European Network on New Sensing Technologies for Air Pollution Control and Environmental Sustainability - *EuNetAir*

COST Action TD1105

WG3-WG4 JOINT SCIENTIFIC MEETING: ROUND-TABLE

Duisburg, Germany, 4 - 6 March 2013

Action Start date: 01/07/2012 - Action End date: 30/06/2016

INTERNATIONAL HELLENIC UNIVERSITY

Presenter's Name	**Professor Nicolas Moussiopoulos**
Function in the Action:	**COST ES1004 Grant Holder**
Role in the Presenting	**Project: MEGAPOLI WP Leader**
Affiliation / Country	**IHU's Vice President / Greece**

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Overview over major MEGAPOLI project results

Alexander BAKLANOV,
Danish Meteorological Institute,
Mark Lawrence (MPIC), Spyros Pandis (FORTH)
and MEGAPOLI consortium
(see: http://megapoli.info)

Final MEGAPOLI Symposium
26-28 September 2011
CNRS Headquarters, Paris, France

WHY Megacities?

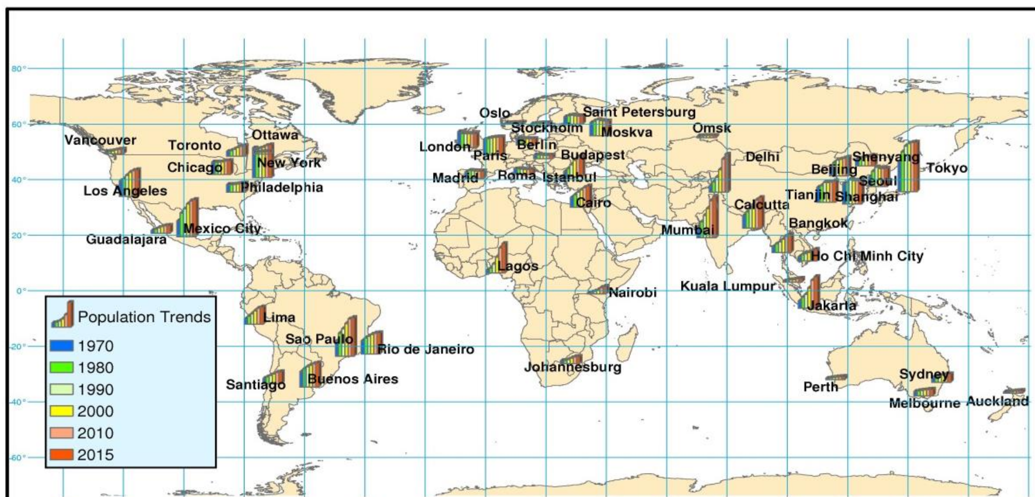
- **Urban: > 50% of world popul. - < 1% land**
- **MCs: 10% of world popul. / < 0.2% land**
- **19 megacities > 10 Million people**
- **22 cities with 5-10 million people**
- **370 cities with 1-5 million people**
- **433 cities with 0.5-1 million people**

Source: UNCHS 2007

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

- Growing emissions and urbanisation => environment and climate on different scales
- Rapid and unbalanced growth
- Problems of fast growth: cities are increasingly subject to dramatic crises
- Highest growth rates in medium size cities
- New urban population ≈ poor urban population
- Problems aggravated in developing countries by economic and financial crises



Population trends in megacities

Source: UN 2002

Megacities: Emissions, Impact on Air Quality and Climate, and Improved Tools for Mitigation Assessments (MEGAPOLI)

EC 7FP project for: ENV.2007.1.1.2.1. Megacities and regional hot-spots air quality and climate

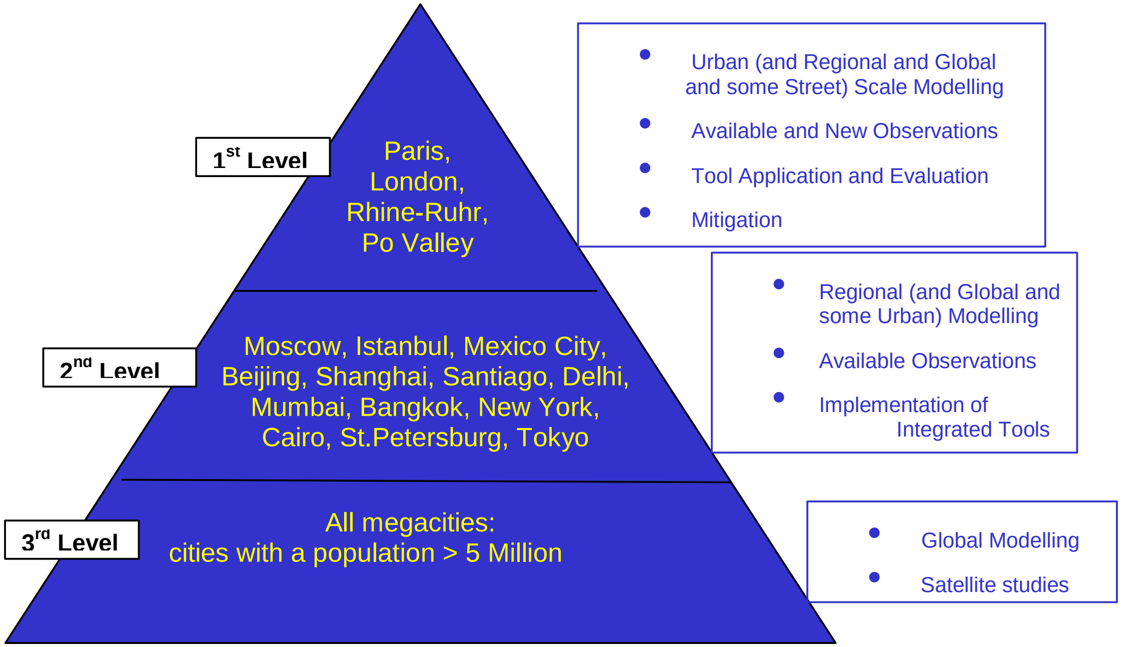
Project duration: 2008 – 2011; Budget: 5,1 mln. Euro
27 European research organisations from 11 countries are involved
Coordinator: A. Baklanov (DMI)
Vice-coordinators: M. Lawrence (MPIC) and S. Pandis (FORTH)

(Project web-site: http://megapoli.info)

The main aim of the project is

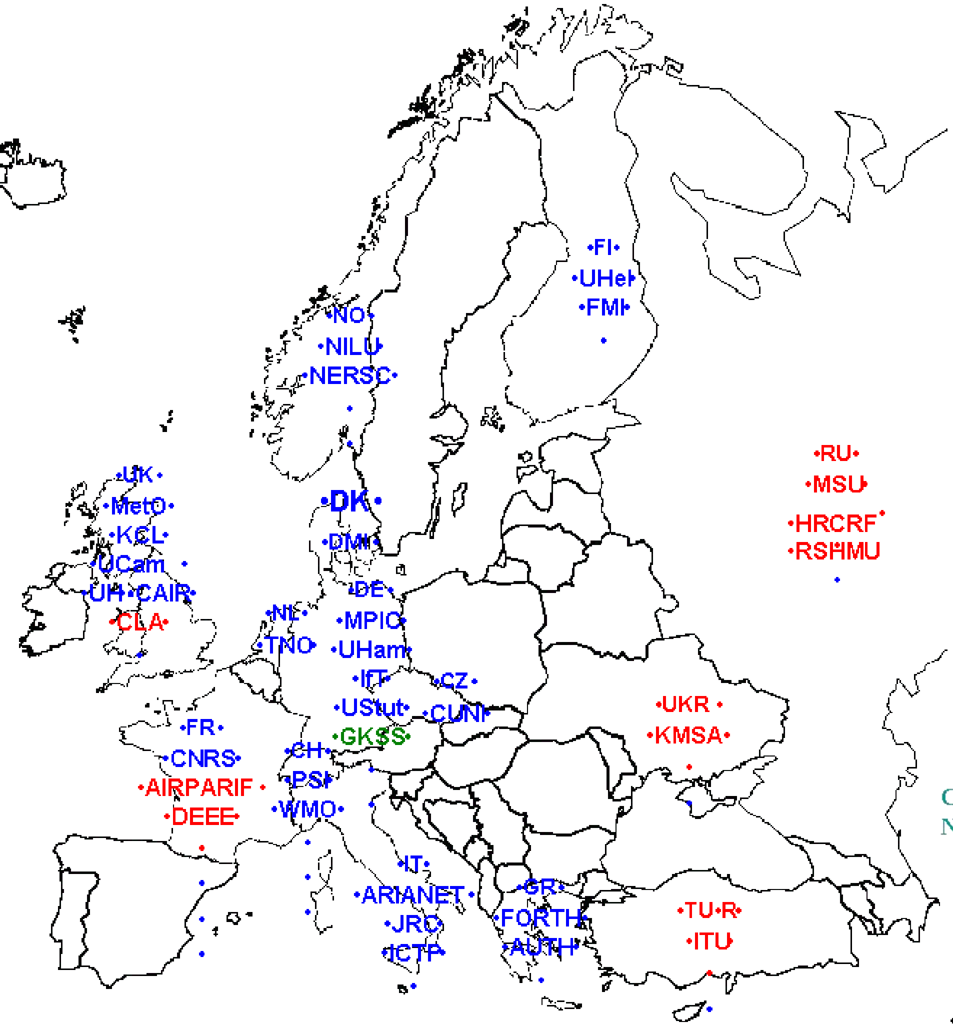
(i) to assess impacts of growing megacities and large air-pollution "hot-spots" on air pollution and feedbacks between air quality, climate and climate change on different scales, and

(ii) to develop improved integrated tools for prediction of air pollution in cities.

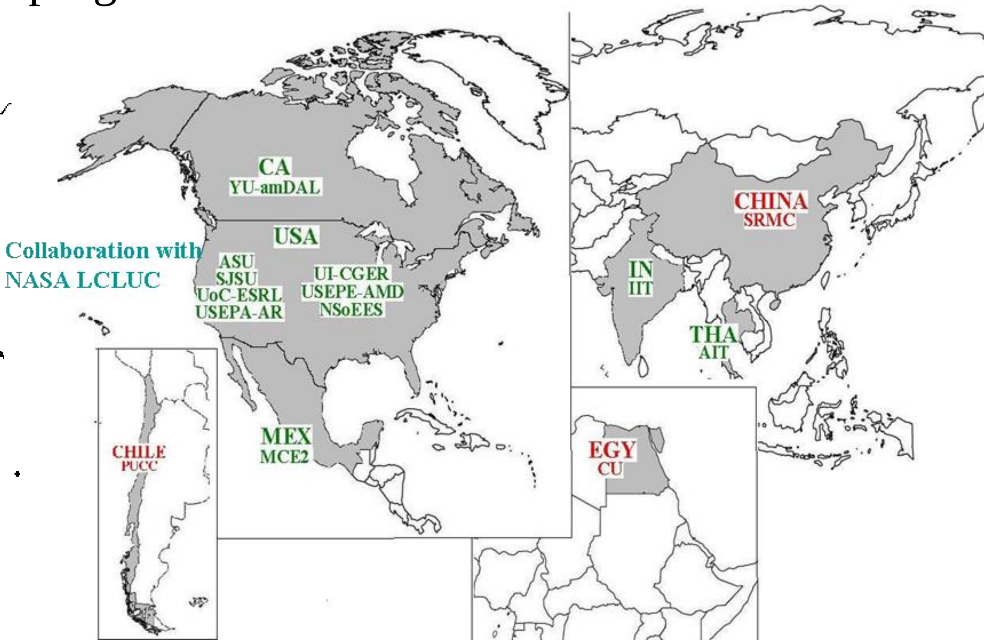


MEGAPOLI main partners & collaborators

(blue – 27 teams from 11 countries EC funded, green/red - external partners/end-users

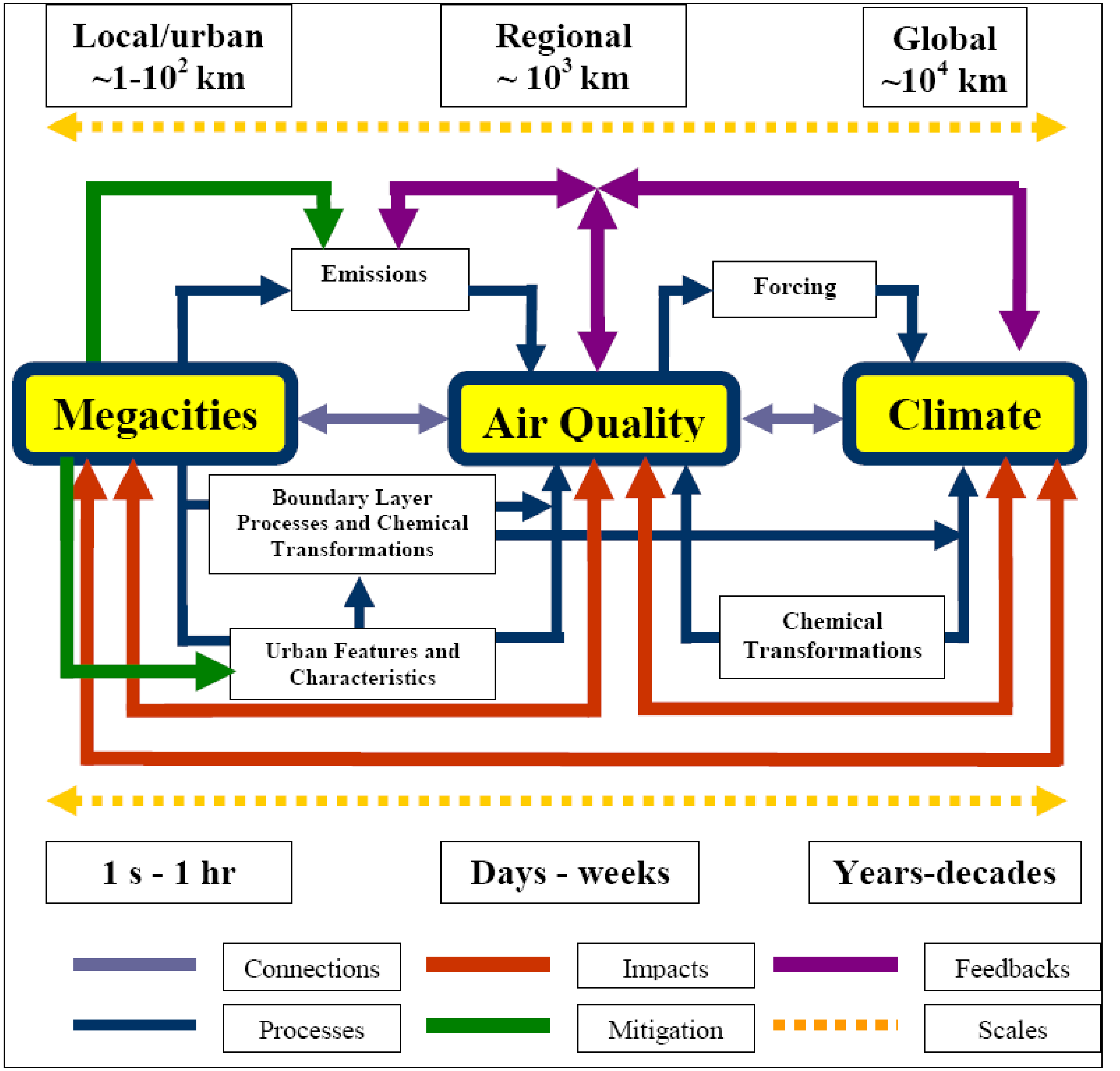


- Sister EC FP7 project CityZen
- Daughter Russian project Megapolis
- A number of collaborating projects in US (eg MILAGRO), Europe (eg PBL-PMES), etc
- French co-project and many international volunteer partners for Paris campaign
- WMO GURME, IGAC, IPCC, COST programs and networks



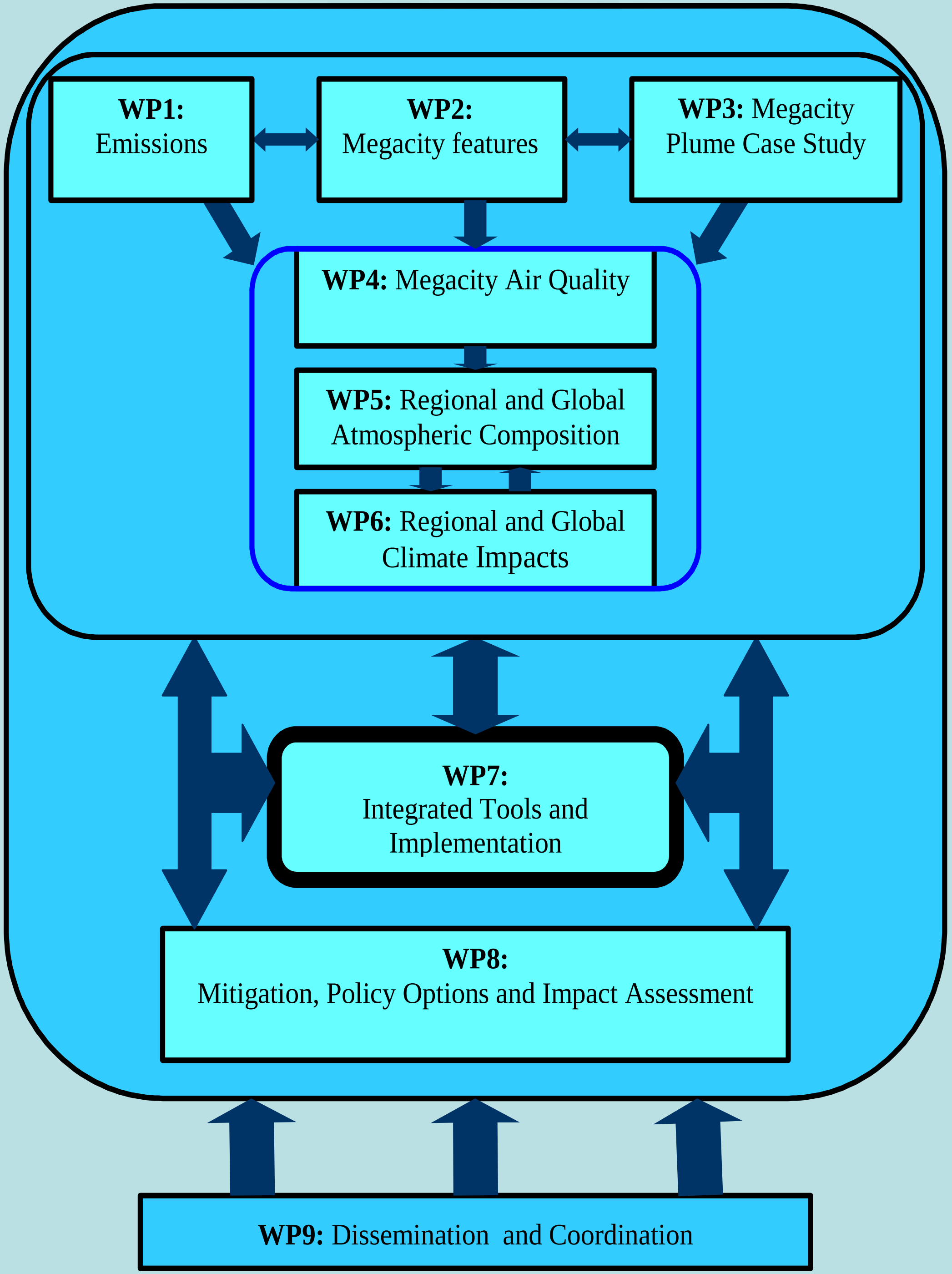
Connections between Megacities, Air Quality and Climate

- Science - nonlinear interactions and feedbacks between urban land cover, 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
- Integrated UAQIFS for megacities



Work Packages (WPs) structure & integration

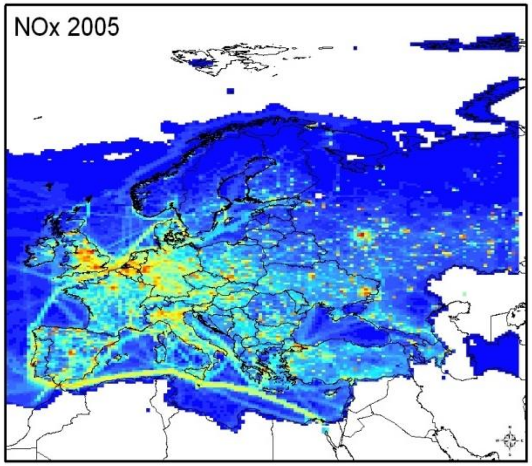
WP No.	Title	Lead Participant(s)
1	Emissions	H. Denier van der Gon
2	Megacity Environments: Features, Processes and Effects	S. Grimmond I. Esau
3	Megacity Plume Case Study	M. Beekmann U.Baltensperger
4	Megacity Air Quality	N.Moussiopoulos
5	Regional and Global Atmospheric Composition	J. Kukkonen A. Stohl
6	Regional and Global Climate Effects	W. Collins F. Giorgii
7	Integrated Tools and Implementation	R. Sokhi H. Schlünzen
8	Mitigation, Policy Options and Impact Assessment	R. Friedrich D. van den Hout
9	Dissemination and Coordination	A. Baklanov S. Pandis M. Lawrence

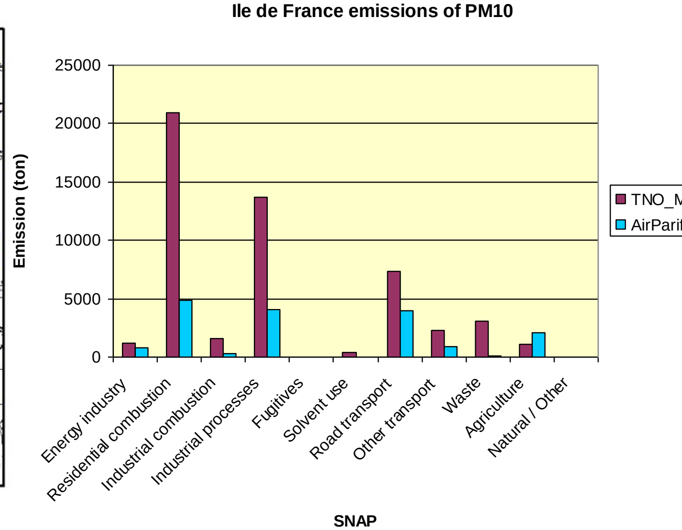


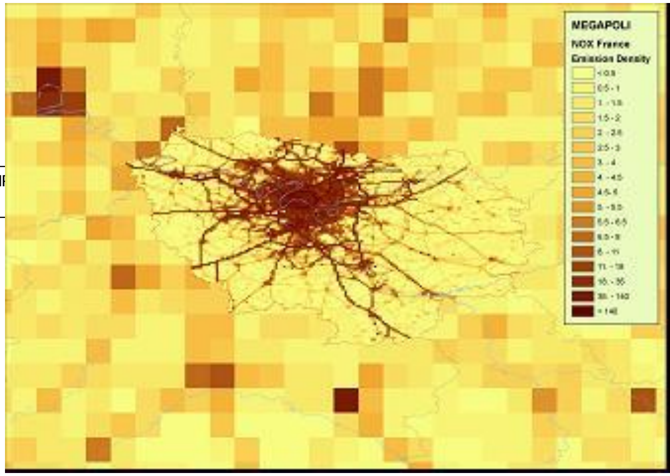
<u>Task 1:</u> Develop and evaluate integrated methods to improve megacity emission data

<u>SQ4:</u> How accurate are the current emission inventories for megacities in Europe and around the world? What are the major gaps?

MEGAPOLI Emission Inventories





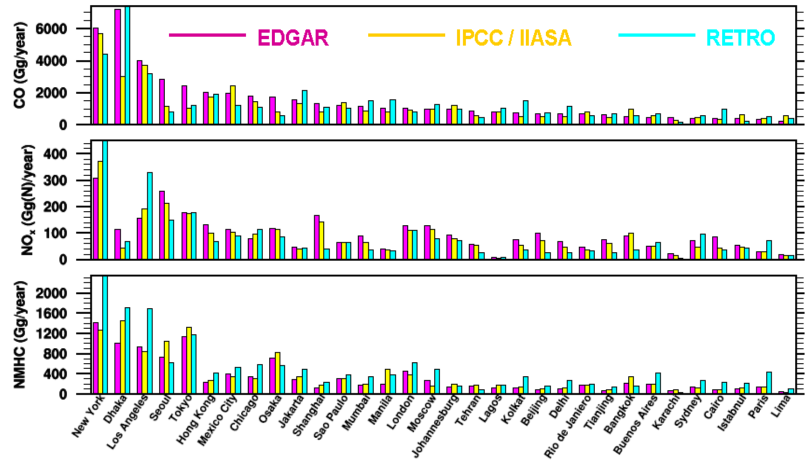


- In MEGAPOLI a state-of-the-art (global and) regional European (6x7km) emission data base was combined and cross-checked with bottom-up emission inventories (1x1km) for Paris, London, Rhine-Ruhr area (Germany) and the Po-valley (Italy).
- The allocation of the emission in the regional down-scaled inventory can deviate substantially (up to a factor of 4) from the MC bottom-up inventories.
- The major discrepancies caused by e.g. residential combustion and industry sectors were documented and explained.
- Emission inventories are not consistent across scales and this is likely to have significant impact on predicted air pollution and exposure levels.
- Comparing various MC emission estimates patterns provided better insight in per capita emissions and knowledge gaps for global MC-scale assessments.
- Anthropogenic heat flux (AHF) model was developed and used to compute the AHF inventories for globe, Europe and London.

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

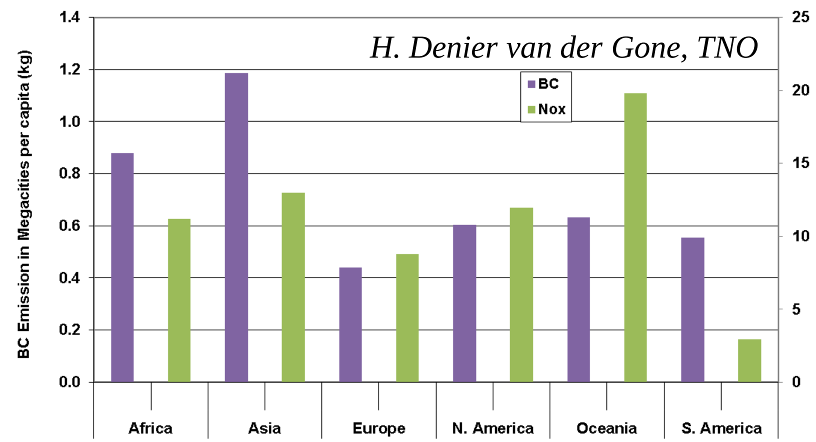
(Gurjar et al., Atmos. Env., 42 (2008) 1593–1606)



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

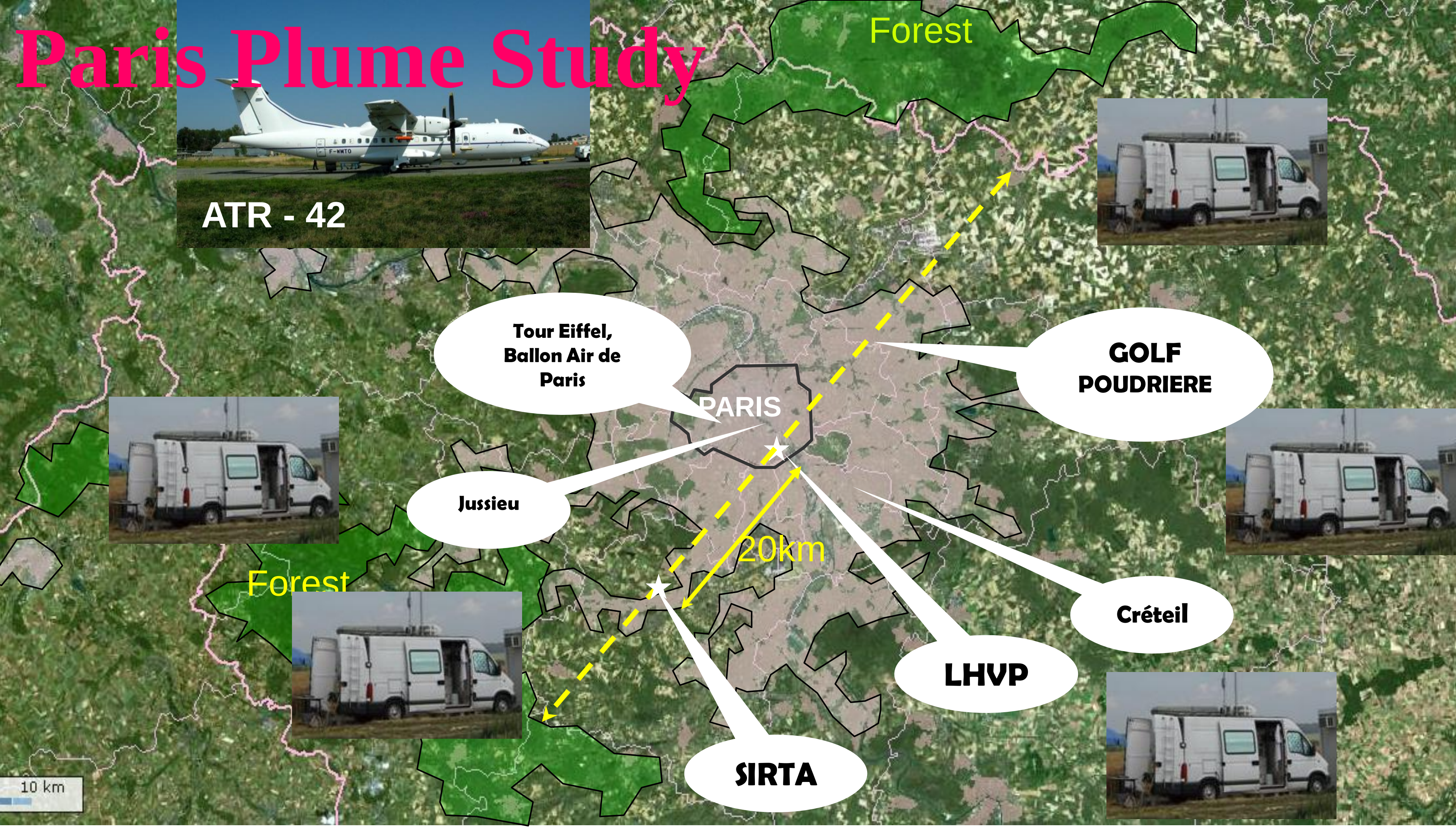


Average emission of Black Carbon varies from 0.4 kg/capita in MCs of Europe to 1.2 kg/capita in Asian MCs, respectively

<u>Task 2:</u> Investigate physical and chemical processes starting from the megacity street level, continuing to the city, regional and global scales

<u>SQ3:</u> What are the major physical and chemical transformations of air pollutants as they are moving away from megacities? What happens to the organic particulate matter, volatile organic compounds, etc?

Paris Plume Study



Summer campaign – 1-31 Jul 2009; Winter campaign – 15Jan-15Feb 2010

Aim: to quantify sources of primary and secondary carbonaceous aerosol in a megacity plume

3 primary sites => full in situ measurements / + met at SIRTA.

3 secondary sites => lidar and spectrospcopic measurments / or in some situ

3 mobile labs => full in situ measurements (PSI + MPI) + Univ Duisburg

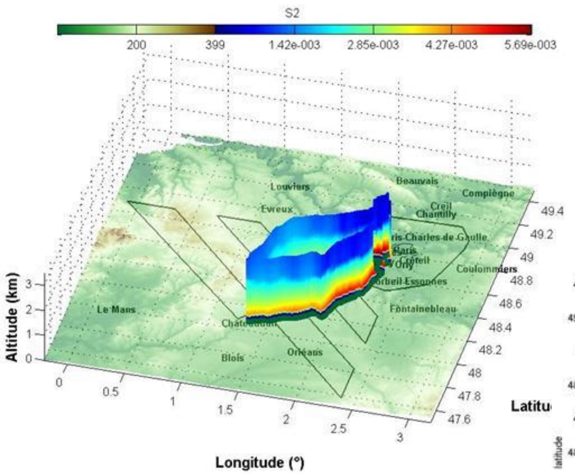
1 mobile lab => lidar measurements (CEA) **1 mobile lab** => MAXDOAS (MPI)

1 aircraft ATR-42 => full in situ measurements (SAFIRE, CNRS, MPI)

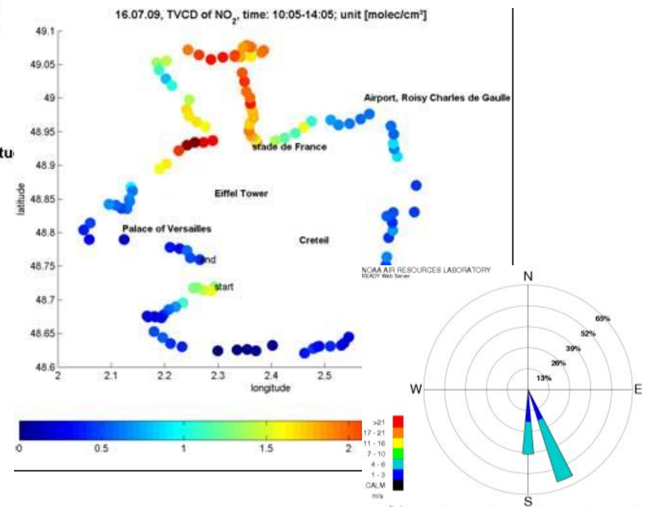
Details: M. Beekmann, CNRS

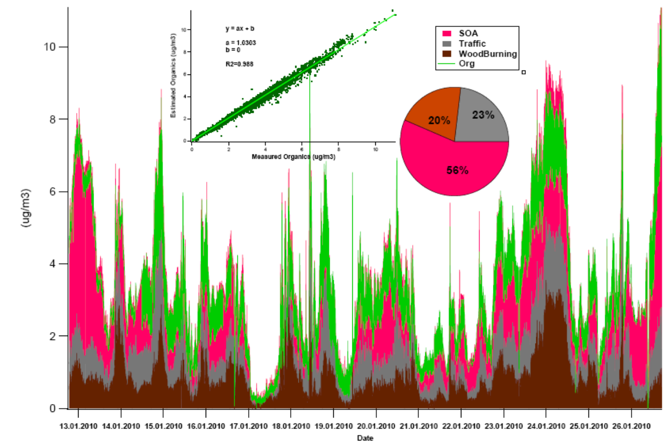
Paris Measurement Campaigns

Lead by M. Beekmann, CNRS & U. Baltensperger, PSI



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





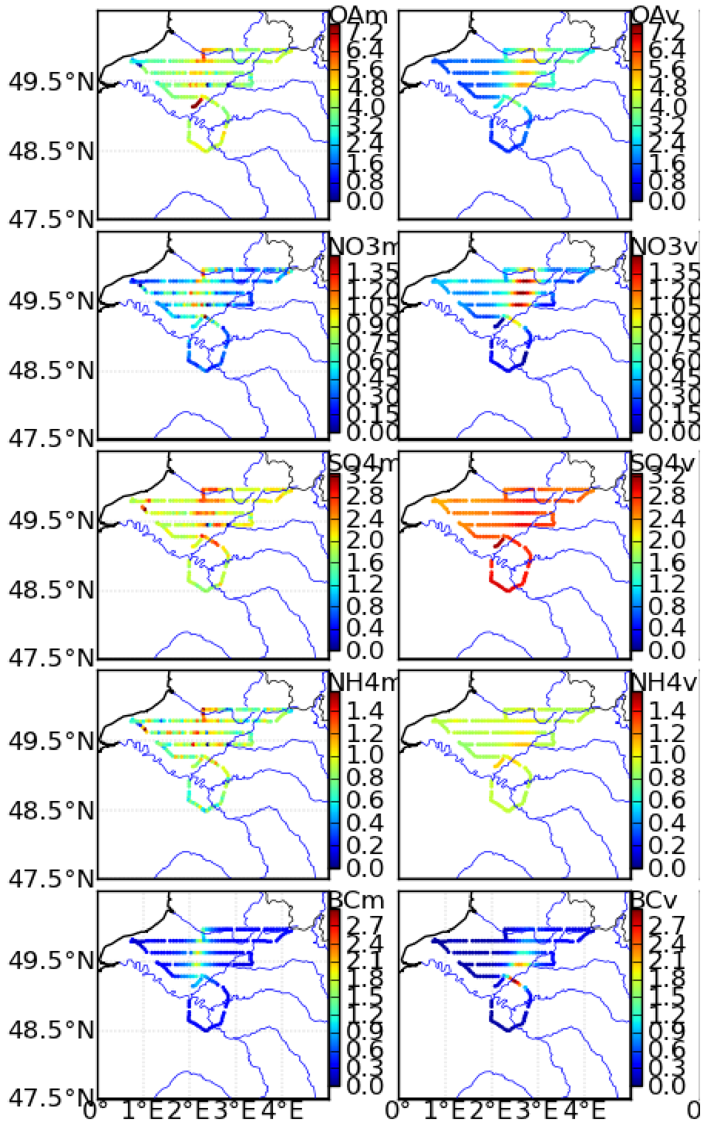
(Courtesy of Monica Crippa et al.; PSI Team)

Main achievements:

- The pollution plume was still well defined at more than 100 km downwind from the agglomeration, which gives a clear framework for studying SOA build-up in the plume.
- Significant new particle formation events were frequently observed during the campaigns.
- During the winter campaign, large PM levels were observed both due to a strong local wood burning source and due to continental advection.
- Database for model studies and validation is available

See details - in campaign overviews by M. Beekmann and a number of WP3 presentations

Major transformations of air pollutants in MC plume



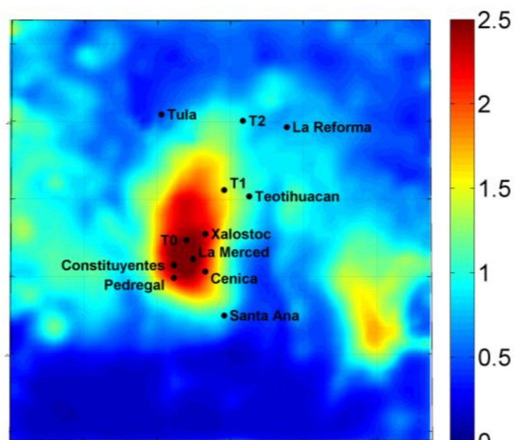
Comparisons of OA, NO3, SO4, NH4, BC from measurement (left) and CHIMERE (right), July 16

Physical changes:

- Dilution: reduces rapidly (10s km) passive concentrations; Paris plume for BC and VOCs could up to 150 km
- UHI increases urban BL height and effects MC plume mixing
- Evaporation of semi-volatile particulate matter components
- Rapid dry deposition of nitric acid, etc.; wet deposition

Chemical changes:

- Formation of ozone, sulfates, and secondary PM; max O3 and SO4 downwind of MCs
- Organic PM exported by MCs is quite different chemically from that emitted by the sources inside MC
- Aged organic PM is a lot more hygroscopic and less volatile than the original PM



Average fine particulate nitrate concentrations in and around Mexico City (210x210 km) during MILAGRO .

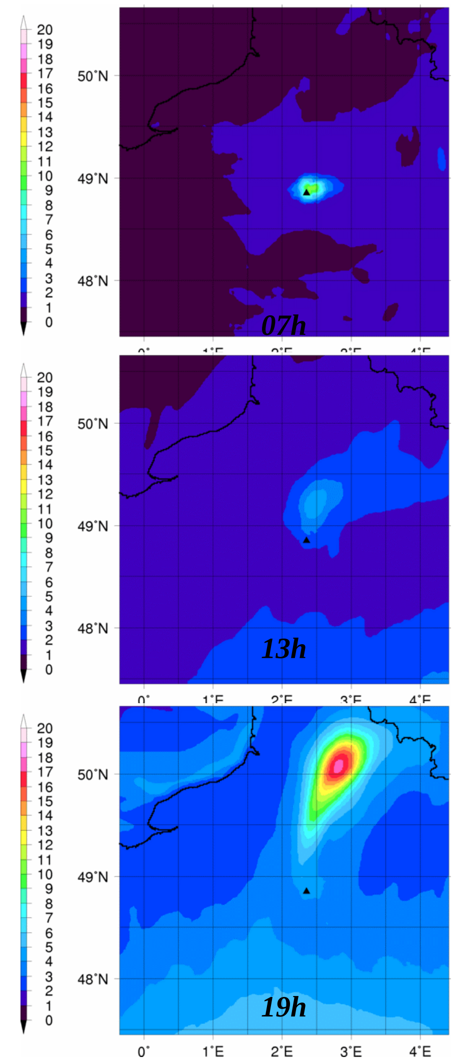
The secondary peak (about 10% of max peak in city center) within 50 km from Center due to a combination of dilution, evaporation, and rapid dry deposition of nitric acid.

FORTH contribution

Task 3: **Assess regional and global impacts of megacity plumes, including: atmospheric transport (local pollution build-up and its regional/global transport) and chemical transformation of gas and aerosol pollutants emitted in megacities**

SQ2: How do megacities affect air quality on regional and global scales? What is the range of influence for major air pollutants (ozone, particulate matter, etc.)?
SQ7: What is the impact of large-scale dynamic processes on air pollution from megacities?

How do megacities affect air quality on regional and global scales? What is the range of influence for major air pollutants?



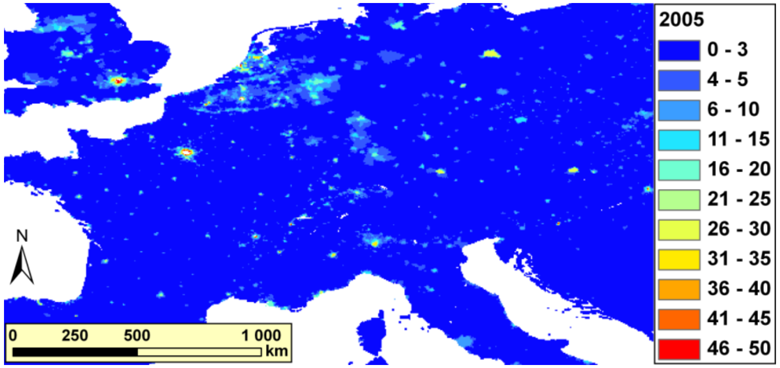
Simulated CHIMERE urban OA Paris plume on July 16 2009 at different times. Courtesy to Q;J. Zhang CNRS-LISA, from Del. 3.6.

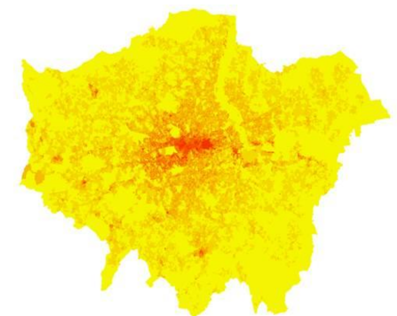
- MC impacts are quite variable in space and time and are often in directions different than that of the average prevailing winds.
- Average transport distance for elemental carbon and other primary fine PM components are around 100-200 km for MCs examined.
- Secondary PM species were found to be transported the furthest with sulfate and secondary organic aerosol often transported on average over 350 km.
- Maximum transport distances are significant higher, with secondary particulate matter impacts reaching as far as 2000 km away from MC.
- MC impacts on atmospheric composition of surrounding regions can be substantial, esp. for primary pollutants (> 50% increases NOx).
- MCs tend to cause a decrease of O3 mixing ratios in cities, while increasing O3 downwind of the cities (by up to 10 ppb).
- Globally MCs impacts on total burdens of directly emitted gases are comparable to their relative contribution to the global total emissions (several %), while the impact on global O3 is much smaller (< 1%).
- European MCs (St.Petersburg, Moscow, Ruhr Valley) are most significant contributors to deposition of aerosols in Arctic.

<u>Task 4:</u> Determine the main mechanisms of regional meteorology/climate forcing due to megacity plumes
<u>Task 5:</u> Assess global megacity pollutant forcing on climate

<u>SQ5:</u> How large is the current impact of megacities on regional and global climate?
<u>SQ6:</u> How will the growth of megacities affect future climate at global and regional scales?

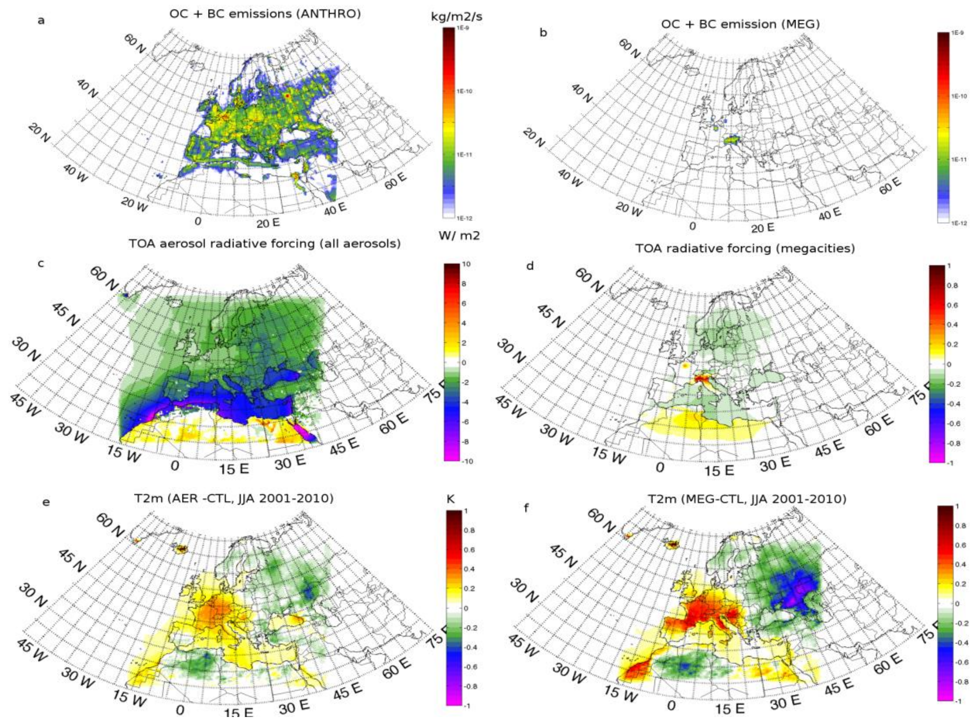
<u>SQ5:</u> How large is the current impact of MCs on local and regional climate?





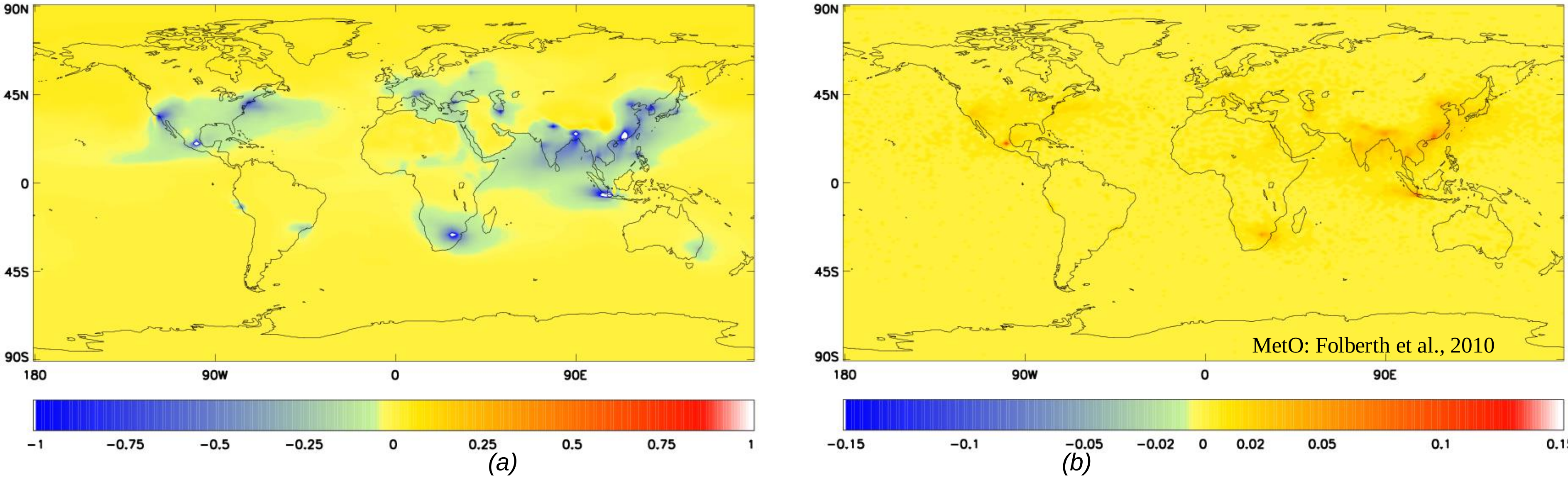
<= Anthropogenic heat flux (AHF) for Europe and London. (*D1.4 Rep: L Allen et al., KCL, 2010*)

RegCM study for all aerosol (AER) and MCs only (MEG) Average JJA 2001-2010. => (ICTP contribution, F.Solmon)



- MCs have strong UHI, due to differences in surface properties and waste heat from anthropogenic activity, and can be warmer than surrounding rural environments by up to 10°C.
- Anthropogenic heat fluxes for megacities can be very high: up to 50-500 W/m2, locally reaching 1500 W/m2.
- MCs impacts the local environment directly and affects the regional air circulation due to UHI, increased roughness and urban aerosol forcing.

How large is current impact of MCs on global climate?



Global distribution of - (a) short-wave, SW all-sky and (b) long-wave, LW clear sky - top-of-atmosphere (TOA) radiative forcing due to aerosols from megacities /Forcing is denoted in W/m²

MCs contribute a global warming of over 0.2 K after 100 years, with nearly 90% of this being due to carbon dioxide emissions, and most of the rest due to methane.

MCs impact by NOx, VOC and aerosols on global climate under present time (2005) includes 4 main direct radiative forcing impacts of megacity pollutants:

- Ozone production: +5.7±0.02 mW/m2
- Reduction of the methane lifetime due to OH radical production: -2.1±0.13 mW/m2
- Short-wave direct forcing from aerosols: -6.1±0.21 mW/m2
- Long-wave direct forcing from aerosols: +1.5±0.01 mW/m2

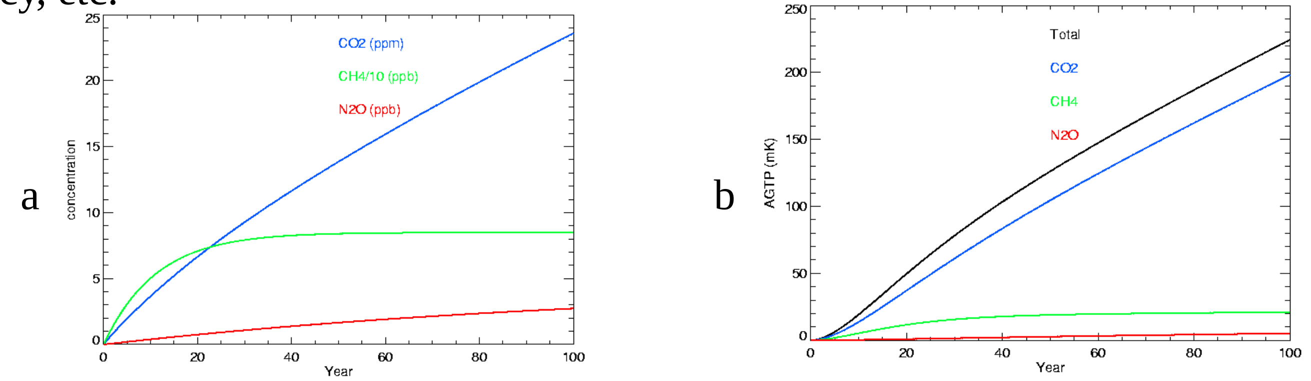
Combined effect of all of these individual terms is a rather small negative forcing, that is a cooling, of -1.0±0.32 mW/m2 under present-day conditions.

<u>SQ6:</u> How will the growth of megacities affect future climate?

<u>Local and regional climate:</u>

• Two types effects of growing megacities on the future climate at different scales were considered:
(1) due to urban features, like UHI, land-use changes, albedo, roughness, moisture regime,
(2) due to atmospheric pollutants emitted by megacities, and their feedbacks on the climate.

• Growth of megacities will considerably affect future urban climate, including increasing urban heat islands altering the formation and movement of precipitation events, increasing thunderstorm intensity and frequency, etc.



Evolution of the concentration changes (a) and temperature changes (b) resulting from a step change of MC emissions.

<u>Global climate:</u>

• Relatively small signal of CO2 (around 0.1 W/m2, equivalent to about 0.2 K by the end of the century) should scale approximately linearly with the evolution of the emissions of CO2 from the future growing megacities.

• Impact of NOx, VOC and aerosols on climate under future conditions (for the base year of 2050) is showing that compared to present-day (-1.0±0.32 mW/m2), the overall forcing reduces substantially, to less than half of the magnitude, and it changes sign, becoming slightly positive at +0.4±0.11 mW/m2;

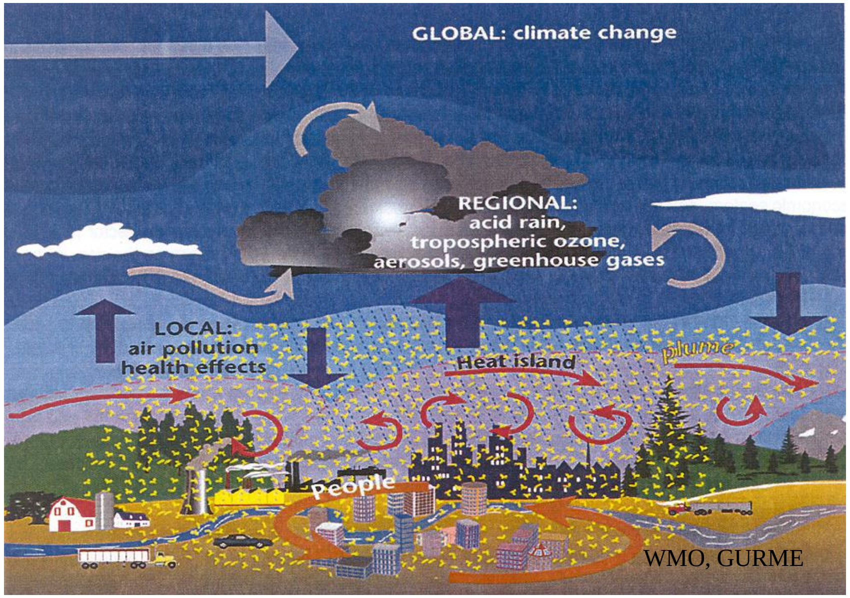
• thus, pollutant emissions from megacities are found to have a very small, slightly warming impact on future climate, adding to the somewhat larger warming impact from CO2.

Task 6: **Examine feedback mechanisms including effects of climate change on megacity air quality**

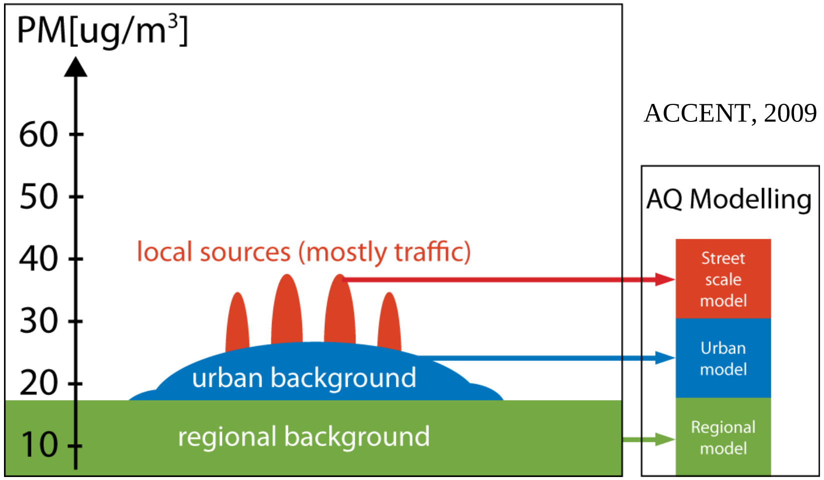
SQ8: **What are the key feedbacks between air quality, local climate and global climate change relevant to megacities? For example, how will climate change affect air quality and microclimate in megacities?**

SQ9: **How should megacities (emissions, processing inside megacities, meteorology) be parameterised in regional and global models?**

MC features in focus:



Why do cities have a different climate ?



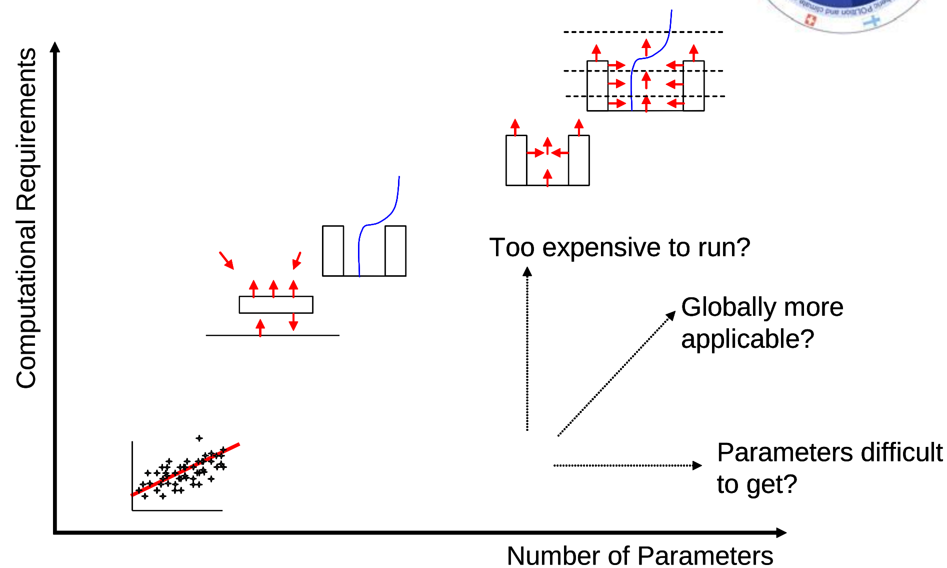
…and air quality ?

- **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.**

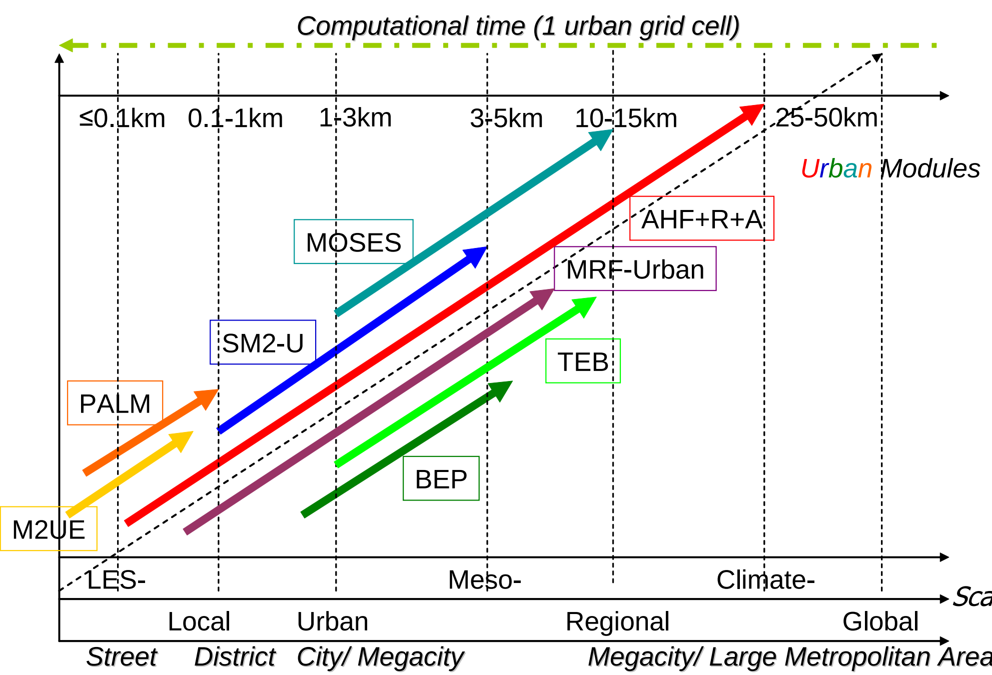
Strategy to urbanize different models

Main types of UC schemes:

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



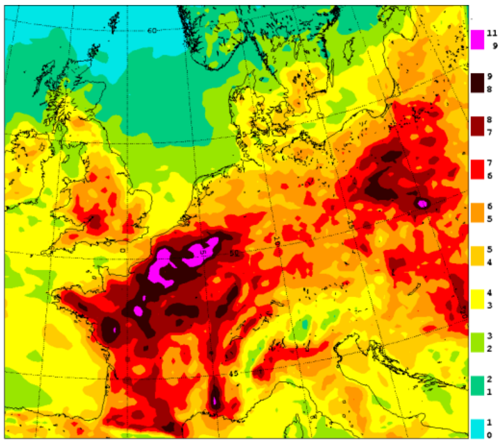
MP hierarchy of urban canopy schemes f different type and scale models:



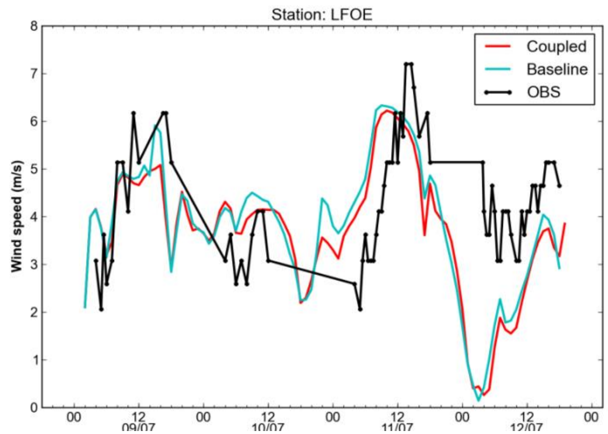
- Simple modification of land surface schemes (AHF+R+A)
- Medium-Range Forecast Urban Scheme (MRF-Urban)
- Building Effect Parameterization (BEP)
- Town Energy Budget (TEB) scheme
- Soil Model for Sub-Meso scales Urbanised version (SM2-U)
- UM Surface Exchange Scheme (MOSES)
- Urbanized Large-Eddy Simulation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

See details - Mahura and Grimmond pres.

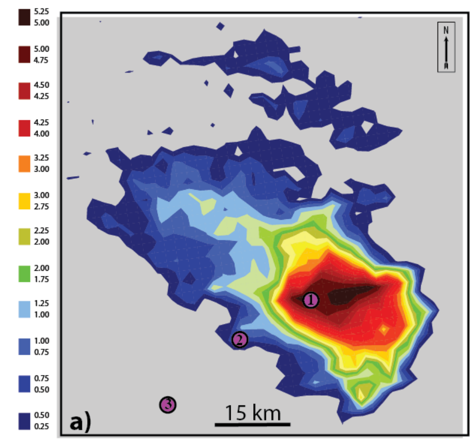
What are the key feedbacks between air quality, local climate and global climate change relevant to megacities?



Indirect aerosol effects by EnviroHIRLAM: Monthly averaged CCN number concentration (x107 m-3) at 850 hPa, Korsholm et al, DMI



AUTH comparison timeseries of PM10 concentrations calculated by taking into account ("coupled") or without ("baseline") the direct aerosol effect.



Difference plots for 2 m temperature (ºC) for Paris metropolitan area between outputs of the urbanized vs. control runs of Enviro-HIRLAM on 21.07.2009 at 6 UTC, Gonzalez et al, DMI

- Direct impact of climate change on air quality in MCs is significant due to temperature (BVOC fluxes, wild fires, deposition, O3, CH4, SOA, pSO4, pNO3), radiation (photolysis), clouds, precipitation change.
- In changing climate O3 concentrations will further increase if no emission reduction measures take place, however expected O3 emission reduction gives stronger decrease of O3 concentrations.
- Coastal megacities climate change-induced increase in the temperature gradient between land and sea resulting in more intensive and frequent sea breeze events and associated cooler air and fog.
- The impact of the direct aerosol effect was found to be substantial with regard the turbulent characteristics of the flow near the surface.
- Aerosol indirect effects can significantly modify meteorological parameters, such as daytime temperatures and PBL height, while NO2 concentrations are moderately affected.
- Compared to the direct and indirect aerosol feedbacks, urban feedbacks exhibit the same order of magnitude effects on mixing height, but with strong sensitivity of chemistry and a strong non linearity.

Task 7: **Develop integrated tools for prediction of megacity air quality**
Task 8: **Evaluate these integrated tools and use them in case studies**

Q10: **What type of modelling tools should be used for the simulation of multi-scale megacity air quality - climate interactions?**

Methodology and Research Tools

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

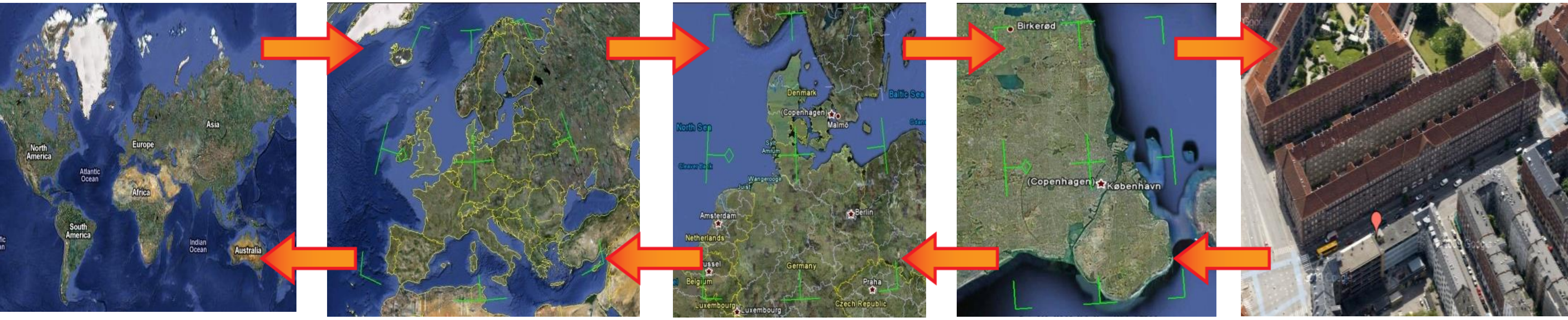
- Land-use characteristics and scenarios
- Anthropogenic heat fluxes
- Emission inventories and scenarios
- Atmospheric processes model down- and up-scaling

ACT, Meteorology, Climate Models

<u>Global</u>: ACT: MPIC, MACC; GCM: UKMO;
<u>Regional</u>: ACTM *Ensemble*, RCM: RegCM, ..
<u>Megacity</u>: Enviro-HIRLAM, MEMO, METRAS, PMCAMx, …;
<u>Street</u>: LES, M2UE, MIMO, MITRAS, …

Temporal and spatial scales and ways of integration:

- Level 1 – Spatial: One way (Global -> regional -> urban -> street);
- Level 2 – Spatial: Two way (Global <=> regional <=> urban);
- Level 3 – Time integration: Time-scale and direction; Direct and Inverse modelling.



Two-way Nesting, Zooming, Nudging, Parameterizations, Urban increment methodology (AUTH)

A simple approach to calculate urban increments

Methodology:

◆ Spatial sampling: Extract initial (sample) increments using either of two methods.

- ➢ Measurement station pairs.
- ➢ Urban scale models.

◆ Multiple regression analysis to formulate a functional relationship between urban increments and emissions, city size and meteo variables (wind speed, atmospheric stability etc.).

◆ Generalisation: Use functional relationship to estimate urban increment for cities across Europe.

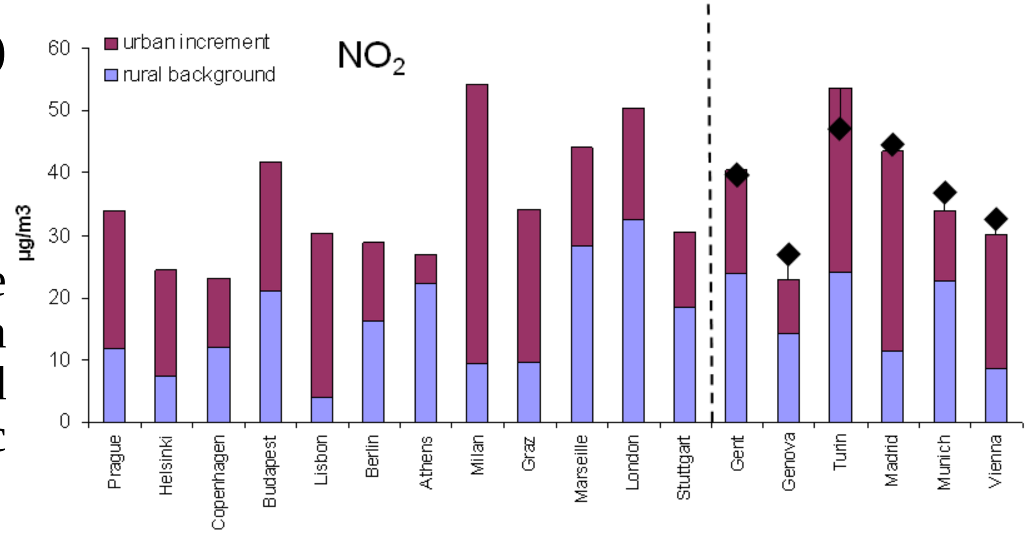
Data requirements:

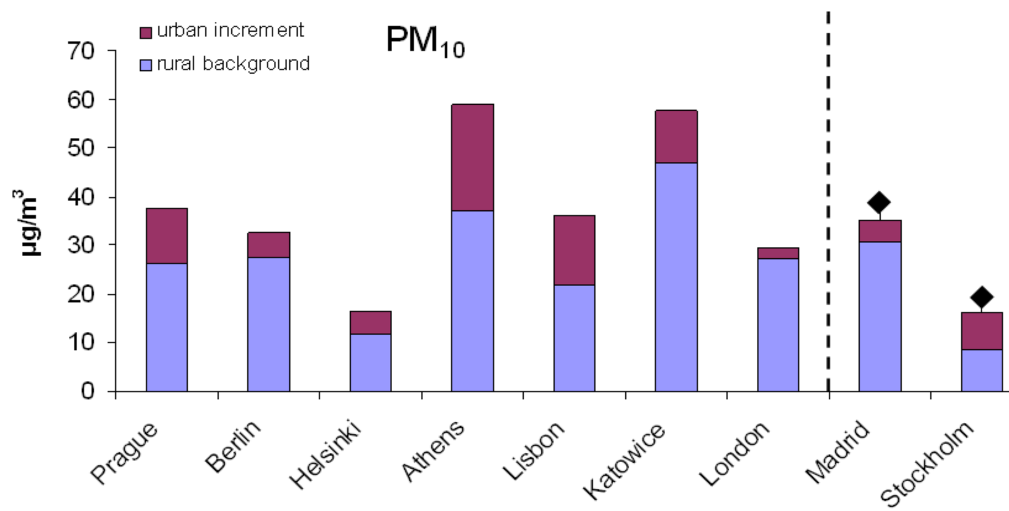
■ Meteorological regional scale model output: wind speed, temperature and cloud cover necessary to calculate stability.

■ "Fine" scale emissions (e.g. TNO).

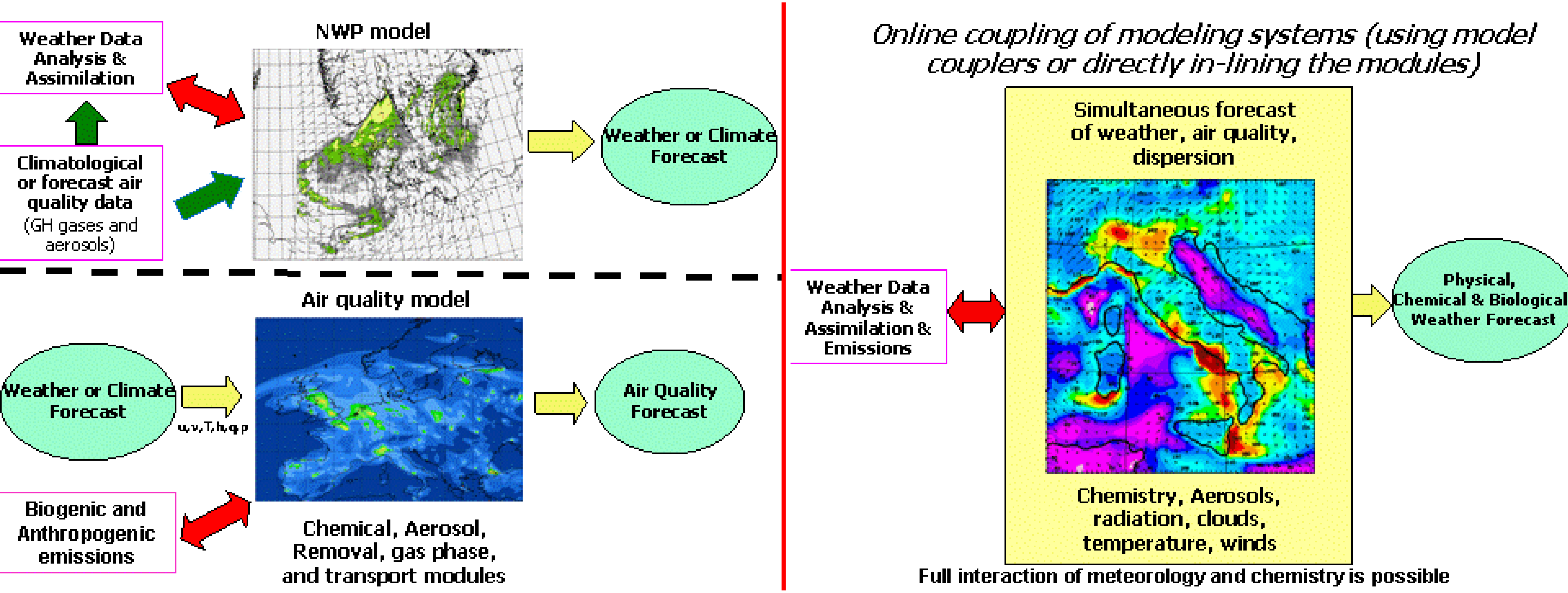
■ Urban entity characteristics (area and shape) per grid cell, available through GIS-framework.

■ CTM regional scale model results (concentrations) for European grid.





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.

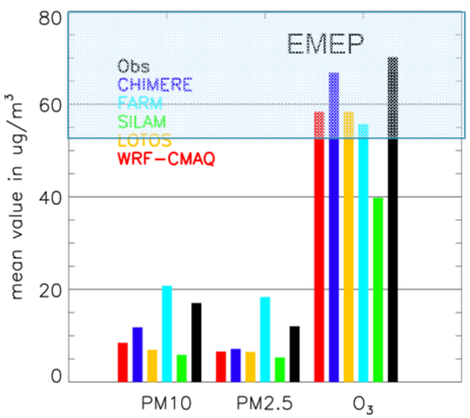
• Order C – fully online integrated with two-way feedbacks, meteorology <=> chemistry & emissions; Models: UKCA WRF-Chem, Enviro-HIRLAM, EMAC (former ECHAM5/MESSy).

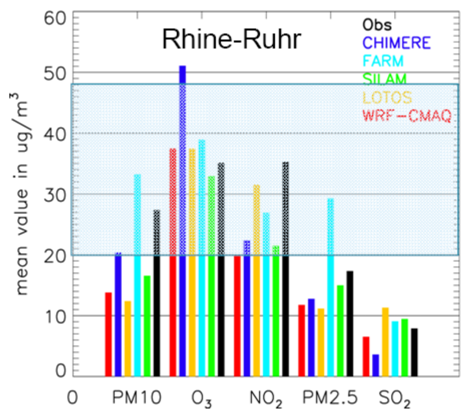
MP modelling systems evaluation

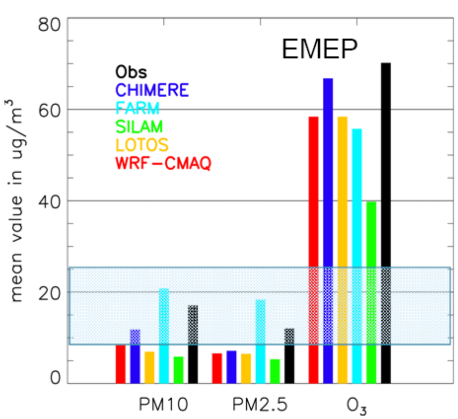
MP modelling systems evaluations realised for:

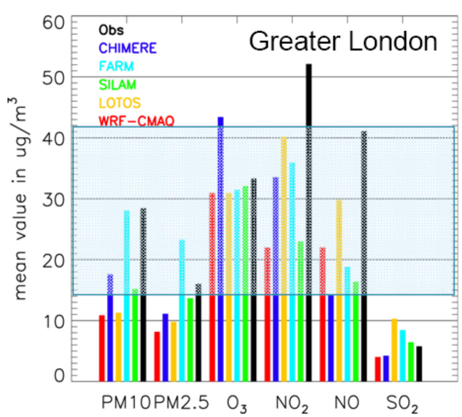
(i) Paris campaign studies – regional models ensemble and WP3 models

(ii) Annual model runs for year 2005









Evaluation scheme successfully applied to CHIMERE, FARM, SILAM, LOTOS-EUROS, WRF-CMAQ for year 2005

□ **No one-and-best model identified**

□ **Small dependence of model performance on station**
site characteristics (rural / urban)

□ **Ozone results**

– Annual means within typical (66%) model performances

– Frequency distribution of deviations very wide

– Values frequently underestimated

– Integral values (AOT40) overestimated

– Exceedances underestimated

□ **PM10 results**

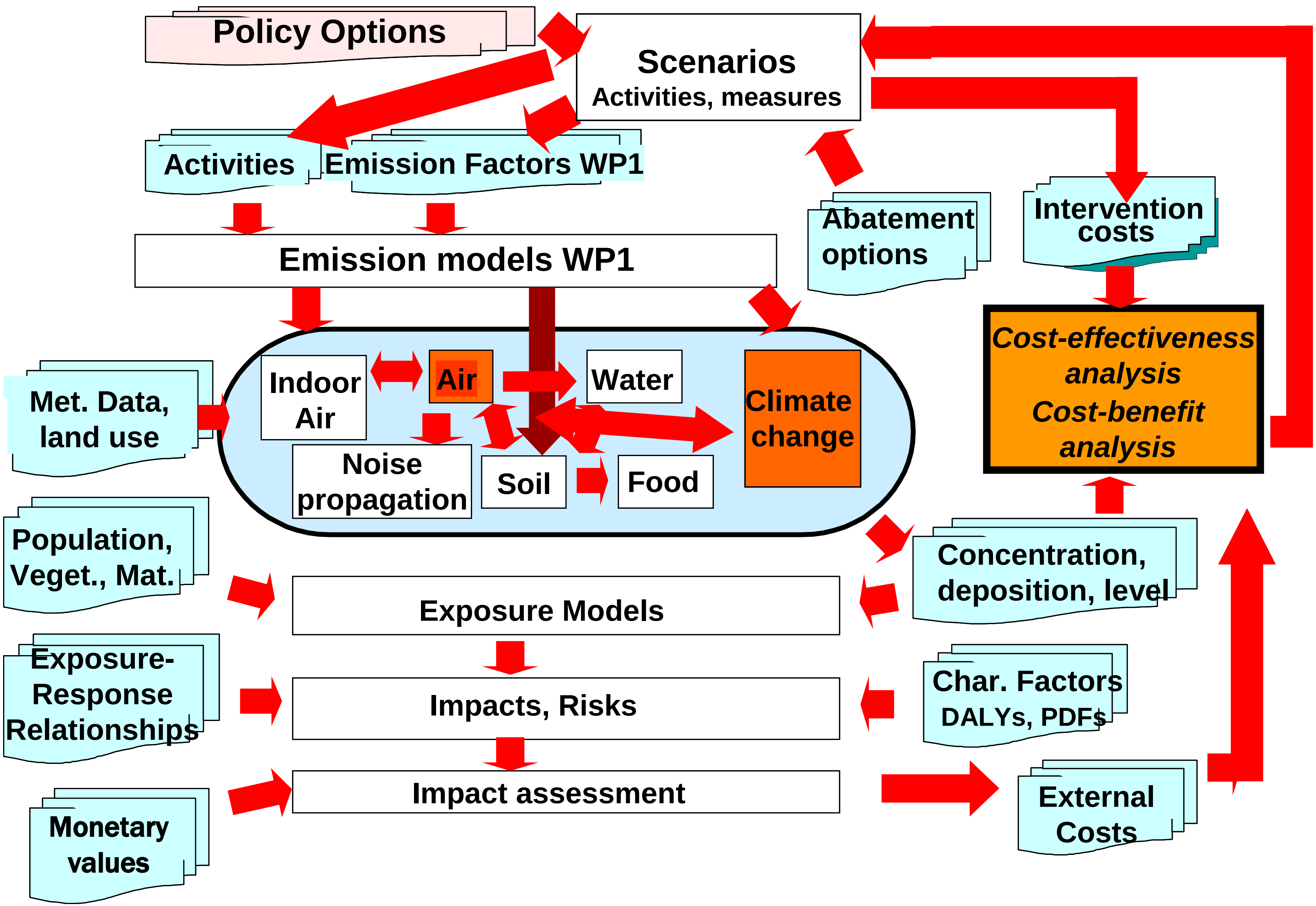
– Models have similar performance for all weather clusters

– High pressure systems simulated within 50% error

– North-easterly (Rhine-Ruhr) or south-westerly / westerly (London)
weak flows less well simulated

See details - in WP5 and WP7 overviews by H. Schlünzen and M. Sofiev, as well in WP3

Integrated Assessment Modelling System



Task 10: Develop a methodology to estimate the impacts of different scenarios of megacity development on human health and climate change

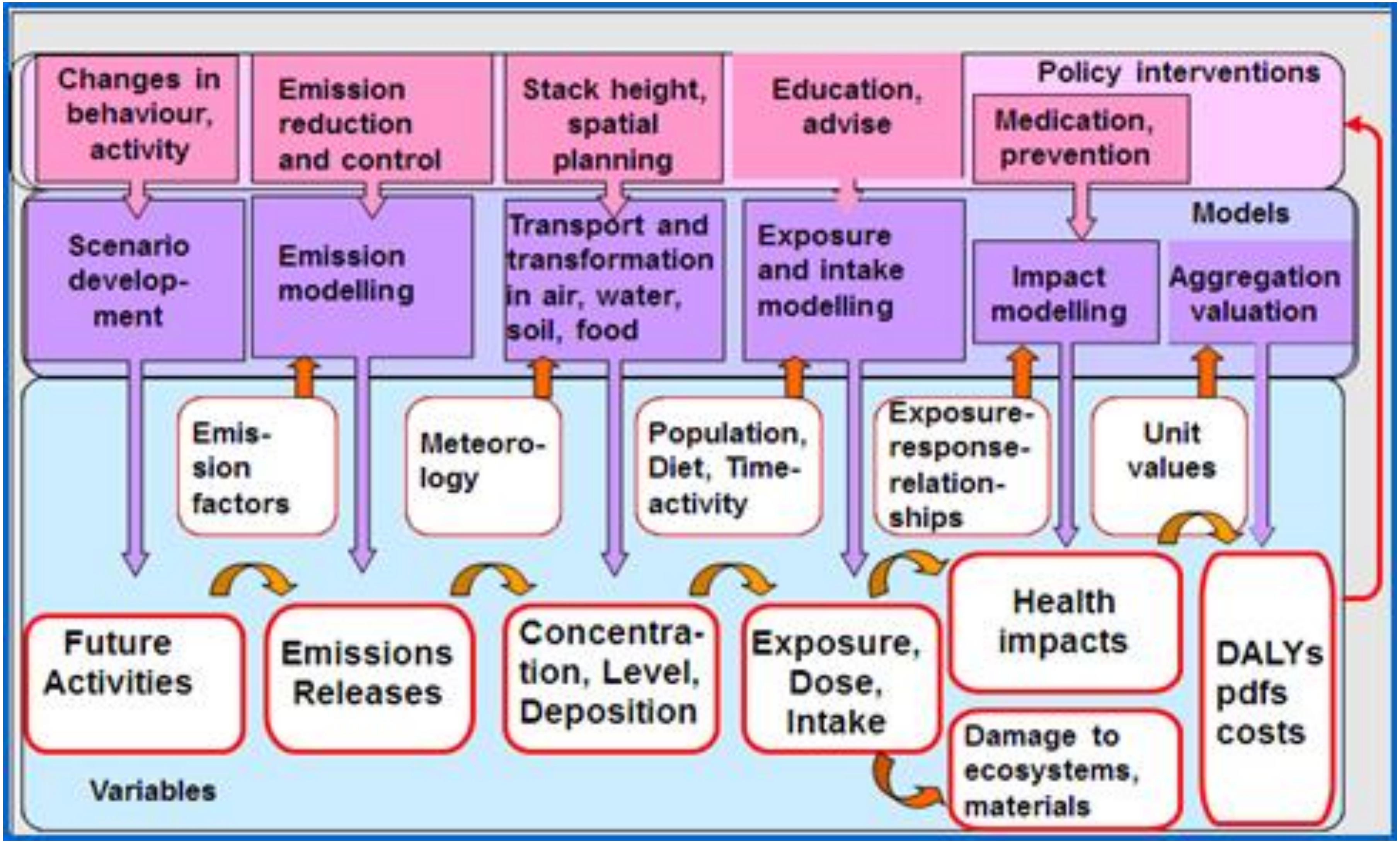
Task 11: Propose and assess mitigation options to reduce the impacts of megacity emissions

SQ11: Which policy options are available to influence the emissions of air pollutants and greenhouse gases in megacities and how can these options be assessed?

SQ1: What is the change of exposure of the overall population to the major air pollutants as people move into megacities? What are the health impacts of this exposure?

Methodology

The Full Chain Approach

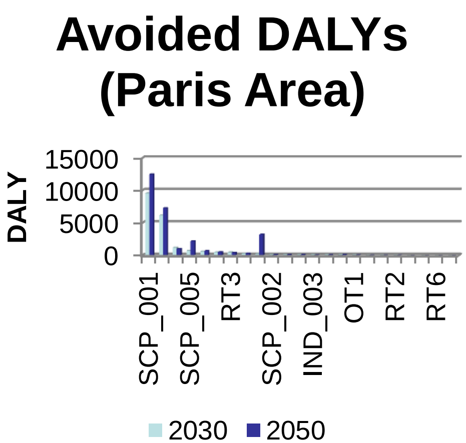


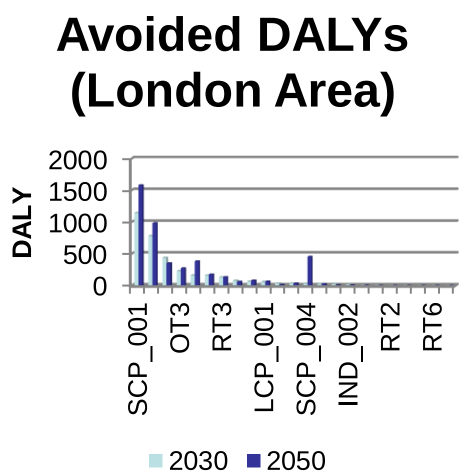
Considered Measures and Policy Options

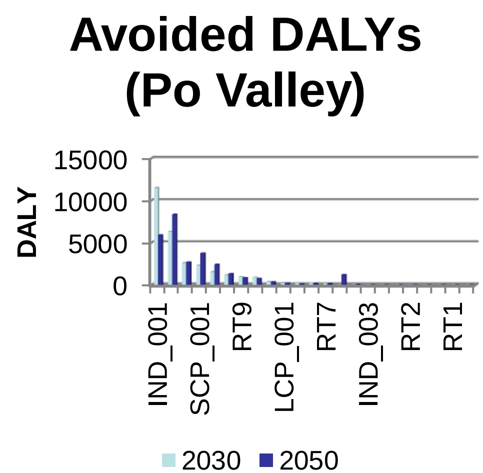
- **Energy sector (LCP) =>2 measures**
- **Energy sector (Small combustion) =>5 measures**
- **Industry =>4 measures**
- **On-road => 9 measures**
- **Offroad => 4 measures**

Pollutants: GHG, NO_x, SO_2, NMVOC, NH_3, PM10, PM2.5

Ranking of the measures with the most avoided DALYs (disability adjusted life years)



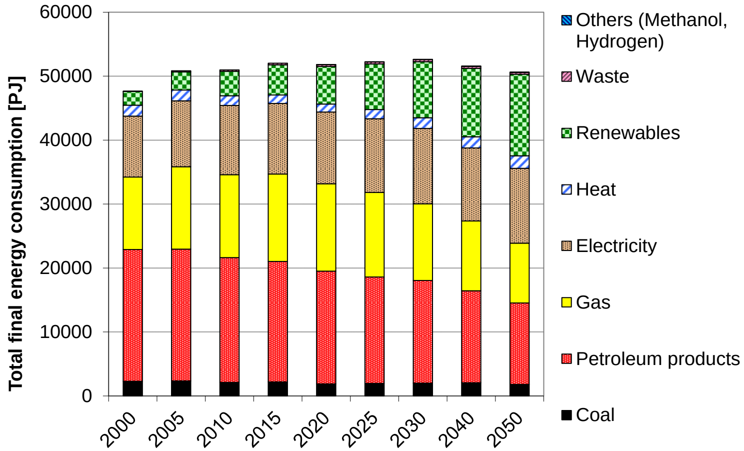




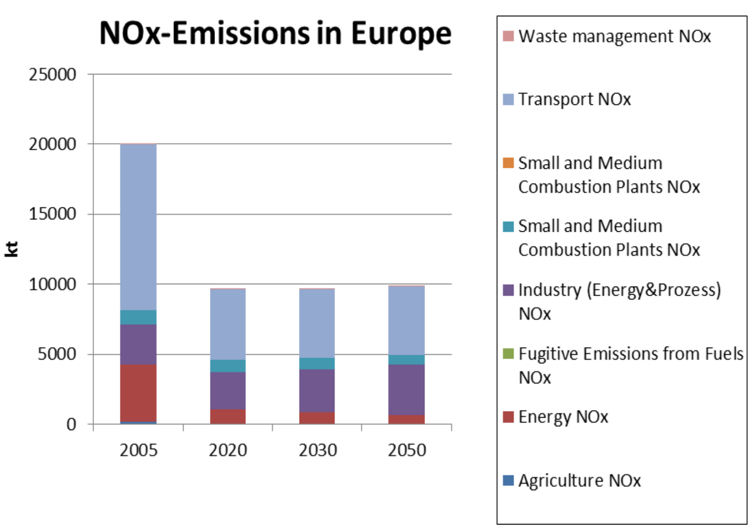
- ➢ Energy-efficient modernisation of old buildings
- ➢ Replacement of solid fuels fired small combustion plants with efficient combustion techniques
- ➢ Switch to renewable heat supply in residential sector
- ➢ Expansion of district heating networks
- ➢ Combined climate protection measures in cement industry
- ➢ Kerosene tax for aviation

See details - in WP8 overviews by J. Theloke, UStutt

SQ11: Which policy options are available to influence the emissions of air pollutants and greenhouse gases in megacities and how can these options be assessed?



Development of the total final energy consumption for EU-30 in the baseline scenario. *UStutt contribution*



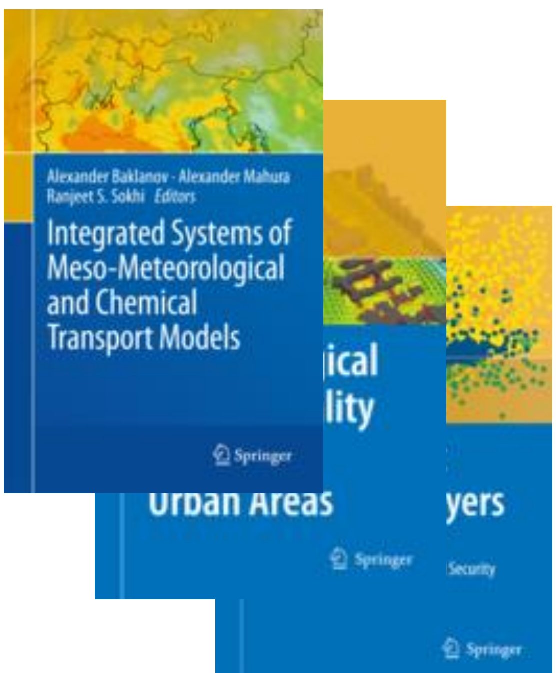
- MCs present a major challenge for the regional and global environment.
- Adaptation by humans to significant climate change in major MC areas is possible.
- Well-planned, densely populated settlements can reduce the need for land conversion and provide proximity to infrastructure and services, but sustainable development must also include:

(i) appropriate air quality management plans;
(ii) adequate access to clean technologies; and
(iii) improvement of data collection and assessment.

- Successful result will be to arrive at integrated control and mitigation strategies that are effectively implemented and embraced by the public.

MEGAPOLI Dissemination

- MEGAPOLI public web-site: http://megapoli.info
- MEGAPOLI Newsletter (12 issues and Volume)
- MEGAPOLI Sci. Reports (>50)
- Several Books published by Springer, etc.
- 3 Science Journal Special Issues
- A number of scientific papers (>70 and rising)



Thank You !

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