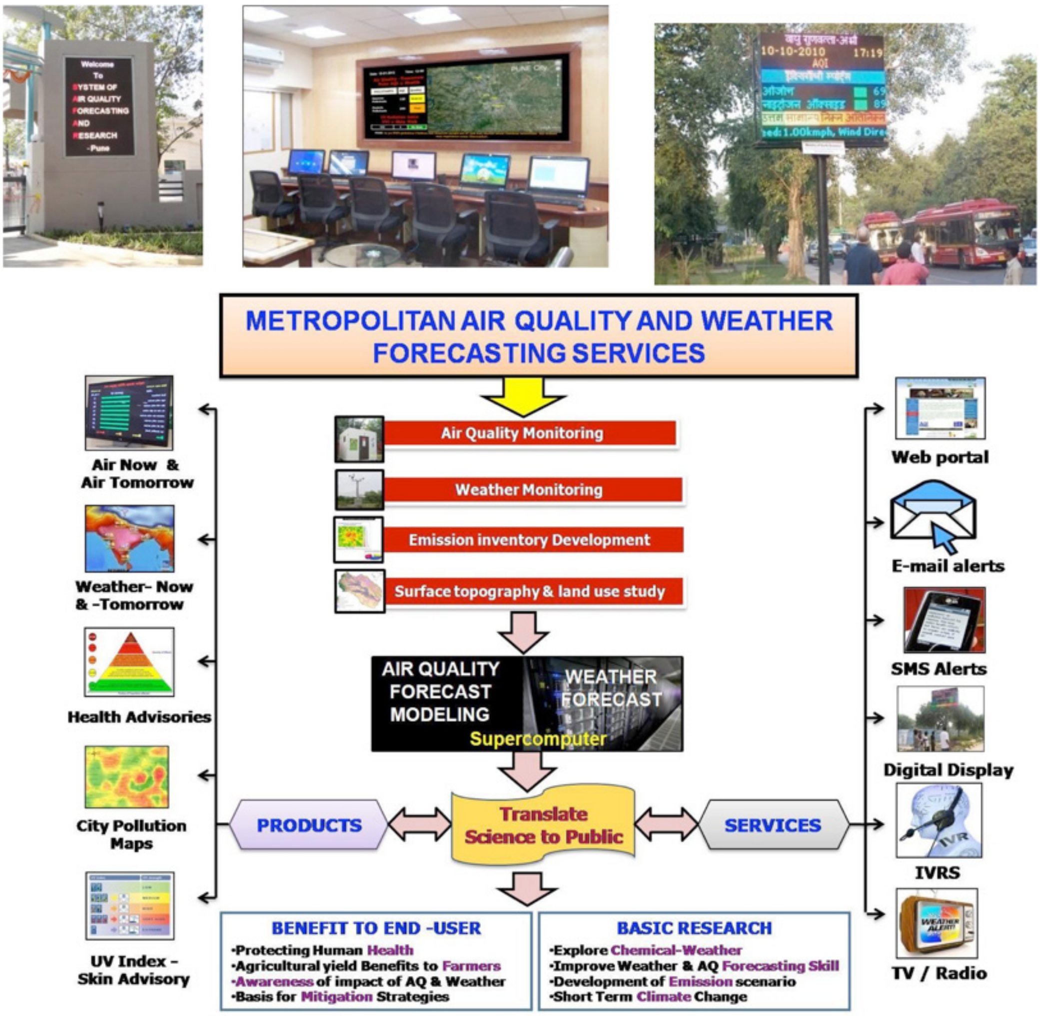

Figure 18. System of Air Quality Forecasting and Research – India (examples of the communication mechanisms) AQ = air quality; IVRS = interactive voice response service; SMS = short message service; TV = television.

Source: WMO (2015*g*)

4.8 Evaluation

Assessing the impact of an Integrated Urban Service (for example, avoided lives lost, casualties or costs reduced by preparing for a situation) is a very difficult task. "Before–after" event comparisons are a possible solution. Evaluation with a focus on the intended user-oriented outcomes of the Integrated Urban Service is crucial for demonstrating reliability of the Integrated Urban Service for its intended purpose and relevancy to stakeholders, including human response and behaviour. Stockholm has recently completed a research project that identified collaborative development with the health sector on indicators such as "heat-induced mortality" or "long-term mortality to combined exposure to NO_2 and PM2.5", which can be understood and used for evaluation of the services and their further improvements (http://urbansis.climate.copernicus.eu/project-deliverables/).

4.8.1 *Methodology*

When defining the Integrated Urban Services, target parameters need to be determined for specific applications for evaluation. The required accuracy (bias and uncertainty) must be considered. This should be discussed with users so that measurable thresholds are explicitly used.

In addition, the different components of the Integrated Urban Services (Figure 7) have to be evaluated to understand their impacts on the overall results. As part of the evaluation methodology, there must be diagnostic/process-oriented assessments and uncertainty analysis.

In using appropriate evaluation tools, demonstrable skill in Integrated Urban Services tools should be identified and documented through a peer review process.

4.8.2 *Interactive evaluation with users*

Results from the evaluation should be clearly communicated to users and stakeholders. This feeds the iterative co-design of the Integrated Urban Services, and the utility of the products should be part of the assessment.

Evaluation for climate impacts are difficult to assess using available data. Dynamic evaluation can help, where the evaluation is done using the same Integrated Urban Services for different situations.

New ways of evaluation should be considered as partners, stakeholders and users adapt to the Integrated Urban Services. Testbeds with comprehensive datasets covering all fields relevant for the target parameters and variables (for example, flooded areas, soil water content or human behaviour) are needed for model development, diagnostic evaluation and quantitative user evaluation (see Box 9).

Box 9. Urban testbeds

A testbed is a city that includes all essential information needed for the establishment, provision and evaluation of Integrated Urban Services, as well as information on the measures taken as a result of the Integrated Urban Services, on the behaviour of people and on the target parameters.

The purpose of a testbed is to facilitate development of the models, perform diagnostic and statistical evaluation, and, most importantly, to establish co-design and co-develop practices and build relationships between partners.

Not all cities implementing Integrated Urban Services need to be testbeds. However, as operational Integrated Urban Services systems are implemented a need for the "test bed"-like functionality will emerge. This should be kept in mind when designing and planning an Integrated Urban Services system.

4.9 Research and development

Research and knowledge gaps identified initially, or by the evaluation process, will trigger new research to support the ongoing development of Integrated Urban Services. Along with other advances, an iterative and continuous enhancement process requires the establishment of a research and development programme. Integrated Urban Services is a novel multidisciplinary approach, so research is critically needed for development, even at the initial stages.

Therefore, a research programme on observation technology, networks, basic physical (meteorological and hydrological) and chemical processes, and the development of numerical models and tools is an integral and central component of a reliable and accurate Integrated Urban Service. Research on specific city systems, socioeconomic impacts, human behaviour and identification of benefits is also required. Establishing testbeds in different cities, with the data being openly available, will help to advance the co-design and co-development of Integrated Urban Services. Identifying the most appropriate tools for the implementation of an Integrated Urban Service should be a transparent process, which should itself be an element of research and continuous monitoring.

As partners involved in the operational provisions of the Integrated Urban Service are not necessarily the ones responsible for research and development, partnerships should be established between research and operational bodies to foster the rapid transition of research results to operational use. Academia should be involved, for their contribution, and also to ensure a traceable and rigorous way forward, including the training of next-generation scientists.

4.10 Capacity development

Integrated Urban Services is rapidly evolving in all its aspects from advances in observations to delivery mechanisms. Capacity development efforts must evolve alongside learning needs, and cover new observing and forecasting technologies, advance in science, and communications between users and service providers. The opportunities for capacity development can be offered by universities, research institutions, NMHSs, international organizations, professional organizations, governmental offices and community programmes.

The required learning solutions will be: wide ranging, formal and informal, traditional and new, international and local – from degree programmes, short courses, online resources and training, workshops, conferences, study tours and secondments, through to searchable knowledge repositories that include case studies, simulations, coaching and mentoring opportunities, and twinning between services from different areas.

Identified capacity development needs include the following:

(a) The multidisciplinary nature of Integrated Urban Services will require an expansion of the scientific knowledge of those who were educated in traditional, disciplinary-focused areas, and also for sociologists and economists, with training on collaboration within Earth system specialists (see examples in Box 10).
(b) For providers, stakeholders and users of Integrated Urban Services, a deeper level of knowledge is required on Earth systems sciences and impacts on urban environments. This will require revisions of curricula of other professions, such as urban planning and architecture.
(c) Special considerations for urban observations will require dedicated training (see section 4.2), including guidance in the form of information sharing and hands-on training with new instruments.
(d) Expansions to data and databases (see section 4.3) will require knowledge of the characteristics of new data sources, terminology, access mechanisms and tutorials on data usage for operational staff and end users.
(e) Increased complexity of modelling including higher-resolution products and a large range of timescales will require guidance, cases and practise using advanced modelling systems (section 4.4).

(f) Integrated Urban Services will require interaction between multiple providers, new stakeholders and users. Terminology and knowledge gaps exist, including evaluation impacts and success metrics. User-adaptive knowledge management systems to share examples of applications, challenges and solutions will be needed (see section 4.5).

(g) Decision support systems employing statistical, rules-based and advance artificial intelligence techniques are used to integrate, synthesize and present information from diverse systems to support decision-making processes. The algorithms behind the first guess predictions need to be understood but also supported by basic products (see section 4.6).

(h) Communications capabilities require increased focus on impacts, communicating in short time frames and probabilities of extreme events (see section 4.7). Communications training may require practise with cases and simulations, as well as coaching during implementation of the new services.

(i) Impact-based evaluations require cross-sector collaborations and specific data for validation and verification. Multidisciplinary techniques need to be developed and promulgated (section 4.8).

(j) Integrated Urban Services research requires multidisciplinary approaches, reaching beyond physical sciences into human systems. Knowledge of research methodologies may require expansion accordingly (see section 4.9).

Education and training programmes and activities offered by WMO should be effectively utilized to achieve these capacity development needs for all Members. Such activities include the WMO Regional Training Centre network, capacity development activities under various WMO programmes as well as opportunities provided by the advanced service providers with training capabilities, and universities.

Box 10. Interdisciplinary training

Traditional domain-specific education is still the cornerstone of current curriculum building. A successful training model of the professionals who develop and implement an Integrated Urban Service needs to ensure that they are able to talk to each other, understand each other and work in a multidisciplinary way.

Examples of interdisciplinary training include:

1. WMO–University of Reading Course on Urban Meteorology, Environment and Climate Services, 28 August–8 September 2017 at University of Reading Malaysia campus (https://public.wmo.int/en/resources/meteoworld/urban-meteorology-environment-and-climate-services).
2. School of Integrated Climate System Sciences (https://www.clisap.de/de/grad-school/sicss/about-sicss/).
3. Summer school on Online Integrated Modelling of Meteorological and Chemical Transport Processes (http://aveirosummerschool2014.web.ua.pt/).

The Associated Programme on Flood Management has adopted a similar approach to the three examples above for the last 17 years (http://www.floodmanagement.info).

5. IMPLEMENTATION OF INTEGRATED URBAN SERVICES AND THE WAY FORWARD

5.1 Resources for implementation

This Guidance focuses on WMO Members. To optimize and mobilize resources, it is fundamental that within the Member countries the partnerships are formed between NMHSs, public/private organizations, academic institutions and businesses. Additional resources will probably be needed over and above current operations.

5.1.1 *Programme resources*

As articulated in the previous sections, diverse observations and other data are required to support accurate forecasts and evaluation of Integrated Urban Services. City agencies are encouraged to share their observational and data infrastructure with the providers of the Integrated Urban Services.

Modelling systems (section 4.4) supporting implementation of the Integrated Urban Services need to have higher (spatial) resolution than those traditionally operated by NMHSs. These models need to interface with service models. All relevant agencies should collaborate to undertake Integrated Urban Services work.

It is important to have a legal framework that clearly defines government agency (and other) mandates, interactions, roles and responsibilities to enable creation and maintenance of Integrated Urban Services.

A communication office should be established so that multiagency joint action can be coordinated.

5.1.2 *Technical expertise*

WMO programmes and activities, such as the World Weather Research Programme, World Climate Programme, Global Framework for Climate Services, Hydrology and Water Resources Programme, Global Atmosphere Watch Programme, Public Weather Service, Global Data Processing and Forecast Systems, Disaster Risk Reduction, WMO Integrated Observing Systems, WMO Information Systems, HIWeather Research Project, Technical Commissions and Regional Centres, are in a position to provide important guidance and support to enhance the expertise of NMHSs in specific areas of service. Such guidance addresses the fields of observation and monitoring, modelling, forecasting, early warning (such as climate watch, disaster preparedness, disaster prevention and disaster risk reduction), meteorology, hydrology, climate risk management and adaptation, and public weather services.

Technical support can also be provided by WMO Members already experienced in the specific area of service, especially those that are already running Integrated Urban Services or multi-hazard early warning system projects. Other agencies, universities and research institutions have explored many key aspects of the wide range of processes (for example, biophysical and social) that need to be linked.

5.1.3 *Financial resources*

A long-term investment strategy is needed to meet the evolving services requirements. User fees for special services, such as for businesses, is a possible funding source for sustainable development of the Integrated Urban Service.

5.1.4 *Service resourcing*

Adequate resourcing of all elements of the Integrated Urban Service is important for its development, implementation and sustainability. It is therefore essential to improve the efficiency and effectiveness of resourcing of different elements contributing to urban services such as meteorology, hydrology, air quality, and other relevant areas operated by diverse departments and agencies.

It is important to conduct cost–benefit/social impact analysis to demonstrate value of the Integrated Unban Services and the way they lead to substantial cost savings while supporting more efficient, sustainable and resilient cities.

5.2 Lessons learned during implementation

Numerous cities have already developed Integrated Urban Services. A wide range of lessons have been learned, including:

(a) Initiation of integrated services is often opportunistic (for example, following an extreme event or in preparation for a major event).
(b) It is essential to engage relevant stakeholders (for example, agencies, the public, neighbouring WMO Members, the city government, the private sector and businesses) from the beginning. The initial stage of engagement would include development of mutual appreciation of the challenges, understanding capabilities and requirements, raising awareness, developing a common language and establishing lines of communications.
(c) It is necessary to understand and/or establish regulatory and institutional frameworks that clearly define government agency mandates, interactions, roles and responsibilities to enable creation and maintenance of Integrated Urban Services (see Box 11 for an example).
(d) Operational implementation should include cross-sector technology transfer mechanisms (for example, research, development, testbeds and capacity-building) and cross-sector service provision (for example, warnings, advisories, risk and impact communications, capacity-building and evaluation).

Box 11. Initiating Integrated Urban Services: Shanghai legislation and action plans

Shanghai Meteorological Service of the China Meteorological Administration 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 specific sites 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 and its capacity for risk management is enhanced.

The standing committee of the Shanghai municipal people's congress passed the Measures for Implementation of the Meteorology Law of the People's Republic of China in Shanghai on 26 October, 2006. It clarifies the mandate of the Shanghai Meteorological Service in disaster risk reduction. Weather departments are required to provide special services through multiagency 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.

The General Office of Shanghai Municipal Government issues action plans for weather disasters such as heavy fog, freezing rain and snowstorm, heatwaves, strong winds and lightning.

The agencies responsible for issuing warnings are members of the Shanghai Emergency Management Response Committee, which actively participate in the multi-hazard early warning system 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. Shanghai Meteorological Service is a member of the committee. The primary responsibility of Shanghai Meteorological Service is "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.

5.3 Gaps in science and knowledge

Each city has its own unique set of hazards and risks. When designing Integrated Urban Services, tailored approach that makes the best use of science and technology for operational practices is required.

At the same time, early implementation of the Integrated Urban Services revealed open scientific and technological issues that hinder full implementations of the Integrated Urban Services (listed below). Although progress has been made on most of these issues, further work addressing them will allow significant advances in the service delivery capacity. It is therefore important that those adopting a new Integrated Urban Service be aware of and take steps to address the following:

(a) How to take and make use of observations in urban areas (for routine services or for research): it is necessary to re-visit and address the issue of representativeness of high-resolution observations and siting in urban areas in street canyons, to above the city roofs and the whole urban boundary layer.
(b) Representation of urban characteristics in models: the depiction of the urban fabric/texture (for example, surface type, building density, height, type, anthropogenic effects, surface roughness or sewer system) and the description of hydrometeorological and environmental processes that depends on the temporal and spatial resolution of the model. This affects the data assimilation schemes, the uncertainty analysis, the approaches to ensemble and the coupling of models.
(c) Urban atmosphere scales requirements (driving other submodels): awareness of what scales contribute the most to the performance of forecasts or assessments is important. Understanding downscaling from global-regional models to urban scale requires knowledge and appropriate representation of the interactions between the processes on different scales and at the end defines the quality of the tailored products and services.
(d) Impact of cities themselves on urban and regional weather, climate, hydrology patterns and water, environment (impact of urban activities on urban and regional air quality, water quality and quantity, ecosystem, urban heat island effects and disease transmission) and evolution of this impact die to socio-economic changes.
(e) Impact of changing climate on cities (for example, connection of the changing climate with urban air quality, long-term impacts of precipitation and sea level change on water quantity and quality, changing frequency of heatwaves, duststorms, wildfires and other high-impact events that affect public health, economy and ecosystems).
(f) Impacts of major geophysical hazards – earthquakes/volcanic eruptions/space weather – and their social and environmental consequences on urban activities (for example, on infrastructure including telecommunications, transport systems, housing, food/water supply and disease).
(g) New, targeted and customized delivery platforms using an array of modern communication techniques, developed in close consultation with users, to ensure that services, advisories and warnings result in appropriate action and then inform how best to improve the services.

5.4 **Way forward**

The next steps that could be taken to instigate the development of Integrated Urban Services, include:

(a) The earlier adopters of the Integrated Urban Service can assist the other WMO Members in articulating that the integrated approach is an essential part for the design and planning of the urban environment due to the influence that urban development might have on the weather-, climate-, hydrological- and environmental-related risks (including floods, droughts, air quality and weather extremes).
(b) NMHSs should engage with academic and other research institutions (governmental and non-governmental) to become familiar with state-of-the-art research related to the urban environment.
(c) The implementers of the urban services, stakeholders, decision-makers and service users should initiate the dialogue to develop a common language among the various disciplines and applications.
(d) The agencies involved in the urban observations should start sharing their data with the early implementers of the Integrated Urban Services to better understanding their observations and advance the network to meet the requirements for developing and implementing the services.

(e) NMHSs working with their partners should develop methodologies (for example, analytics and artificial intelligence) for efficient use of complex urban-scale large databases (for example, big data) taking stock of the tools that already exist, their limitations and potential for improvement.
(f) Model developers from different disciplines (weather, climate, hydrology and atmospheric composition) should initiate joint activities on the development of techniques that allow for enhancement of the modelling capabilities of the urban atmosphere.
(g) The agencies involved in services delivery should consider new and innovative technologies to effectively deliver their services to policy-makers and city designers/planners to assist them in creating sustainable cities.
(h) The service providers should start working closely with the end users to develop appropriate methodologies for evaluation of the quality and value/impact of their services.
(i) NMHSs and their partners in the academic and research community should revisit the existing approaches in the adaptation on scientific advances in their operational practices that would facilitate faster transition of these advances into operations. The services providers should improve the collaboration with decision- makers to initiate development of the efficient decision support systems that can be understood by a broad and interdisciplinary audience.

6. RECOMMENDATIONS

The general recommendations of this Guidance are summarized below:

(a) WMO Members are encouraged to contribute to the development and promotion of Integrated Urban Services in their Member countries.
(b) NMHSs should work with their partners and governmental institutions on national and city scales to ensure that legal and institutional frameworks that clearly define partners mandates, roles and responsibilities to enable, create and maintain Integrated Urban Services are in place.
(c) NMHSs should engage with relevant stakeholders (for example, agencies, universities, the public, other Members, city governments and the private sector), right from the beginning to ensure clear articulation of the value of Integrated Urban Services, to obtain user feedback and to co-design of future services.
(d) NMHSs should work closely with relevant partners to conduct further research, particularly multidisciplinary cross-cutting studies, to develop Integrated Urban Services capabilities.
(e) WMO Members are encouraged to facilitate wider accessibility of data by influencing ownership issues and providing technical support to enable Integrated Urban Services.
(f) WMO Members are encouraged to initiate demonstration projects to promote and advance development and implementation of Integrated Urban Services.

ANNEX 1. MEMBERS OF THE AN INTER-PROGRAMME WORKING GROUP ON INTEGRATED URBAN HYDROMETEOROLOGICAL, CLIMATE AND ENVIRONMENT SERVICES

Name	*Affiliation*	*Expertise*	*Representing*
Sue Grimmond, Chair	University of Reading, United Kingdom	Urban climate, urban meteorology	CAS
Veronique Bouchet (co-Chair)	ECCC, Canada	Urban meteorology/air quality	(CAS) and CBS
Luisa Molina (co-Chair)	Massachusetts Institute of Technology, United States	Air quality	CAS
Pablo Saide	University Corporation for Atmospheric Research, United States	Air quality	CAS
Felix Vogel	ECCC, Canada	Greenhouse gas emissions, IG3IS urban focus	CAS
Brian Golding	Met Office, United Kingdom	Meteorology (high-impact weather)	CAS
Valèry Masson	Météo-France	Urban meteorology, climate service, urban observations	CAS
Ulrich Loehnert	University of Koeln, Germany	Data assimilation	CAS
Junichi Yoshitani	Shinshu University, Japan	Urban hydrology	CHy
Jens Hesselbjerg Christensen	University of Copenhagen, Denmark	Urban climate	WCRP
Reinhard Spengler	DWD, Germany	Urban observations	CBS
Bert Heusinkveld	Netherlands	Urban observations	CIMO
Hannah Nissan	Columbia University, United States	Climate services (heatwaves)	GFCS
Teodoro Georgiadis	Institute of Biometeorology, Italy	Capacity development and training	Education and Training Office
Elena Akentyeva	Roshydromet, Russian Federation	Assessment of climate variability	CCl
Miao Shiguang	China Meteorological Administration (CMA), China	Climate Watch System	CCl
Emmanuel Rohinton	Glasgow Caledonian University, United Kingdom	Climate services	CCl
James A. Voogt	International Association of Urban Climate (IAUC) President Canada	Urban meteorology and climate	CCl
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Name	*Affiliation*	*Expertise*	*Representing*
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Jason Ching	University of North Carolina, United States	Data requirements	CCl
Rachid Sebbari	Météo Maroc	Climate data management	CCl
Bjarne Pedersen	Clean Air Asia	User requirements	Clean Air Asia (users)
Jianguo Tan	China Meteorological Administration -Shanghai	Shanghai multi-hazard early warning system and integrated service	CBS
Maryke van Staden	Local Governments for Sustainability (ICLEI)	User requirements; Low Carbon Cities	ICLEI (users)
Karen Seto	Yale University, United States	Urban resilience and sustainability	Intergovernmental Panel on Climate Change (IPCC)

ANNEX 2. DEMONSTRATION CITY CONTRIBUTORS

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Johannesburg	South Africa	Kobus Pienaar, North-West University
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REFERENCES

Baklanov, A., M. Lawrence, S. Pandis, A. Mahura, S. Finardi, N. Moussiopoulos, M. Beekmann, P. Laj, L. Gomes, J.-L. Jaffrezo, A. Borbon, I. Coll, V. Gros, J. Sciare, J. Kukkonen, S. Galmarini, F. Giorgi, S. Grimmond, I. Esau, A. Stohl, B. Denby, T. Wagner, T. Butler, U. Baltensperger, P. Builtjes, D. van den Hout, H.D. van der Gon, B. Collins, H. Schluenzen, M. Kulmala, S. Zilitinkevich, R. Sokhi, R. Friedrich, J. Theloke, U. Kummer, L. Jalkinen, T. Halenka, A. Wiedensholer, J. Pyle, W.B. Rossow, 2010: MEGAPOLI: concept of multi-scale modelling of megacity impact on air quality and climate. *Advances in Science and Research*, 4:115-120, https://www.adv-sci-res.net/4/115/2010/asr-4-115-2010.html.

Comisión Nacional del Agua, 2013: *Programa Nacional Contra Contingencias Hidráulicas (PRONACCH)*, https://www.gob.mx/conagua/acciones-y-programas/programa-nacional-de-prevencion-contra-contingencias-hidraulicas-pronacch.

Dousset, B., F. Gourmelon, K. Laaidi, A. Zeghnoun, E. Giraudet, P. Bretin, E. Mauri and S. Vandentorren, 2011: Satellite monitoring of summer heat waves in the Paris metropolitan area. *International Journal of Climatology*, 32:313–323.

Earth Economics, 2018: *Building Urban Resilience with Nature: A Practioner's Guide to Action*, http://100resilientcities.org/wp-content/uploads/2018/11/100-Resilient-Cities-and-Earth-Economics-Building-Urban-Resilience-with-Nature.pdf.

Grimmond, C.S.B., M. Roth, T.R. Oke, Y.C. Au, M. Best, R. Betts, G. Carmichael, H. Cleugh, W. Dabberdt, R. Emmanuel, E. Freitas, K. Fortuniak, S. Hanna, P. Klein, L.S. Kalkstein, C.H. Liu, A. Nickson, D. Pearlmutter, D. Sailor and J. Voogt, 2010: Climate and more sustainable cities: climate information for improved planning and management of cities (producers/ capabilities perspective). *Procedia Environmental Sciences*, 1:247–274, https://doi.org/10.1016/j.proenv.2010.09.016.

Harada, K. and F. Imamura, 2005: Effects of coastal forest on tsunami hazard mitigation — A preliminary investigation. In: *Tsunamis* (K. Satake, ed.). Advances in Natural and Technological Hazards Research, Volume 23. Dordrecht, Springer, https://link.springer.com/chapter/10.1007/1-4020-3331-1_17.

Hong Kong 2030+: Towards a Planning Vision and Strategy Transcending 2030, 2016, http://www.hk2030plus.hk/.

ICLEI Local Governments for Sustainability, 2018: *ICLEI Corporate Report 2016-2017*, http://icleiseas.org/wp-content/uploads/2018/03/ICLEI-corporate-report-2016-17_2018-update.pdf.

Mills, G., H. Cleugh, R. Emmanuel, W. Endlicher, E. Erell, G. McGranahan, E. Ng, A. Nickson, J. Rosenthal and K. Steemer, 2010: Climate information for improved planning and management of mega cities (needs perspective). *Procedia Environmental Sciences*, 1:228–246, https://doi.org/10.1016/j.proenv.2010.09.015.

National Academy of Sciences, 2012: *Urban Meteorology: Forecasting, Monitoring, and Meeting Users' Needs*, https://www.nap.edu/read/13328/chapter/1#ii.

United Nations, 2017: *New Urban Agenda*, A/RES/71/256*, http://habitat3.org/wp-content/uploads/NUA-English.pdf.

WISE, 2015: WISE Program by WISE Institute. WISE: Weather Information Service Engine. Funded by KMA (project brochure)

World Meteorological Organization, 2004: *Guidelines on Biometeorology and Air Quality Forecasts* (WMO/TD-No. 1184). Geneva.

———, 2006: *Initial Guidance to Obtain Representative Meteorological Observations at Urban Sites* (WMO/TD-No. 1250). Geneva.

———, 2009: *Guide to Hydrological Practices* (WMO-No. 168). In 2 Volumes. Geneva.

———, 2010: *Manual on Stream Gauging* (WMO-No. 1044). In 2 Volumes. Geneva.

———, 2014*a: Establishing Integrated Weather, Climate, Water and Related Environmental Services for Megacities and Large Urban Complexes – Initial Guidance*, Sue Grimmond (Chair), Gufran Beig, Barbara Brown, Greg Carmichael, Chen Baode, Fang Zheqing, Gerald Fleming, Agustin Garcia, Liisa Jalkanen, Haleh Kootval, Li Hong, Karla Longo, Mu Haizen, Peng Li, Shi Jianping, Tan Jianguo, Tang Xu, Deon Terblanche, Woo WangChun and Zhang Jianlei. Geneva, https://www.wmo.int/gfcs/sites/default/files/events/Expert Workshop/WMO_Megacity_IMP_Plan.pdf.

———, 2014*b*: *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8). Geneva.

———, 2014*c*: *Guidelines for Hydrological Data Rescue* (WMO-No. 1146). Geneva.

———, 2014*d*: *The WMO Strategy for Service Delivery and its Implementation Plan* (WMO-No. 1129). Geneva.

———, 2015*a*: *Seventeenth World Meteorological Congress: Abridged Final Report with Resolutions* (WMO-No. 1157). Geneva.

———, 2015*b*: *Role and Operation of National Meteorological and Hydrological Services: A Statement by the World Meteorological Organization for Directors of NMHSs*, https://www.wmo.int/pages/about/documents/WMOStatement_for_Directors_of_NMHSs_en.pdf.

———, 2015*c*: *Seamless prediction of the Earth system: from minutes to months*. ISBN 978-92-63-11156-2, (WMO No. 1156). Geneva.

———, 2015*d*: *Basic Documents No. 1, 2015 Edition* (WMO No. 15). Geneva.

———, 2015*e*: *World Hydrological Cycle Observing System Guidelines* (WMO-No. 1155). Geneva.

———, 2015*f*: *WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services* (WMO-No. 1150). Geneva.

———, 2015*g*: *System of Air Quality Forecasting and Research (SAFAR – India).* GAW Report No. 217, https://library.wmo.int/opac/index.php?lvl=notice_display&id=19465#.WtlKU7bMxQM.

———, 2016: *Executive Council, Sixty-eighth Session: Abridged Final Report with Resolutions and Decisions* (WMO-No. 1168). Geneva.

———, 2017*a*: *Executive Council, Sixty-ninth Session: Abridged Final Report with Resolutions and Decisions* (WMO-No. 1196). Geneva.

———, 2017*b*: *Draft Guide to WIGOS* (WMO-No. 1165) (Updated on 2 May 2018). http://www.wmo.int/pages/prog/www/wigos/WGM-2018.html .

———, 2017*c*: *WIGOS Metadata Standard* (WMO-No. 1192). Geneva.

World Meteorological Organization/Global Framework for Climate Services, 2018: *Step-by-step Guidelines for Establishing a National Framework for Climate Services* (WMO-No. 1206). Geneva.

World Meteorological Organization/Global Water Partnership Associated Programme on Flood Management, 2006: *Environmental Aspects of Integrated Flood Management* (WMO-No. 1009). Geneva.

———, 2017: *Selecting Measures and Designing Strategies for Integrated Flood Management: A Guidance Document*, http://www.floodmanagement.info/guidance-document/.

World Wildlife Fund, 2017: *Natural and Nature-based Flood Management: A Green Guide*, https://www.worldwildlife.org/publications/natural-and-nature-based-flood-management-a-green-guide.

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