CHALLENGES FOR IMPROVING URBAN AIR QUALITY
LESSONS FROM GLOBAL CITIES

Ranjeet S Sokhi

Centre for Atmospheric and Climate Physics Research (CACP)
University of Hertfordshire, UK
Co-chair of WMO/GURME

UNECE EXPERT PANEL ON CLEAN AIR IN CITIES
27 November 2019, Bratislava

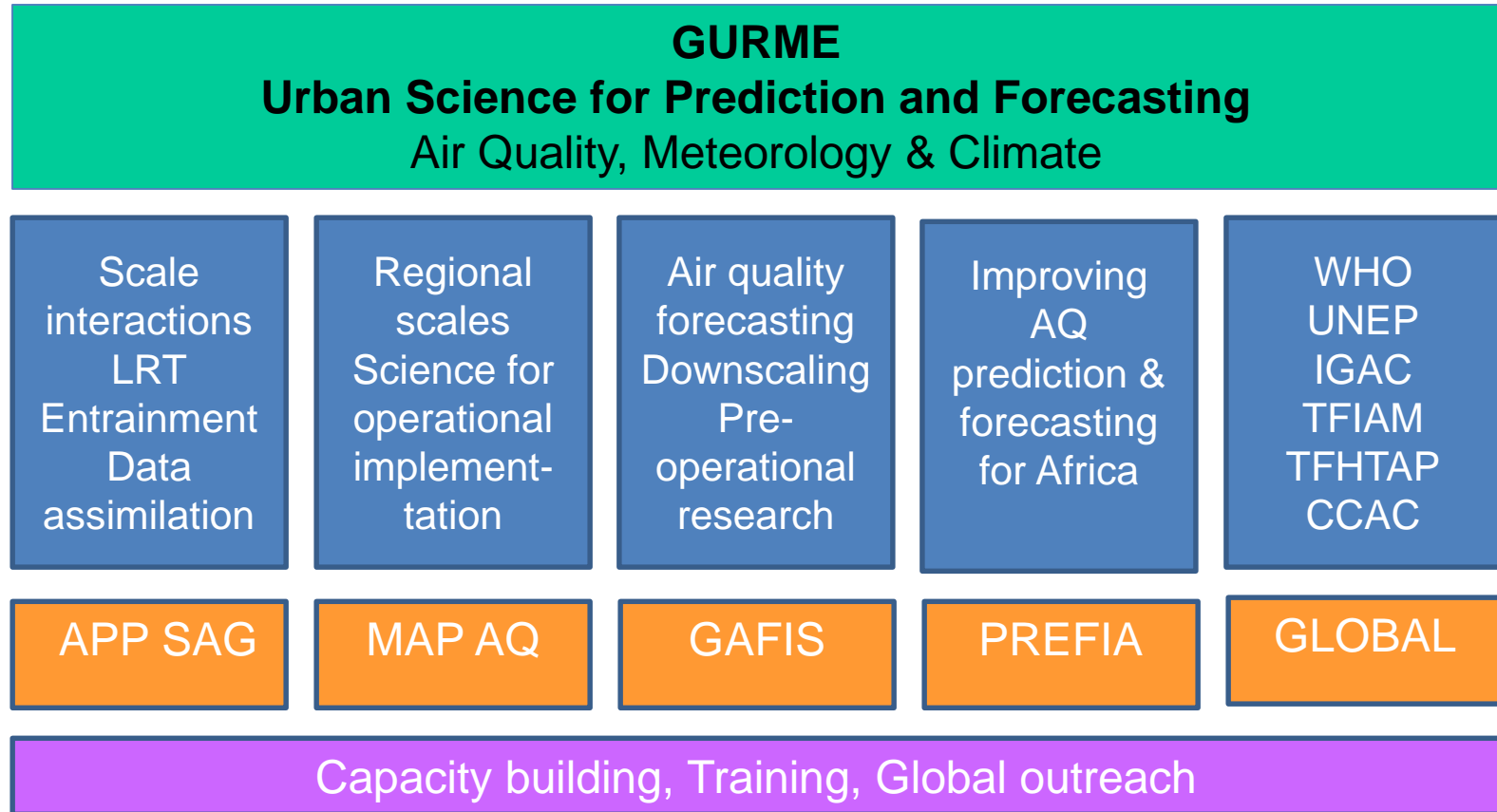University of Hertfordshire · UH · WMO · GAW · GURME

Acknowledgments

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- Mexico Secretariat of the Environment (SEDEMA) and Barcelona Supercomputing Center (Luisa Molina)

- Shanghai Meteorological Service (Tan Jianguo)

- National Centre for Atmospheric Science (NCAS), UK

- Natural Research Environment Council (NERC), UK

University of Hertfordshire

WMO

GAW

GURME

WMO/GAW Urban Research Meteorology and Environment Project (GURME) - Community Interconnections

GURME
Urban Science for Prediction and Forecasting
Air Quality, Meteorology & Climate

| Scale interactions LRT Entrainment Data assimilation | Regional scales Science for operational implement-tation | Air quality forecasting Downscaling Pre-operational research | Improving AQ prediction & forecasting for Africa | WHO UNEP IGAC TFIAM TFHTAP CCAC |

| APP SAG | MAP AQ | GAFIS | PREFIA | GLOBAL |

Capacity building, Training, Global outreach

GAW

WMO

Challenges facing global cities

- Mexico city
  - Photochemical ozone

- Singapore
  - local/LRT

- Chilean cities
  - Complex terrain/episodes

- Delhi
  - Long range transport

- European cities
  - Local/regional, multi-pollutant, climate
  - Exposure

Mexico City – what's achieved and remaining challenges

Late 1980s - early 1990s:

All criteria pollutants frequently exceeded AQ Standards; O_3 peaked above 300 ppb many days

- **Reduction in all criteria pollutants**
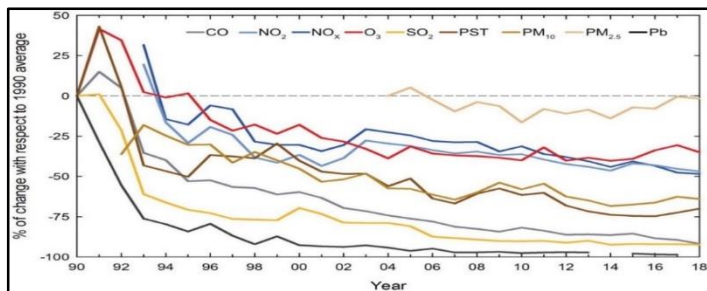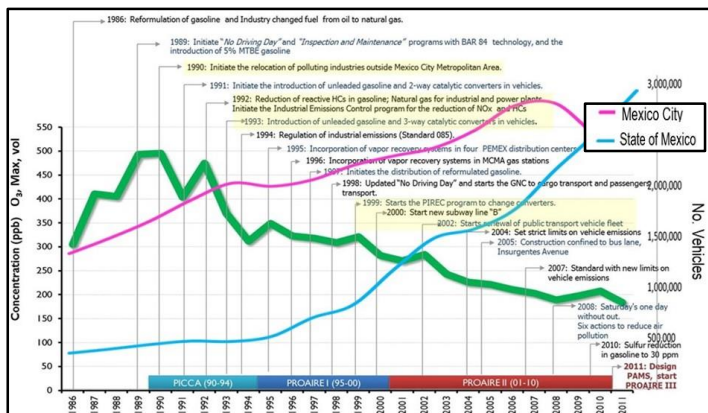
% Reduction from 1990 based on annual average

AQ Management Programs – significant measures implemented

➢ Extensive ambient **AQ monitoring stations**
➢ **Emissions inventory** (update every 2 yrs)
➢ Air Quality **Standards** (PM10, PM2.5, NO_2, SO_2, CO, Pb, O_3)
➢ **Transportation**
  - removal of lead from gasoline and its reformulation
  - mandatory use of catalytic converters
  - reduce sulfur content in diesel fuel
  - reinforce vehicle inspection and "no driving day" rule
  - implement air pollution contingency program
➢ **Industrial and residential sectors**
  - substitute fuel oil in industry and power plants with natural gas
  - reformulate LPG for cooking and water heating
  - promote energy efficient buildings and solar water heating
➢ Collaborate with **national and international researchers**
➢ Develop **Air Quality Forecasting System**
➢ Engage **Health sector** in evaluation of air pollution impacts
➢ Enhance **communication** with public and stakeholders

Ongoing Challenges:

Reduction in O_3 and PM slow

Complex interactions between **emissions, meteorology and atmospheric chemistry**
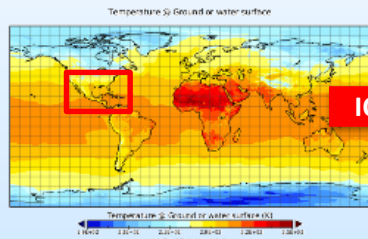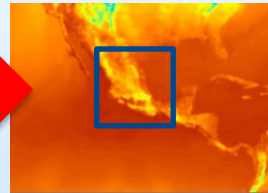
(Source: Molina et al., Atmosphere, 2019)

Linkages within the operational system (Mexico City)
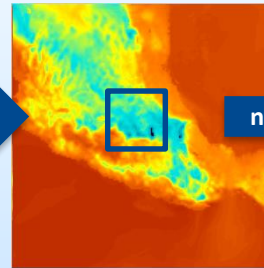
Downscaling

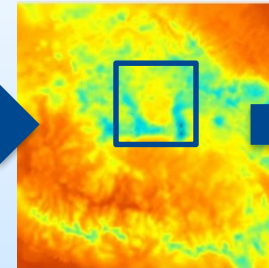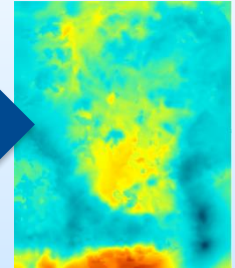### METEOROLOGICAL MODEL (WRF)

NCEP GFS
0.25º x 0.25º

IC/BC

WRF-ARW
27 km x 27 km

nesting

WRF-ARW
9 km x 9 km

nesting

WRF-ARW
3 km x 3 km

nesting

WRF-ARW
1 km x 1 km

Meteo

Meteo

AIR QUALITY MODEL (CMAQ)

Meteo

UCAR MOZART4
1.9 º x 2.5º
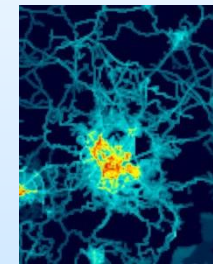
BC
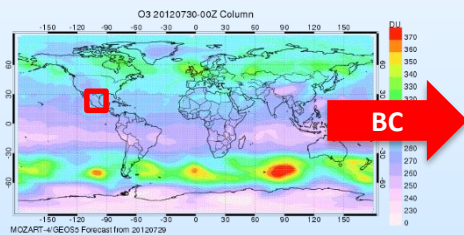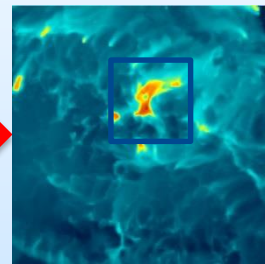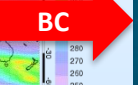
CMAQ
3 km x 3 km

nesting
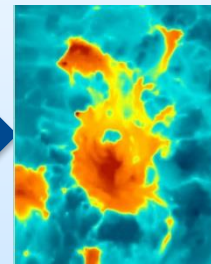
CMAQ
1 km x 1 km

Emis

EMISSION MODEL (HERMES-Mex)
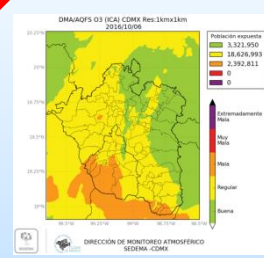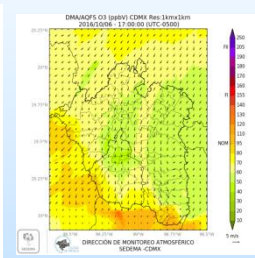
HERMES-Mex
1 km x 1 km

Post-procesos

PRODUCTS
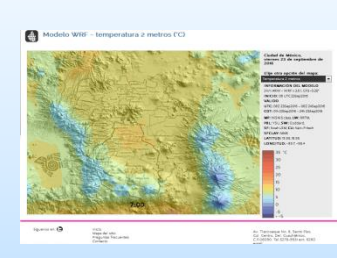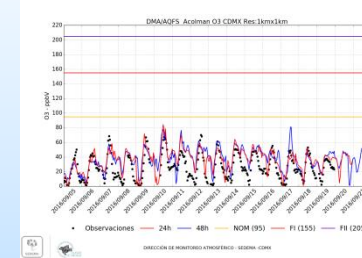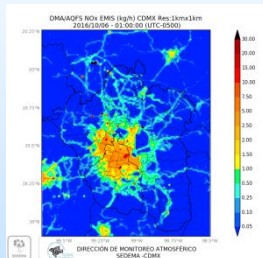
Singapore – mixed local and LRT contributions

Map of Sijori Growth Triangle (total population = 8.6M) formed by the urban areas (indicated by line shading) of Singapore, Johor Bahru in Malaysia to the north and the Indonesia's island of Batam to the south.

Yellow and red dots are locations of **ambient and roadside air quality monitoring stations**

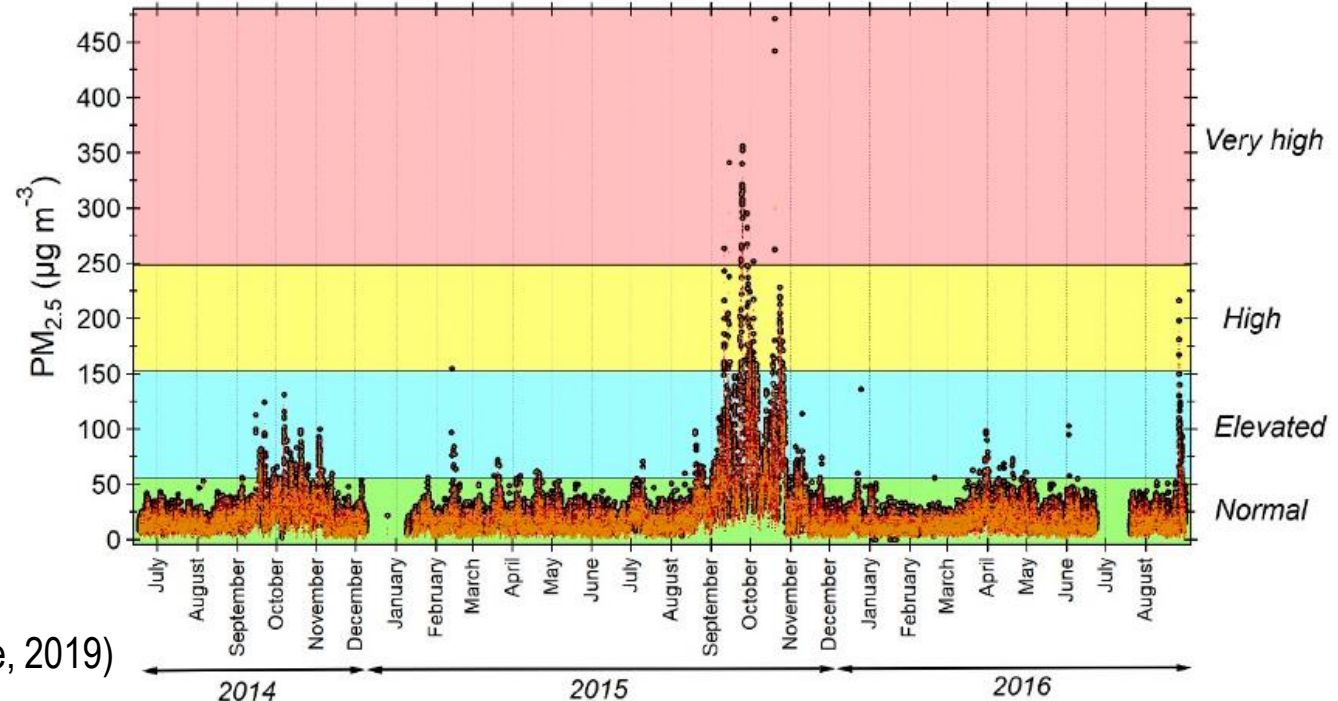(Source: Molina et al., Atmosphere, 2019)

> **Main air pollution challenges:**
> - **Local emissions** from vehicles and industry.
> - **Transboundary air pollution** from the highly industrialized and urbanized neighboring cities of Johor Bahru and Batam.
> - **Haze episodes** from neighboring Indonesia's wildfires

Chilean cities - PM2.5 episodes

- **Causes**:
  - Emissions due to anthropogenic activities
  - Complex topography
  - Episodic meteorological conditions

- Warnings issued to the public and implementation of temporary measures

Future tasks

Improvements to emission inventories, specially to wood burning stoves

Ensemble predictions (maybe do 2 cycles a day?)

Evaluation of model representation of the nocturnal boundary layer
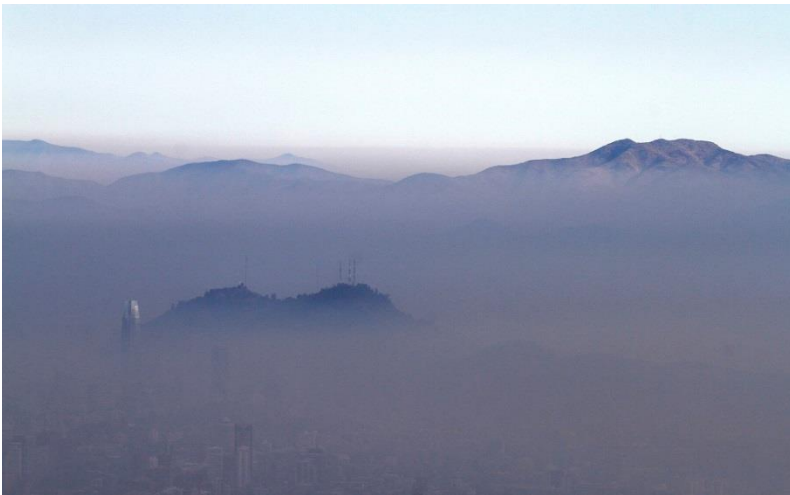
Santiago during en episode

Wood burning stoves in Temuco

Understanding LRT affecting Delhi

SAFAR Dust forecasting

SAFAR Dust AOD2018-06-10_03:00:00

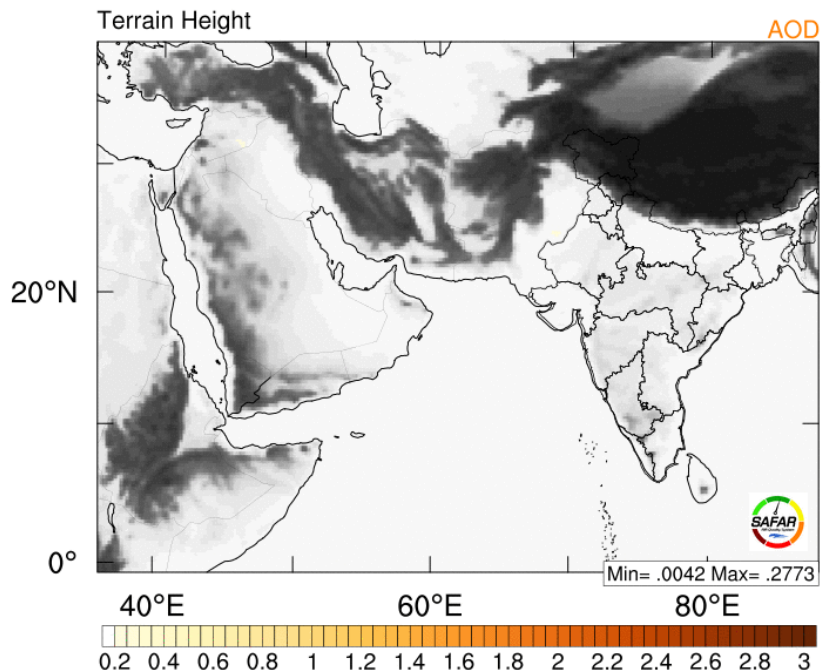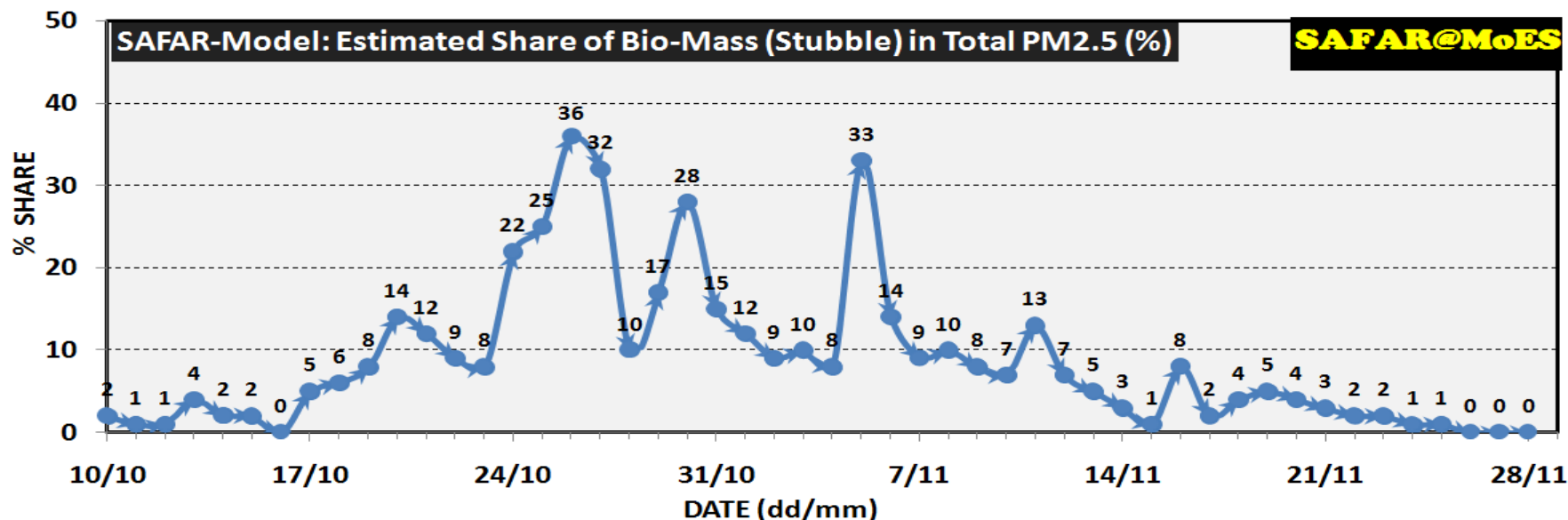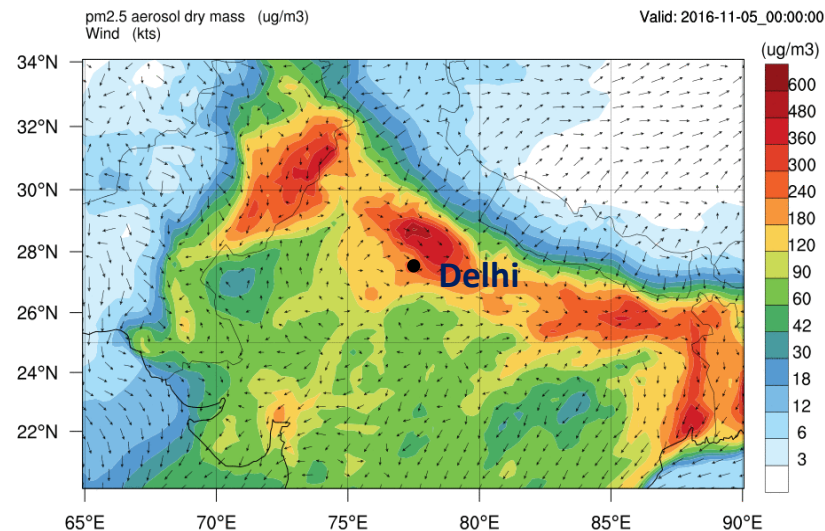## PM2.5 Forecast - NARL

SAFAR-Model: Estimated Share of Bio-Mass (Stubble) in Total PM2.5 (%)

NCAS - UH
Air Quality Forecast System
https://sci.ncas.ac.uk/airquality/

ICs and BCs
NCEP GFS/ ECMWF

WRF
Meteorological model

Weather prediction
Met variables

Emissions (SMOKE)
Biogenic (MEGAN) and Anthropogenic

ICs and BCs
MACC, CMAQ

CMAQ
Chemistry Transport Model

Predicted concentrations
O_3 PM_{10} $PM_{2.5}$ NO_2

City Emissions Data
Road Network, Traffic, Local Emissions

Met Data Pre-processor

Air Quality Data Pre-processor

Emissions Data Pre-processor

Population activity data

City Scale Model e.g. OSCAR

HiREA AQ and Exposure Forecasting

Concentrations and Exposure
PM_{10} $PM_{2.5}$ NO_2 and O_3

Air Quality Products
Exposure Assessment, City Scale Concentration Maps, Clean Air Routes

PM2.5 Total Concentration (2008)

Total Exposure

0–100
100–1000
1000–10000
10000–100000
100000–1000000
1000000–10000000
10000000–100000000

NCAS-UH Air Quality Forecast
High PM2.5 air pollution affecting S. England

PM2.5 episode over the UK (March – April 2014)

Composition of PM2.5 at Rural Site (HAR)

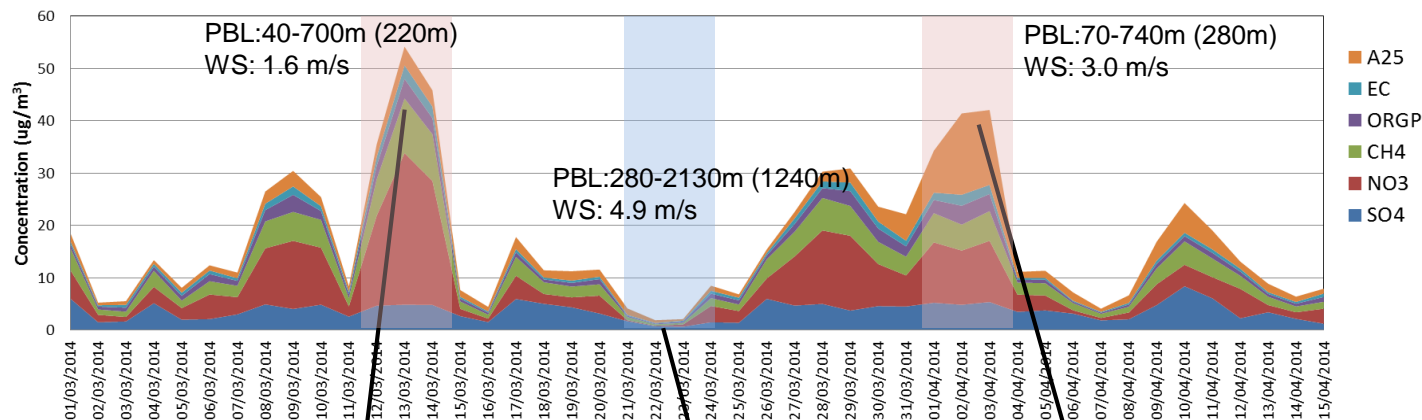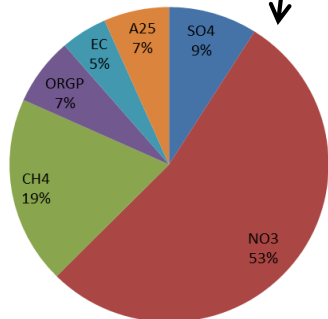PBL:40-700m (220m)
WS: 1.6 m/s

PBL:280-2130m (1240m)
WS: 4.9 m/s

PBL:70-740m (280m)
WS: 3.0 m/s

Legend: A25, EC, ORGP, CH4, NO3, SO4

13 March 2014

Nitrate dominated

SO4 9%, A25 7%, EC 5%, ORGP 7%, CH4 19%, NO3 53%

22 March 2014

OTH, A25 28%, EC 5%, ORGP 8%, CH4 14%, NO3 7%, SO4 38%, SO4, EC, ORG, CH4, NO3
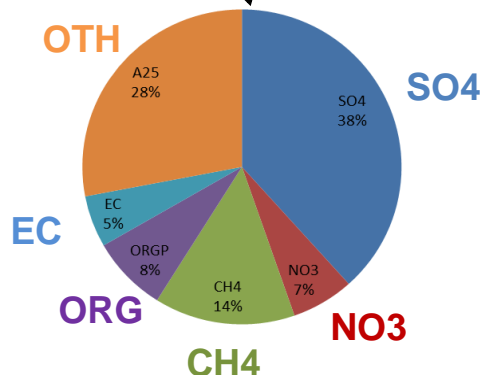
2 April 2014
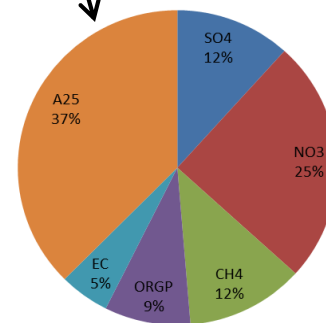
Mixed - Nitrate and Dust

SO4 12%, NO3 25%, CH4 12%, ORGP 9%, EC 5%, A25 37%

North London Tunnel site (PM10)

- Brake Wear (11%)
- Petrol Exhaust (12%)
- Diesel Exhaust (21%)
- Resuspension (27%)
- Road Surface Wear (11%)
- Unexplained (18%)

Source: Lawrence et al 2013
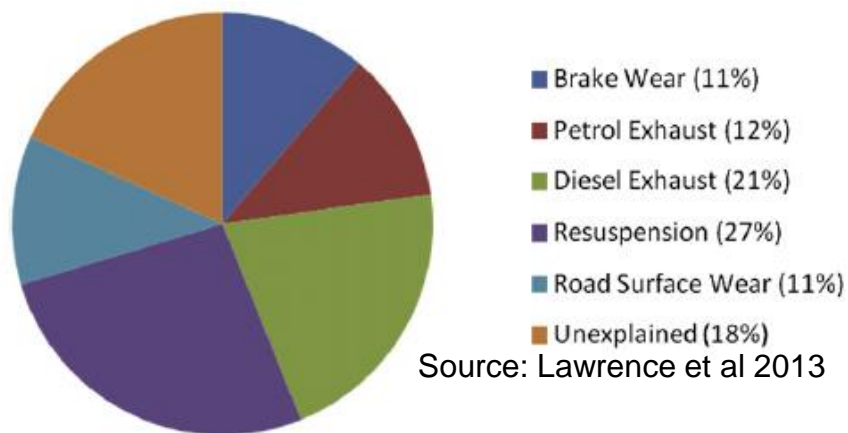
- Use of ESCAPE and TRANSPHORM city data
- Detailed measurements in Rotterdam and Thessaloniki

Key messages:
- ~50% of PM10 can be non-exhaust
- Coarse fraction should be included in control strategies of PM10
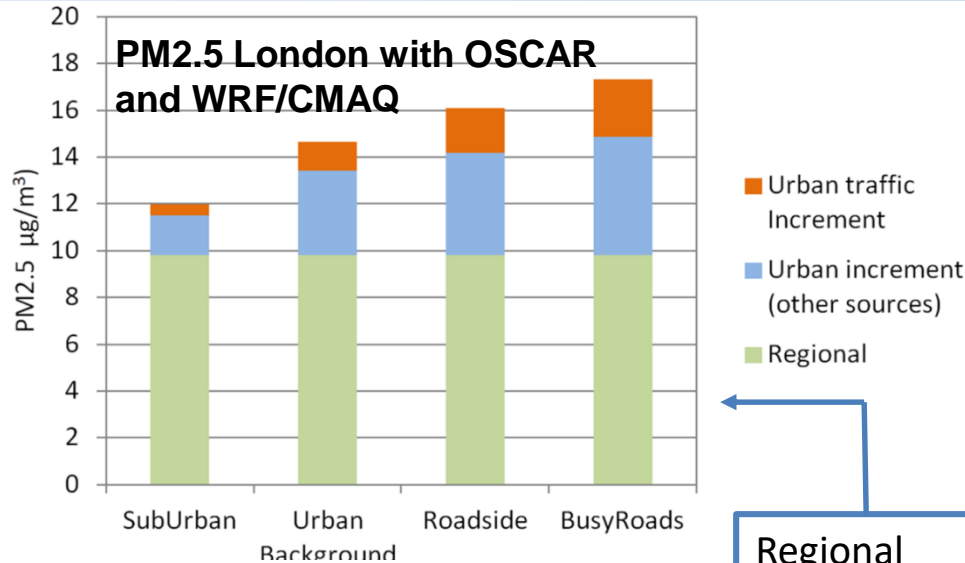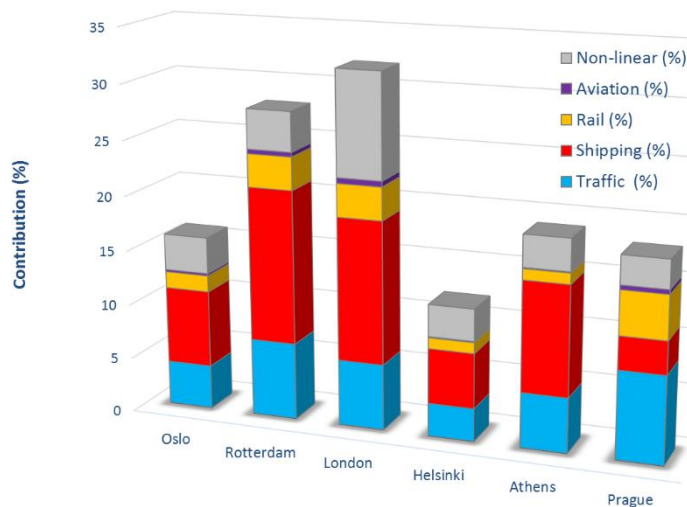- Non-exhaust will become more important in the future

$PM_{2.5}$ Rotterdam sites
□ weekend ■ working
PM2.5

PM_{10} Rotterdam sites
□ weekend ■ working
PM10

TRANSPHORM
transport   pollution   health
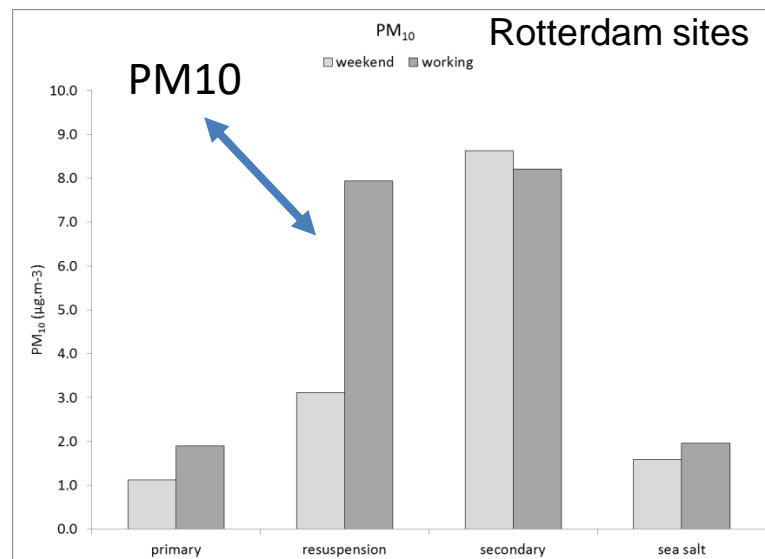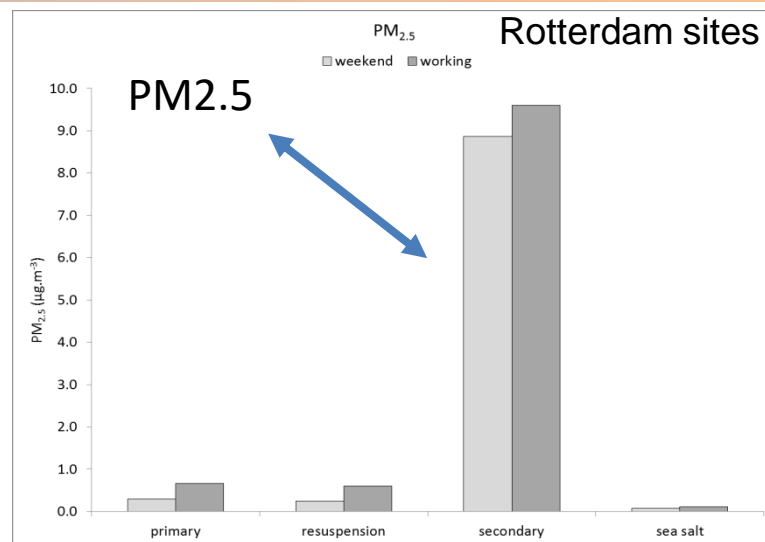
Transport related Air Pollution and Health impacts - Integrated Methodologies for Assessing Particulate Matter

PM2.5 London with OSCAR and WRF/CMAQ

Legend:
- Urban traffic Increment
- Urban increment (other sources)
- Regional

Regional background source contribution to PM2.5 at target cities

Regional component

Pollutant	Source orientated response
PM10	Coarse e.g. road dust
PM2.5	Regional dominant, exhaust
EC	Combustion, exhaust
BaP	Wood burning
PN	Combustion, exhaust

Source contribution to PM exposure in Oslo
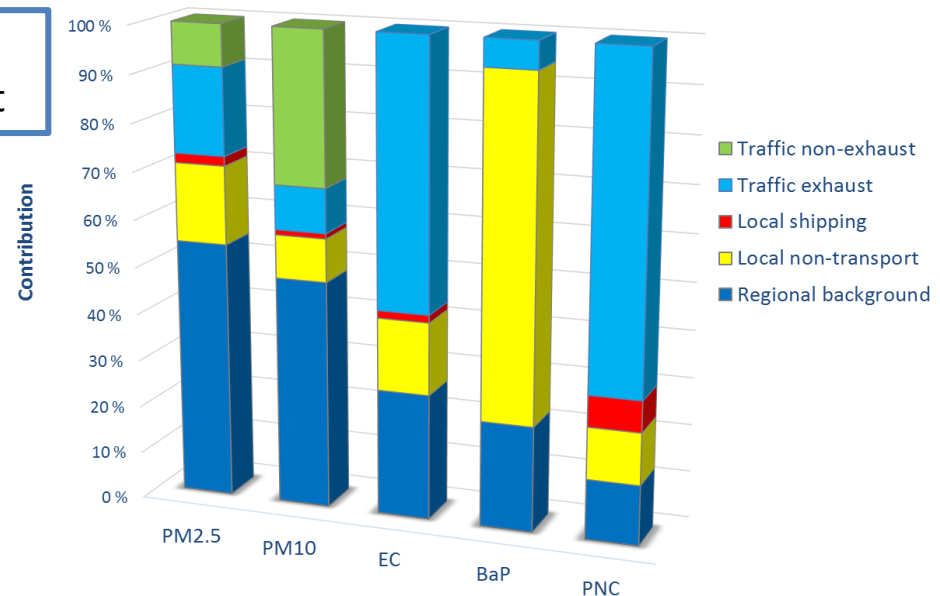
Calculations using the EPISODE model

delta_C DJF (2050-2000)

mean = 0.33
stdev = 0.89

delta_C MAM (2050-2000)

mean = 0.34
stdev = 0.97

delta_C JJA (2050-2000)

mean = -0.14
stdev = 0.96

delta_C SON (2050-2000)

mean = 0.37
stdev = 1.20

Coupling WRF/CMAQ and HADGem-ES
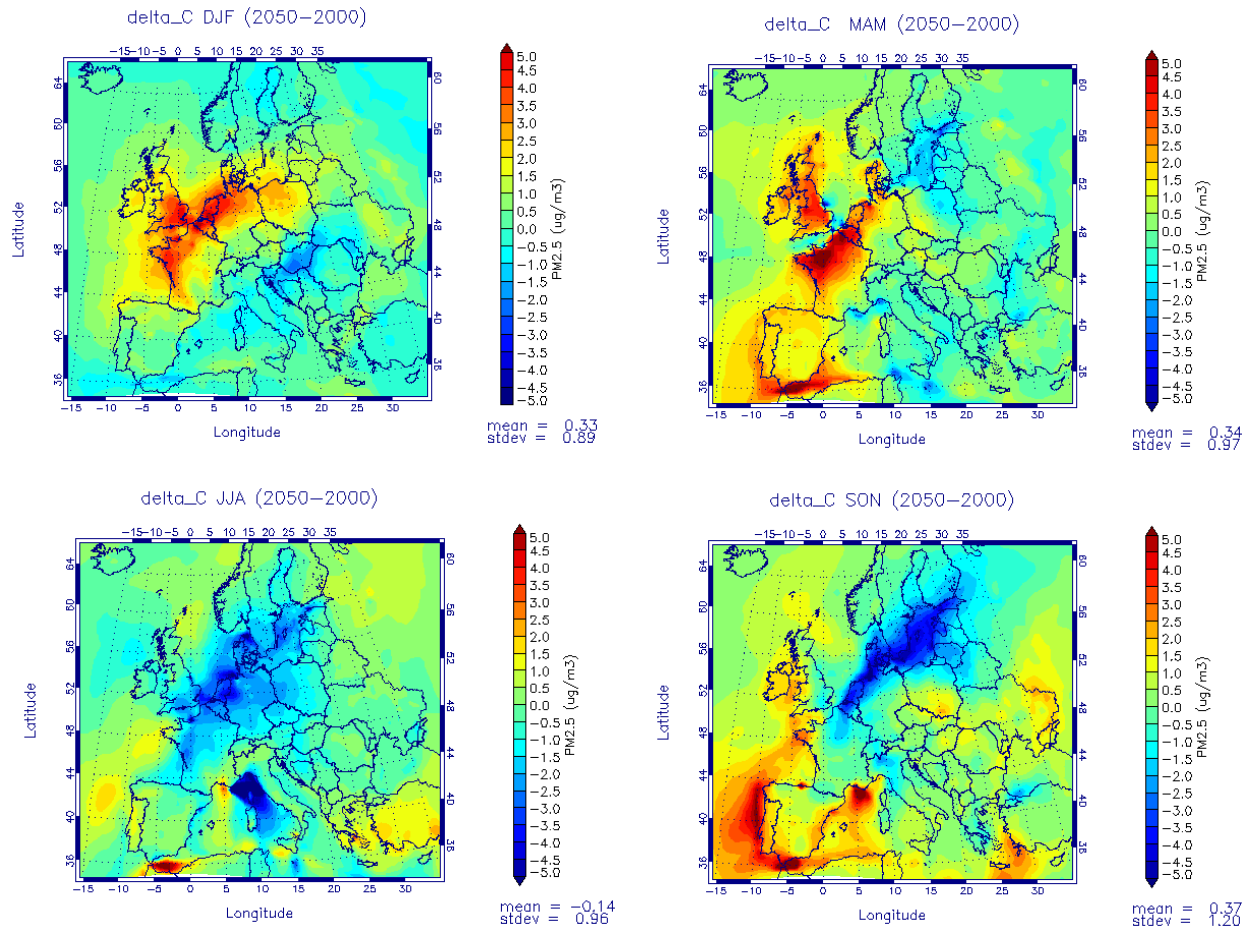
Key messages:
- There is considerable seasonal and spatial variation in PM2.5 levels
- While the influence of emissions reduction is stronger, climate change effects will become more important as air pollutant emissions reduce

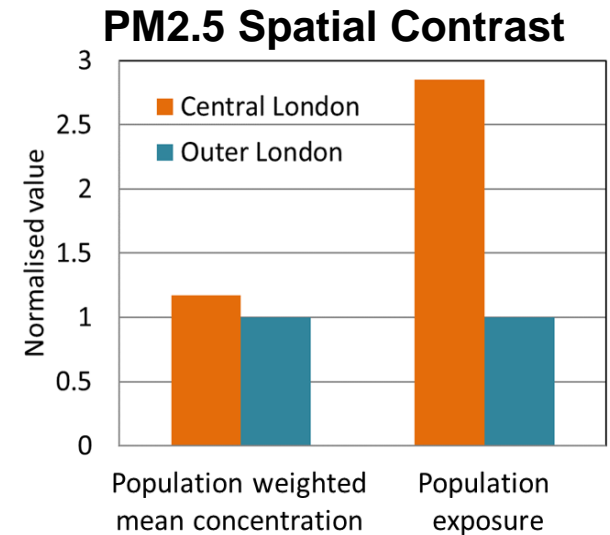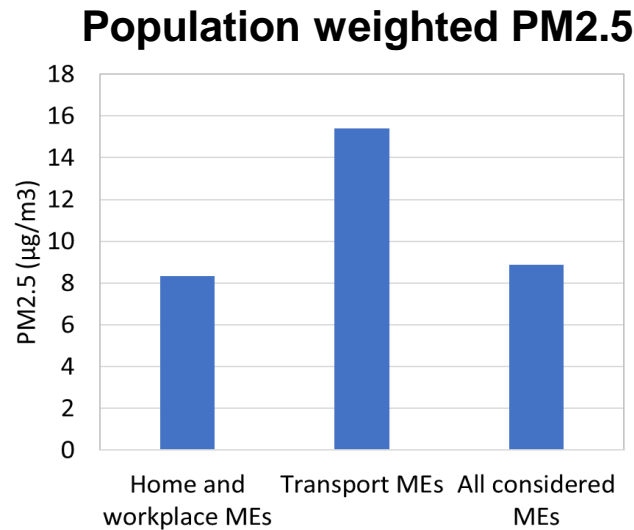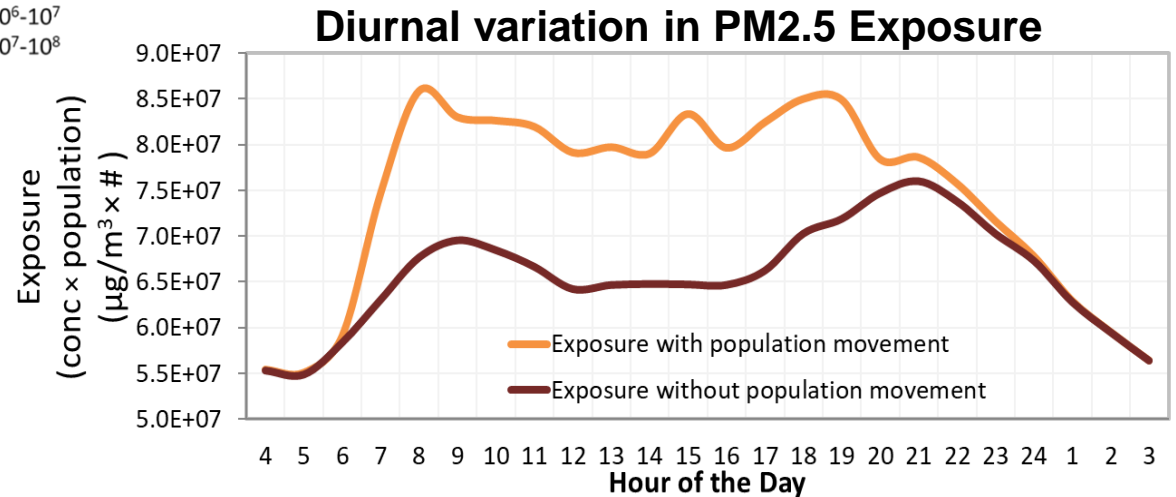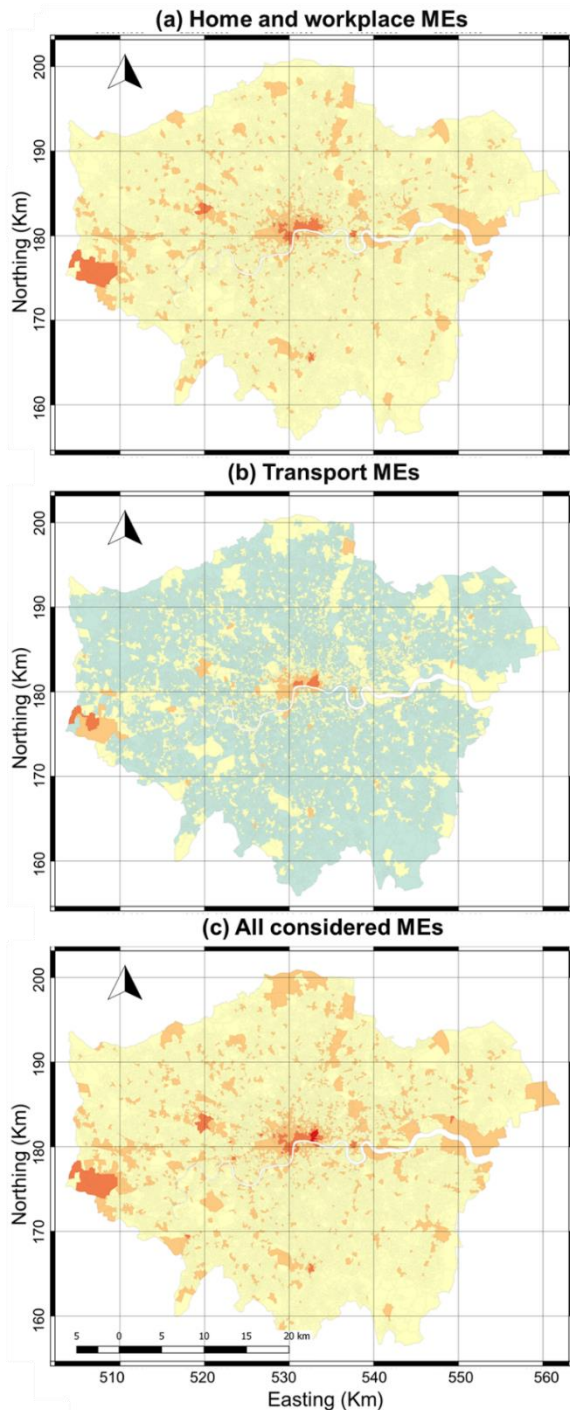What are the implications for cities in the future?

University of Hertfordshire
UH

Work conducted in collaboration with the UK Met Office

Spatial and temporal variation in exposure to PM2.5 over London

(a) Home and workplace MEs

Legend:
- 0-10²
- 10²-10³
- 10³-10⁴
- 10⁴-10⁵
- 10⁵-10⁶
- 10⁶-10⁷
- 10⁷-10⁸

(b) Transport MEs

(c) All considered MEs

Diurnal variation in PM2.5 Exposure

Exposure (conc × population) (μg/m³ × #) vs Hour of the Day

- Exposure with population movement
- Exposure without population movement

Population weighted PM2.5

PM2.5 (μg/m3)

- Home and workplace MEs
- Transport MEs
- All considered MEs

PM2.5 Spatial Contrast

Normalised value

- Central London
- Outer London

- Population weighted mean concentration
- Population exposure

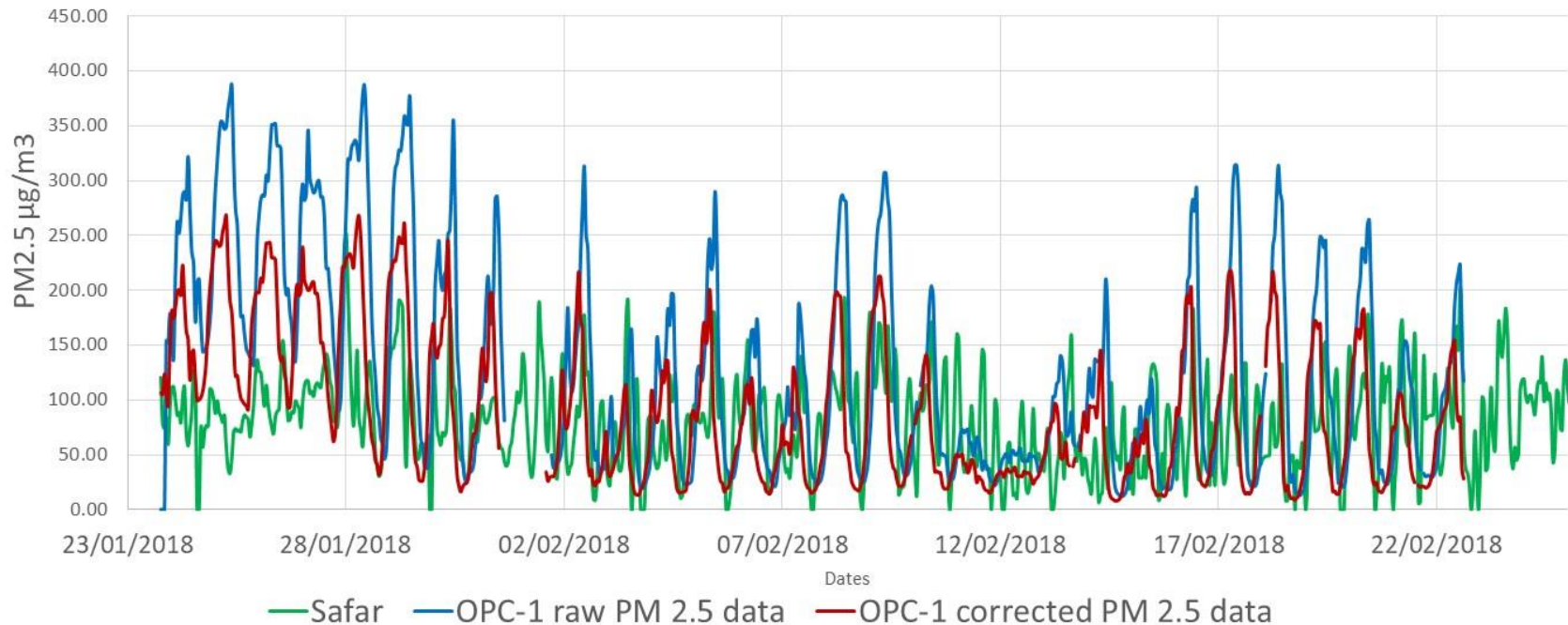Singh et al (2019) Env. Pollution

University of Hertfordshire

Lack of observations
Are lower cost sensors the answer?

Corrections for RH to Low Cost Sensor measurements of PM2.5 – Delhi Site

NPL PM2.5

— Safar — OPC-1 raw PM 2.5 data — OPC-1 corrected PM 2.5 data

Final remarks

- **Understanding local/regional contributions is critical** to reach end goal of air quality improvement

- **Multiple scales, pollutants and sources** – PM components

- **Multiple processes** – complex terrain, dynamics, chemical transformations; complex source distributions; detailed processes based analysis; linking sources - distributions – impacts on multiple scales, climate interactions

- **Advanced multiscale modelling** offer a process-based assessments of air quality and its impacts

- **Move towards exposure and health benefit** taking account of population activity, microenvironments and infiltration

- **How do we make these advances accessible to cities?**