World Meteorological Organization

Weather • Climate • Water

From Urban Weather, Climate and Environment Research to Urban Integrated Services

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17th Iranian Geophysical Conference, 10-12 May 2016, Tehran, Iran

Highlights of the presentation

- Climate, air quality and megacities interactions: gaps in knowledge, research needs.
- Urban hazards: pollution episodes, storm surge, flooding, heat waves, public health.
- Global climate change affects megacities' climate, environment and comfort.
- Growing urbanization requires integrated weather, environment and climate monitoring systems.
- New generation of multi-scale models and seamless integrated urban services are needed.

Based on recently published review paper:

Baklanov, A., L.T. Molina, M. Gauss (2016) Megacities, air quality and climate. *Atmospheric Environment*, 126: 235–249. doi:10.1016/j.atmosenv.2015.11.059

WHY Megacities?

- **UN New Urban Agenda & HABITAT-III**

- **Urban: > 50% of world popul. - < 1% land**
- **MCs: 10% of world popul. / < 0.2% land**
- **19 megacities > 10 Million people**
- **22 cities with 5-10 million people**
- **370 cities with 1-5 million people**
- **433 cities with 0.5-1 million people**

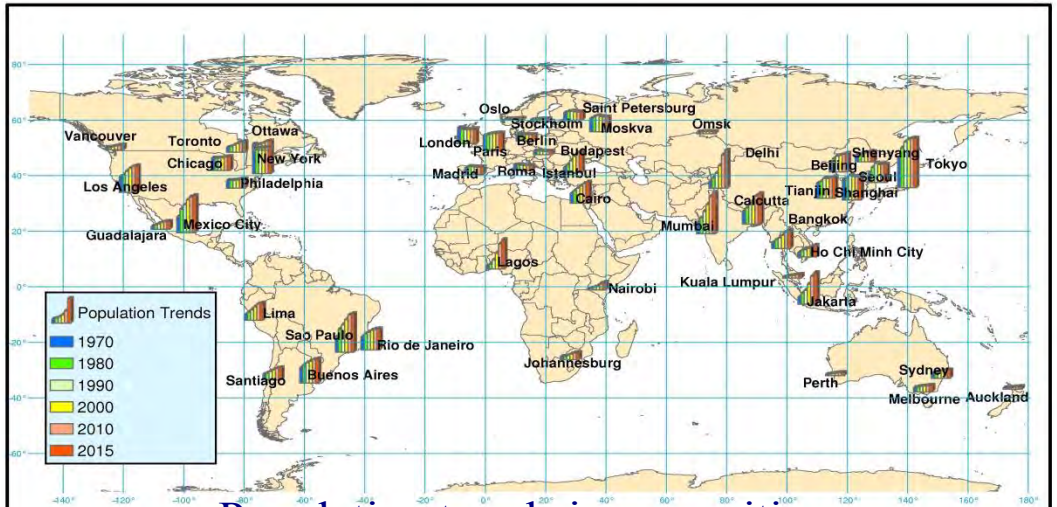
Source: UNCHS 2007

Urbanisation => Crisis? Or Solution?

- Driving forcers in economic growth (80%)
- Growing emissions and urbanisation => environment and climate on different scales
- Rapid and unbalanced growth
- Problems of fast growth: increasingly subject to crises
- Highest growth rates in medium size cities
- New urban population ≈ poor urban population
- Problems aggravated in developing countries by fin. crises

Fast growing MEGACITIES:

- 1950: 4, 1980: 28, 2002: 39, 2015: 59 megacities worldwide;
- 2/3 in developing countries, resp. South and East Asia
- 2002: 394 Mio. people, of these: 246 Mio. in developing countries, > 215 Mio. in Asia; in the year 2015: 604 Mio. worldwide
- Population data tripled between 1970 and 2000: e.g. Mexico City, São Paulo, Seoul, Mumbai, Jakarta, Teheran
- In 2050 urban population will be 66%



Population trends in megacities

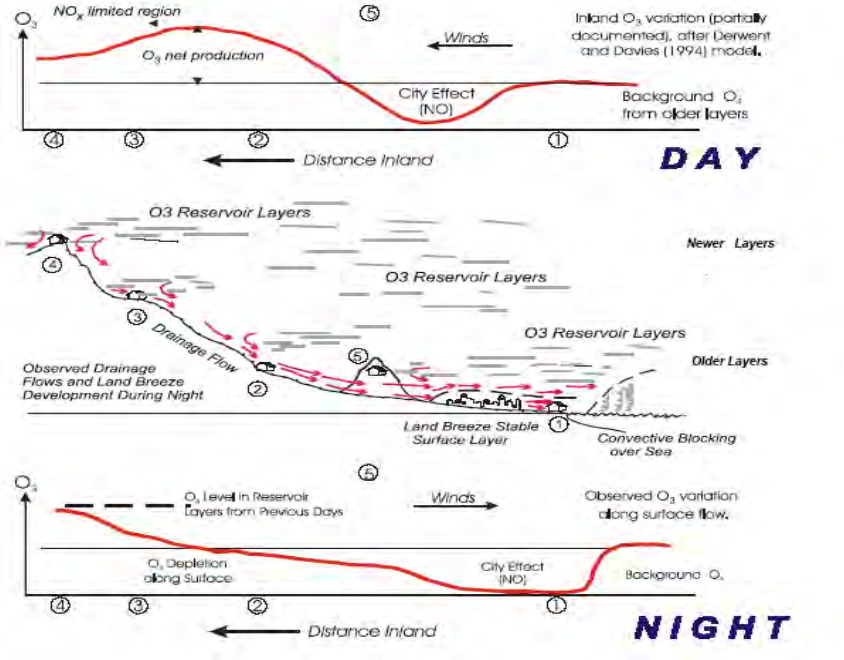
Mountains: Urban Climate & Air Pollution

- Most polluted cities – in mountain valleys
- Multi-scale effects: 2-way interaction of regional and urban scale processes
- Lower ventilation potential for cities in mountains: mountain valleys and circuses
- Nocturnal inversions leading to elevated air pollution episodes
- More vulnerable, significant impact on human health, visibility, ecosystem, climate
- Simplified AQ models fail to produce high pollution episodes in mountain and urban areas

Lanzhou urban pollution in a valley basin, Tibet, China

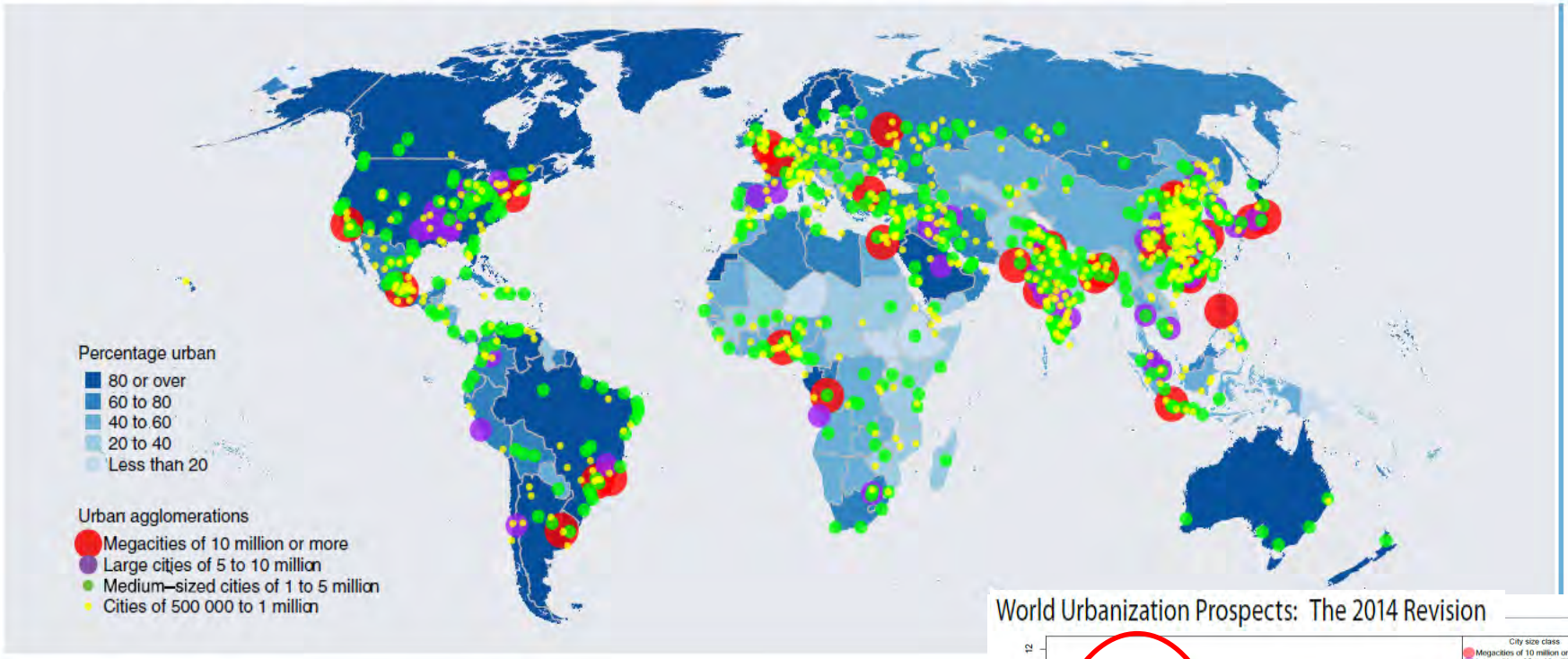
Many large and fast-growing cities situated in mountain regions, e.g. *Alma-Aty, Ankara, Bangalore, Dushanbe, Kabul, Kathmandu, Yerevan, Lanzhou, Santiago, Tashkent, Tbilisi,* ***Tehran***

Climate change affects urban environment: *extreme weather, dry air & water problems, heat waves, pollution episodes, increases pollen season, forest fires, desertification, indirect costs, etc.*



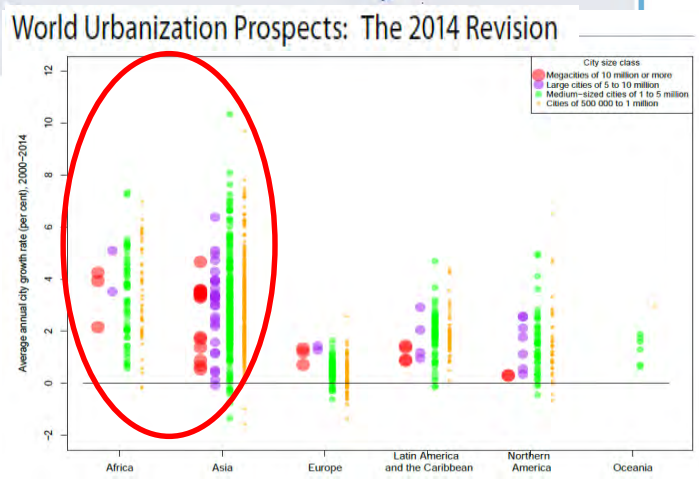
Urban effects on air pollution in Mediterranean region

XXI century – a century of urbanization



Risks in the urban environment:

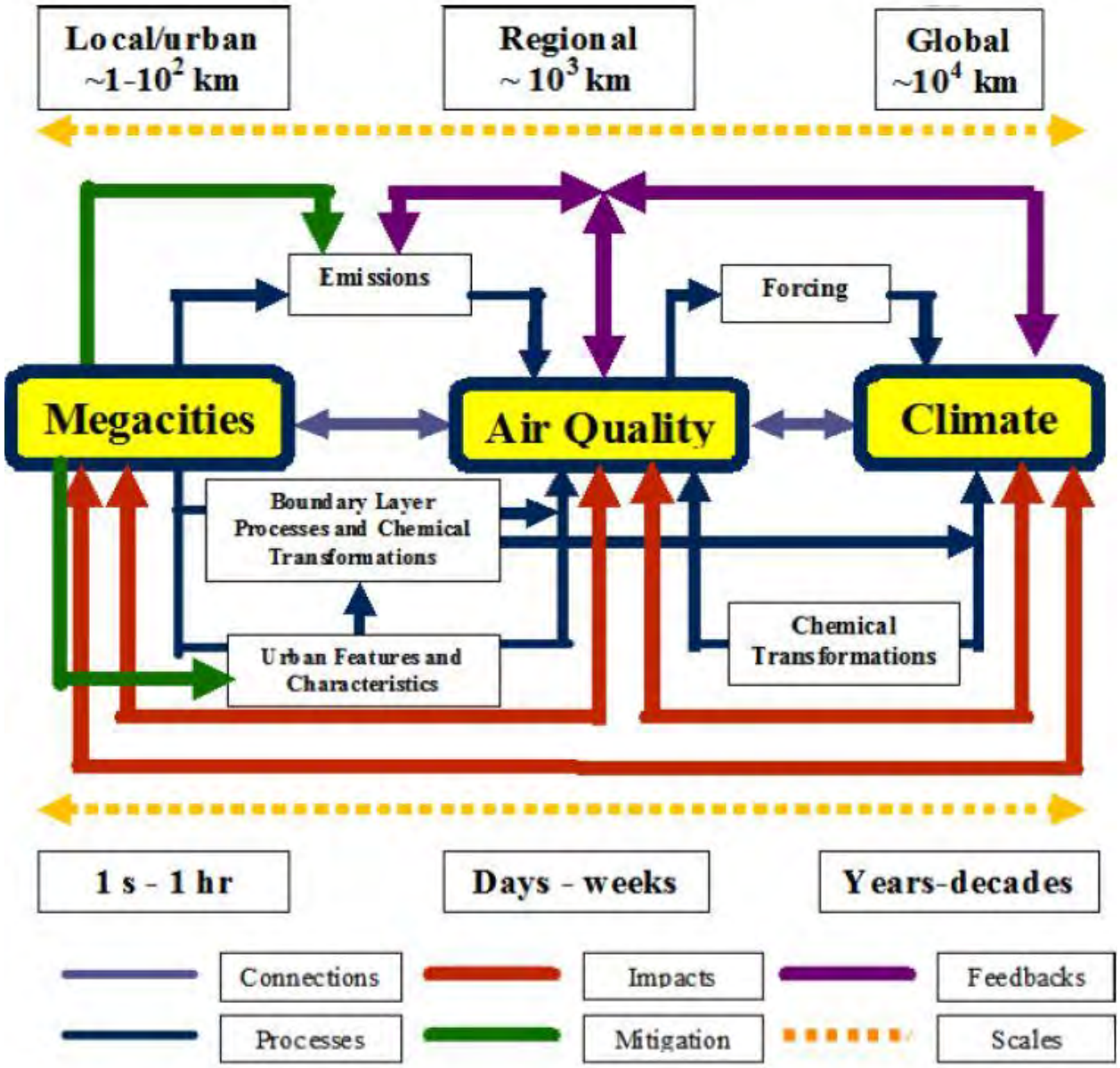
- poor air quality;
- extreme heat/cold and human thermal stress, extreme local winds;
- urban floods;
- sea-level rise;
- energy and water sustainability;
- public health problems caused by the previous
- climate change - 75% GHG emission.



Connections of Megacities, AQ, Weather and Climate

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

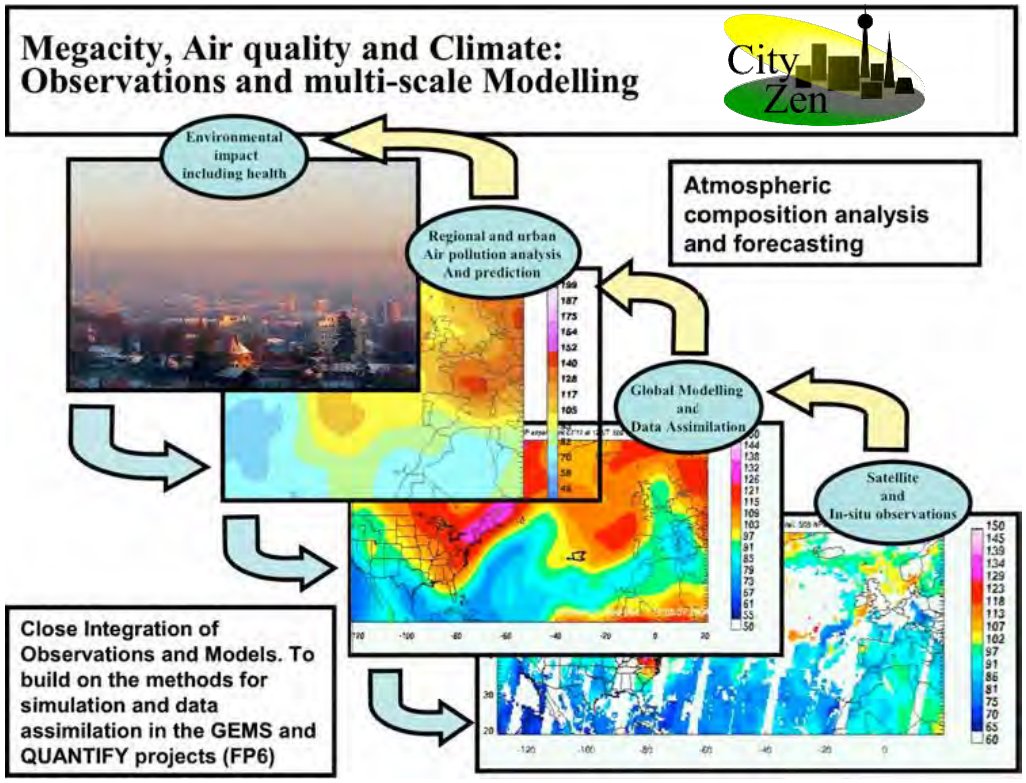
- Science - nonlinear interactions and feedbacks between emissions, chemistry, meteorology and climate
- Multiple spatial and temporal scales
- Complex mixture of pollutants from large sources
- Interacting effects of urban features and emissions
- Chain of meteo-hazards domino effects on city safety and social activities



Nature, 455, 142-143 (2008)

Seamless Methodology and Research Tools

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



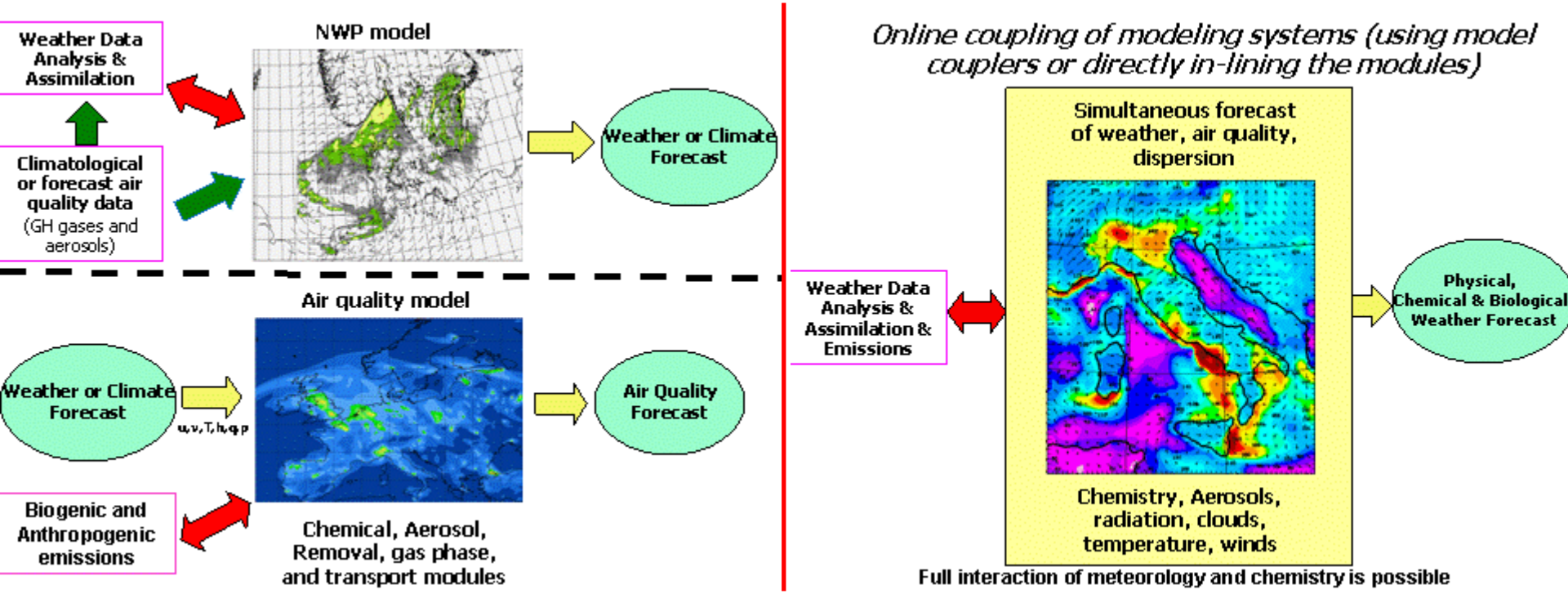
2-way nesting, Zooming, Nudging, Parameterizations, Urban increment (AUTH)

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

Schematic diagram of the offline and online coupled ACT & NWP/CC modelling approaches

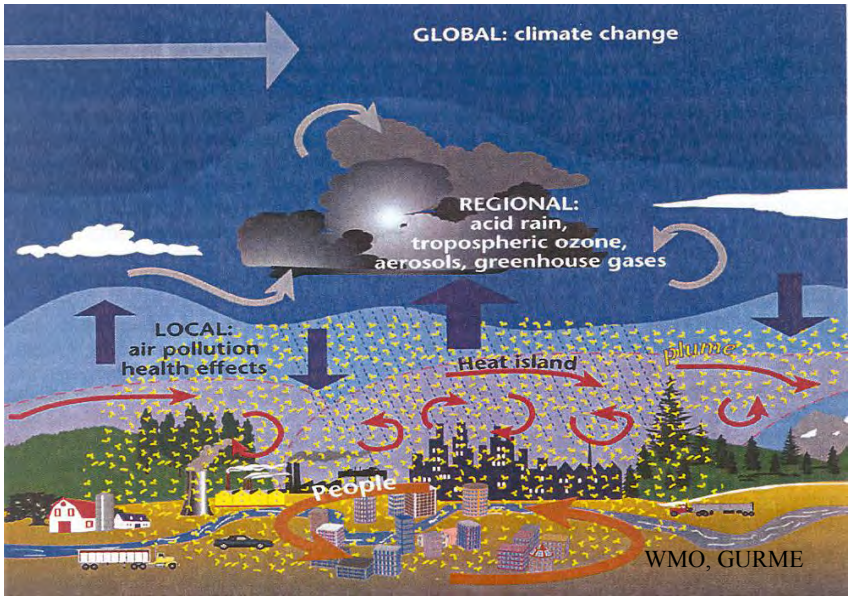


Online coupling can be archived through the use of various available coupling tools or through directly inlining the chemical and aerosol modules into the NWP models.

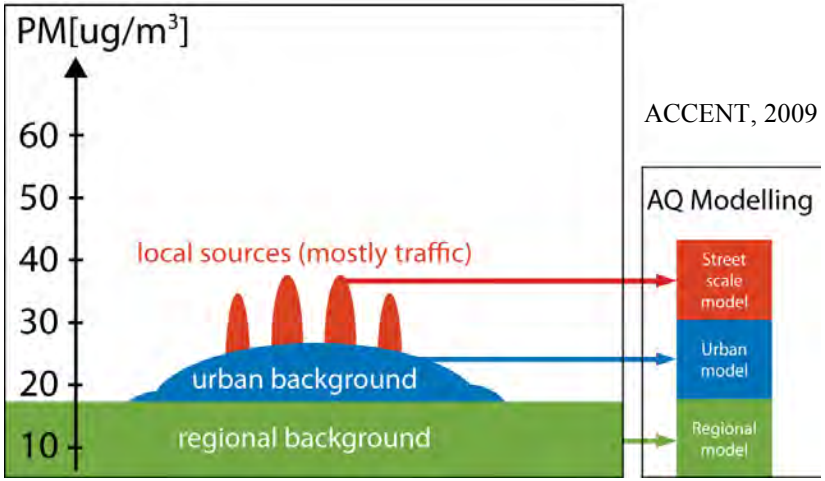
Order of integration and complexity:

- Order A – off-line coupling, meteorology / emissions -> chemistry; Models: All.
- Order B – partly online coupling, meteorology -> chemistry & emission; Models: UKCA, M-SYS, UM/WRFChem, SILAM.
- Order C – fully online integrated with two-way feedbacks, meteorology <=> chemistry & emissions; Models: UKCA WRF-Chem, Enviro-HIRLAM, EMAC (former ECHAM5/MESSy).

Urban features in focus:



Why do cities have a different climate ?



…and air quality ?

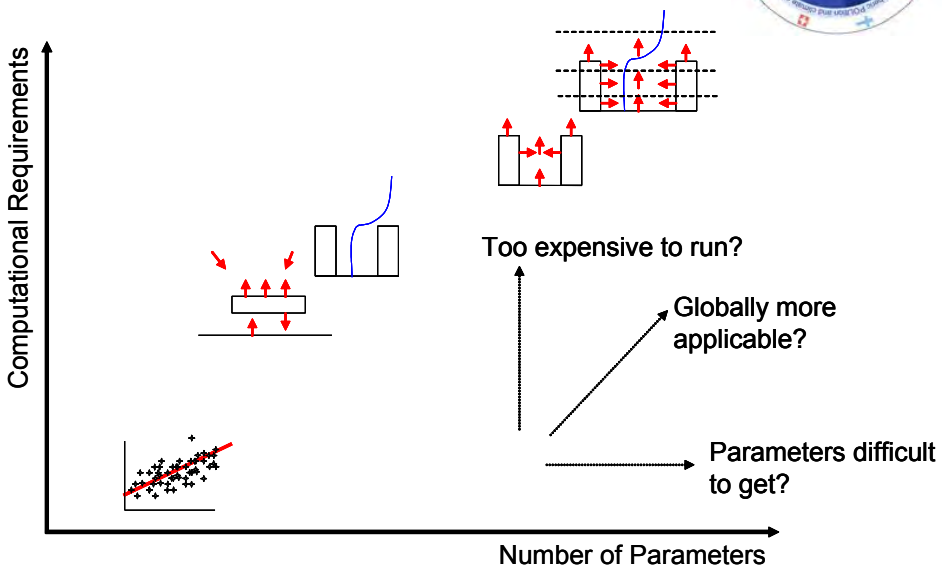
- **Urban pollutants emission, transformation and transport,**
- **Land-use drastic change due to urbanisation,**
- **Anthropogenic heat fluxes, urban heat island,**
- **Local-scale inhomogeneties, sharp changes of roughness and heat fluxes,**
- **Wind velocity reduce effect due to buildings,**
- **Redistribution 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

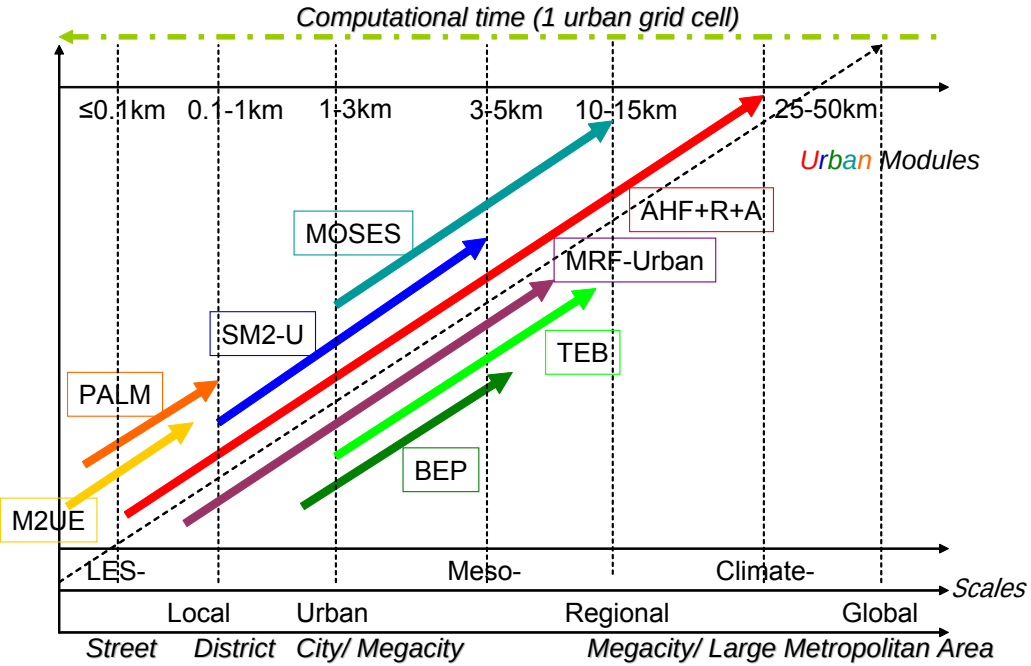
Available models

Main types of UC schemes:

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



MP hierarchy of urban canopy schemes for different type and scale models:



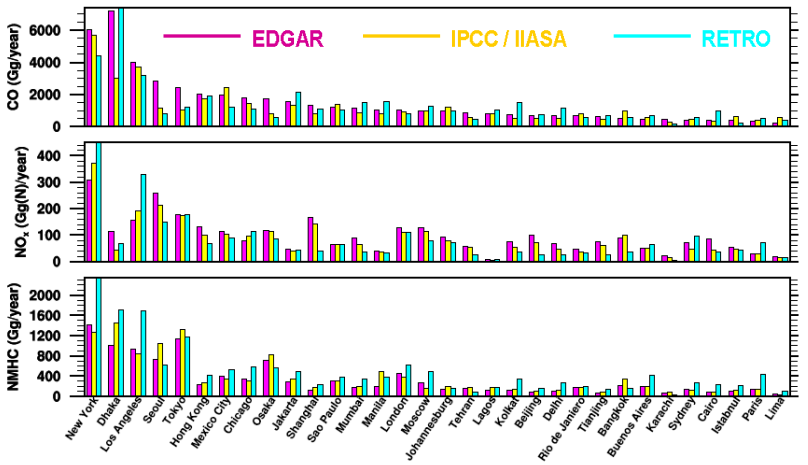
- Simple modification of land surface schemes (AHF+R+A)
- Medium-Range Forecast Urban Scheme (MRF-Urban)
- Building Effect Parameterization (BEP)
- Town Energy Budget (TEB) scheme
- Soil Model for Sub-Meso scales Urbanised version (SM2-U)
- UM Surface Exchange Scheme (MOSES)
- Urbanized Large-Eddy Simulation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

Mahura & Baklanov, 2011

What are the major gaps in MC emissions?

- Compared 3 global EIs and 2 city-level inventories: large differences (factor of 2)
- GEIs underestimate emissions from European and Chinese MCs and overestimate emissions in LA and in Asia (except China)
- MCs in Europe and N & S America, transport is dominating for CO and NOx; in Asia and Africa: CO - dominated by residential biofuel use, NOx - industrial emissions

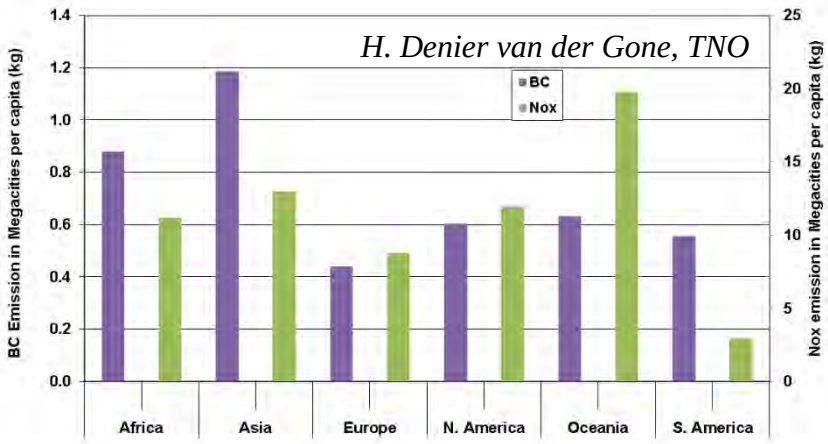
(Butler et al., Atmos. Env., 42, 2008)



Key gaps in our knowledge:

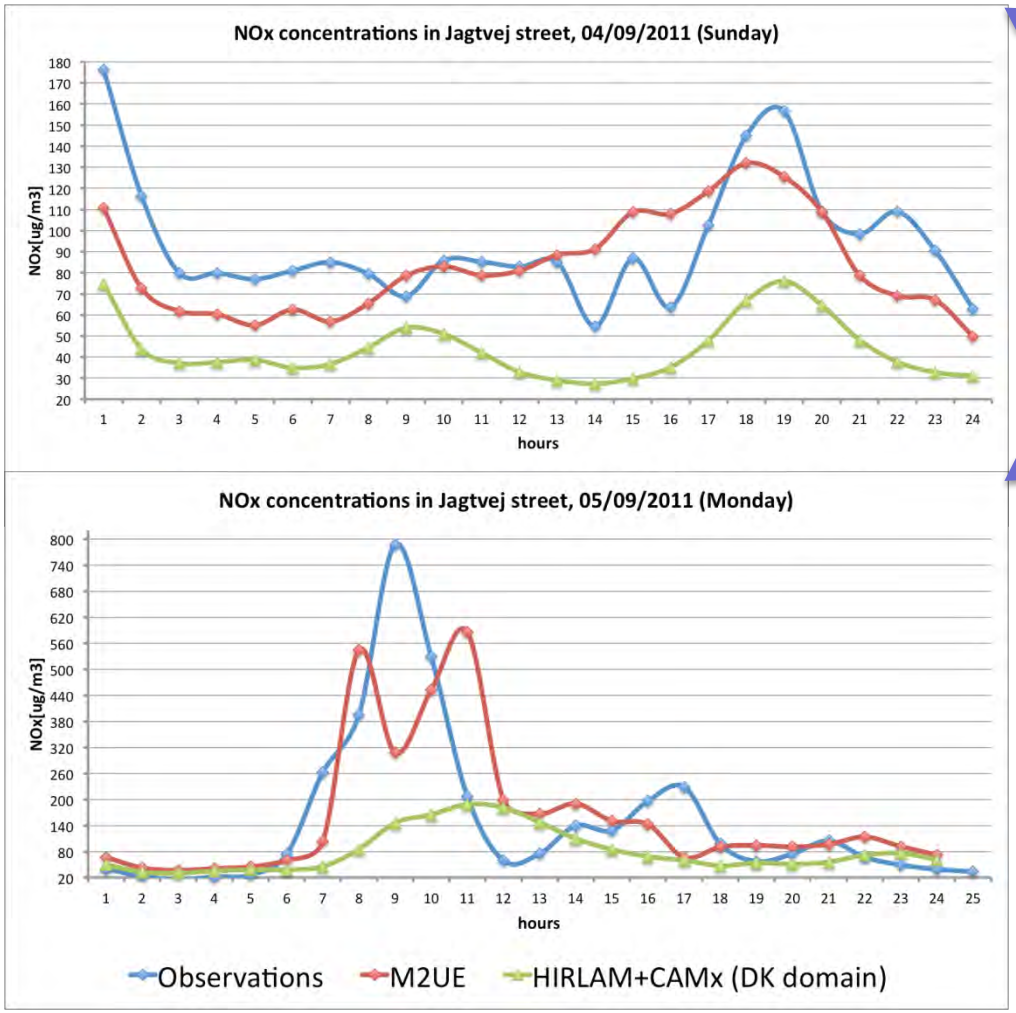
- initial process of developing emissions databases
- variation in fuels, its quality and appliance types between MC and country
- identifying which emissions should be associated with MCs
- notable differences in per capita emissions from the various MCs: reasons?

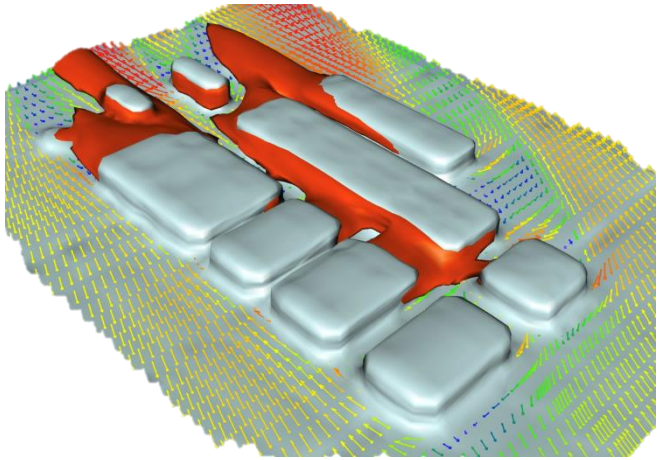
=> Recommendations for how to reduce or minimize emissions in MCs



Average emission of Black Carbon varies from 0.4 kg/capita in MCs of Europe to 1.2 kg/capita in Asian MCs, respectively

Observations vs. Modeling Results





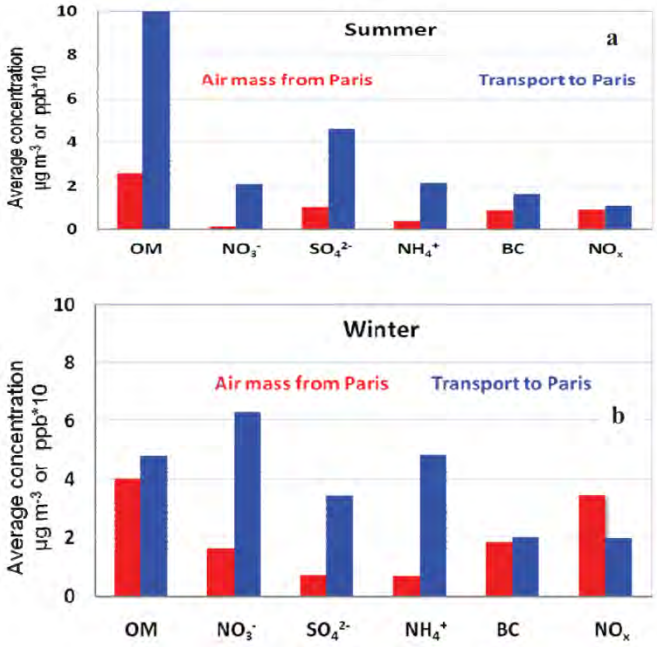
(observations from http://www2.dmu.dk/atmosphericenvironment/byer/forside.htm)

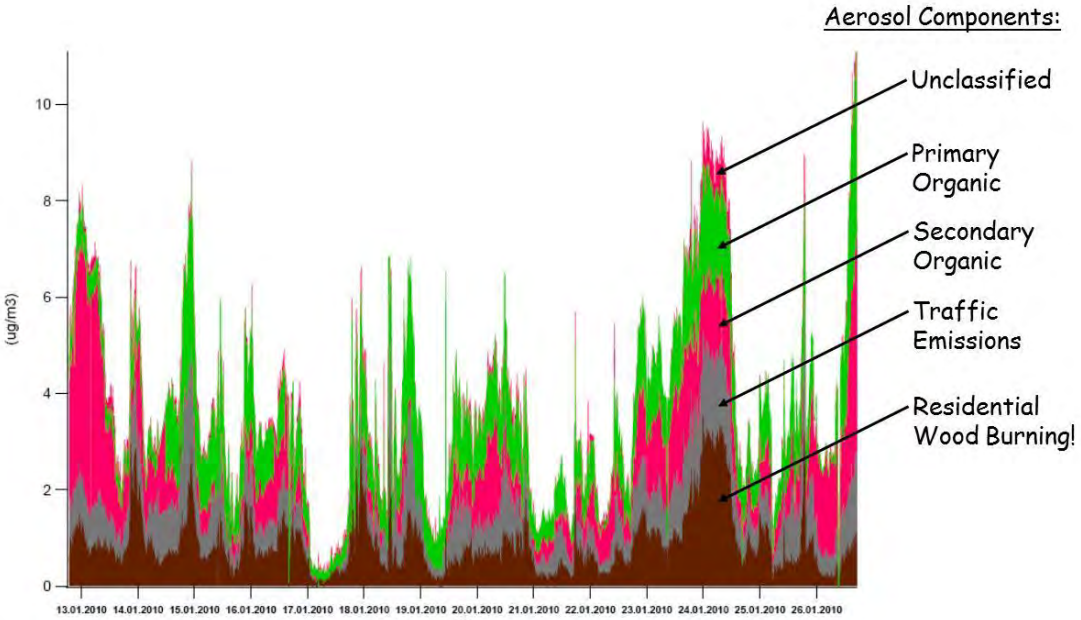
NOx concentration in the street canyon on 5 Sep 2011, 15:00 LST

DMI MACC report by Nuterman et al., 2011

MEGAPOLI Paris Measurement Campaigns

- Aim: Provide new experimental data to better quantify sources of primary and secondary carbonaceous aerosol in a megacity and its plume. Duration: Summer – 1-31 Jul 2009, Winter – 15Jan-15Feb 2010
- 30 research institutions from France and other European countries, MEGAPOLI Teams & Collaborators





(Courtesy of Monica Crippa et al.; PSI Team)

- Surprisingly low fine PM levels
- 70% of fine PM mass is transported into megacity from continental Europe
- Fossil fuel combustion contributes only little to organic fine PM
- Large fraction of carbonaceous aerosol is of secondary biogenic origin
- Cooking and, during winter, residential woodburning are the major primary OA
- BC concentrations are on the lower end of values encountered in megacities worldwide.

(Beekmann et al., ACP, 2015)

Gaps in knowledge & Research needs:

- Requirements for urban observations, use of crowdsourcing data;
- Near-real-time data access and assimilation for urban areas;
- Coupling of air chemistry, aerosols, meteorological, surface, hydrological processes with chains of feedbacks;
- Formation of SOA, interaction of urban aerosols with UHI and clouds
- Seamless approach: scale interaction;
- High-resolution modelling: ‘grey zone’ and needed resolution;
- Urban Test Beds that integrate in situ and remote sensing observations with modeling efforts
- Focus on impact based forecast and risk based warnings
- From Research to Services and Society.

WMO GAW Urban Research Meteorology and Environment Project (GURME)

- To enhance the capabilities of NMHSs in providing urban-environmental forecasting and air quality services of high quality, illustrating the linkages between meteorology and air quality;
- In collaboration with other WMO programmes, WHO and environmental agencies, to better define meteorological and air quality measurements focusing specifically on those that support urban forecasting;
- To provide NMHSs with easy access to information on measurement and modeling techniques;
- To promote a series of pilot projects to demonstrate how NMHSs can successfully expand their activities into urban environment issues.

GURME SAG Chair V. Bouchet, ECCC

GURME Tasks For The Strategic Planning Period 2008-2015

Observational Needs
- Chemical
- Meteorological

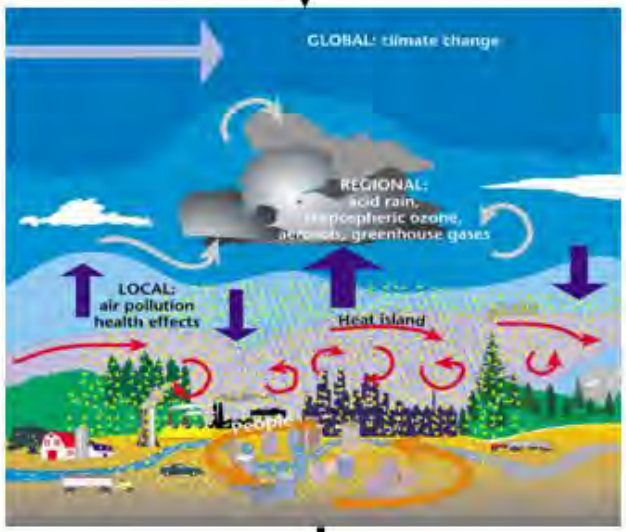
(Tasks: 3,6,17)

Assimilation

Modeling Needs
- Weather prediction
- Chemical weather and air quality prediction

(Tasks: 8,11,13,15)

Demonstration



Coordination

Capacity Building
- Workshops
- Training

(Tasks: 2,4)

Users
- Health
- Agriculture
- Environmental
- Public
- Emergency Response

(Tasks: 9,14,16,18)

Air Quality & Related Products
- Improved Forecasts
- Guidelines
- Pilot Projects

(Tasks: 1,5,7,12)

Education

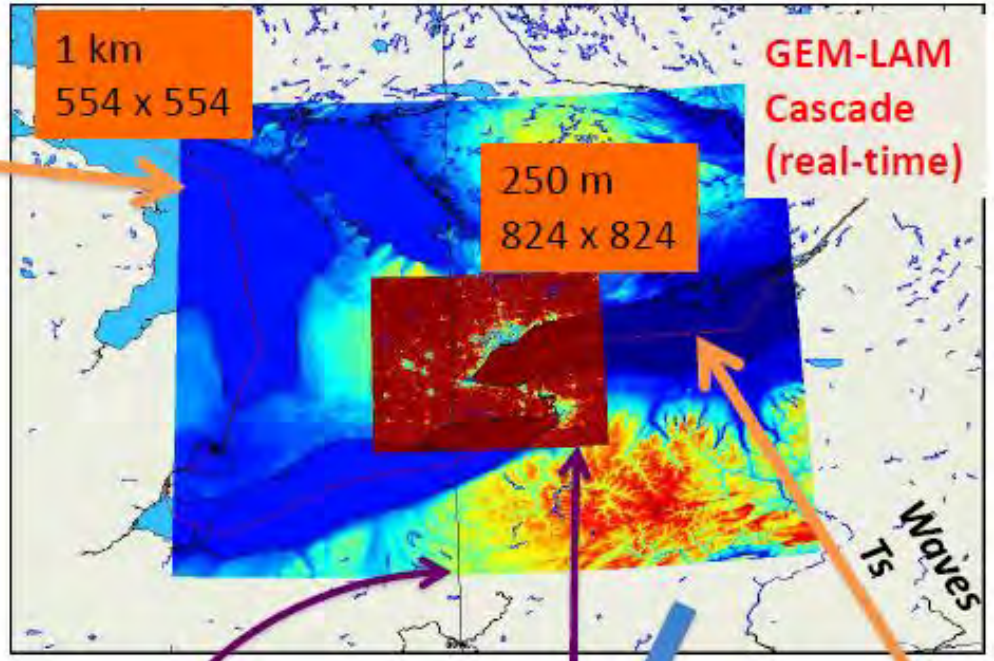
Dissemination

Environment Canada Environnement Canada

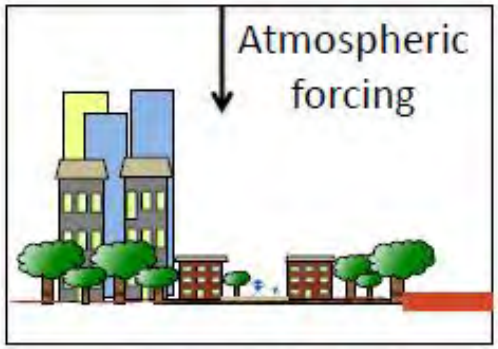
Pan Am 2015 NWP Integrated System

2.5 km National
CMC-Operations
4 runs / day

Upper-air Ics and LBCs



GEM-SURF (200 m)



Canopy/soil physical processes
- TEB (urban)
- SVS (vegetation), or ISBA

Continuous cycle → daily surface forcing

Belair and Leroyer

Wall, Road, Roof : Ts
Soil : T, w, snow

Surface Initial conditions

NEMO (lakes)
optional

Outputs & derived products :
- **Outdoor thermal comfort indices** :
  UTCI, WBGT, PHS (heat stress)
- **High impact weather** : heavy rain, strong wind
  - Fog / visibility

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

Baklanov et al., ACP, 2008

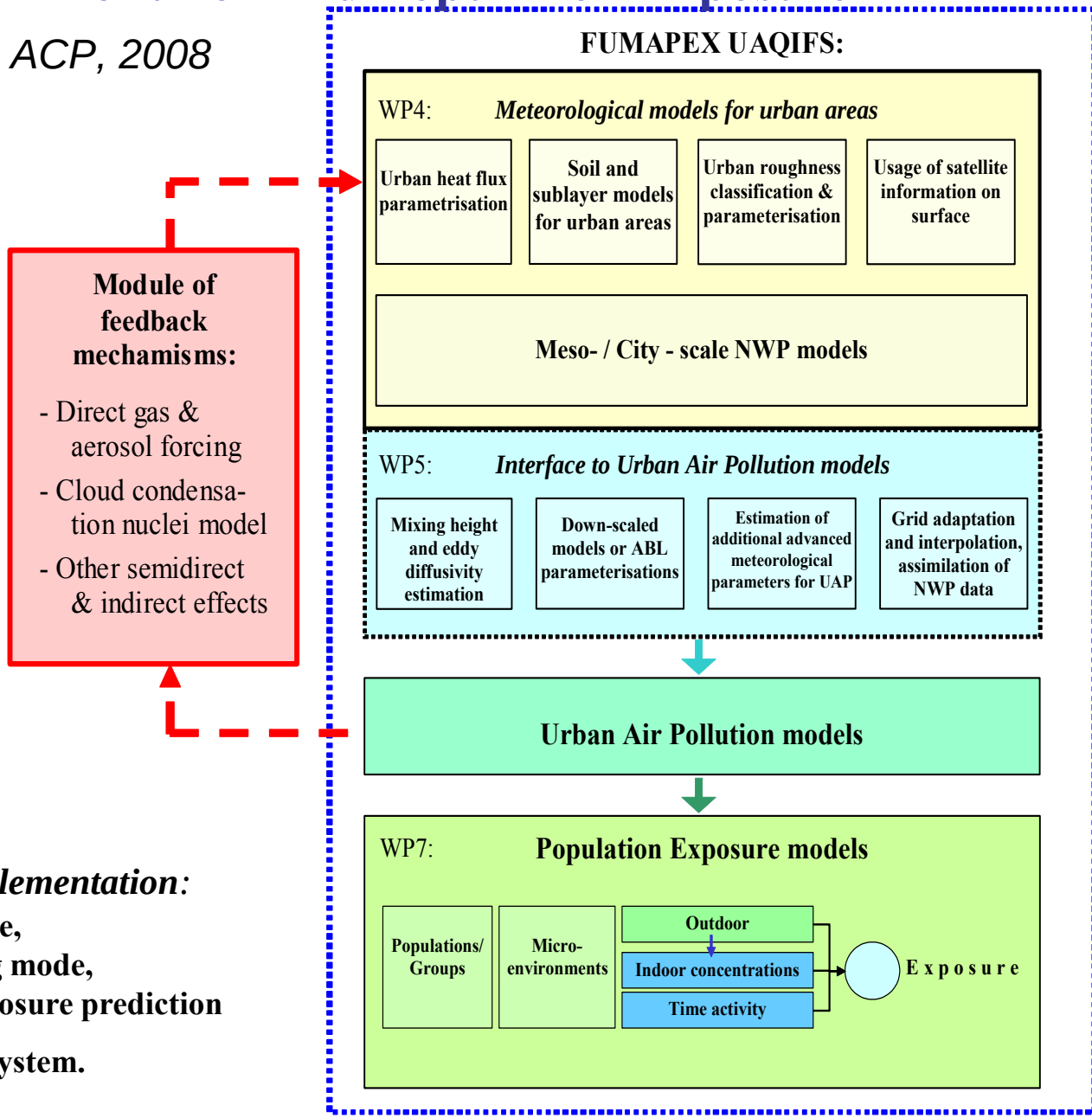
Goal: **Improvements of meteorological forecasts (NWP) in urban areas, interfaces and integration with UAP and population exposure models following the off-line or on-line integration**

Implemented in 6 European cities for operational forecasting:

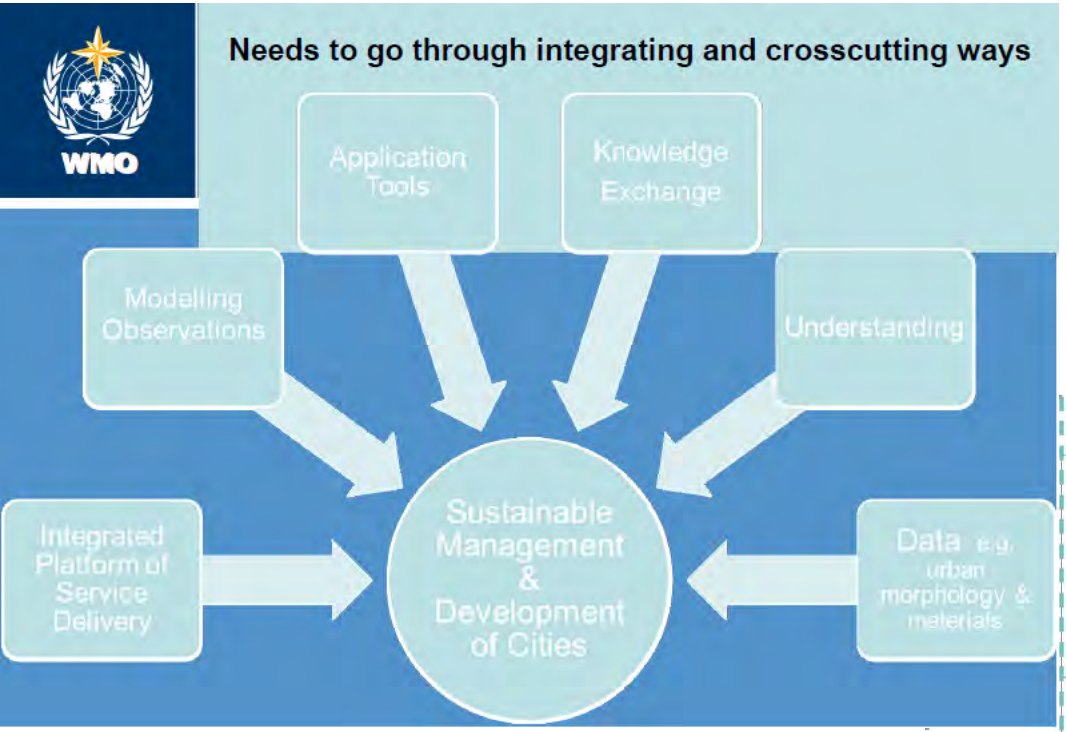
#1 – Oslo, Norway
#2 – Turin, Italy
#3 – Helsinki, Finland
#4 – Valencia/Castellon, Spain
#5 – Bologna, Italy
#6 – Copenhagen, Denmark

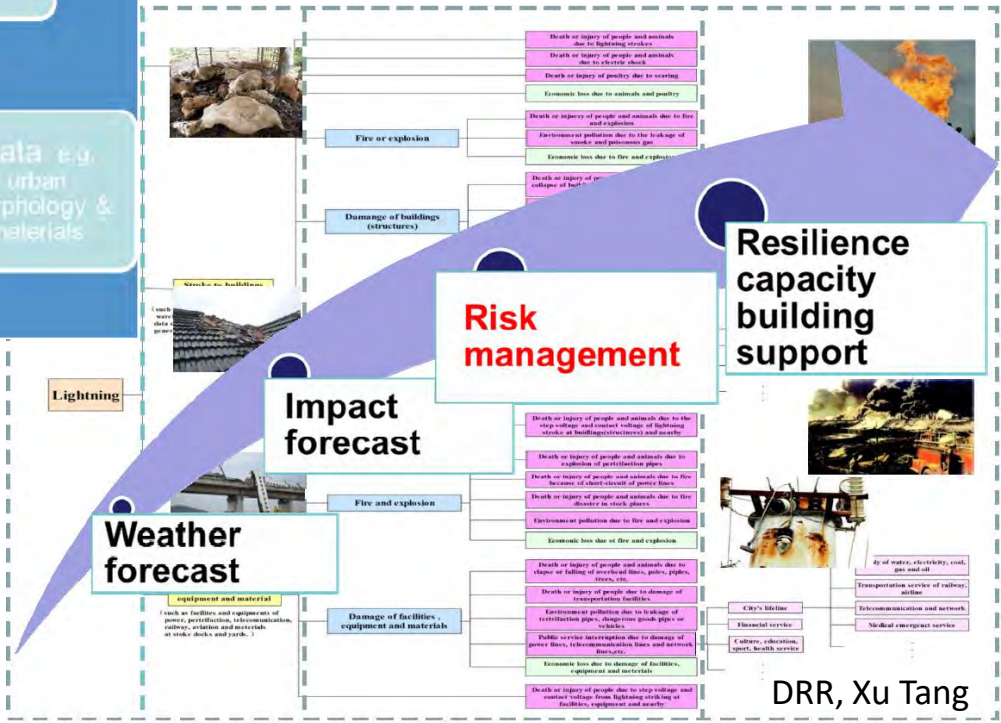
Different ways of the UAQIFS implementation:

(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.



Integrated Service Delivery on Weather and Climate including Supporting Research for Megacity and in Urban Areas, WMO Priority Area (2016-2019) as a response action to UN New Urban Agenda





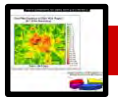
- Cg-17 Resolution 9.8: Establishing WMO Cross-cutting Urban Focus
- WMO GAW APP, GURME SAGs, IGIS
- Guide for Urban Integrated Services
- Input to HABITAT-III conference

METROPOLITAN AIR QUALITY AND WEATHER FORECASTING SERVICES

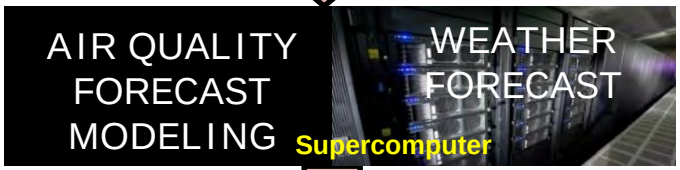
SAFAR project, India — *Beig et al., 2015*


Air Quality Monitoring


Weather Monitoring


Emission inventory Development


Surface topography & land use study

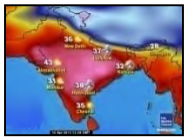


Translate Science to Public

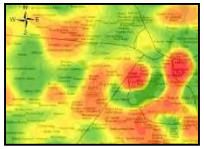
PRODUCTS

SERVICES


AIR-Now & AIR-Tomorrow


Weather -Now & -Tomorrow


Health Advisories


City Pollution Maps


UV Index-Skin Advisory


Web Portal


E-mail Alerts


SMS Alerts


Digital Display

TV /Radio

BENEFIT TO END -USER

- Protecting Human Health
- Agricultural yield Benefits to Farmers
- Awareness of impact of AQ & Weather
- Basis for mitigation strategies

RESEARCH

- Explore Chemical-Weather
- Improve Weather & AQ Forecasting Skill
- Development of Emission scenario
- Short Term Climate Change

WWOSC 'Seamless Earth System Modelling' Book:

http://library.wmo.int/pmb_ged/wmo_1156_en.pdf

CHAPTER 18. URBAN-SCALE ENVIRONMENTAL PREDICTION SYSTEMS

C. Sue Grimmond, Greg Carmichael, Humphrey Lean, Alexander Baklanov, Sylvie Leroyer, Valery Masson K. Heinke Schluenzen and Brian Golding

Integrated Urban Weather, Environment and Climate Systems and Services (IUWECS)

- development of **understanding and knowledge regarding enhanced observational needs to meet the requirements** of integrated services in megacity and other urban environments, and identification of observational source locations in complex environment;
- development of concepts, **scientific capabilities and technology for seamless services**;
- development of the **science and technology required for provision of service applications to society**;
- development of smart delivery approaches, including the application of **new technology to create an "intelligent and wise" city**;
- development of methods for **efficiently making use of large, complex databases** (i.e., "Big Data"); and
- development and implementation of **user-relevant approaches for evaluating the quality and benefits of products** and services.

WMO/GFCS, 2014

Thank you for your attention

Web: http://www.wmo.int

Email: abaklanov@wmo.int