From Urban Air Quality Forecasting and Information Systems (UAQIFS) to Integrated Urban Hydrometeorology, Climate & Environment Systems and Services (IUS) for Smart Cities

WEATHER CLIMATE WATER
TEMPS CLIMAT EAU

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and the EU FP FUMAPEX, MEGAPOLI, EuMetChem and MarcoPolo projects and international WMO GURME and IUS teams*

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World Meteorological Organization
Organisation météorologique mondiale

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Purposes of the study

- This presentation is analyzing a modern evolution in research and development from specific urban air quality systems to multi-hazard and integrated urban weather, environment and climate systems and services.
- It provides an overview of joint results of large international WMO GURME, IUS, and EU FP FUMAPEX, MEGAPOLI, MACC and MarcoPolo projects teams.

Urban AQ Forecasting: way to UAQIFS

- Urban air pollution is still one of the key environmental issues for many cities around the world.
- A number of recent and previous international studies have been initiated to explore these issues.
- In particular relevant experience from the European projects *COST715, FUMAPEX, MEGAPOLI, MACC, MarcoPolo* will be demonstrated.
- FUMAPEX developed for the first time an integrated system encompassing emissions, urban meteorology and population exposure for urban air pollution episode forecasting, for assessment of urban air quality and health effects, and for emergency preparedness issues in urban areas (UAQIFS: Urban Air Quality Forecasting and Information System; *Baklanov, 2006; Baklanov et al., 2007*).
- MEGAPOLI studies aimed to assess the impacts of megacities and large air-pollution hotspots on local, regional and global air quality; to quantify feedback mechanisms linking megacity air quality, local and regional climates, and global climate change; and to develop improved tools for predicting air pollution levels in megacities (*Baklanov et al., 2010, 2016*).

5FP EC project FUMAPEX:

Integrated Systems for Forecasting Urban Meteorology, Air Pollution & Population Exposure

22 teams from 10 European countries
(Baklanov et al., ACP, 2006, 2009)

Project objectives:

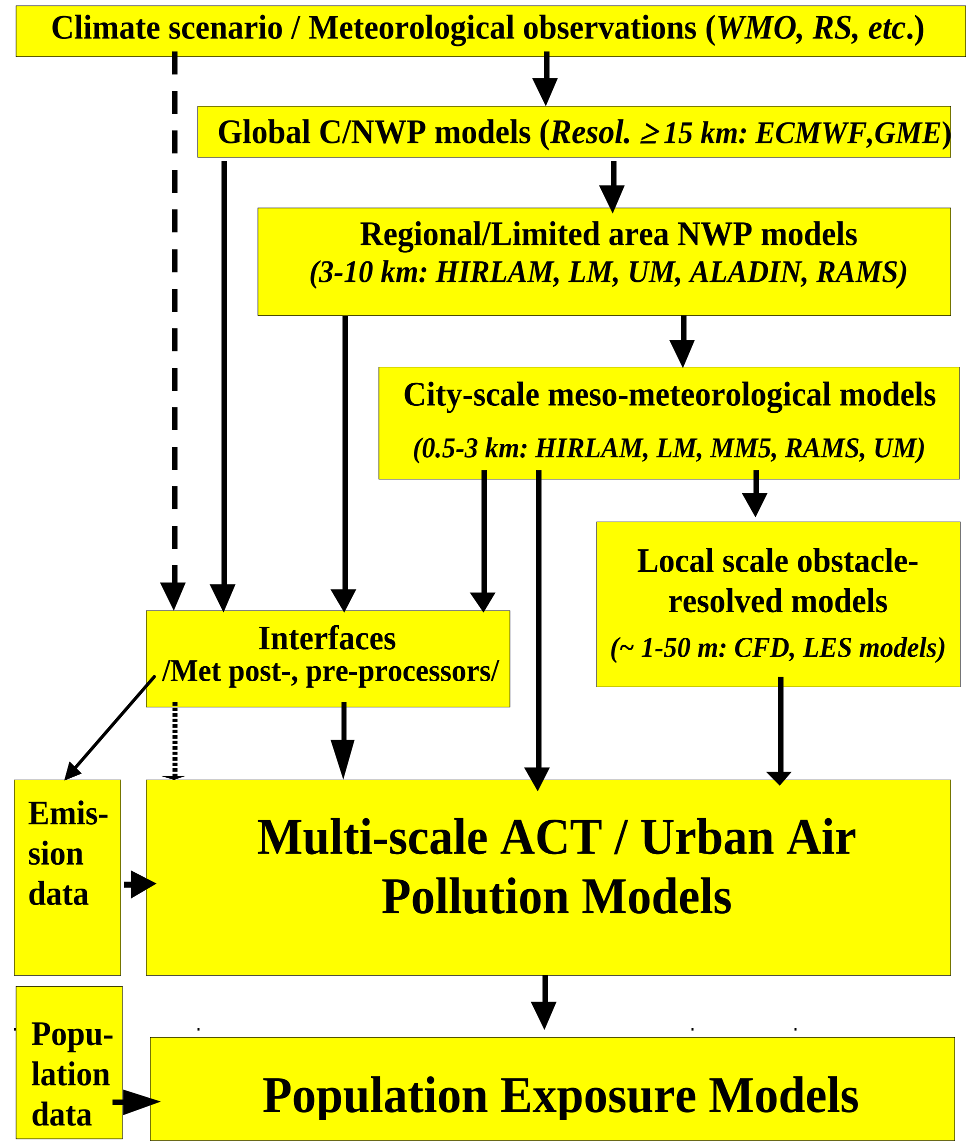
(i) the improvement of meteorological forecasts for urban areas,

(ii) the connection of NWP models to urban air quality (UAQ) and population exposure (PE) models,

(iii) the building of improved *Urban Air Quality Information and Forecasting Systems* (UAQIFS), and

(iv) their application in cities in various European climates.

Multi-scale UAQIFS



FUMAPEX: Integrated Systems for Forecasting Urban Meteorology, Air Pollution and Population Exposure

Baklanov et al., ACP, 2007

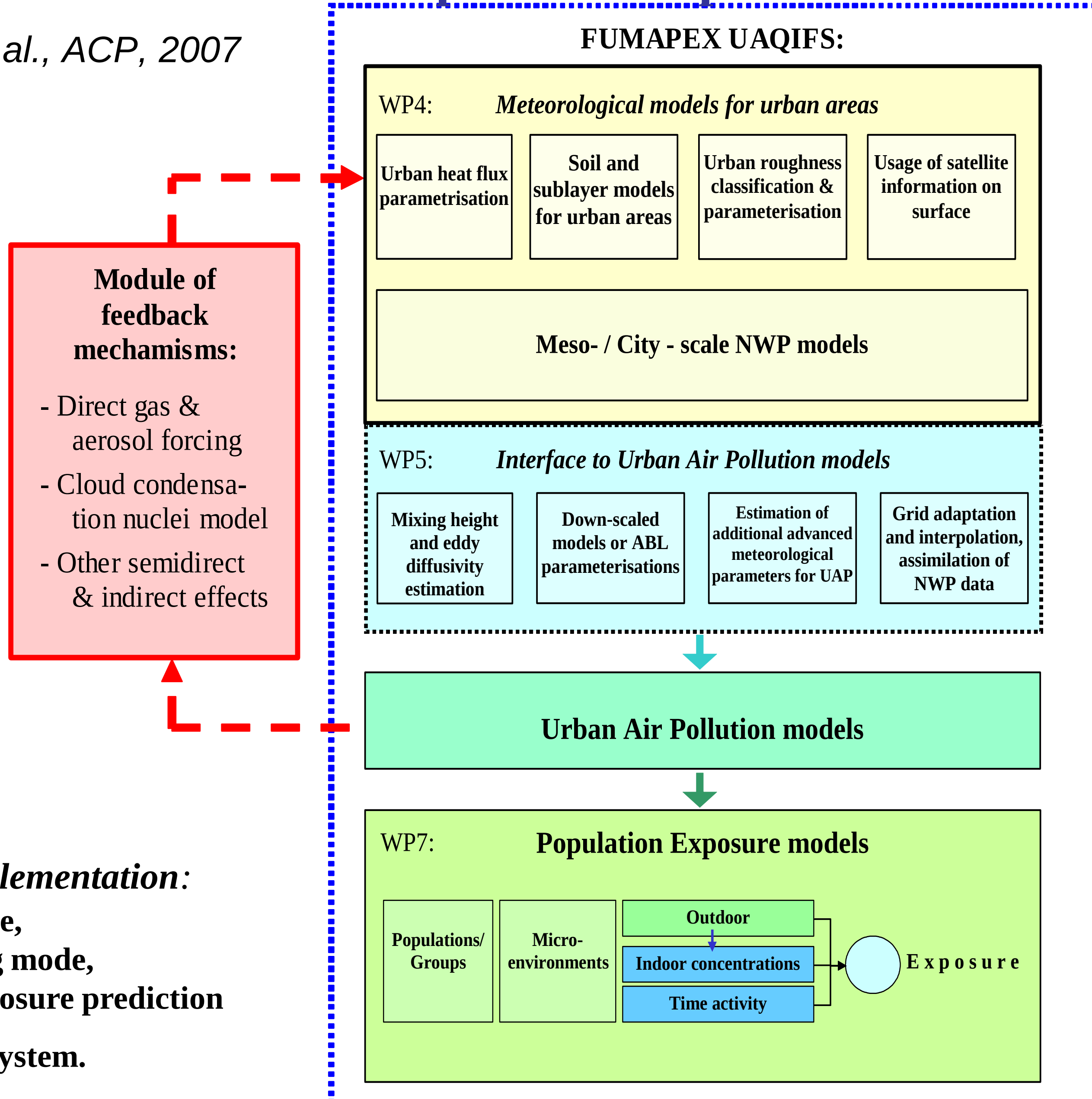
Goal: Improvements of meteorological forecasts (NWP) in urban areas, interfaces and integration with UAP and population exposure models following the off-line or on-line integration

Implemented in 6 European cities for operational forecasting:

#1 – Oslo, Norway
#2 – Turin, Italy
#3 – Helsinki, Finland
#4 – Valencia/Castellon, Spain
#5 – Bologna, Italy
#6 – Copenhagen, Denmark

***Different ways of the UAQIFS implementation*:**

(i) urban air quality forecasting mode,
(ii) urban management and planning mode,
(iii) public health assessment and exposure prediction mode,
(iv) urban emergency preparedness system.



FUMAPEX cities for UAQIFS implementation

#1 – Oslo, Norway
#2 – Turin, Italy
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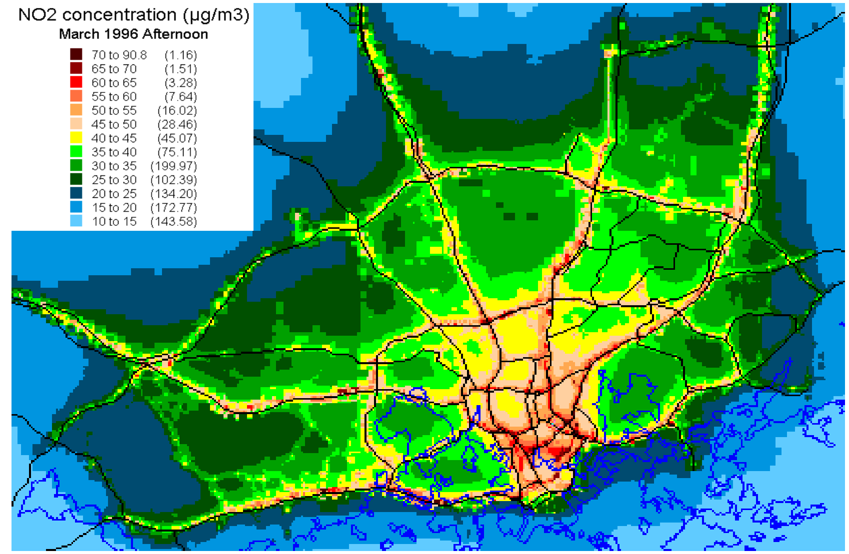
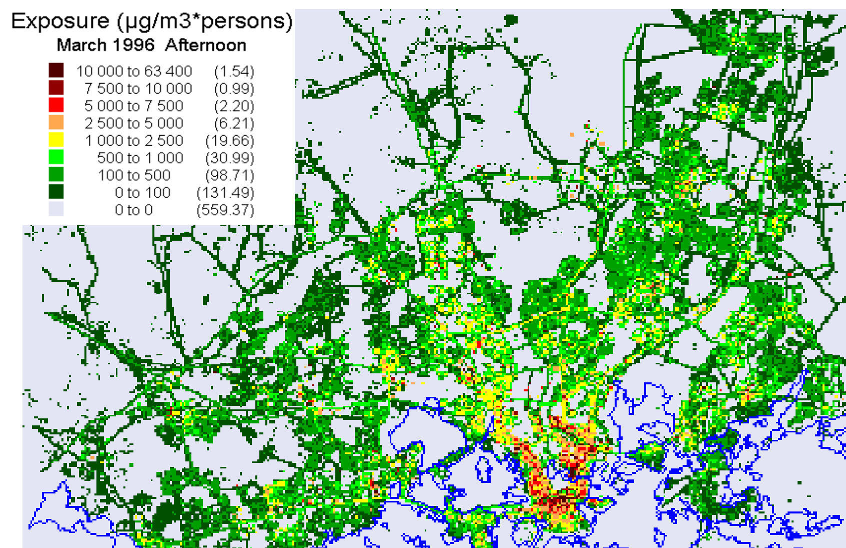


The predicted concentration of NO_2 in the greater Helsinki area ($\mu g/m^3$)



The predicted exposure of population to NO_2 ($\mu g/m^3$ *persons).

Kansanterveyslaitos
Folkhälsoinstitutet
National Public Health Institute

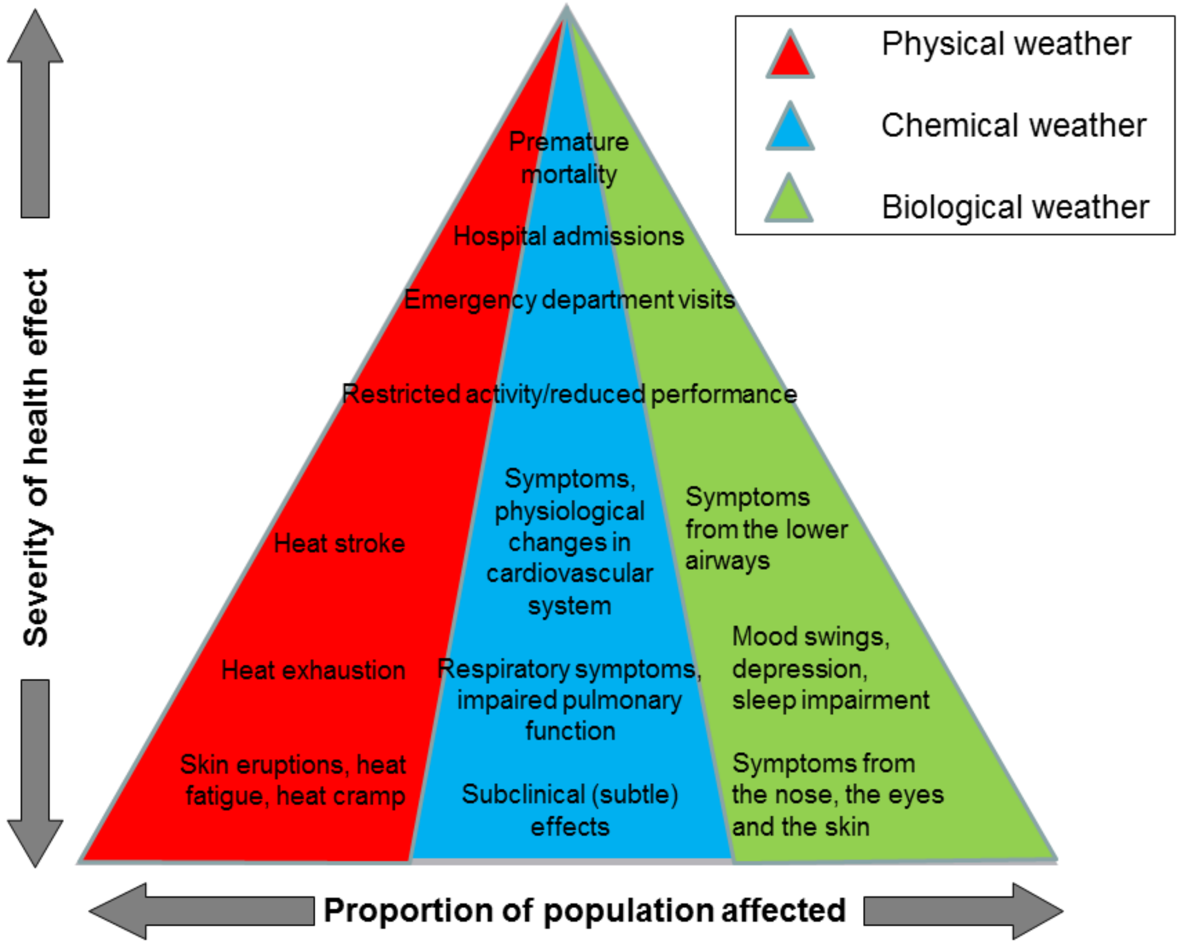
YTV

Meteorological, chemical and biological processes relevant for health effects (and meteorological / chemical / biological)

- Meteorological processes
  - Impacted by physical atmospheric variables.
- Chemical processes
  - Impacted by chemical variables.
- Biological processes
  - Impacted by bioaerosols (e.g. pollen, fungal spores).

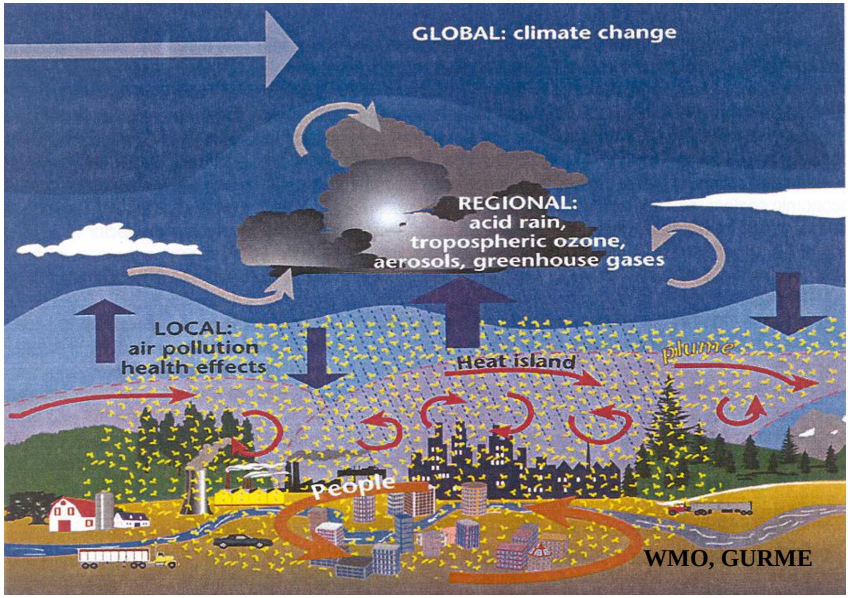
⇒ Interaction of all processes

⇒ Towards Integrated Models

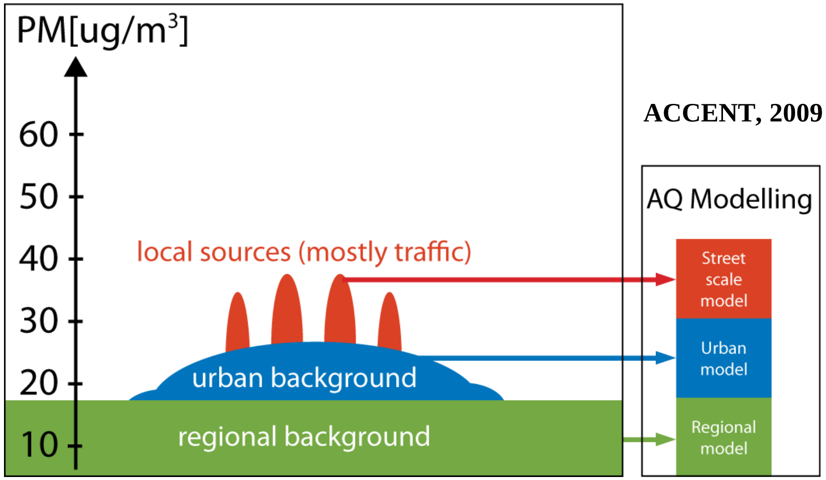


Based on Klein et al. AMBIO, (2012)

Urban features in focus:



Why do cities have a different climate ?



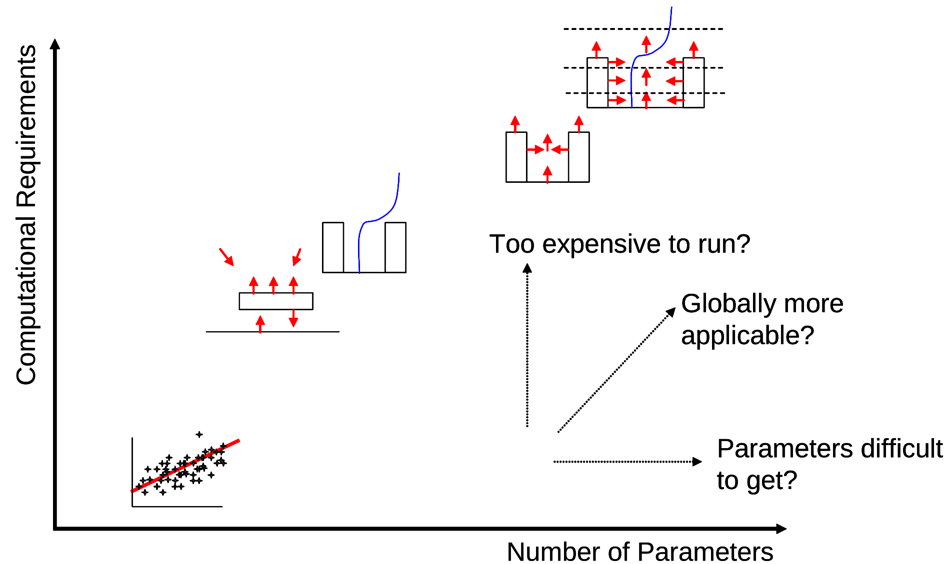
…and air quality ?

- **Urban pollutants emission, transformation and transport,**
- **Land-use drastic change due to urbanisation,**
- **Anthropogenic heat fluxes, urban heat island,**
- **Local-scale inhomogeneties, sharp changes of roughness and heat fluxes,**
- **Wind velocity reduce effect due to buildings,**
- **Redistribution of eddies due to buildings, large => small,**
- **Trapping of radiation in street canyons,**
- **Effect of urban soil structure, diffusivities heat and water vapour,**
- **Internal urban boundary layers (IBL), urban Mixing Height,**
- **Effects of pollutants (aerosols) on urban meteorology and climate,**
- **Urban effects on clouds, precipitation and thunderstorms.**

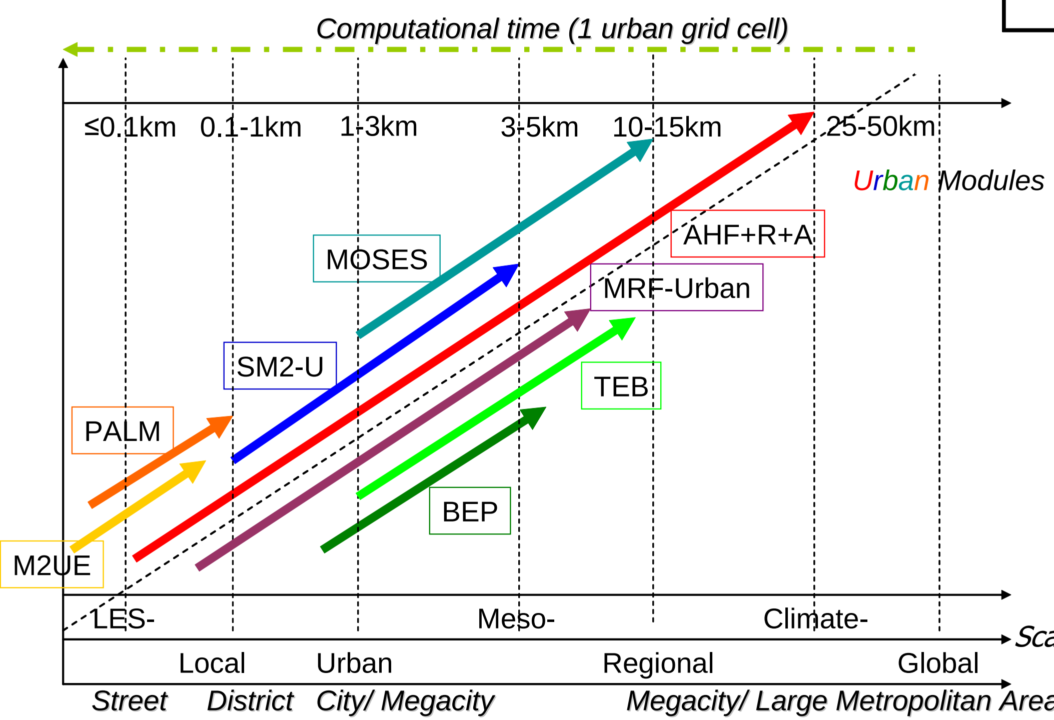
Strategy to urbanize different models

Main types of UC schemes:

- Single-layer and slab/bulk-type UC scheme
- Multilayer UC schemes,
- Obstacle-resolved microscale models



MP hierarchy of urban canopy schemes for different type & scale



- Simple modification of land surface schemes (AHF+R+A)
- Medium-Range Forecast Urban Scheme (MRF-Urban)
- Building Effect Parameterization (BEP)
- Town Energy Budget (TEB) scheme
- Soil Model for Sub-Meso scales Urbanised version (SM2-U)
- UM Surface Exchange Scheme (MOSES)
- Urbanized Large-Eddy Simulation Model (PALM)
- CFD type Micro-scale model for urban environment (M2UE)

MEGAPOLI, 2011

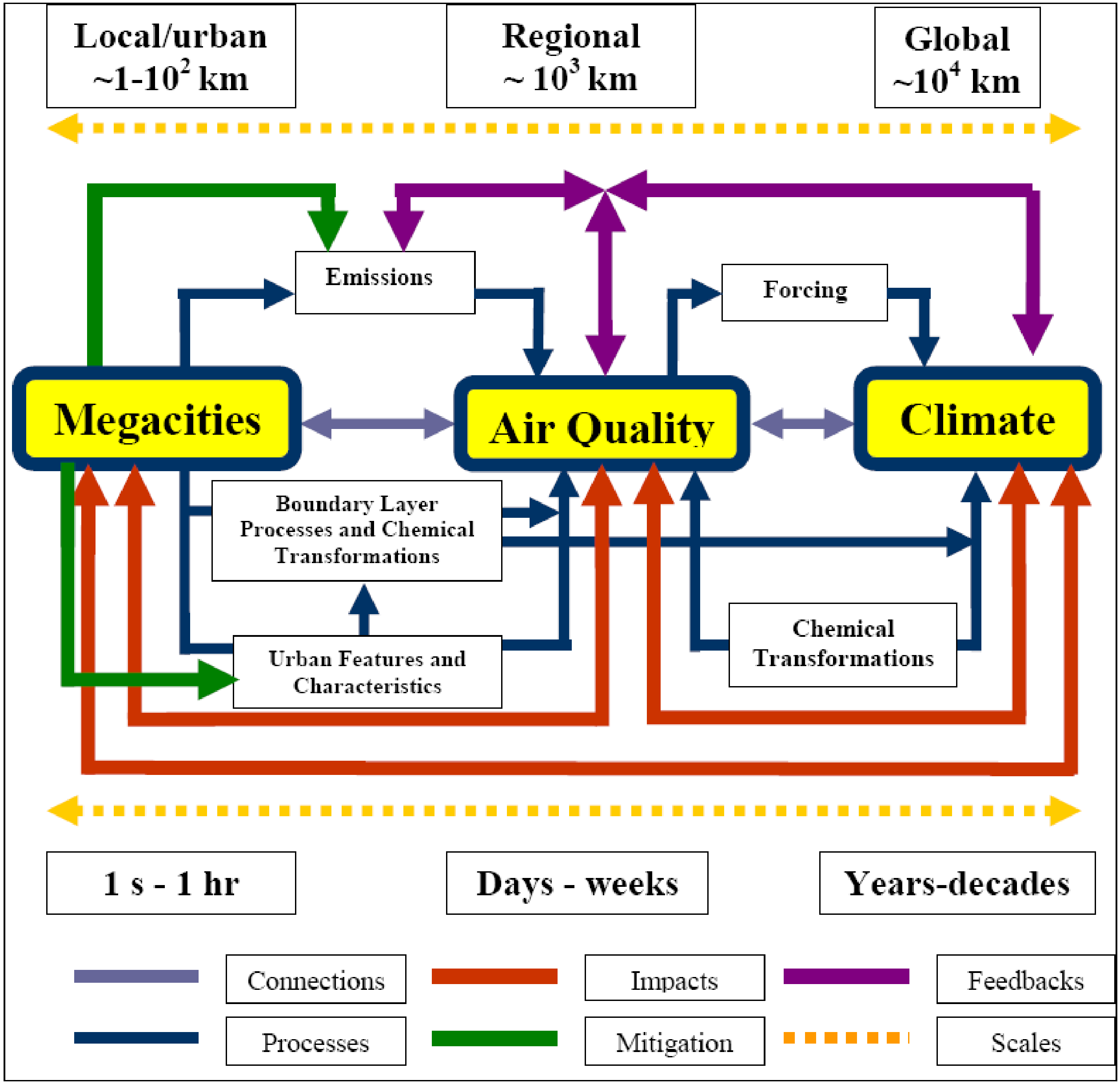
Connections between Megacities, AQ, Weather & Climate

main feedbacks, ecosystem, health & weather impact pathways, mitigation

MEGAPOLI project:

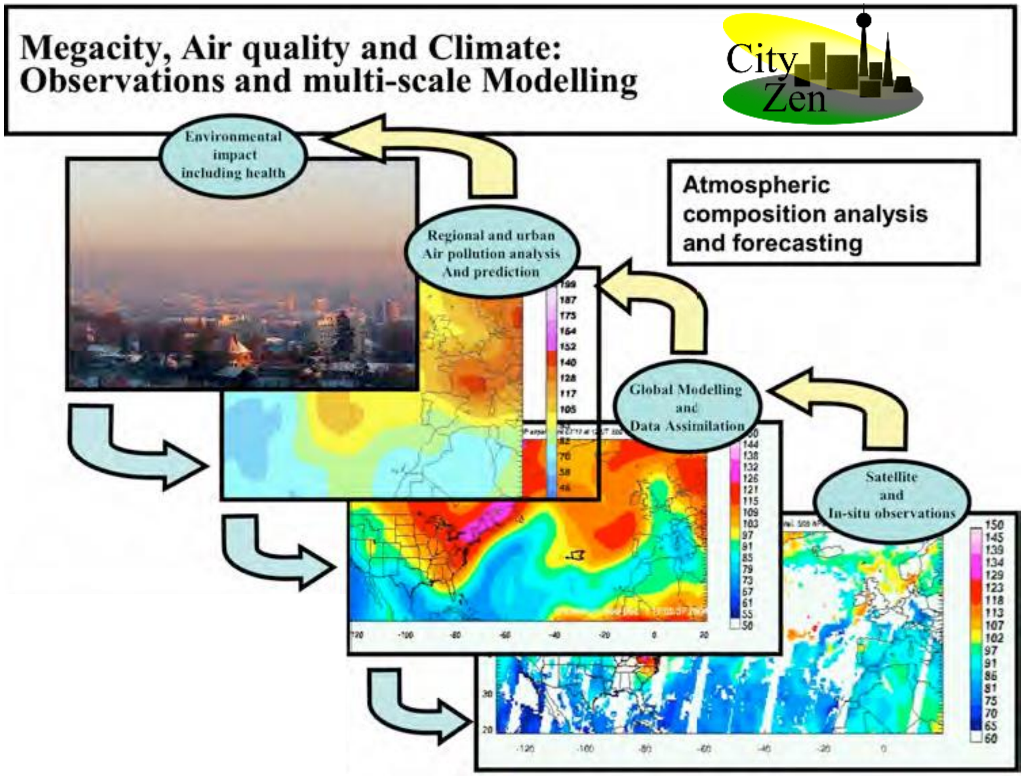
- Science - nonlinear interactions and feedbacks between emissions, chemistry, meteorology and climate
- Multiple spatial and temporal scales
- Complex mixture of pollutants from large sources
- Scales from urban to global
- Interacting effects of urban features and emissions

Nature, 455, 142-143 (2008)

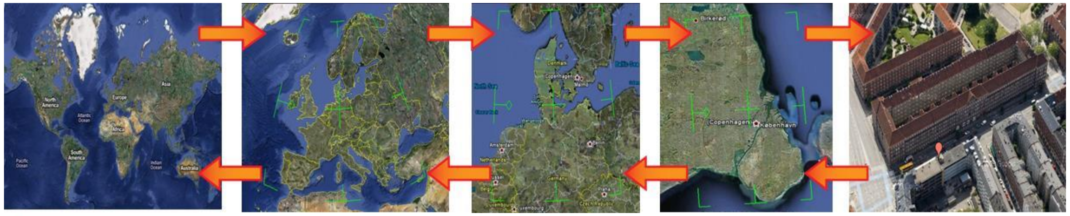


Seamless Methodology and Research Tools

Multi-scale modelling Chain / Framework: from Street to Global



GAW Modelling Application SAG < == > GURME SAG



2-way nesting, Zooming, Nudging, Parameterizations, Urban increment

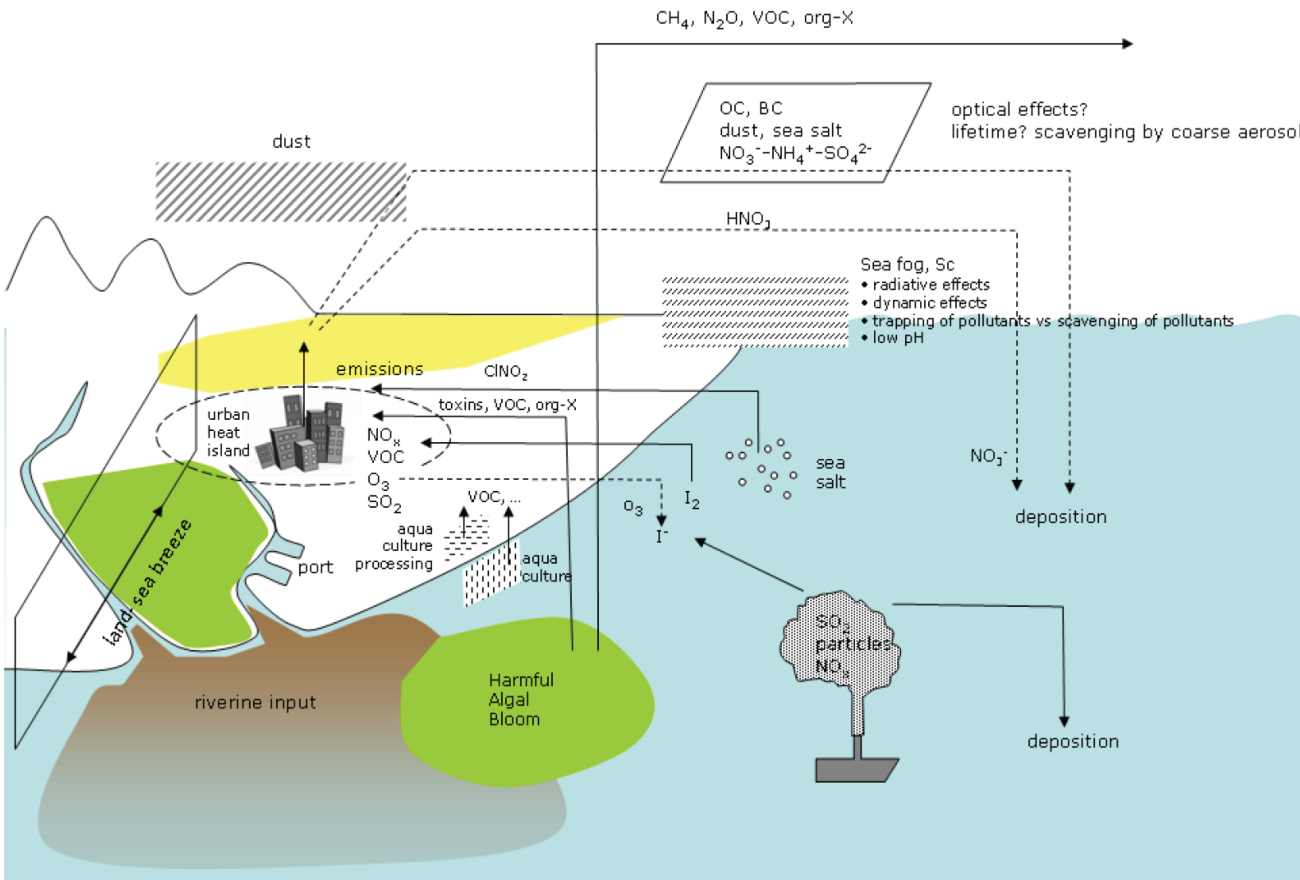
Seamless coupling for:

- Time scales: from nowcasting till decades
- Spatial scales: from street till global
- Processes: physical, chemical, biological, social
- Earth system elements: atmosphere, water, urban soil, ecosystems
- Different types of observations and modelling
- Links with health and social consequences, services and end-users

=> New generation of integrated models

Baklanov, Molina, Gauss, AE, 2016

Coastal Urban Aerosols, Climate and Ecology: processes and feedbacks



OC – organic carbon, BC – black carbon, VOC – volatile organic compounds, org-X – organic halogens compounds

(*von Glasow, Jickells, Baklanov, Carmichael et al., AMBIO, 2013*)

<u>Phenomena in coastal meteorology due to:</u>

sharp changes in heat, moisture, and momentum transfer through contrast in heating, roughness change, moisture supply,

changes in elevation,

changes in surface radiation by coastal clouds and fog,

⇒ sea/land breeze, related thunderstorms, coastal fronts, orographically trapped winds, low let jets, fog, haze, marine stratus clouds,

⇒ two-way non-linear interactions of urban aerosols, heat island and sea breeze,

⇒ Environmental/ecological consequences

Resent evolution: From UAQIFS to Multi-Hazard Early Warning Systems (MHEWS)

- While important advances have been made, new interdisciplinary research studies are needed to increase our understanding of the interactions between emissions, air quality, and regional and global climates.
- Studies need to address both basic and applied research and bridge the spatial and temporal scales connecting local emissions, air quality and weather with climate and global atmospheric chemistry.
- WMO has established the Global Atmosphere Watch (GAW) Urban Research Meteorology and Environment (GURME) project (http://mce2.org/wmogurme/) which provides an important research contribution to the integrated urban services.
- Further, a single extreme event can lead to a cascading effect that generates new hazards and to a broad breakdown of a city's infrastructure.

Hazards and Risks in the Urban Environment:

- Poor air quality
- *Extreme heat/cold and human thermal stress*
- *Hurricanes, typhoons, extreme local winds*
- Wild fires, sand and dust storms
- Urban floods
- Sea-level rise due to climate change
- Energy and water sustainability
- Public health problems caused by the previous
- Climate change: 70% of GHG emission - urban



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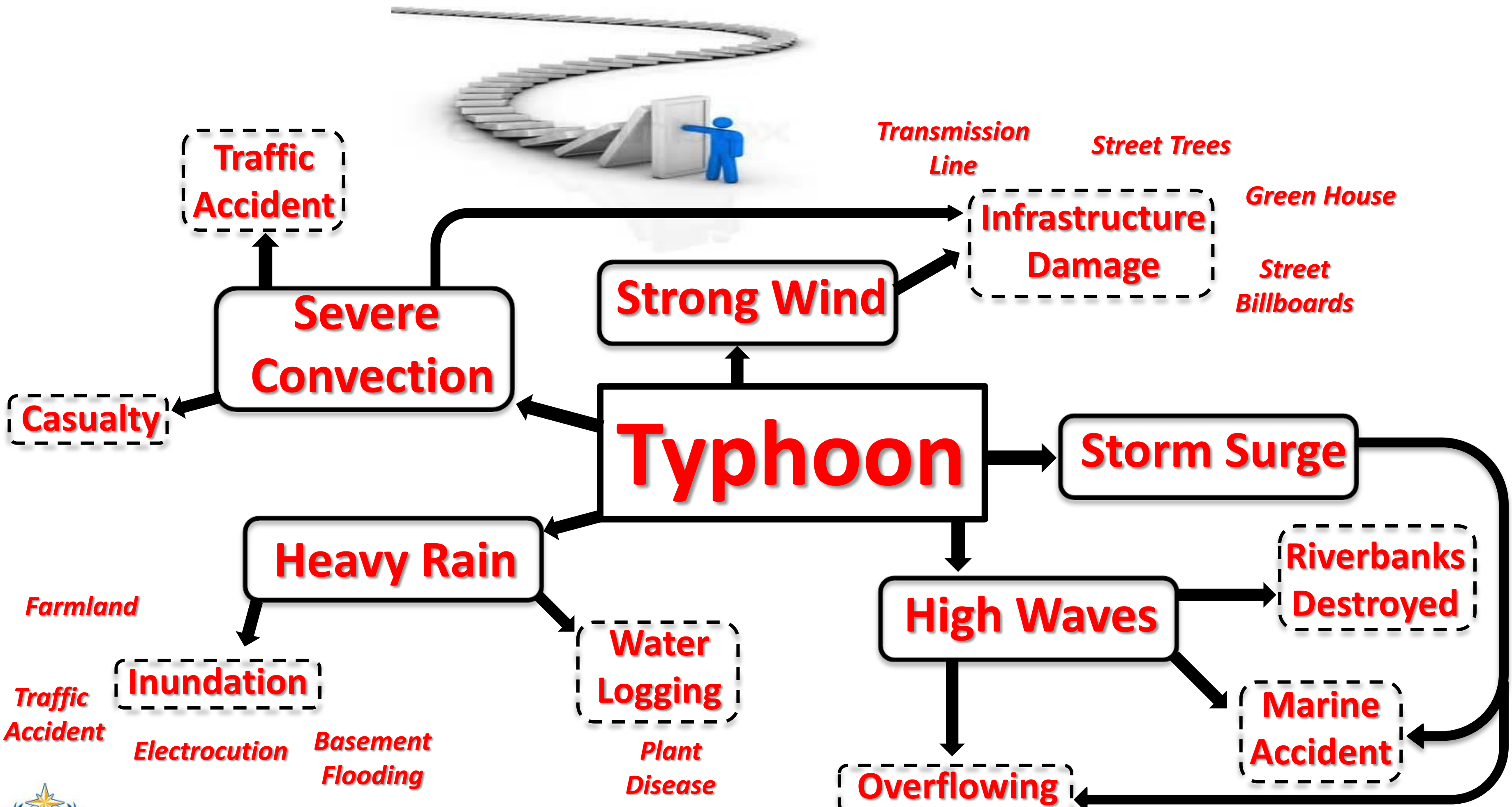
Domino effect: a single extreme event can lead to new hazards and a broad breakdown of a city's infrastructure:

Example of Hazard Domino Effect (Typhoon)



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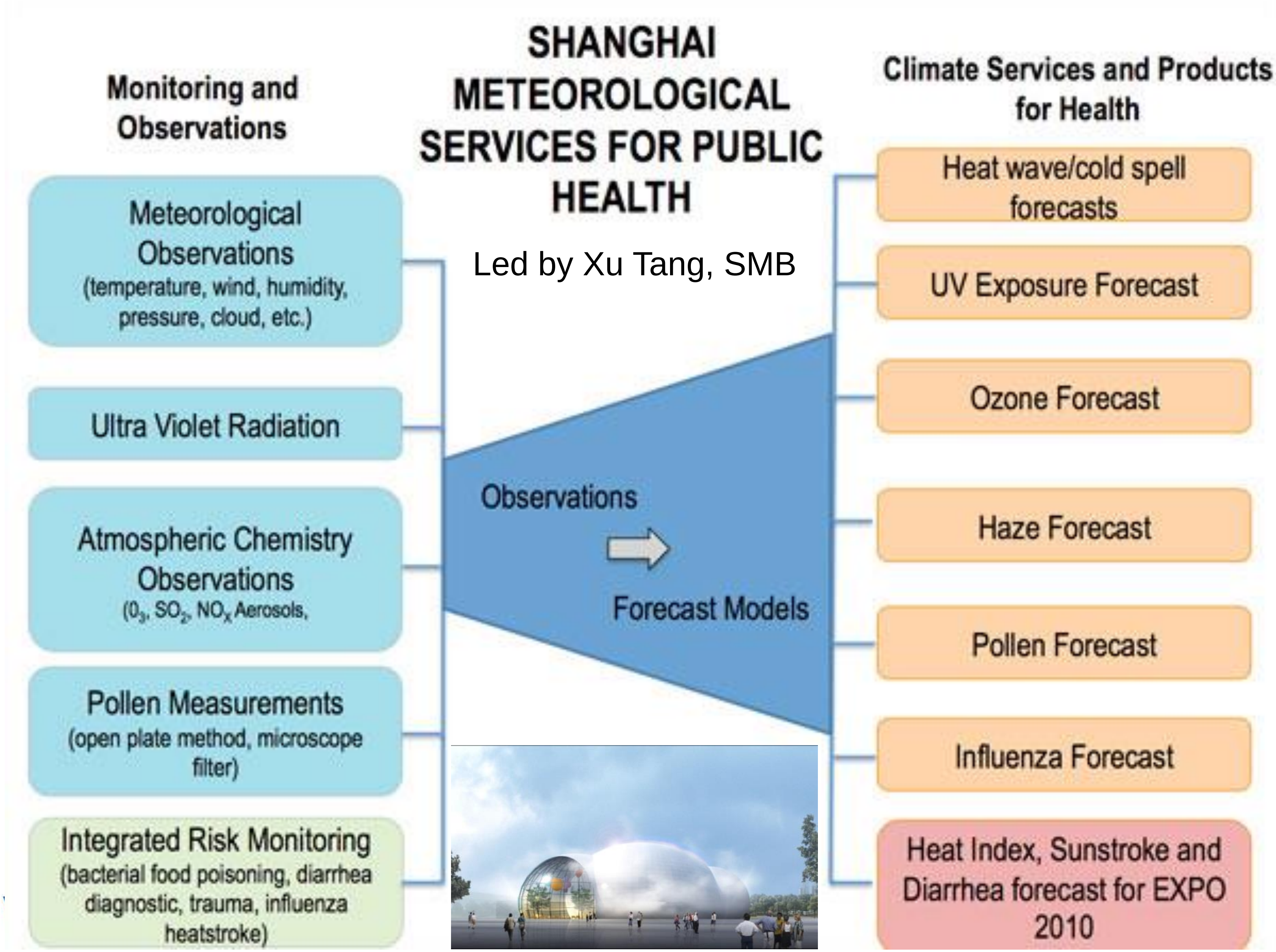
GURME Pilot Project part of Shanghai Multi-Hazard Early Warning System (MHEWS) (by SMB/CMA)

Led by Xu Tang, SMB



<u>Further evolution</u>: from UAQIFS & MHEWS to Integrated Urban System & Sevice (UIS)

- Most (about 90%) of the disasters affecting urban areas are of a hydro-meteorological nature and these have increased due to climate change (*Habitat-III, 2016*).
- Cities are also responsible not only for air pollution emissions, but also for generating up to 70% of the GHG emissions that drive large scale climate change.
- Thus, there is a strong feedback between contributions of cities to environmental health, climate change and the impacts of climate change on cities and these phases of the problem should not be considered separately.
- There is a critical need to consider the problem in a complex manner with interactions of climate change and disaster risk reduction for urban areas (*WMO, 2018, 2019; Grimmond et al., 2014, 2015; Baklanov et al., 2016, 2018*).

* WMO Urban Expert Team

for the WMO Urban Guidance (GIUS) is vailable on:

Volume I: Concept and Methodology; adopted by the 70th WMO Executive Council

Volume II: Demonstration Cities; adopted by the 71st WMO Executive Council

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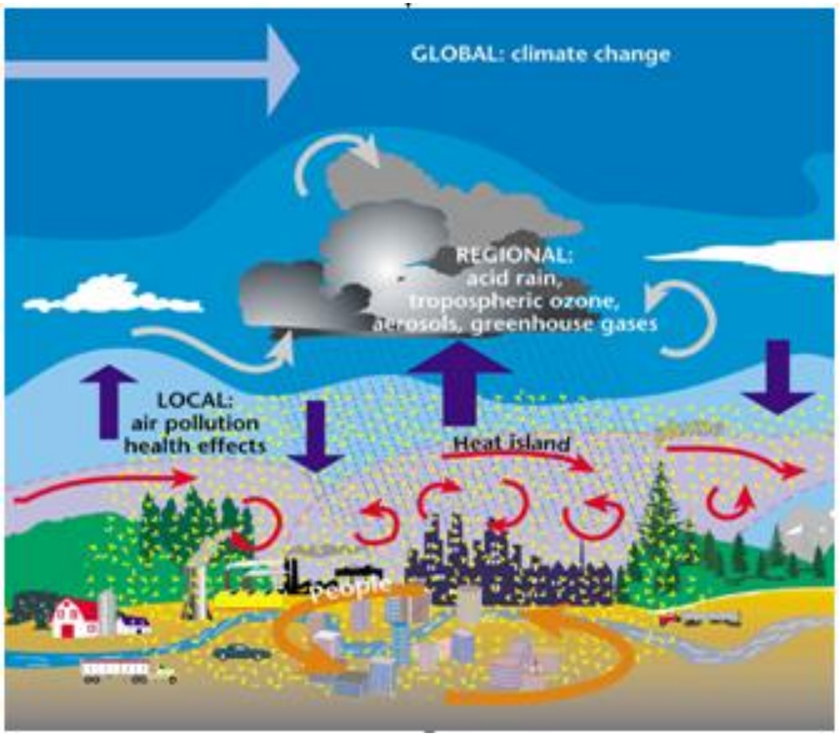
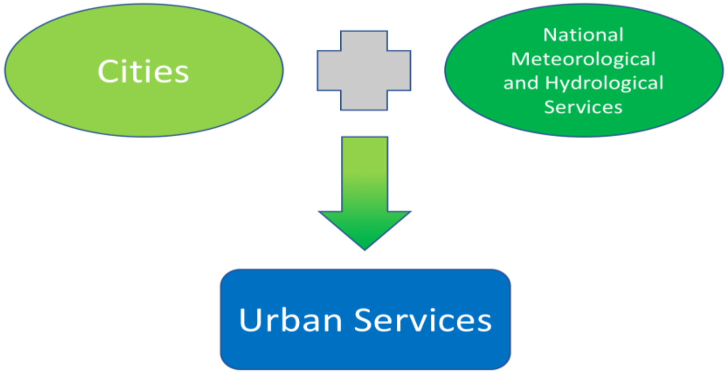
GIUS V1 team: **S. Grimmond, V. Bouchet, L. Molina, A. Baklanov, P. Joe,** C. Ren, V. Masson, G. Mills, J. Tan, S. Miao, H. Schluenzen, J. Fallmann, J.H. Christensen, H. Lean, A. Hovsepyan, B. Golding, R. Sokhi, J. Voogt, F. Vogel, J. Yoshitani, R. Spengler, B. Heusinkveld, M. Badino, J. Ching, P. Parrish, T. Georgiadis, TC Lee and many other contributors from different countries, NMHSs and cities

GIUS V2 team: **Gerald Mills, Luisa Tan Molina, Heinke Schluenzen, James Voogt, Valery Masson,Brian Golding,Chao Ren, Chandana Mitra, Shiguang Miao, Felix Vogel, Jens Hesselbjerg Christensen, Alexander Baklanov, Oksana Tarasova, Paul Joe, Sue Grimmond, Ranjeet Sokhi** and many other contributors from different countries, NMHSs and cities

Statement of the Problem

- 90% of disasters for urban areas are of hydro-meteorological nature
  - increased with climate change
- 70% of GHG emissions generated by cities
- Strong feedback
  - Two phases should not be considered separately
- Critical need to consider the problem in a complex manner with interactions of climate change and disaster risk reduction for urban areas
- Solution: Integrated Urban Systems and Services (IUS)





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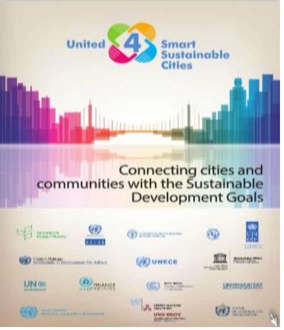
Climate smart and sustainable cities



Resilient → Multi-Hazard Early Warning Systems for Weather, Hydrology, Air Quality at Urban Scales

Sustainable → Long Term Planning
Climate Services for Weather, Hydrology and Air Quality at Urban Scales

World Meteorological Organization
Weather • Climate • Water

Goal:

Science-based Integrated Urban Hydro-Meteorological, Climate and Environmental Services (IUS)

- IUS includes a combination of dense obs. networks, high-resolution forecasts, MHEW, and climate services.
- The services should meet the special needs of urban stakeholders and assist cities in setting and implementing mitigation and adaptation strategies that will enable them to build resilient, thriving sustainable cities.
- IUS should consider seamless provision of services across all time scales.

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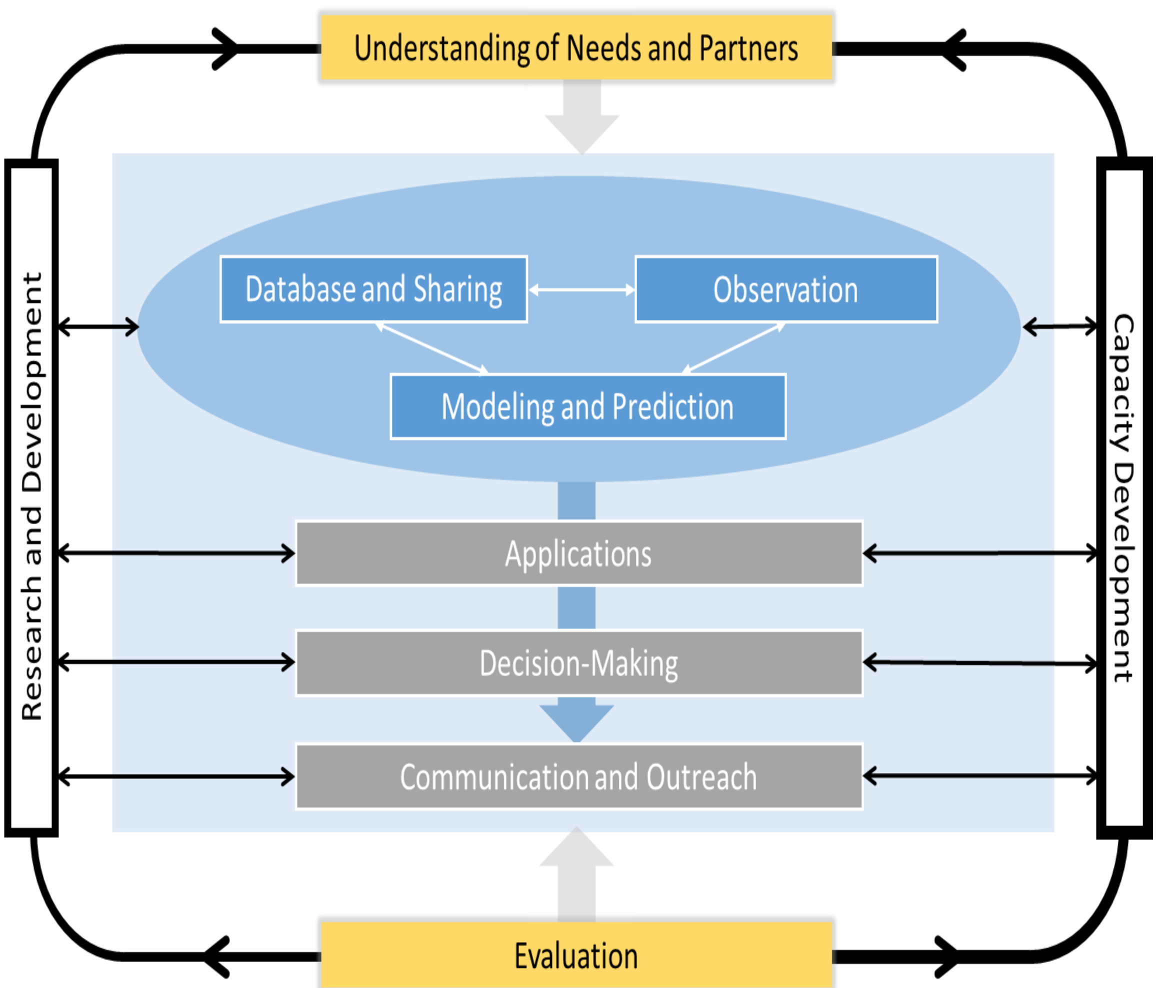
Components of the development an Integrated Urban Weather, Environment and Climate Service (IUS)



UIS focuses on improving and integrating the following main elements and sub-systems:

- Weather (especially high impact weather prediction at the urban scale),
- Climate (urban climate, climate extremes, sector specific climate indices, climate projections, climate risk management and adaptation),
- Hydrology and water related hazards (flash river floods, heavy precipitation, river water stage, inundation areas, storm tides, sea level rise, urban hydrology),
- Air quality (urban air quality and other larger scale hazards: dust storms, wildfires smog, etc.)

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IUS Guidance: Volume I: Concept and Methodology; adopted by 70th WMO Executive Council
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Supporting Platform for Building a Climate Resilient Society

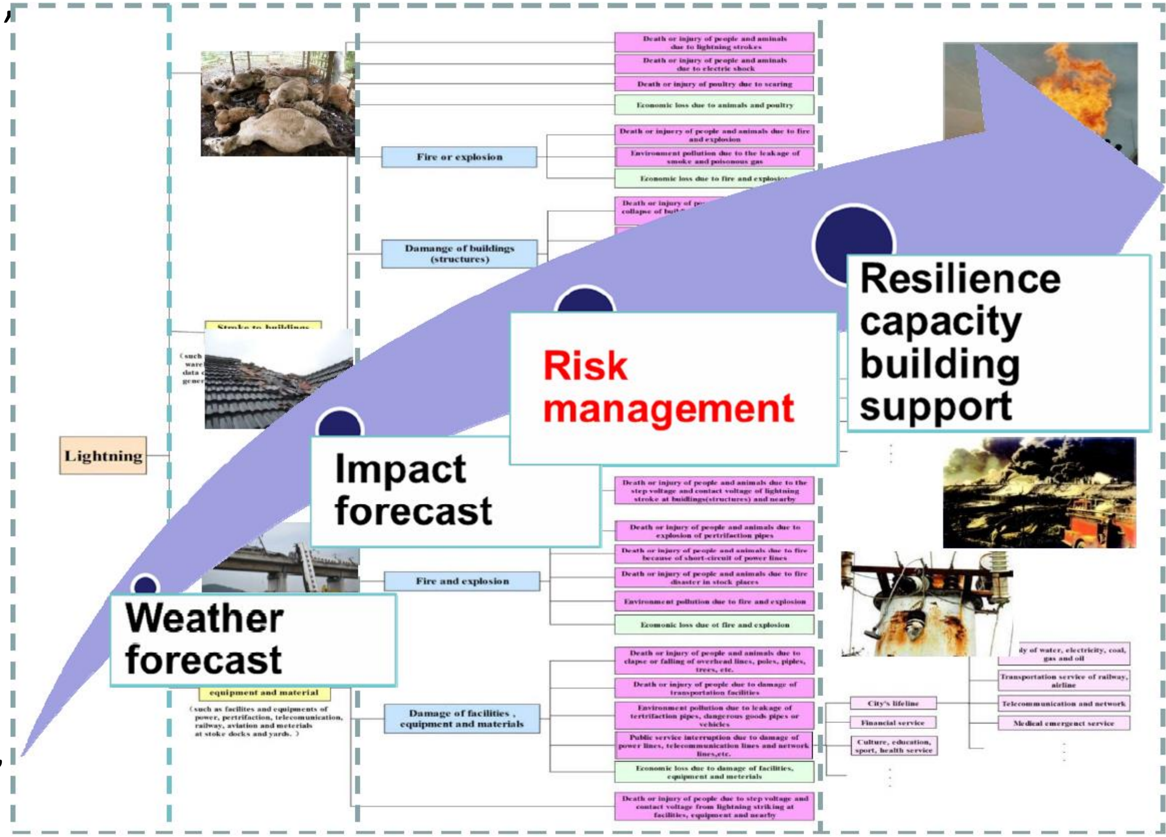
	Ecosystem and healthy living planning	Info. dissemination & interaction	Green energy Business cont planning	Security of infrastructure & utilities	Emergency risk management	Public health and safety	Adaption engineering	Transportation, agriculture & food security
Severe weather								
Risk mapping								
Airborne hazard								
Climate extreme								
Water related hazard								
Observation & modelling								

Integrated Urban Weather, Water and Environment DRR Service delivery including User Interface for Urban Climate Services

https://2a9e94bc607930c3d739becc3293b562f744406b.googledrive.com/host/0BwdvoC9AeWjUazhkNTdXRXUzOEU/bulletin_63-1_en.pdf

IUS: Translating Research to Improved Urban Services

- **Multi-purpose**: forecasts, research, planning, mitigations, service
- **Multi-function:** High impact weather, air quality, floods, urban climate, special end user needs
- **Multi-scale:** macro/mesoscale, urban, neighbourhood, street canyons, buildings
- **Multi-variable:** thermal, dynamic, chemical, hydrological, biometeorological, ecological
- **Multi-tool/platform**: radar, wind profiler, ground-based, airborne, satellite based, in situ observation, sampling;
- **Multi-linked**: linkages between all platforms, big data solutions



Tan et al., 2015

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Better communications – impacts & risks

Guidance on Integrated Urban Hydro-Meteorological, Climate and Environmental Services (IUS)

Volume I: Concept and Methodology; adopted by the 70th WMO Executive Council

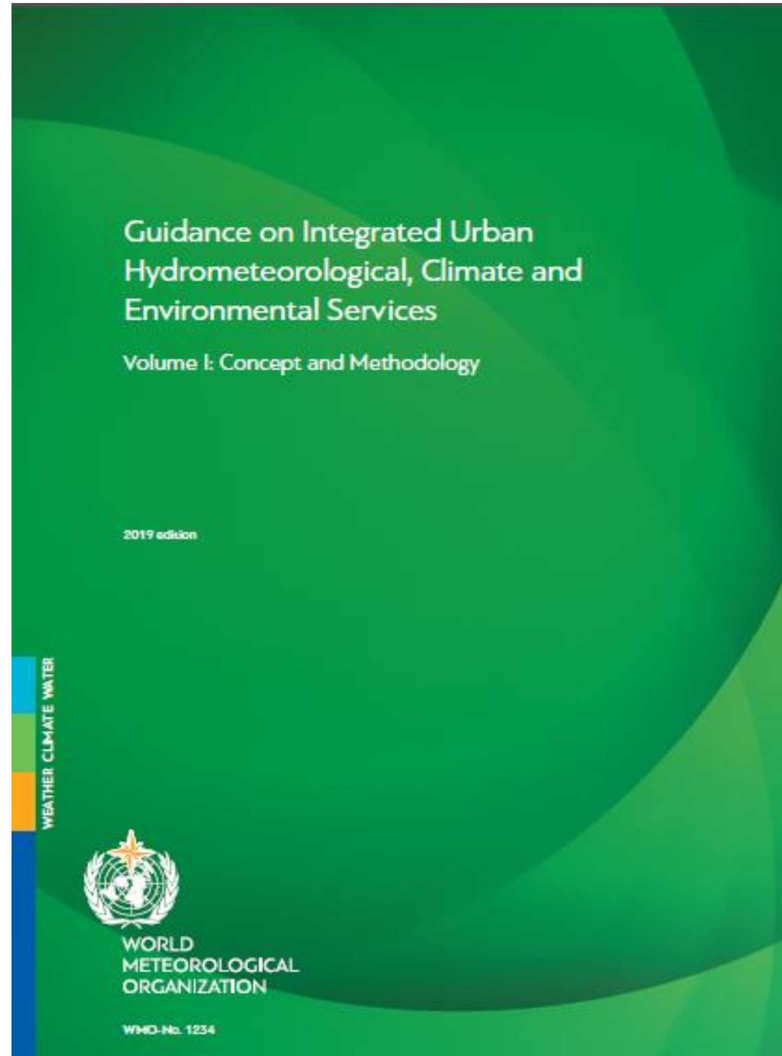
Volume II: Demonstration Cities; adopted by the 71st WMO Executive Council

Volume III: *Guidelines for practical realization and delivery (in elaboration)*

Aim: To document and share the ***best available practices*** that will allow Members to ***improve the resilience of urban areas to a great variety of natural and other hazards***

Benefits of IUS:

- Resiliency through multi-hazard early warning systems (MHEWS)
- Sustainability through urban long-term planning
- Capability and capacity through cross-cutting services
- Efficiency through infrastructure cost-sharing with partners
- Consistency (hence effectiveness and efficiency)
- Effective Service through Partnerships/ Communication of Risk



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Available on:

V1. https://library.wmo.int/doc_num.php?explnum_id=9903 and

V2: https://elioscloud.wmo.int/share/s/Rf3EW264RZWGJuLrCuzo9w

Mexico City

air pollution, hydrometeorological hazards, heatwaves, associated health and geophysical risks (e.g. flooding, landslides, wildfires)

Paris

heatwaves, river flooding, air quality

Toronto

extreme rainfall (convective weather), strong winds, thermal stress (heat/cold waves), air quality episodes, lake/river flooding

Hong Kong

tropical cyclones, convective weather events, extreme temperatures, coastal inundation and flooding, water scarcity, air pollution

* CityIPCC 4 cities case studies (*Baklanov et al., 2020*)
* IUS Guidance Vol. II: 87 countries analyzed, 30 demonstration cities (*WMO, 2019*)

Examples of Integrated Urban Service Realisation

Hong Kong Local Experiences on IUS

Urban Integrated Services and Urban Design, Planning and Construction

Extreme Weather Events (HKO)
- Tropical cyclone and storm surge
- Thunderstorm and lightning
- Rainstorm, flooding and landslide
- Extreme hot & cold weather events
- Drought

Air quality modeling and forecast (EPD)
- Air Quality Health Index

Utilization of climate information (HKO)
- Climate change
- Disaster risk reduction (DRR)
- Urban climate evaluation

Evaluation
(Some examples)
- Wind load on buildings and infrastructures
- Coastal structure design
- Drainage system and slope safety
- Lightning safety
- Thermal comfort and health impact
- Energy demand / saving
- Water resources
- High air pollution area detection
- City resilience and disaster preparedness
- Urban heat island
- Air Ventilation Assessment (AVA)

Examples of Urban Planning & Infrastructure Construction
- Design standard and code of practices for buildings and infrastructures (e.g. “Building Wind Code”, Drainage Master Plan, Port Work Design Manual, etc.)
- Mitigation measures to natural terrain landslides
- Drainage tunnels and Underground Stormwater Storage Tanks
- Blue-Green infrastructure
- Total water management strategy
- Climate change mitigation and adaptation measures
- Road networking design and urban density control
- Implementation of AVA and Urban Climatic Map into planning of new development and old district renewal

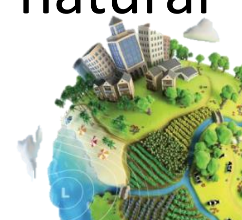
HKO & EPD In WMO, 2018 (Courtesy of C. Ren)

HKO - Hong Kong Observatory

EPD - Environmental Protection Department

Conclusions: IUS for Smart Cities

- WMO is promoting safe, healthy and resilient cities through the development of Integrated Urban Weather, Environment and Climate Services (IUS).
- The aim is to build urban services that meet the special needs of cities through a combination of dense observation networks, high-resolution forecasts, multi-hazard early warning systems, disaster management plans and climate services.
- This approach gives cities the tools they need to reduce emissions, build thriving and resilient communities and implement the UN Sustainable Development Goals.
- The Guidance on Integrated Urban Hydro-Meteorological, Climate and Environmental Services, developed by a WMO inter-programme working group and the Commission for Atmospheric Sciences and Commission for Basic Systems, documents and shares the good practices that will allow countries and cities to improve the resilience of urban areas to a great variety of natural and other hazards (*WMO, 2018, 2019*).



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Thank You!

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