INSTITUTO DE ASTRONOMIA, GEOFÍSICA E CIÊNCIAS ATMOSFÉRICAS

USP
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Approaches for an integrated study of urban air pollution

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Outline of Seminar

- Motivation
  - Health effects
  - Climate

  - What to study:
  - Gaps in knowledge
    - Measurements (including low-cost sensors)
    - Regulated (PM,O3) and other important species (VOC, OM, BC)
    - Hot spots

    - Emissions

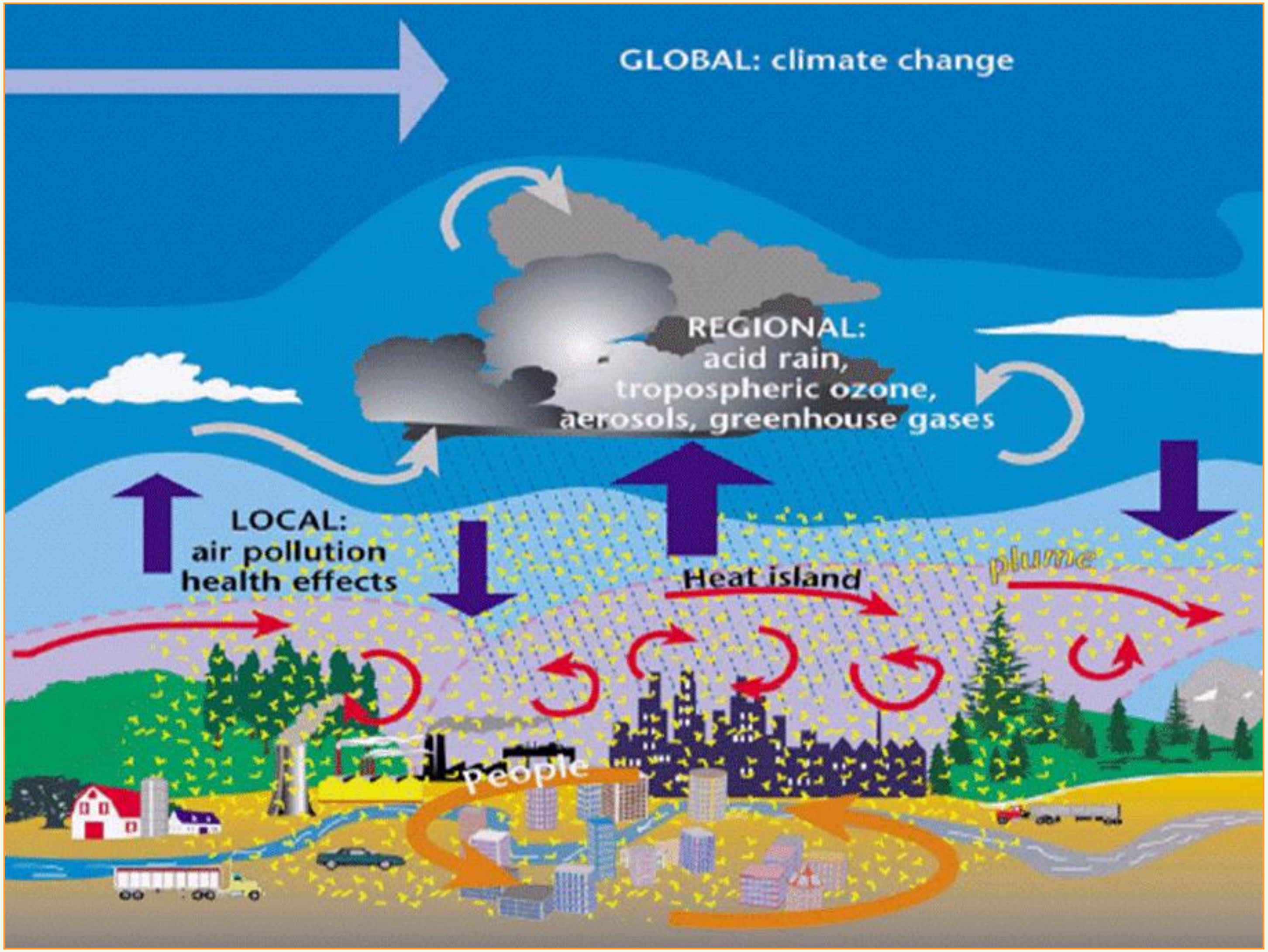
Modeling

air quality

emissions

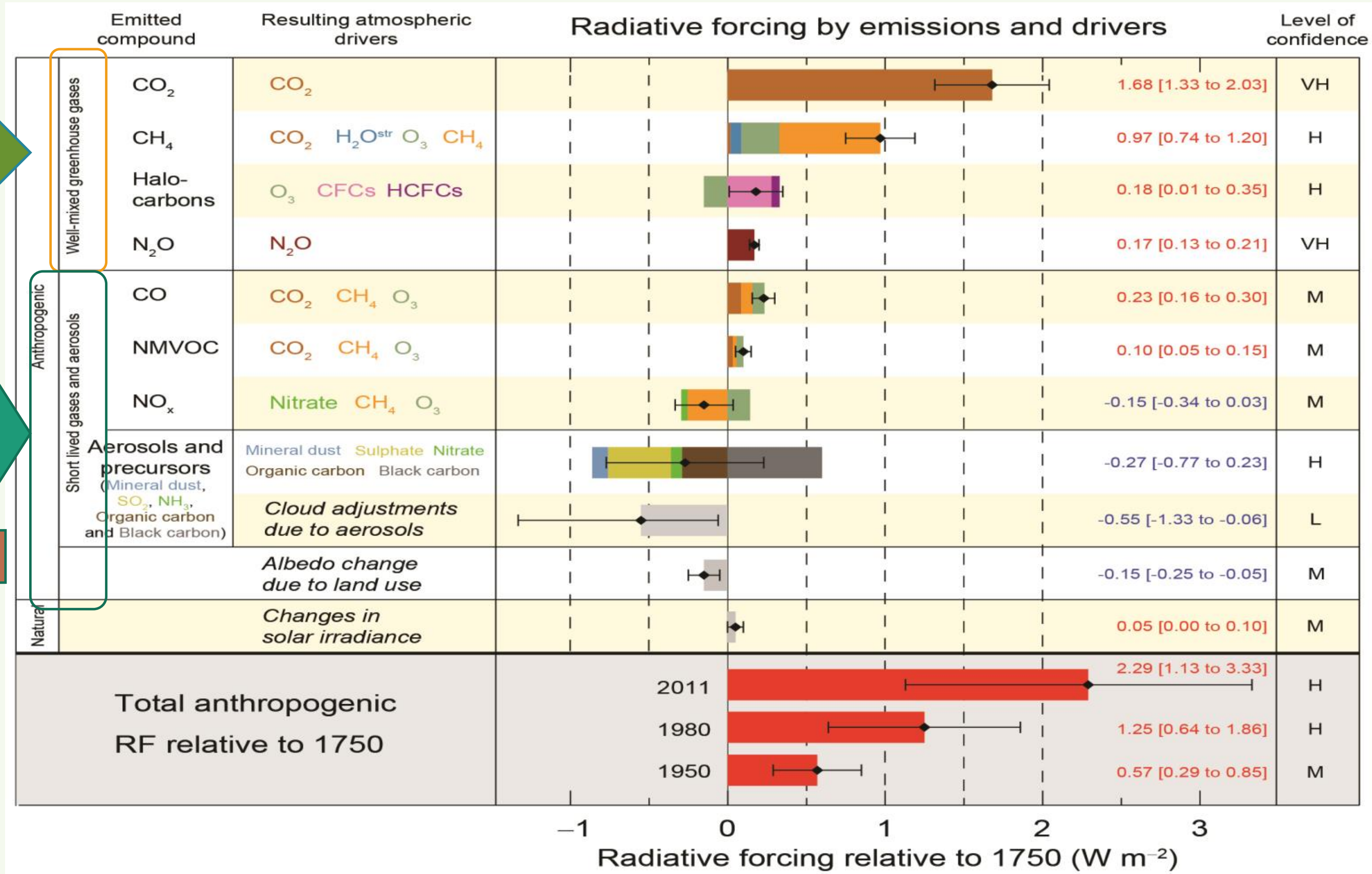
high-resolution

Urban air pollution integrated approach



Source: WMO, GAW program

Long residence time



"short-lived health- and climate relevant air contaminants (SHCC)"

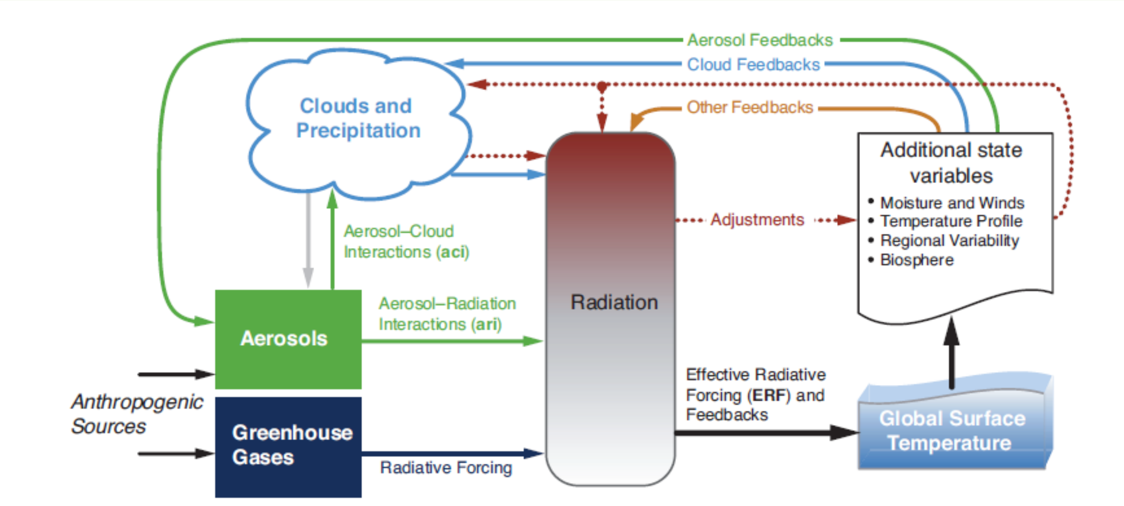
Radiative Forcing – IPCC, AR5

Tackling Short-Lived Climate Pollutants (SLCPs)

- Term SLCP is not as commonly used with local governments . More generic terms: **air pollution / pollutants**
- **SLCPs have short lifetimes, affecting near-term climate**
- Include methane, black carbon, hydrofluorocarbons (HFCs), and tropospheric ozone (black carbon is a component of fine particulate matter – need to monitor PM2.5, PM10)
- Black carbon and tropospheric ozone associated with **adverse health effects**.
- **tackling climate change mitigation and air pollution following an integrated approach** – many actions can benefit both air quality and reducing GHG emissions, benefiting the community.

Why do we care about pollution?

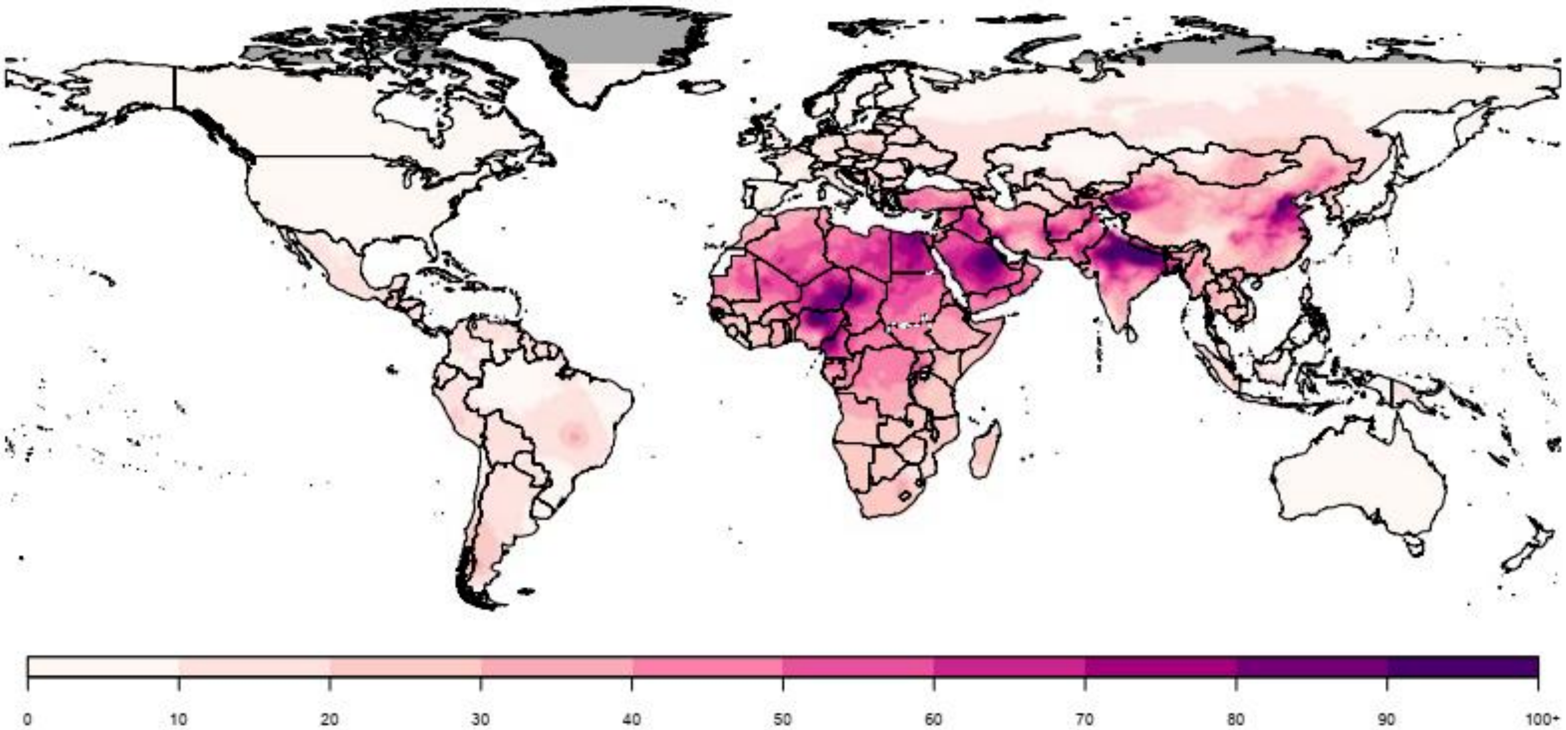
- Health effects
- Climate effects



Overview of forcing and feedback pathways for greenhouse gases, aerosols and clouds

Source: IPCC AR5

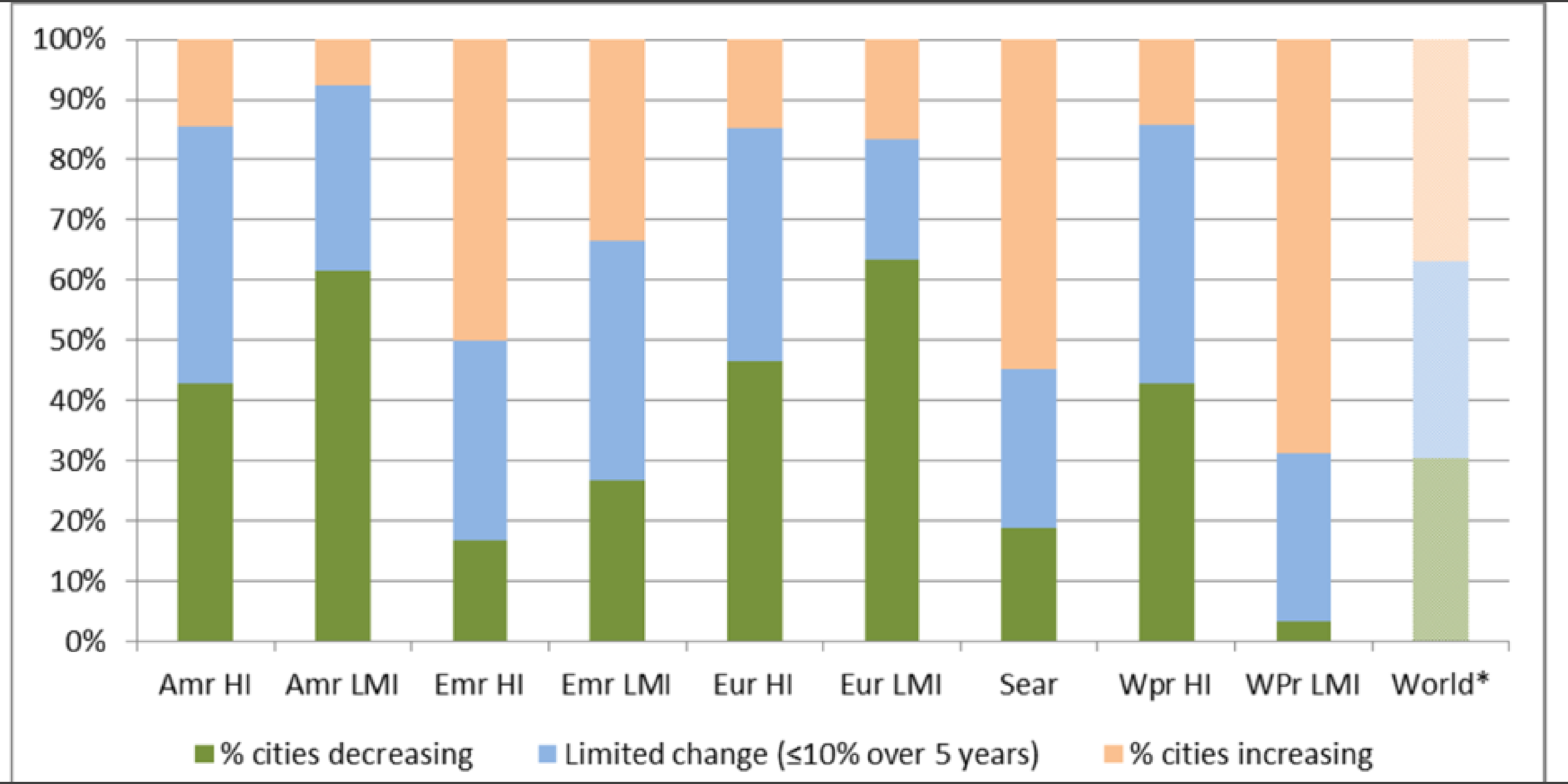
Exposure to ambient particulate matter of a diameter equal or less than 2.5 μm (PM2.5) modelled for the year 2016 in ug/m3



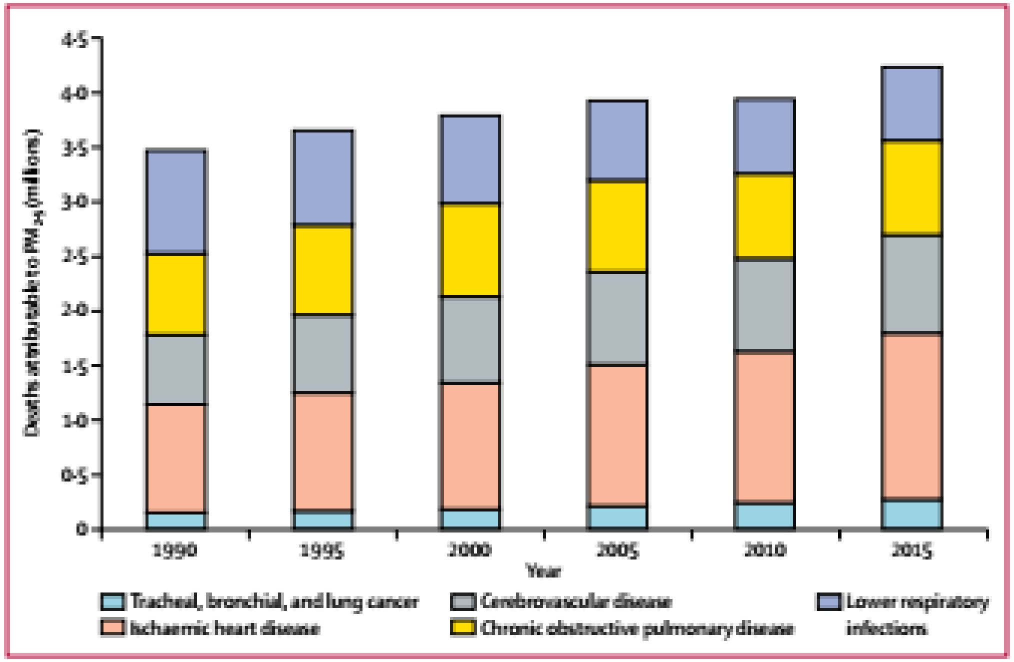
WHO, 2018

Percentage of cities with increasing and decreasing PM2.5 or PM10 annual means, by region

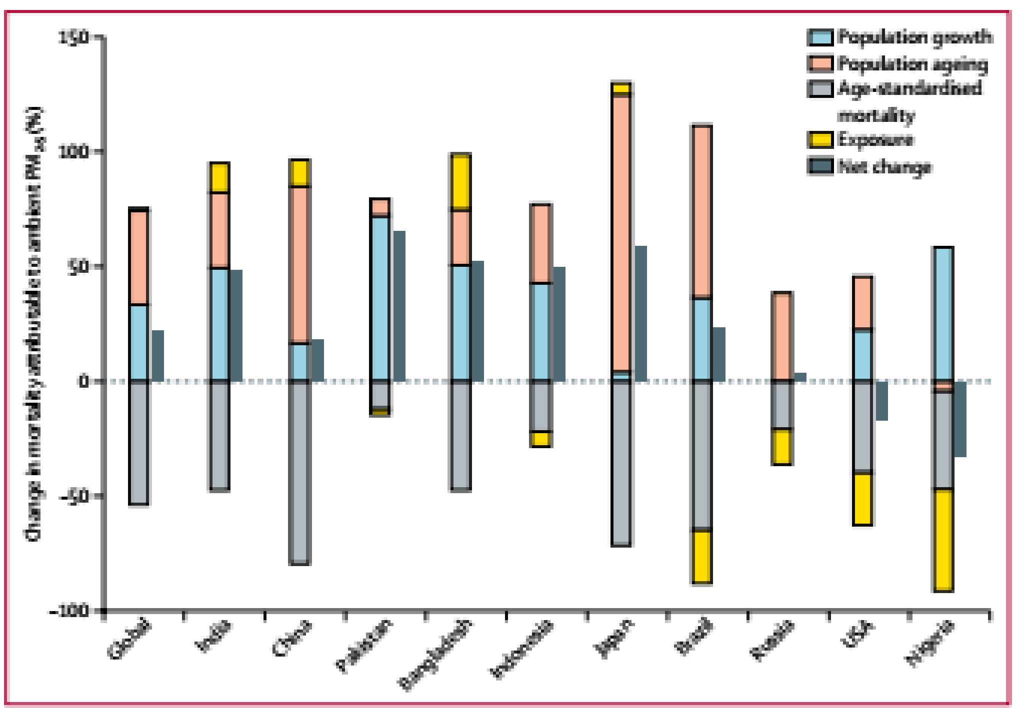
- Amr: America; Emr: Eastern Mediterranean; Eur: Europe; Sear: South-East Asia, Wpr: Western Pacific; LMI: Low- and middle-income; HI: high-income. *The world figure is regional population-weighted.



WHO, 2018



Deaths attributable to ambient PM2.5 by year and cause



Changes in mortality atributable to PM2.5 according to population-level by country from 1990 to 2015

Lancet 2017; 389: 1907–18
http://dx.doi.org/10.1016/S0140-6736(17)30505-6

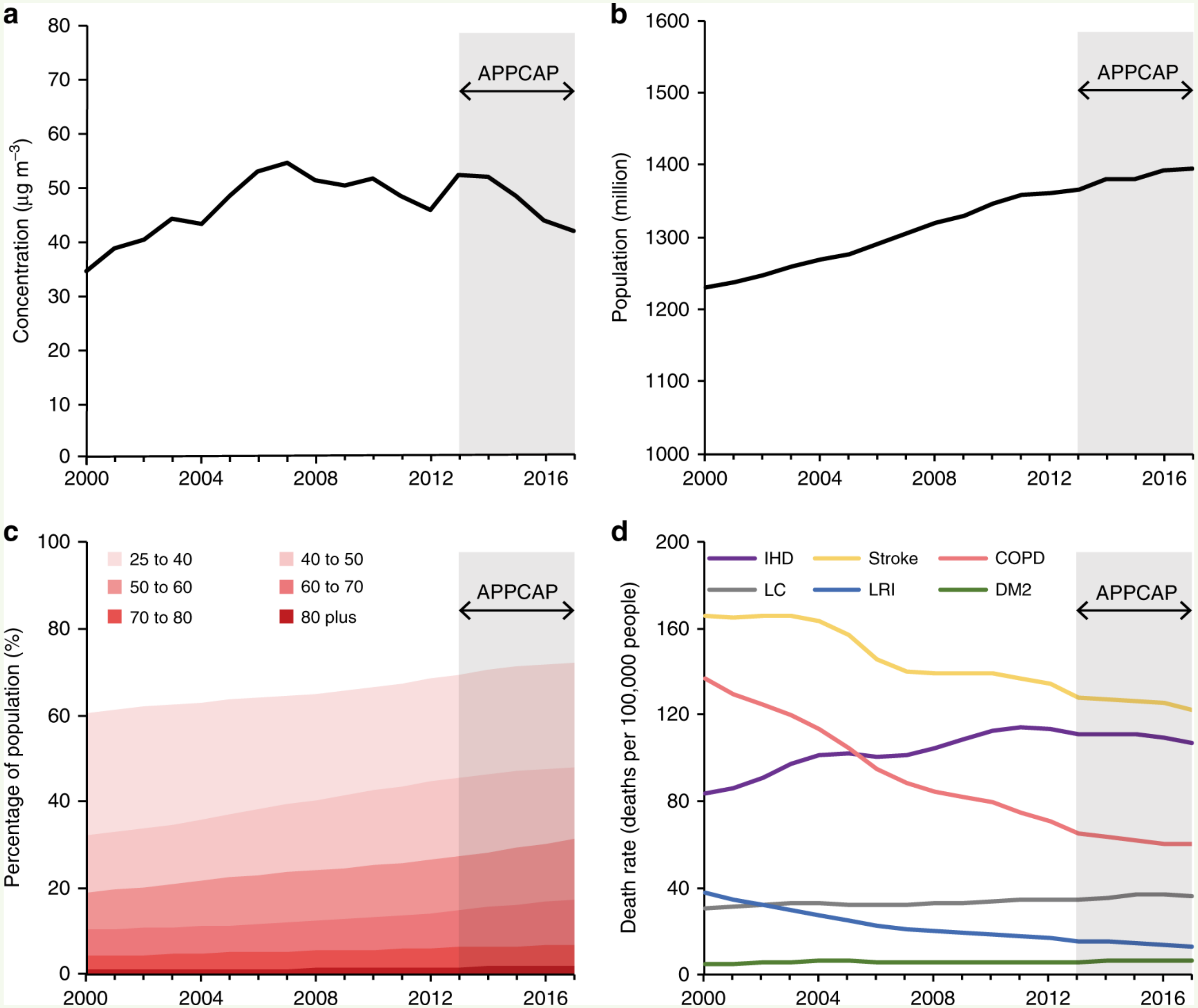
Population weighted annual mean PM2.5 in cities

- Method of calculating the indicator

Population weight annual mean of **PM = SUM {(Pi/P)*Ci}**

where:

Ci = annual mean PM10 or PM2.5 concentration in sub-population Pi,
P = SUM (Pi), which is the total population in cities with data.



a population-weighted $PM_{2.5}$ concentration.

b total population.

c age structure

D age-standardized death rate of diseases.

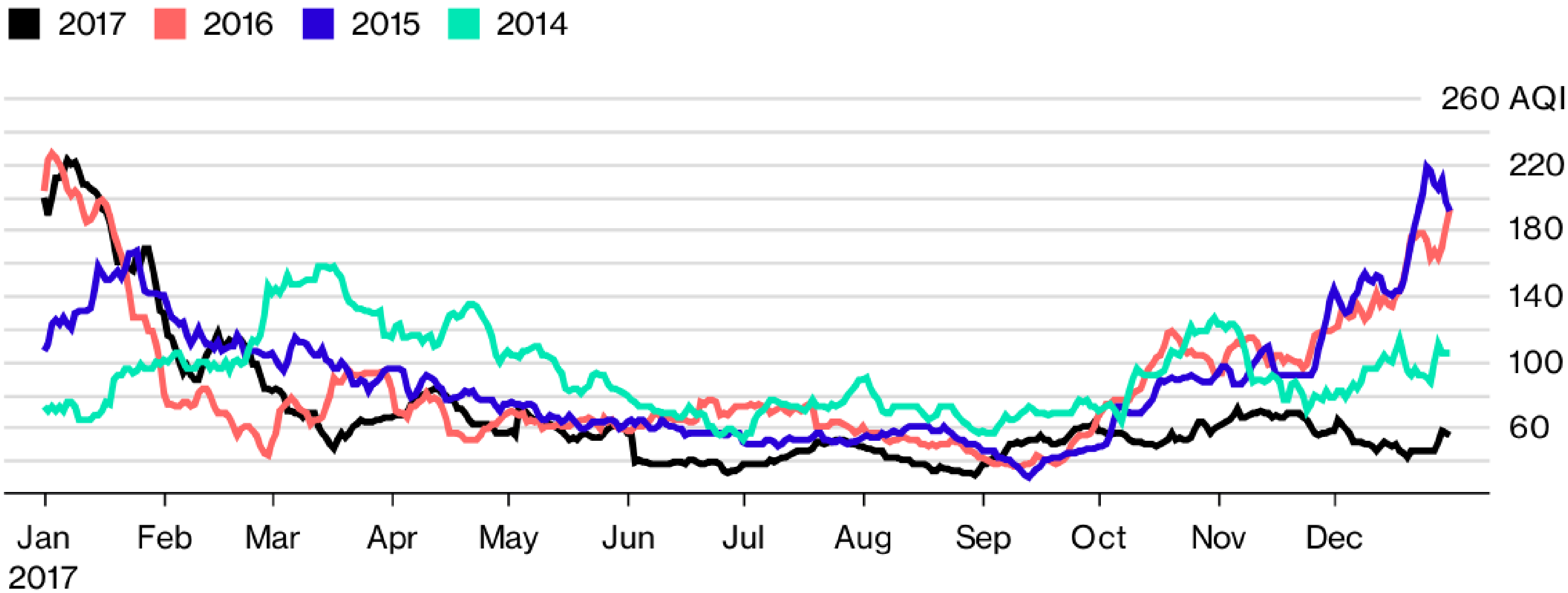
IHD, COPD, LC, LRI, and DM2 refer to ischemic heart disease, chronic obstructive pulmonary disease, lung cancer, lower respiratory infection, and diabetes mellitus type 2,

Air Pollution Prevention and Control Action Plan (**APPCAP**)

Yue, H., He, C., Huang, Q. *et al. Nat Commun* **11,** 1462 (2020).

Bluer Skies in Beijing

Pollution levels in China's capital fell as the government clamped down on coal burning



Note: Chart illustrates 30-day moving average of air pollution levels

Source: China Air Quality Index

Bloomberg

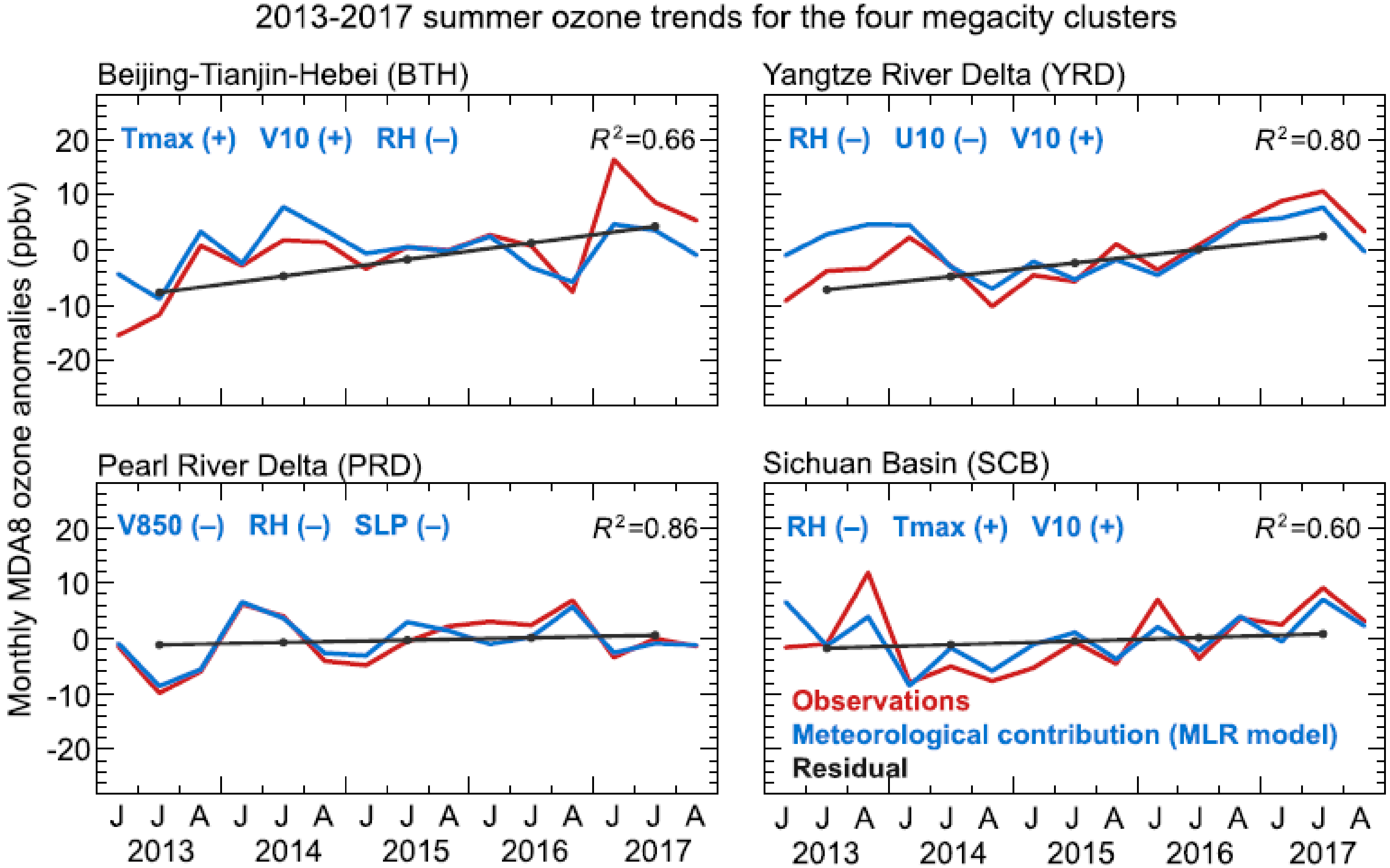


Fig. 2. Time series of monthly mean MDA8 ozone anomalies in summer (JJA) 2013–2017 for the four megacity clusters of Fig. 1: BTH, YRD. PRD, SCB. MDA8 ozone values for individual 0.5° × 0.625° grid cells are averaged over each cluster and month, and anomalies are computed relative to the 2013–2017 means for that month of the year. In each panel, observations (red line) are compared with results from an MLR model driven by meteorological variability (blue line). The linear trend of the 3-mo average residuals for each year is shown in black. The MLR model uses the top three meteorological predictors (Table 1) for each 0.5° × 0.625° grid cell in the cluster, and the results are then averaged for each cluster. The dominant variables in each cluster are indicated in legend with the sign of their correlation to MDA8 ozone. The coefficients of determination (R^2) for the MLR model are shown in the right corner of each plot for the detrended time series (removing the residual linear trend).

Examples of important questions in urban areas

- **Main urban sources of SLCPs**:
  - Fossil fuel powered **transportation**
  - Open biomass burning (**waste**, cooking, etc.)
  - Heating **buildings** - commercial and residential
  - Fossil fuel powered **industries**, including energy plants

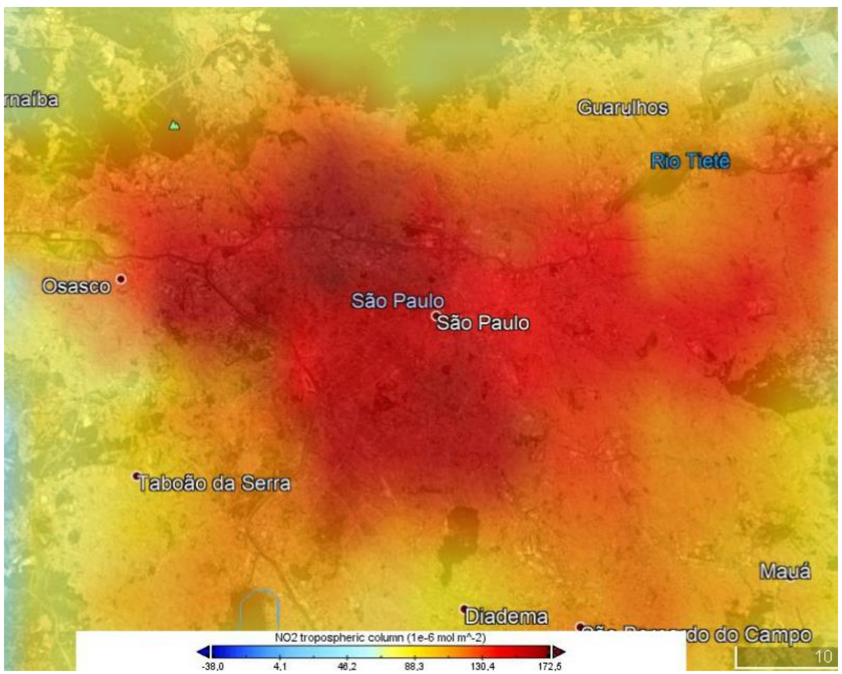
- Location is key, **SLCP pollution varies from city to city**, e.g.:
  - Sao Paulo, Bogota, Medellin & Quito: transport

WHAT CAN WE LEARN FROM THIS PANDEMY

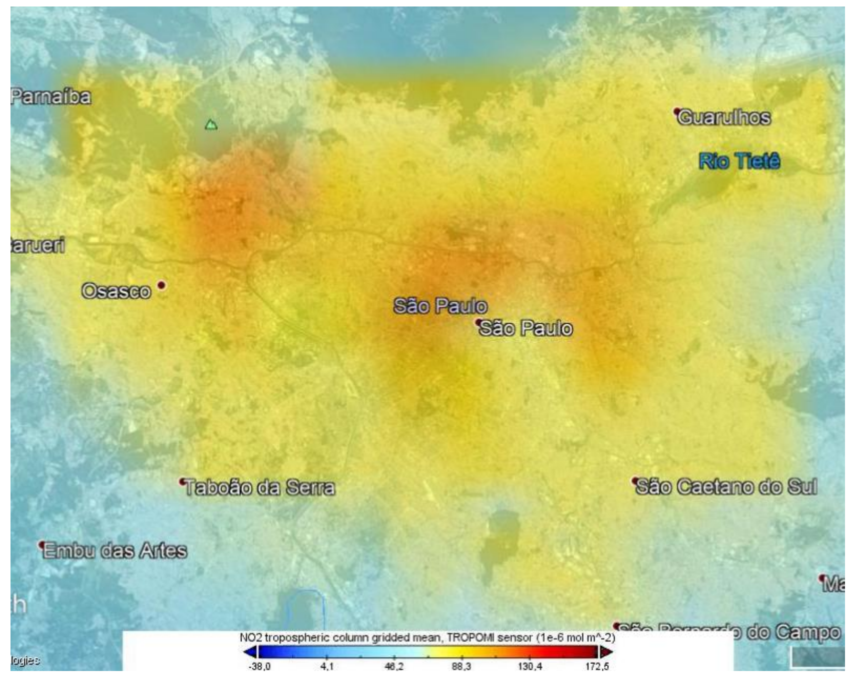
With lockdowns, quarantines and "stay home"

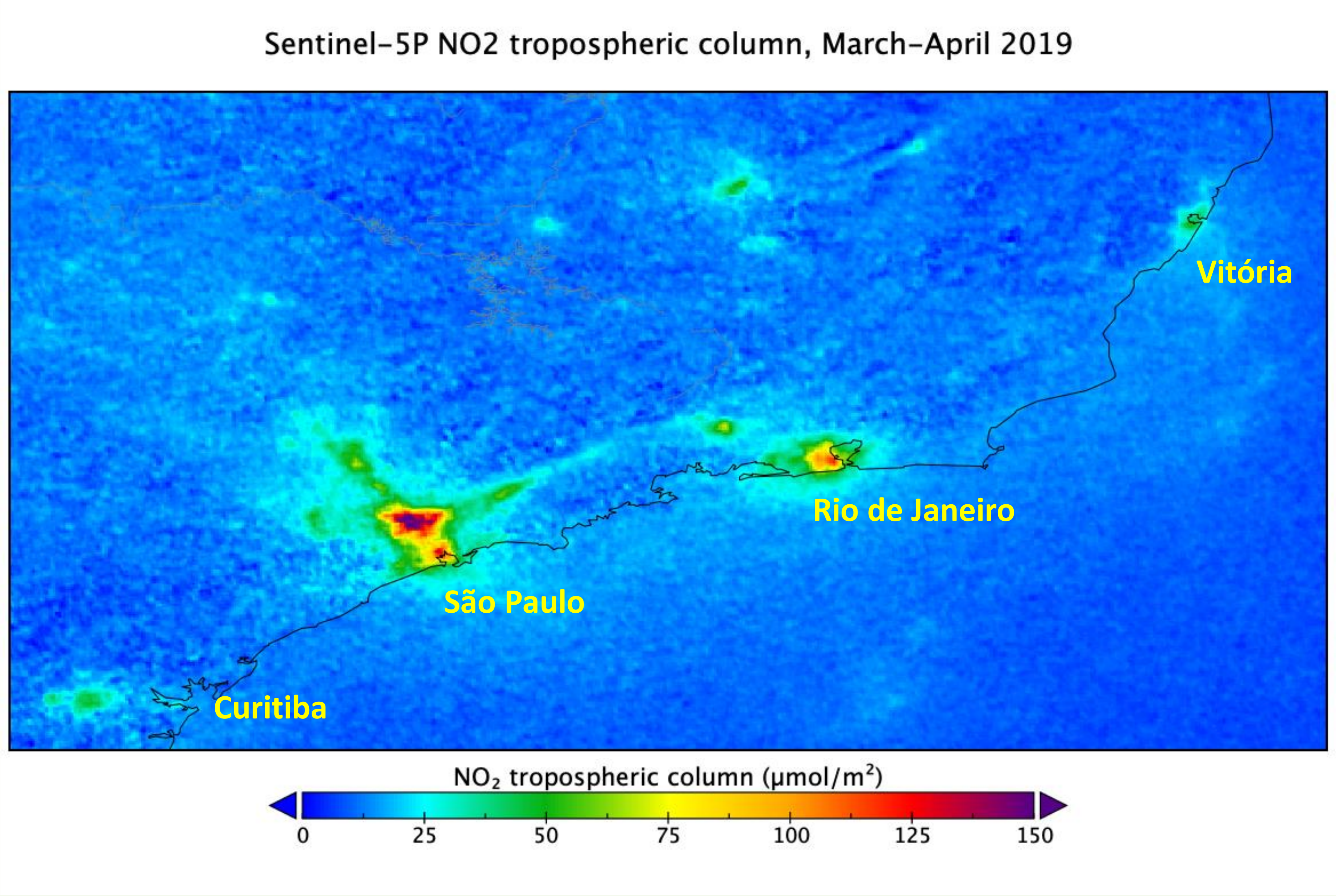
Cities are presenting significative reductions of air pollution

2019 - March

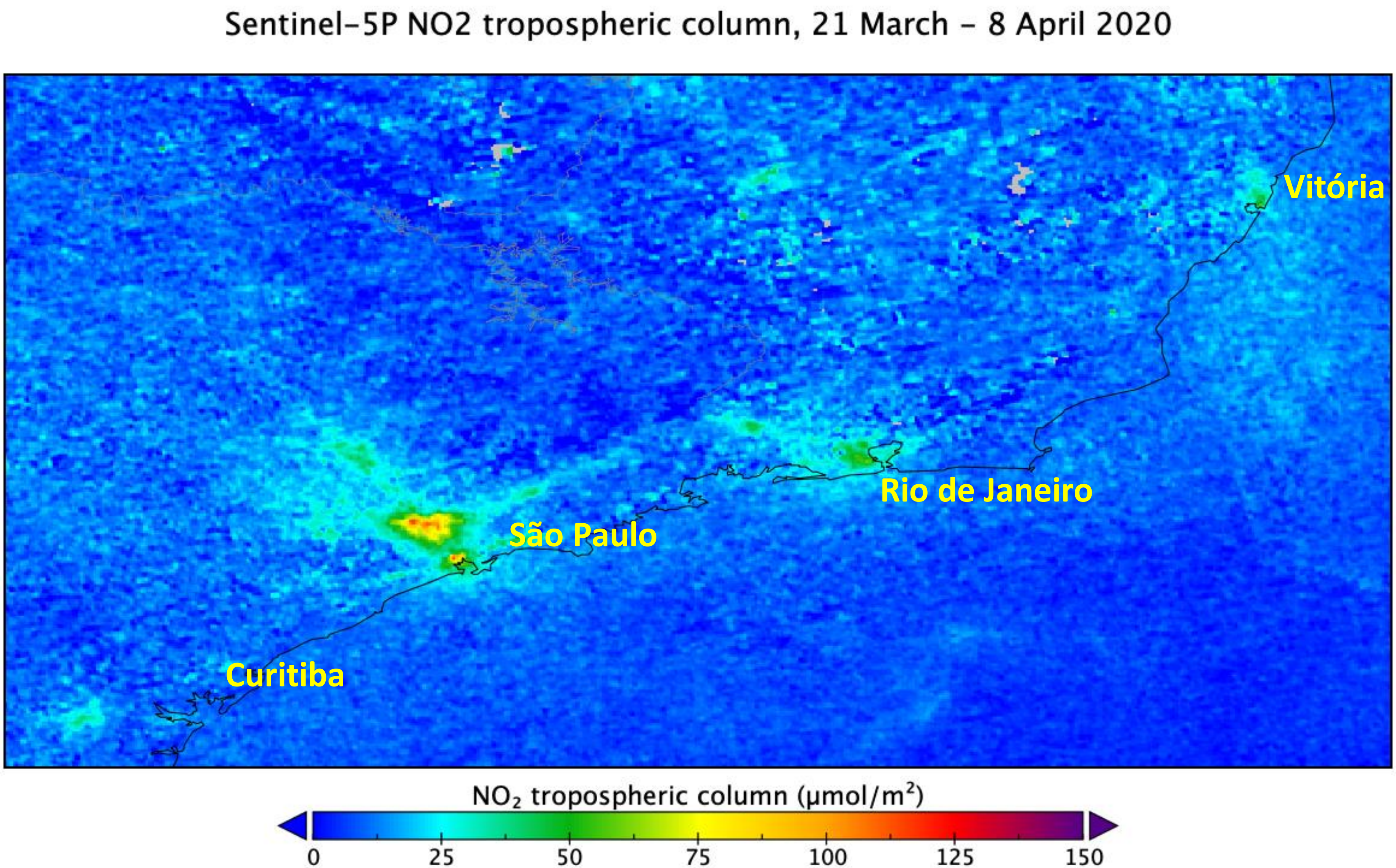


2020 – March 21 – April 8





Sentinel-5P NO2 tropospheric column, March-April 2019
Vitória
Rio de Janeiro
São Paulo
Curitiba
NO₂ tropospheric column (µmol/m²)
0
25
50
75
100
125
150



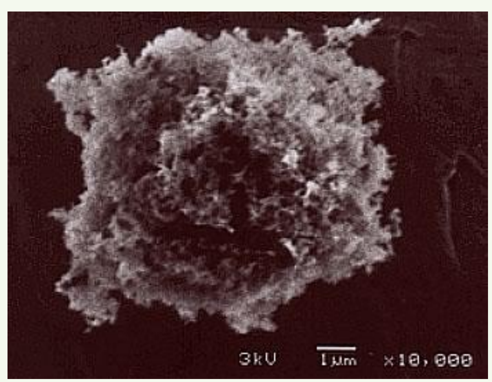
Eskes, Henk – KNMI

Challenges

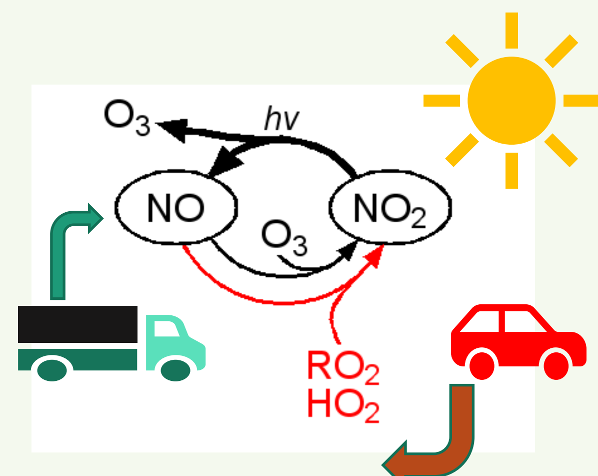
Main Air Pollution Problems

Modelling of the Atmospheric Process

- PM2.5
  - Secondary organic formation
  - Secondary inorganic formation
  - Nano-particles

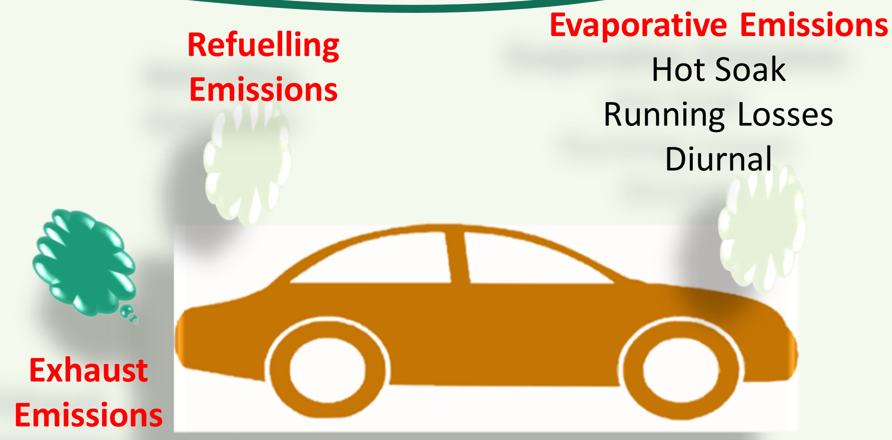


- OZONE
  - Contribution of different fuels
  - Evaporative emissions



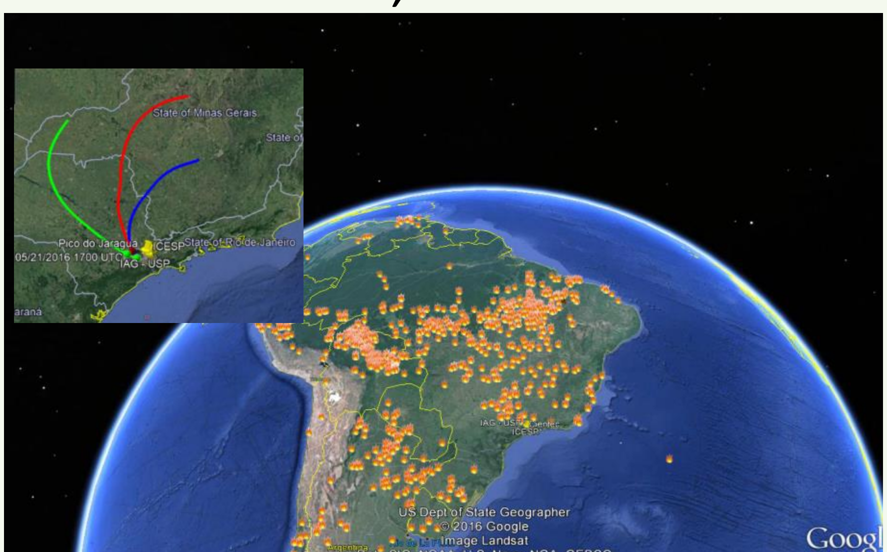
Challenge
Sources not properly accounted

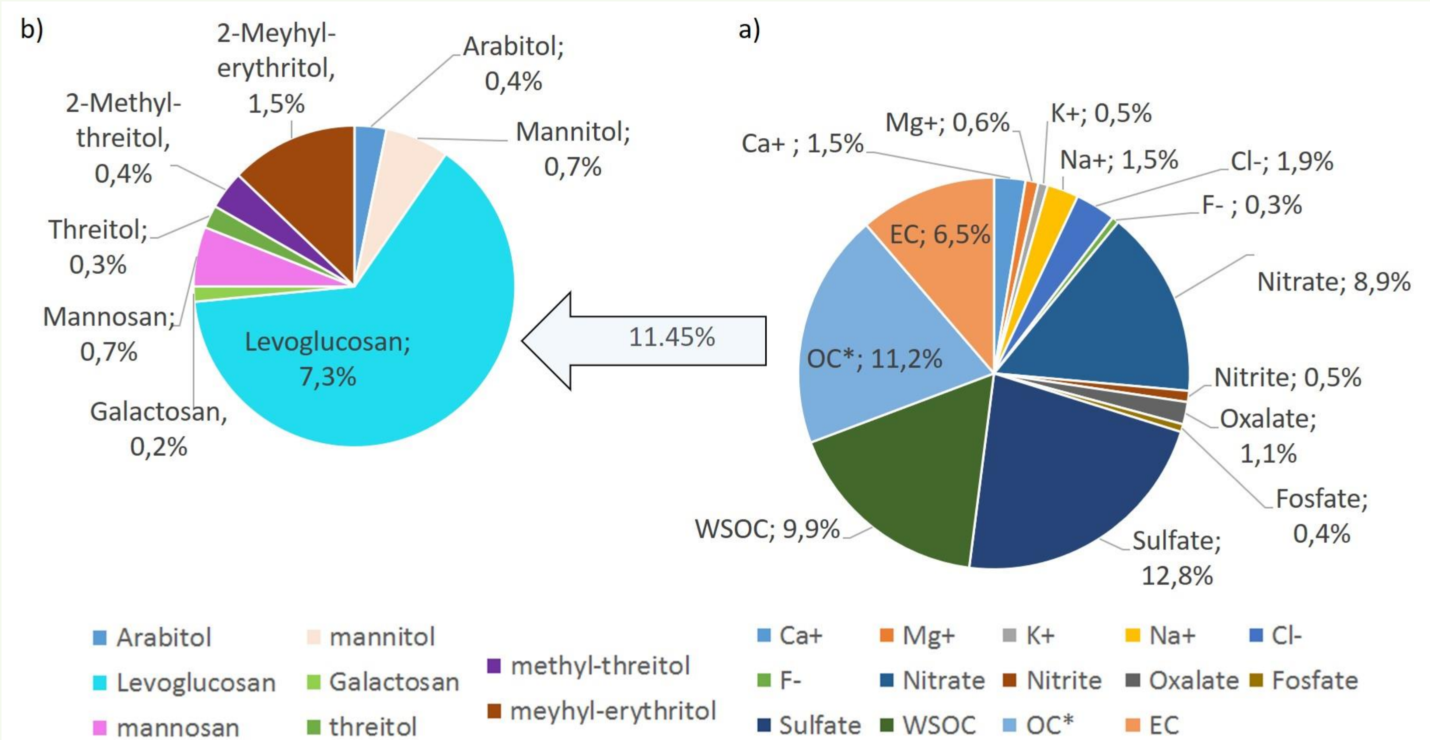
- Evaporative emissions during refuelling
- Solvents: painting and industries
- Biomass burning
  - Vegetation residues
  - Wood, charcoal



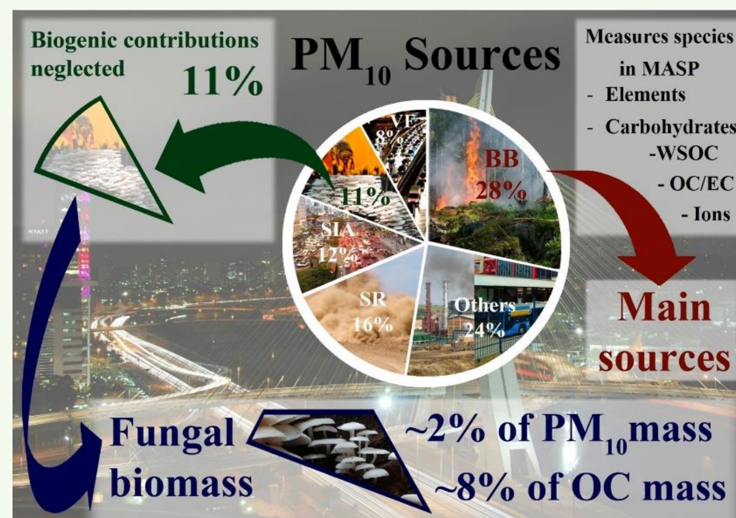
Vehicular Emissions

Combustion (Exhaust system)
Evaporation (Fuel Storage and delivery system)





Contribution (a) ions, WSOC, OC and EC to the PM10, (b) the contribution of each carbohydrate to OC, together accounting for 11.5% of the total OC mass.



Biomarkers as indicators of fungal biomass in the atmosphere of São Paulo, Brasil. Sci. Tota. Envir., 2017

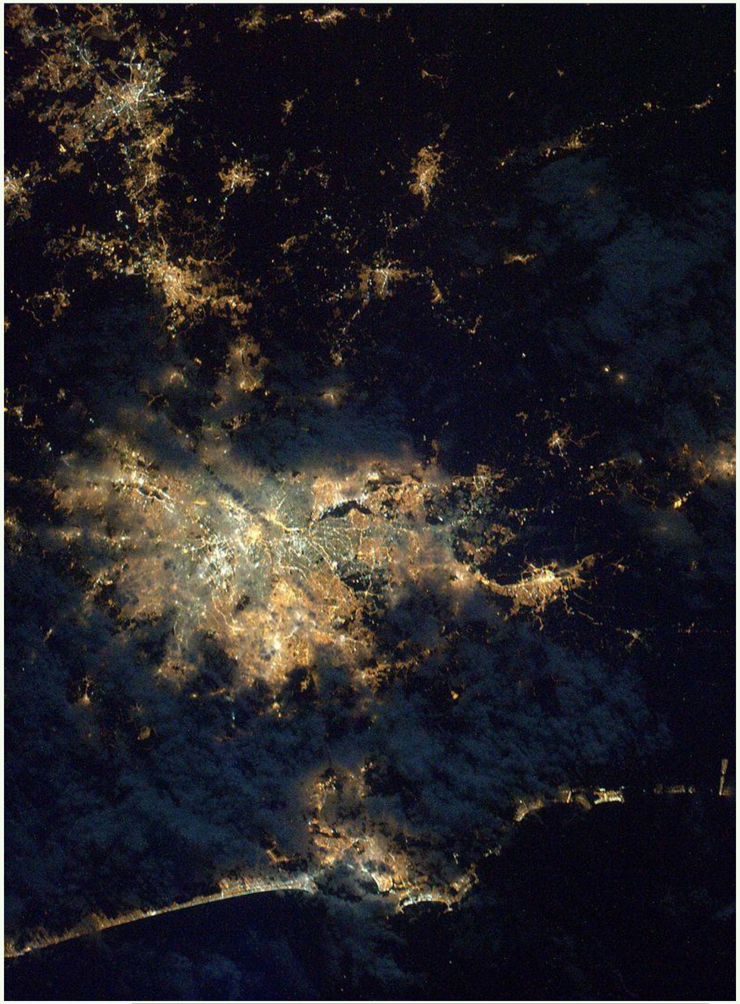
CHALLENGE

Air quality measurements and Modeling

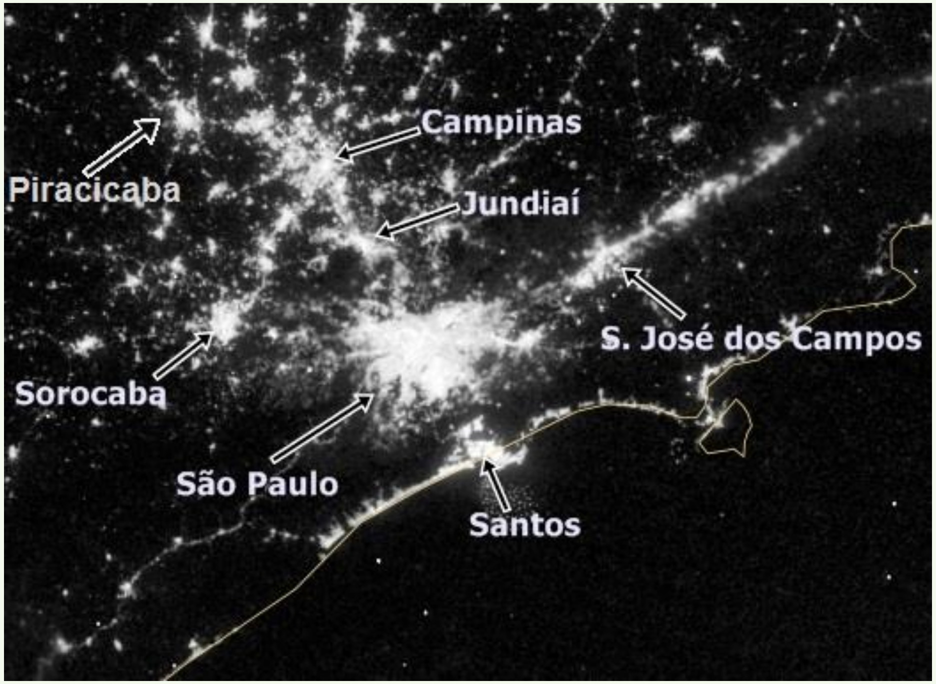
- Middle size cities impacted by the large metropolitan areas (example São Paulo)
- Impact of biofuels: gasohol, biodiesel
- Biomass burning, industrial emissions

São Paulo Macrometropolis

more than 30 million inhabitants



For Regional Modelling



Latin America and the Caribbean Population

- 648,476,231 (in 2017 according to United Nations)

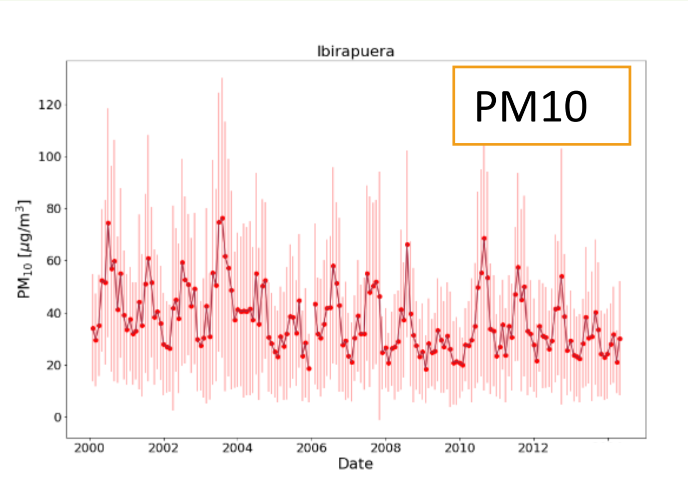
- Latin America and the Caribbean population is equivalent to 8.62% of the total world population.
- The population density in Latin America and the Caribbean is 32 per Km^2 (83 people per mi^2).
- The total land area is 20,158,154 Km^2 (7,783,104 sq. miles)
- 79.7 % of the population is urban (516,362,188 people in 2017)
- The median age in Latin America and the Caribbean is 29.6 years.

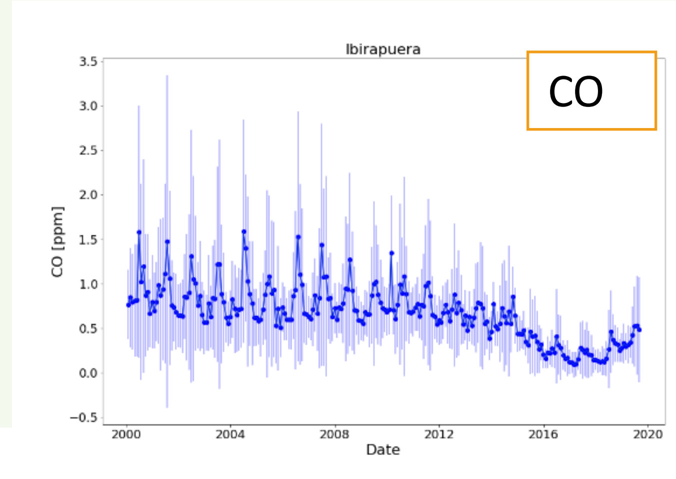
Worldometers (http://www.worldometers.info/world-population/latin-america-and-the-caribbean-population/)

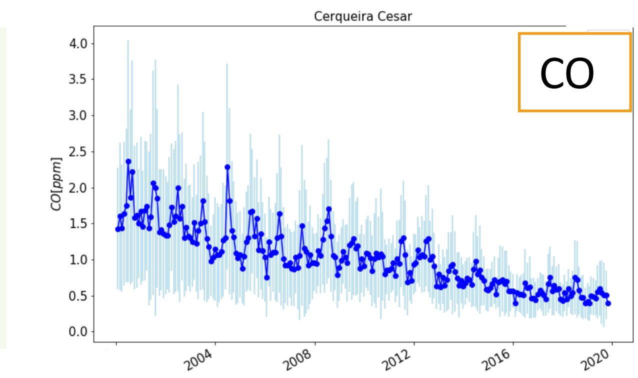
AIR POLLUTION IN NUMBERS
AIR POLLUTION AFFECTS NEARLY ALL OF US
An estimated 6.5 million deaths were associated with air pollution in 2012. This is 11.6% of all global deaths.
CITIES EXCEEDING WHO GUIDELINES FOR SAFE AIR*
60%
Over 60% of the cities and towns in high-income European countries
17%
17% of the cities and towns in North America
90%
Over 90% of cities and towns in low- and middle-income countries of Europe, Latin America, Asia and the Middle East
35%
Over 35% of the cities and towns in high-income Asian countries
*From the 3,000 cities and towns that are monitoring and reporting air pollution levels
DISEASE BURDEN CAUSED BY AIR POLLUTION
36%
of all lung cancer deaths
35%
of COPD (Pulmonary disease) deaths
34%
of stroke deaths
27%
of heart disease deaths
90%
90% of people living in cities do not breathe safe air
8%
Air pollution levels have risen 8% globally from 2008-2013
30%
Almost 1/3 of cities monitoring air pollution have reduced air pollution levels by 5% in the last 5 years
50%
Almost half of cities monitoring air pollution in high-income countries reduced air pollution levels by 5% in 2008-2013.

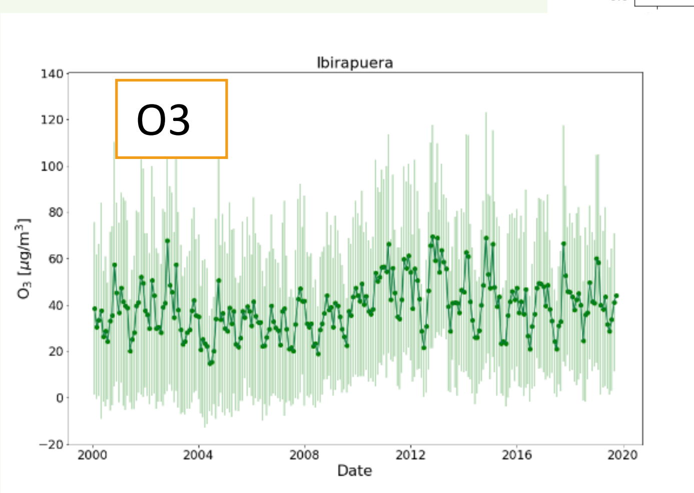
AIR POLLUTION REDUCTIONS
People in The Americas are breathing cleaner air than 5 years ago
60%
About 60% of urban residents in low- and middle-income countries in the Region of the Americas are breathing cleaner air than they did 5 years ago, about the same progress seen in high-income countries in the Region of the Americas.
EATHELIFE
ir. Healthy future.
World Health Organization
CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

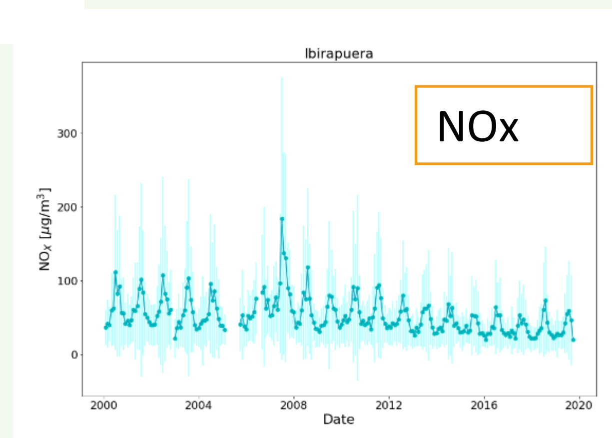
Pollutants concentration in MASP







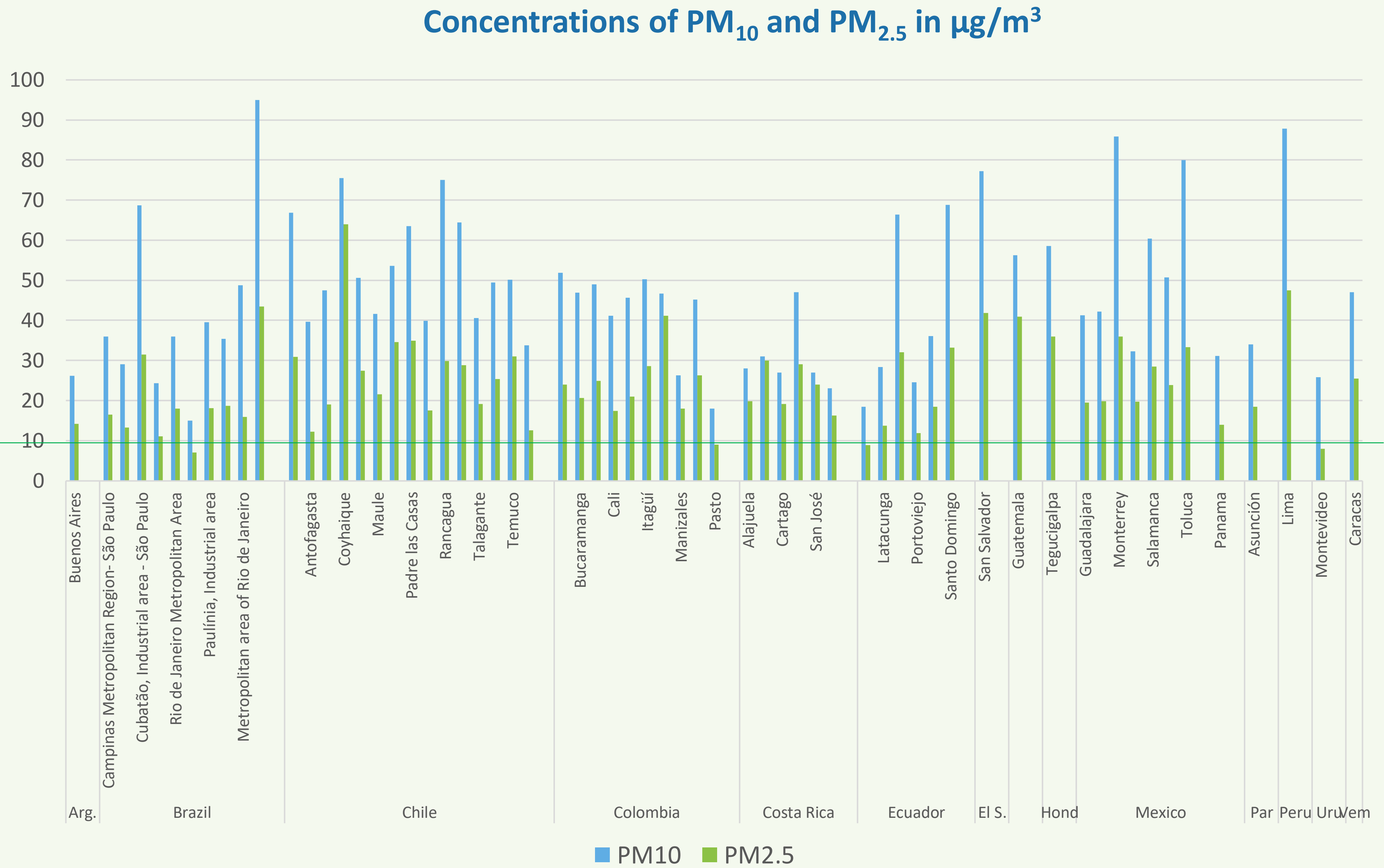




Prepared by the authors from the study data.

Distribution of Air Quality Monitoring Stations among cities in Latin America and Caribbean

Riojas-Rodriguez et al., 2016. Rev. Panm Salud Publica 40(3)

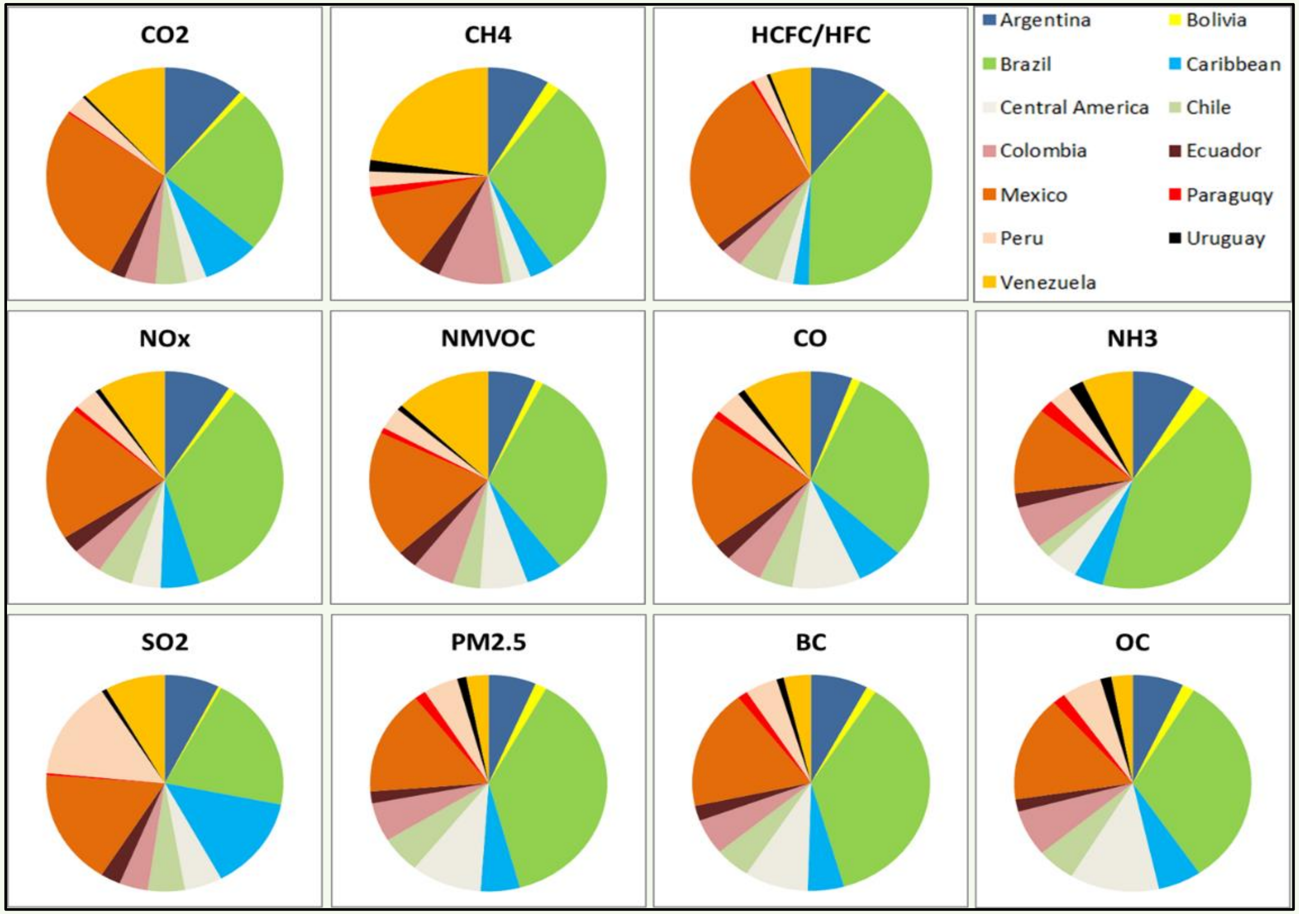


Concentrations of PM_{10} and $PM_{2.5}$ in µg/m³
100
90
80
70
60
50
40
30
20
10
0
Buenos Aires
Campinas Metropolitan Region- São Paulo
Cubatão, Industrial area - São Paulo
Rio de Janeiro Metropolitan Area
Paulínia, Industrial area
Metropolitan area of Rio de Janeiro
Antofagasta
Coyhaique
Maule
Padre las Casas
Rancagua
Talagante
Temuco
Bucaramanga
Cali
Itagüí
Manizales
Pasto
Alajuela
Cartago
San José
Latacunga
Portoviejo
Santo Domingo
San Salvador
Guatemala
Tegucigalpa
Guadalajara
Monterrey
Salamanca
Toluca
Panama
Asunción
Lima
Montevideo
Caracas
Arg.
Brazil
Chile
Colombia
Costa Rica
Ecuador
El S.
Hond
Mexico
Par
Peru
Uru
Vem
PM10
PM2.5

Emissions and impacts of SLCP in LAC

Integrated Assessment of Short-Lived Climate Pollutants in Latin America and the Caribbean

Sectoral distributions of emissions of key air pollutants and methane in LAC in 2010



THIS DOES NOT INCLUDE FOREST AND OTHER VEGETATION FIRES

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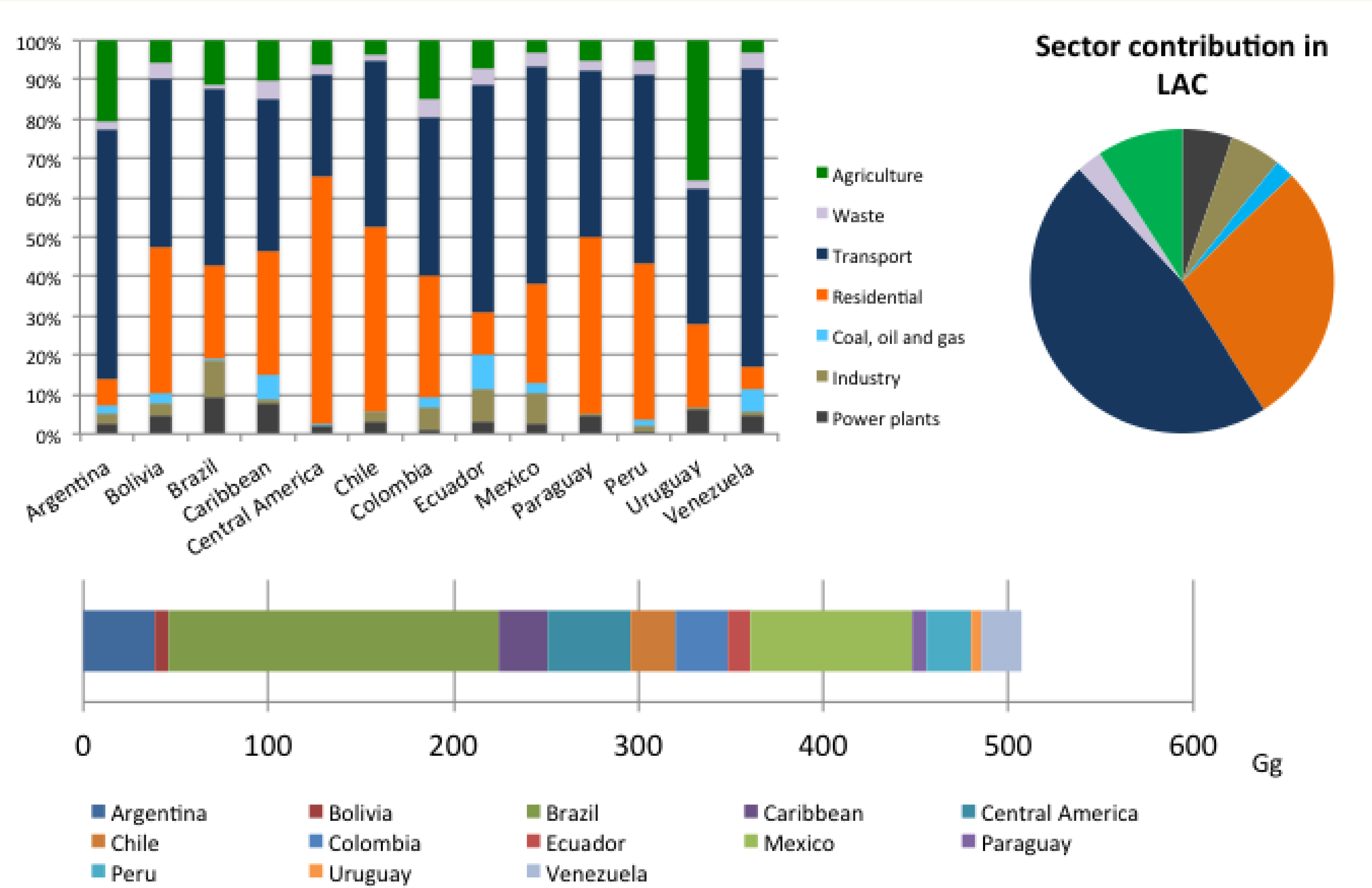
Sectoral and regional contribution to black carbon emissions in the LAC region in 2010



Based on the reference scenario, the influence of LAC emissions on climate, human health and agriculture will increase significantly by 2050

Future scenarios

PM2.5

- Premature mortality from exposure to PM2.5 pollution is expected to almost double by 2050, compared to 2010
- (from 47000 in 2010 to 62000 in 2030).

Ozone

- Premature mortality from exposure to ambient O3 doubles between 2010 and 2050 under the reference scenario.
- (from 5000 premature deaths in 2010 to 7000 by 2030 and 10000 by 2050).
- Lost in productivity for major crops- soybean, wheat, maize and rice. Crop losses of approximately 7.4 million tonnes in 2010.

UNEP

CLIMATE & CLEAN AIR COALITION TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

Measures to improve air quality and climate

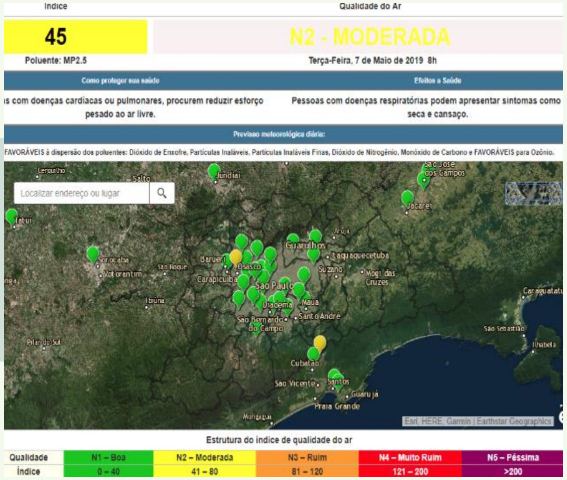
- Euro VI standards including diesel particle filters (DPF)
- Clean cooking and heating stoves
- Modernized coke ovens
- Controls in biomass and waste combustion

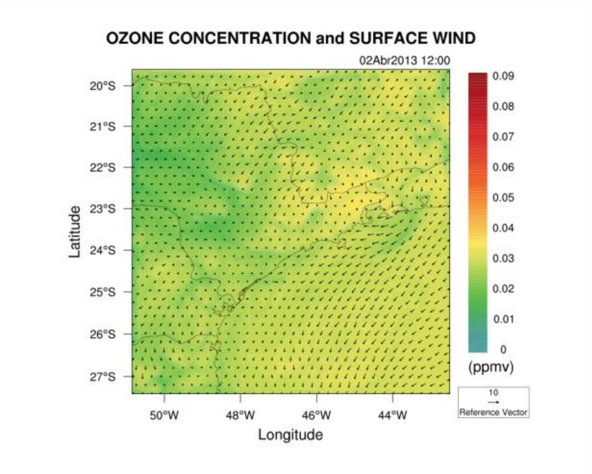
* Monitoring of pollutants concentrations
* Air quality modeling
* Emissions inventories

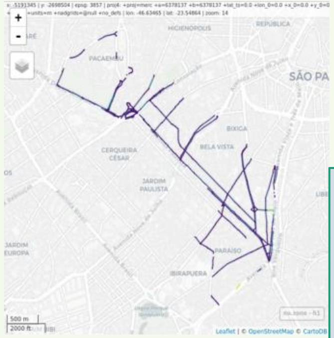
Low-cost/portable sensors

Reference stations

Emission + air quality Models



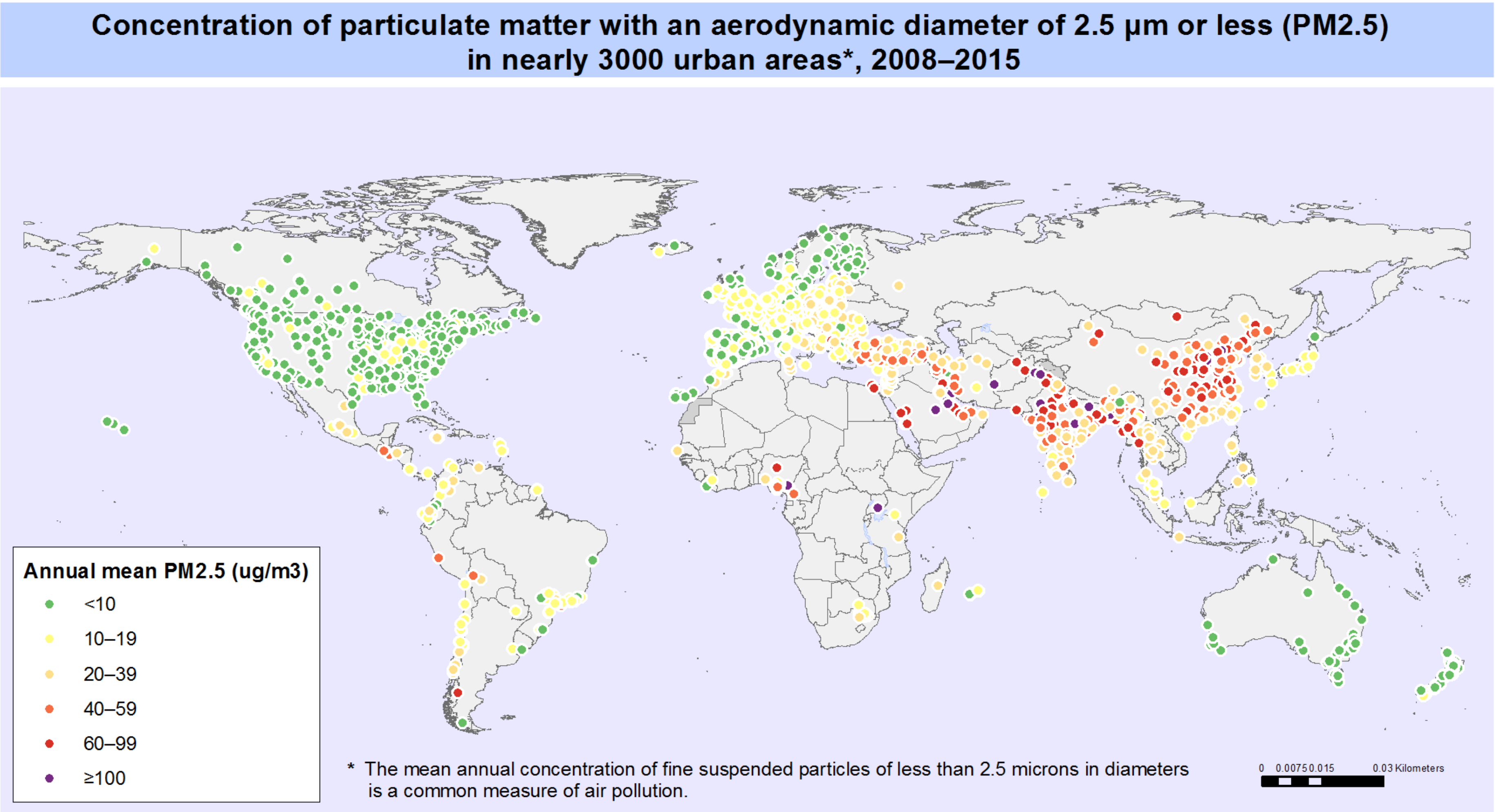




Examples of methods to study air pollution in cities

Street In-grid model

IMPORTANCE OF MONITORING



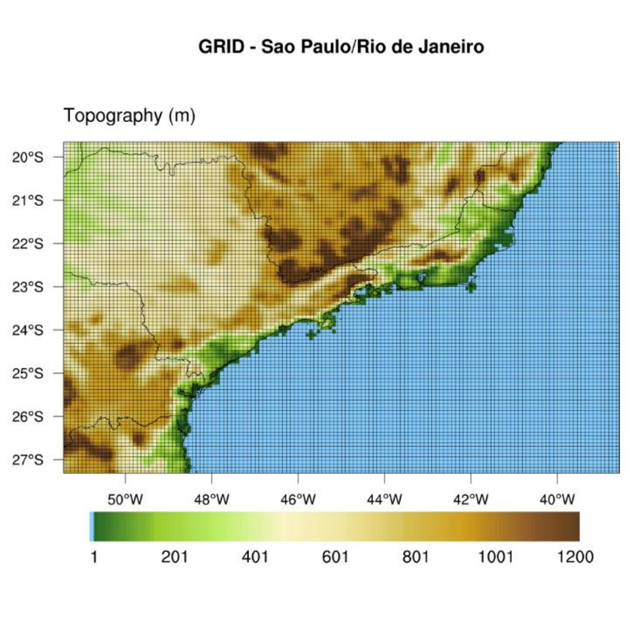
The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted and dashed lines on maps represent approximate border lines for which there may not yet be full agreement.

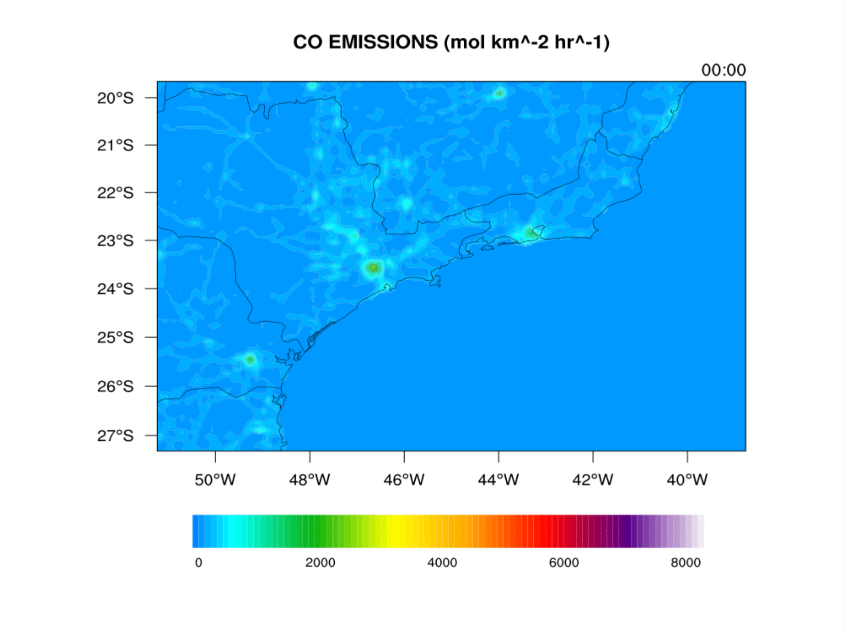
Data Source: World Health Organization
Map Production: Information Evidence and Research (IER)
World Health Organization

World Health Organization

Modelling air quality

- Formation of fine particles and radiative and microphysics process
- Impact of biofuels use in the formation of ozone and new phases of the PROCONVE program
- Transport of pollutants from São Paulo to other areas





Vehicular Emissions INventory (VEIN)

https://CRAN.R-project.org/package=vein

Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2017-193
Manuscript under review for journal Geosci. Model Dev.
Discussion started: 25 September 2017

Geoscientific Model Development
Open Access
EGU

Accepted

VEIN v0.2.2: an R package for bottom-up Vehicular Emissions Inventories

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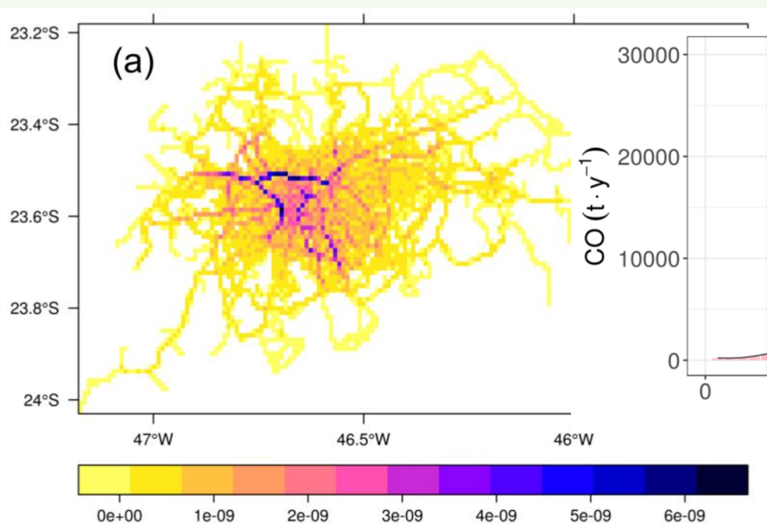
vein: Vehicular Emissions Inventories

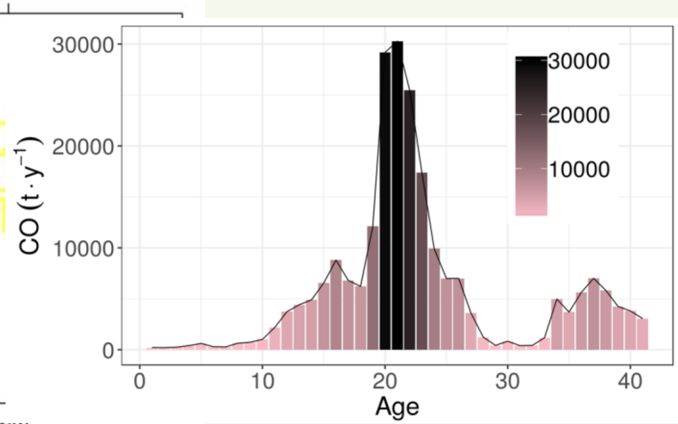
Elaboration of vehicular emissions inventories, consisting in four stages, pre-processing activity data, preparing emissions factors, estimating the emissions and post-processing of emissions in maps and databases.

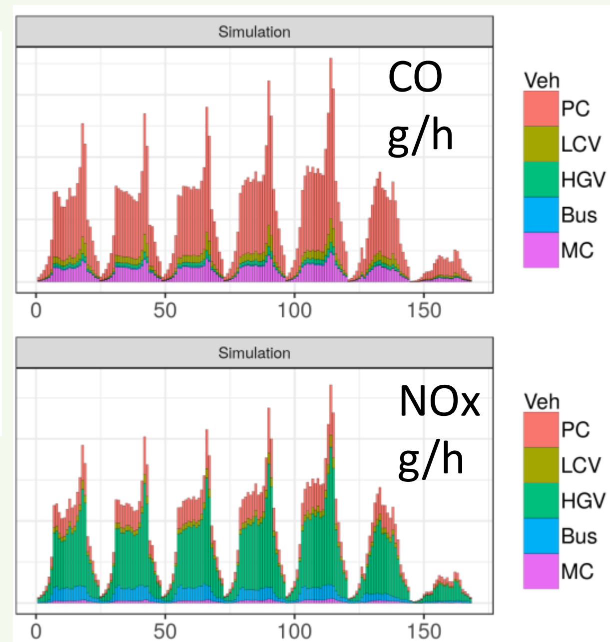
Version:	0.3.9
Depends:	R (≥ 2.10)
Imports:	sf, sp, data.table, graphics, stats, units, methods
Suggests:	knitr, rmarkdown, testthat, covr
Published:	2018-03-01
Author:	Sergio Ibarra-Espinosa [aut, cre]
Maintainer:	Sergio Ibarra-Espinosa <sergio.ibarra at usp.br>
BugReports:	https://github.com/atmoschem/vein/issues/
License:	MIT + file LICENSE
URL:	https://github.com/atmoschem/vein
NeedsCompilation:	no
Citation:	vein citation info
Materials:	NEWS
CRAN checks:	vein results

Downloads:

Reference manual:	vein.pdf
Package source:	vein_0.3.9.tar.gz
Windows binaries:	r-prerel: vein_0.3.9.zip, r-release: vein_0.3.9.zip, r-oldrel: vein_0.3.9.zip
OS X binaries:	r-prerel: vein_0.3.9.tgz, r-release: vein_0.3.9.tgz
Old sources:	vein archive







https://www.geosci-model-dev-discuss.net/gmd-2017-193/

Impact of ethanol/ gasohol on ozone formation

Scenarios for LDV

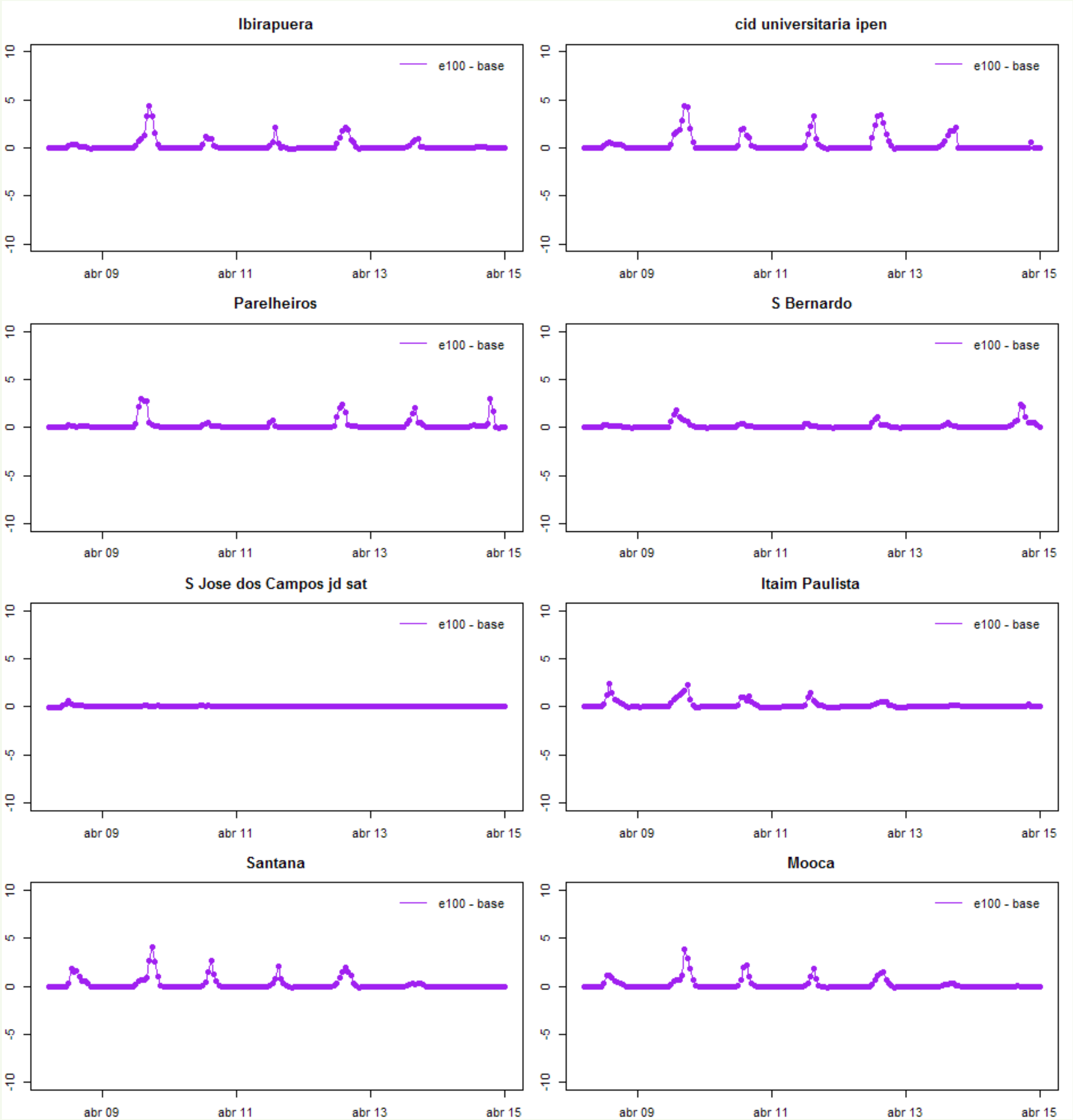
Gasohol and ethanol fleet

1- All the FLEX Fuel vehicles running with gasohol

2- All the Flex Fuel vehicles running with ethanol

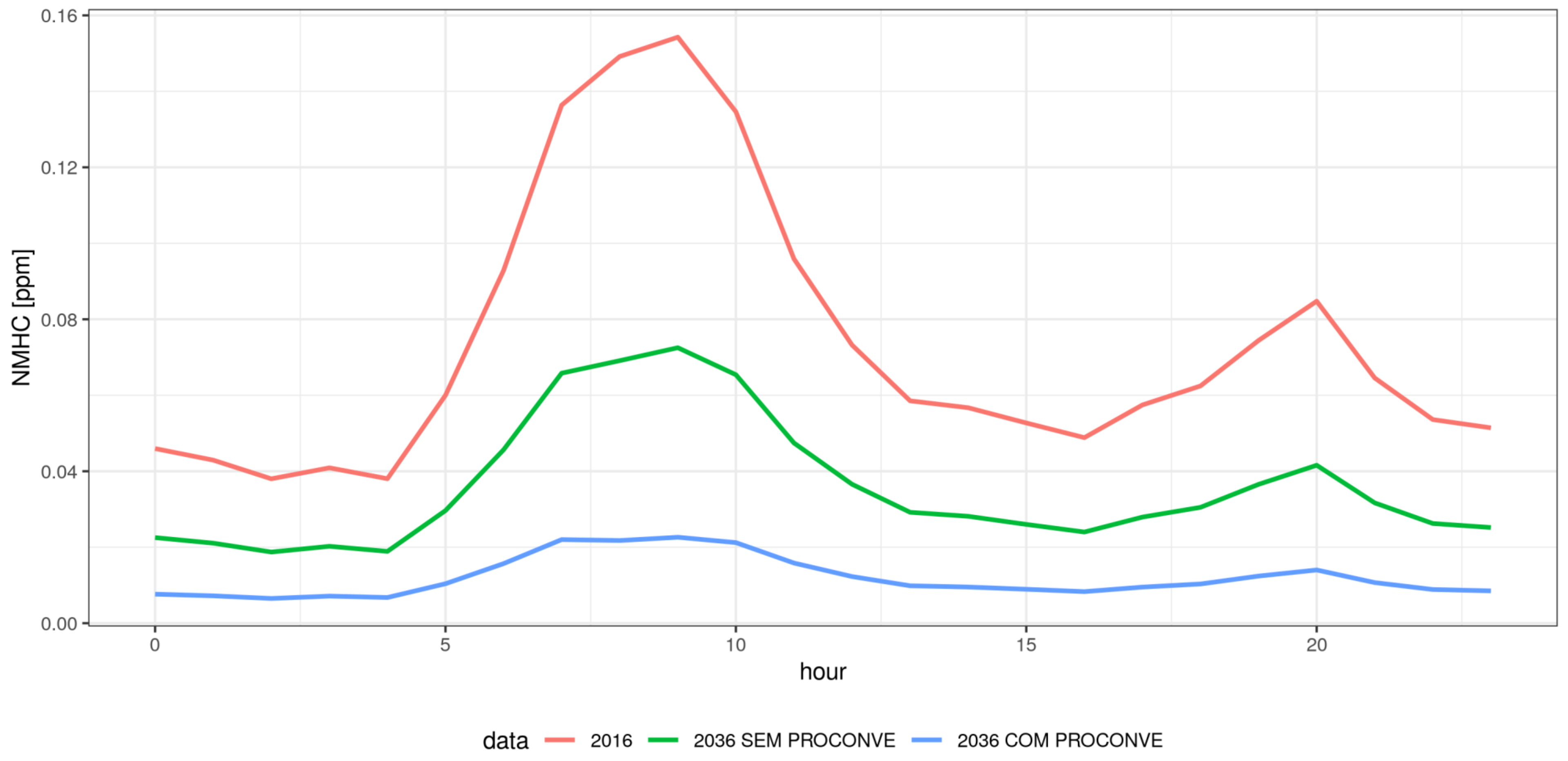
Impact of using Ethanol or Gasohol

Ozone Concentrations



SIMULATIONS OF IMPLEMENTATION OF PROCONVE NEW PHASES

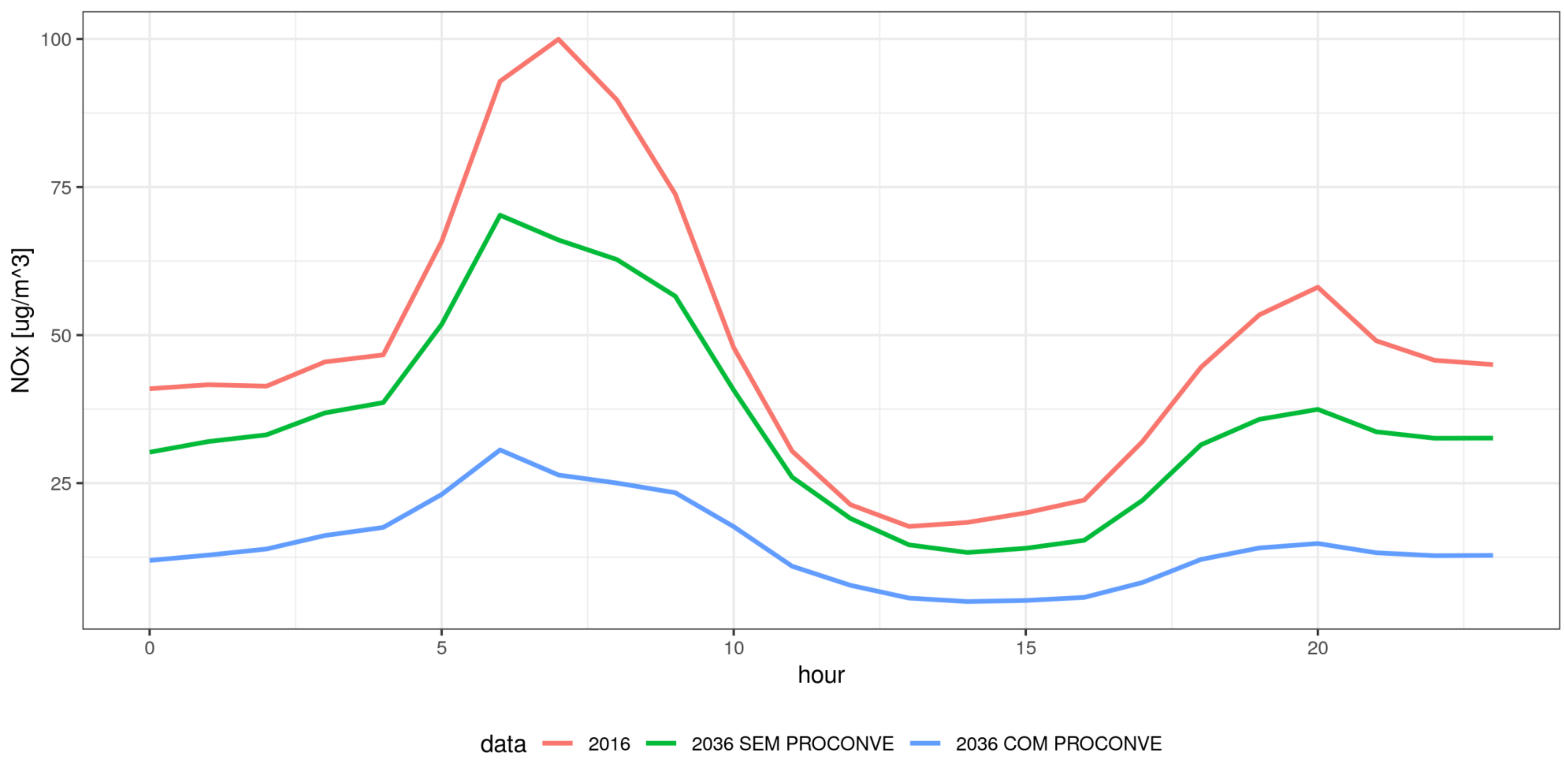
NMHC (ppm) = ETH + HC3 + HC5 + HC8 + HCHO + ALD + ISSO + KET



Simulations by Sergio Ibarra

SIMULATIONS OF IMPLEMENTATION OF PROCONVE NEW PHASES

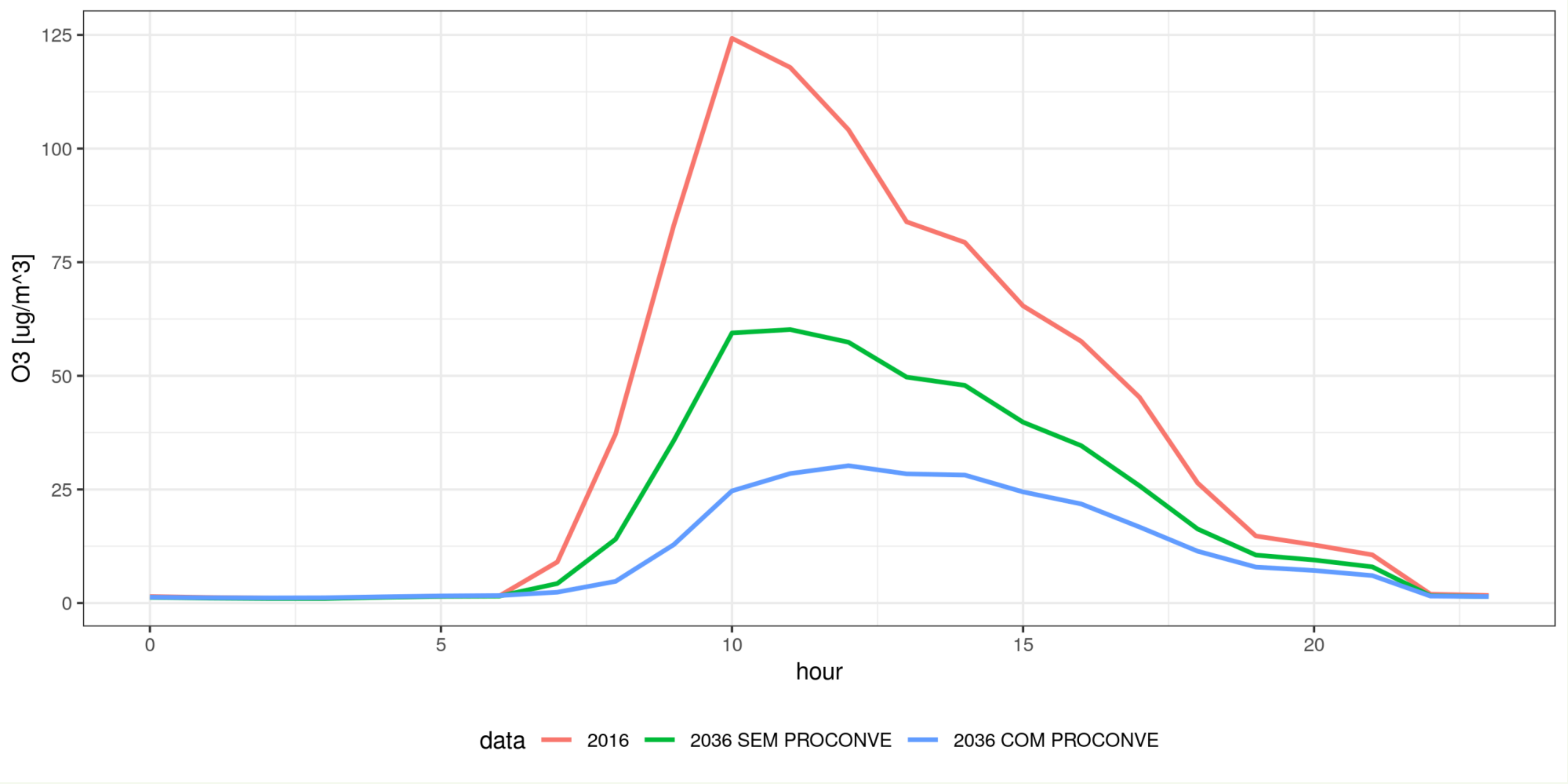
NOx ($\mu g/m^3$)



Simulations by Sergio Ibarra

SIMULATIONS OF IMPLEMENTATION OF PROCONVE NEW PHASES

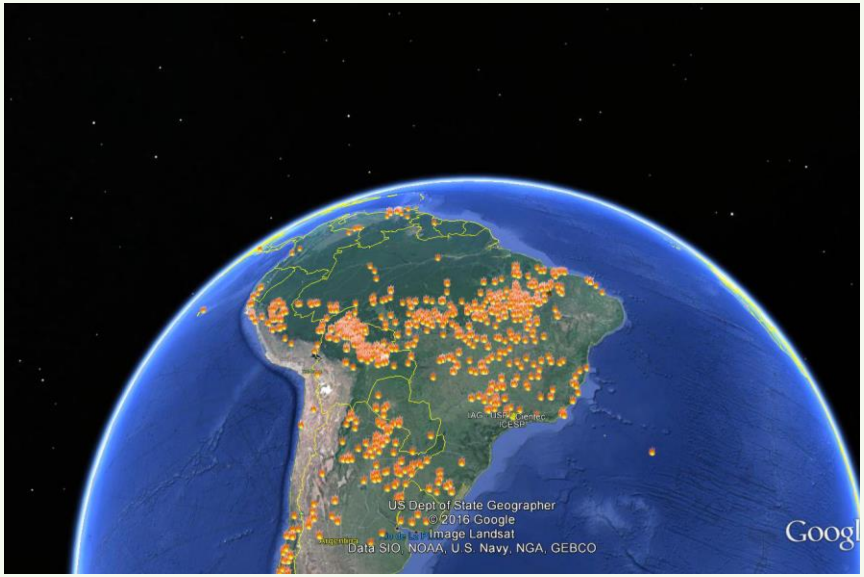
O_3 ($\mu g/m^3$)

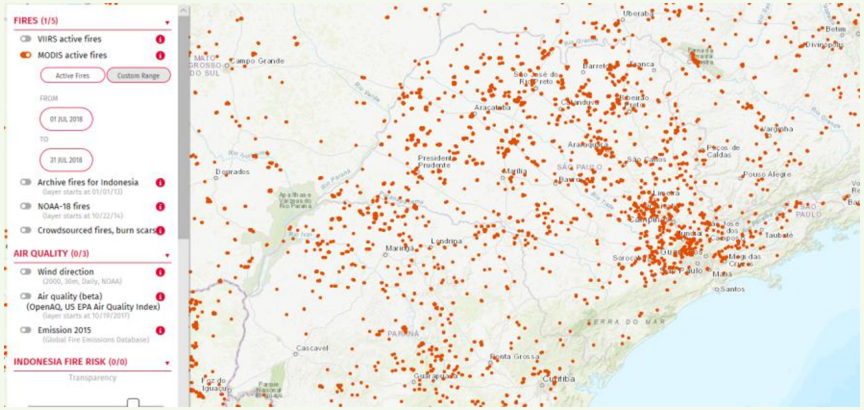


Simulations by Sergio Ibarra

Impact of Biomass Burning

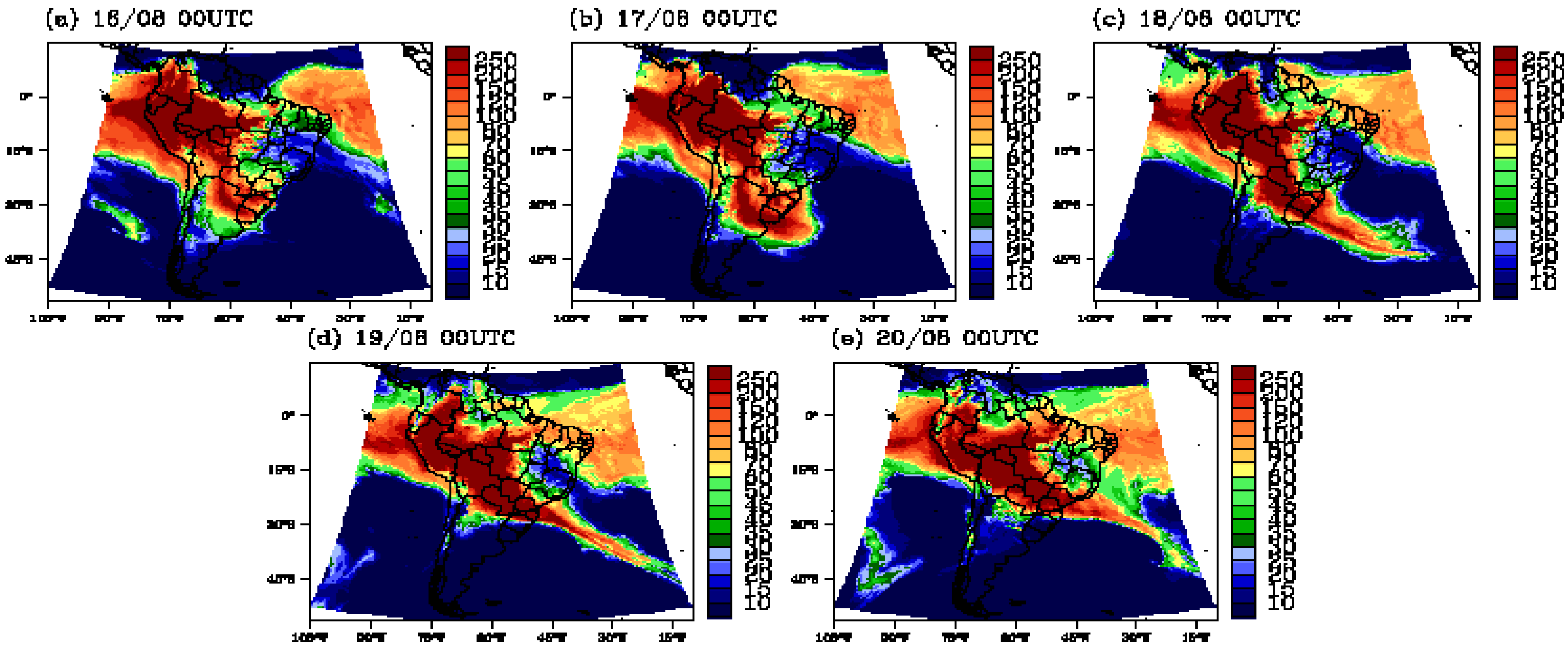
Active fires (July 1st to 31)
fires.globalforestwatch.org.html





AOD for August 2019, 16-20

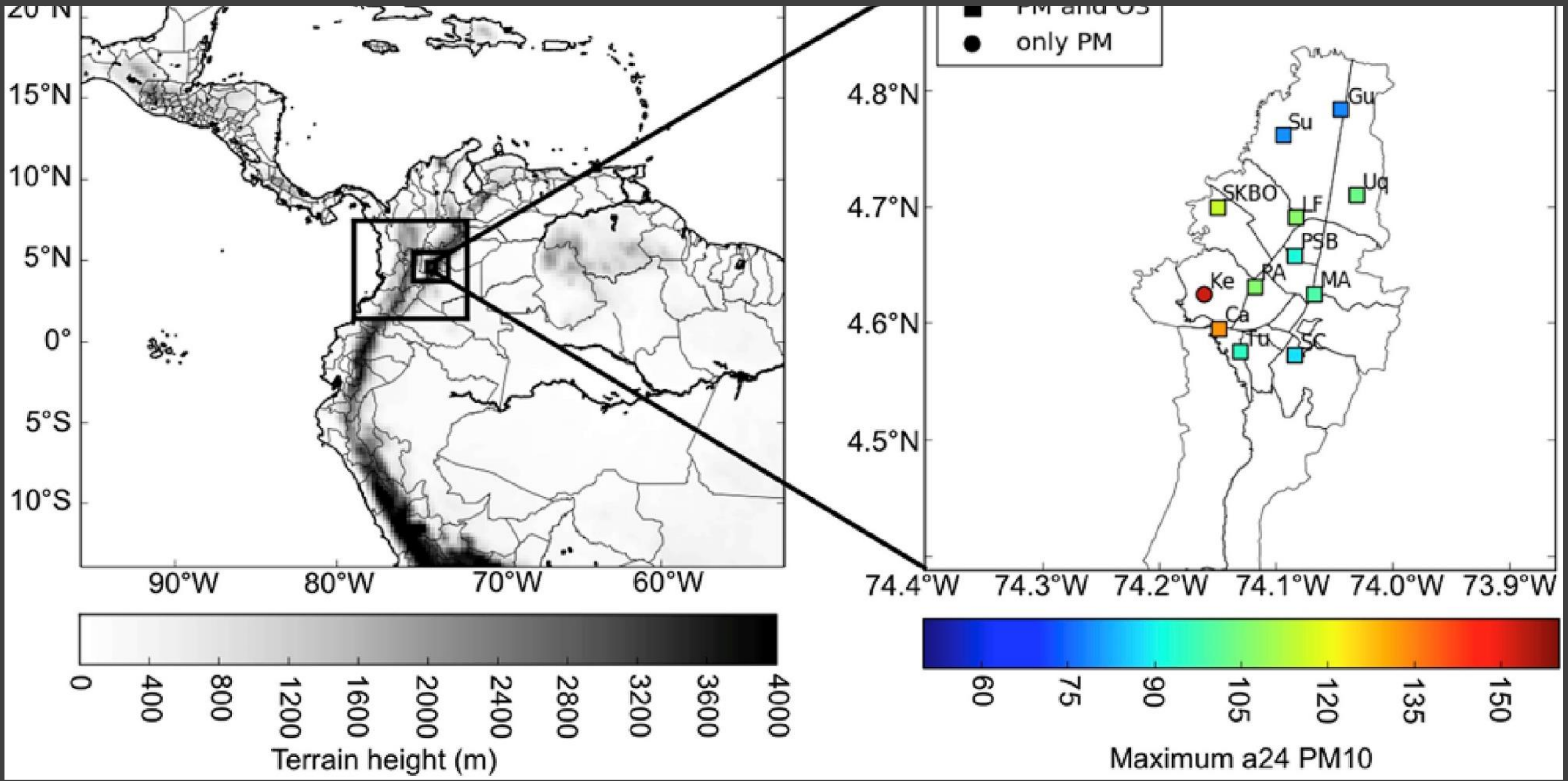
WRF - Chem



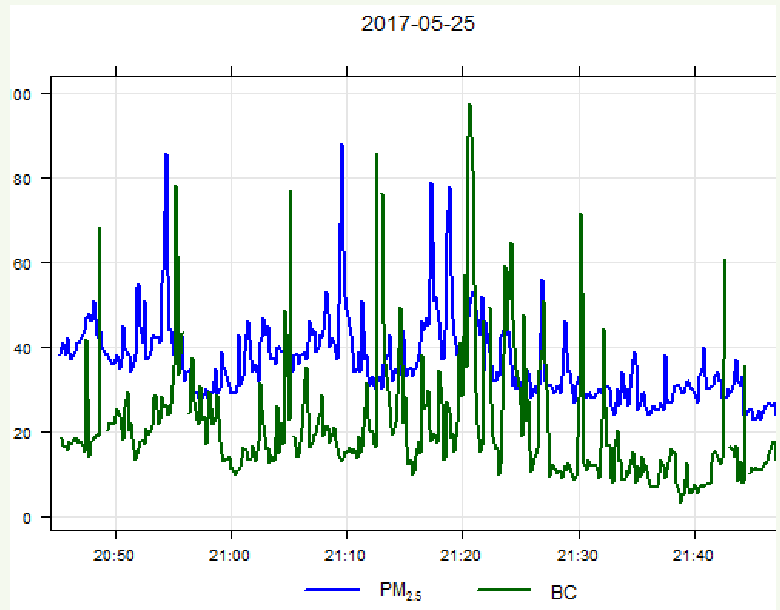
Vara-Vela (under submission)

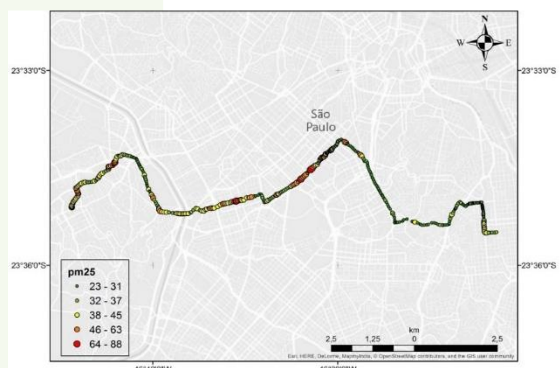
Example in Bogota - Colombia

- Domain configuration for the WRF/CMAQ modeling system. The map on the left represents the 27 km outermost domain (d01), with the 9 km, 3 km, and 1 km resolution domains (d02 d03, and d04 as black boxes. The d04 domain covering Bogotá is on the right with RMCAB monitor locations showing maximum daily 24-h PM_{10} concentrations for the modeling periods. Square stations have PM_{10} observations and O_3 observations; circle stations have only PM_{10} observations.
- Air quality modeling in Bogotá, Colombia using local emissions and natural mitigation factor adjustment for re-suspended particulate matter
- RobertNedbor-Gross[a]Barron H.Henderson[a]María PaulaPérez-Peña[b]Jorge E.Pachón, 2018



Combination of measurement and high resolution modeling





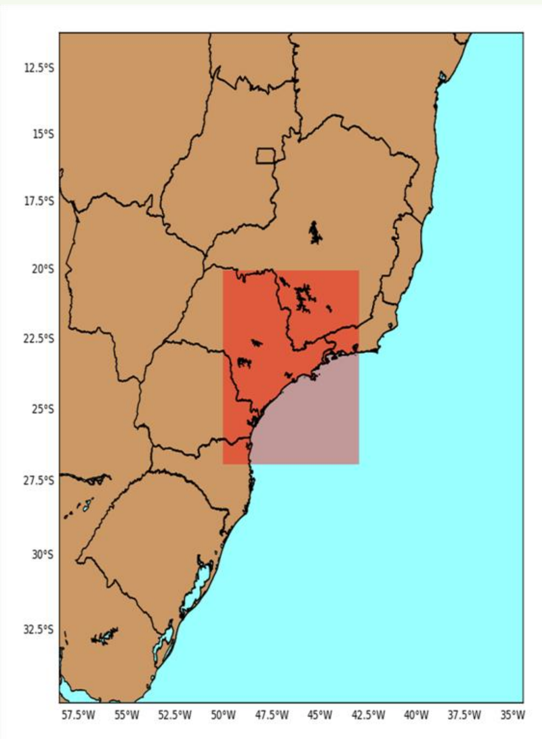
PEDALS: PARTICLES AND BLACK CARBON EXPOSURE TO LONDON AND SAO PAULO BIKE-LANE USERS. FAPESP SPRINT 3/2016

Bicycle users exposure to pollutants

Brand et al., 2019

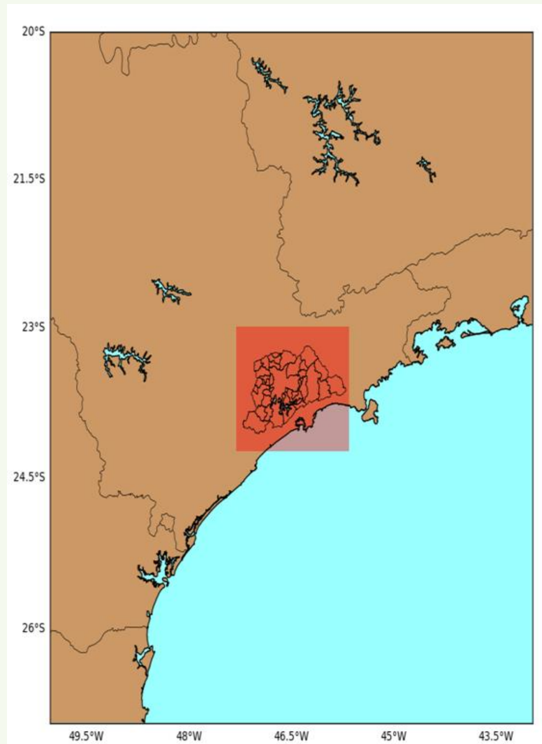
Combination of WRF-Chem with MUNICH

D1



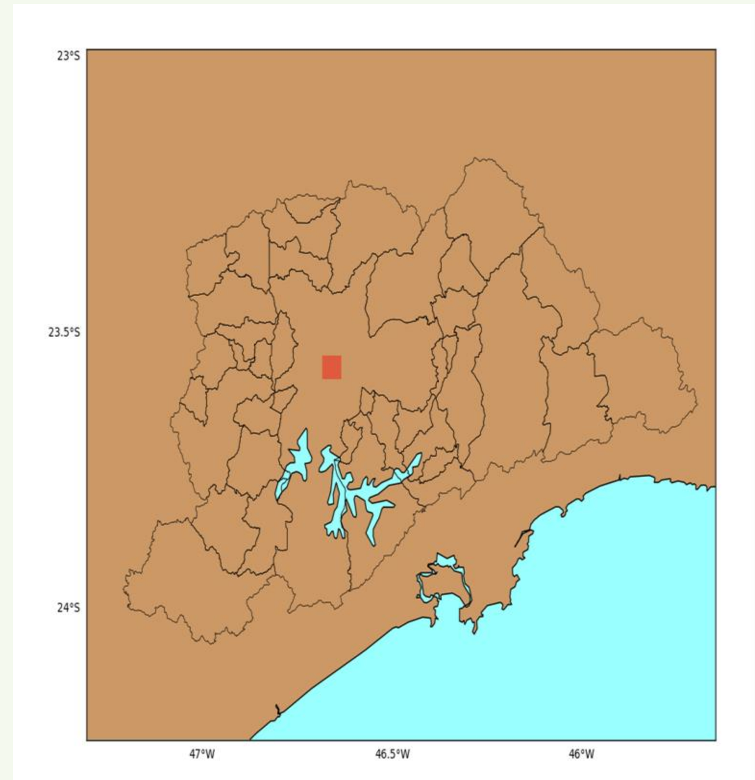
SouthEast Brazil
(ΔX = 25 km)
100 x 108 points

D2



Sao Paulo State
(ΔX = 5 km)
146 x 156

D3



MASP
(ΔX = 1 km)
171 x 141

Gavidia-Calderon et al., 2019

Motivation

MUNICH The **M**odel of **U**rban **N**etwork of **I**ntersecting **C**anyons and **H**ighways

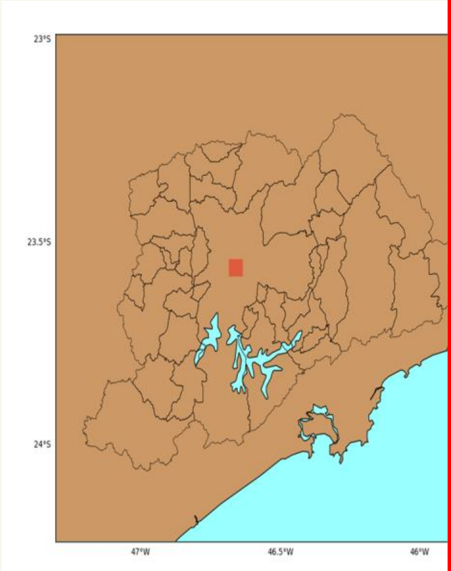
- Mesoscale chemical transport models have good representation of pollutants concentrations, but can't include the urban features (e.g. **urban canyons**) To address the relation between **traffic-related pollution** and its effects in **human health Street-levels models** can be a useful tool.

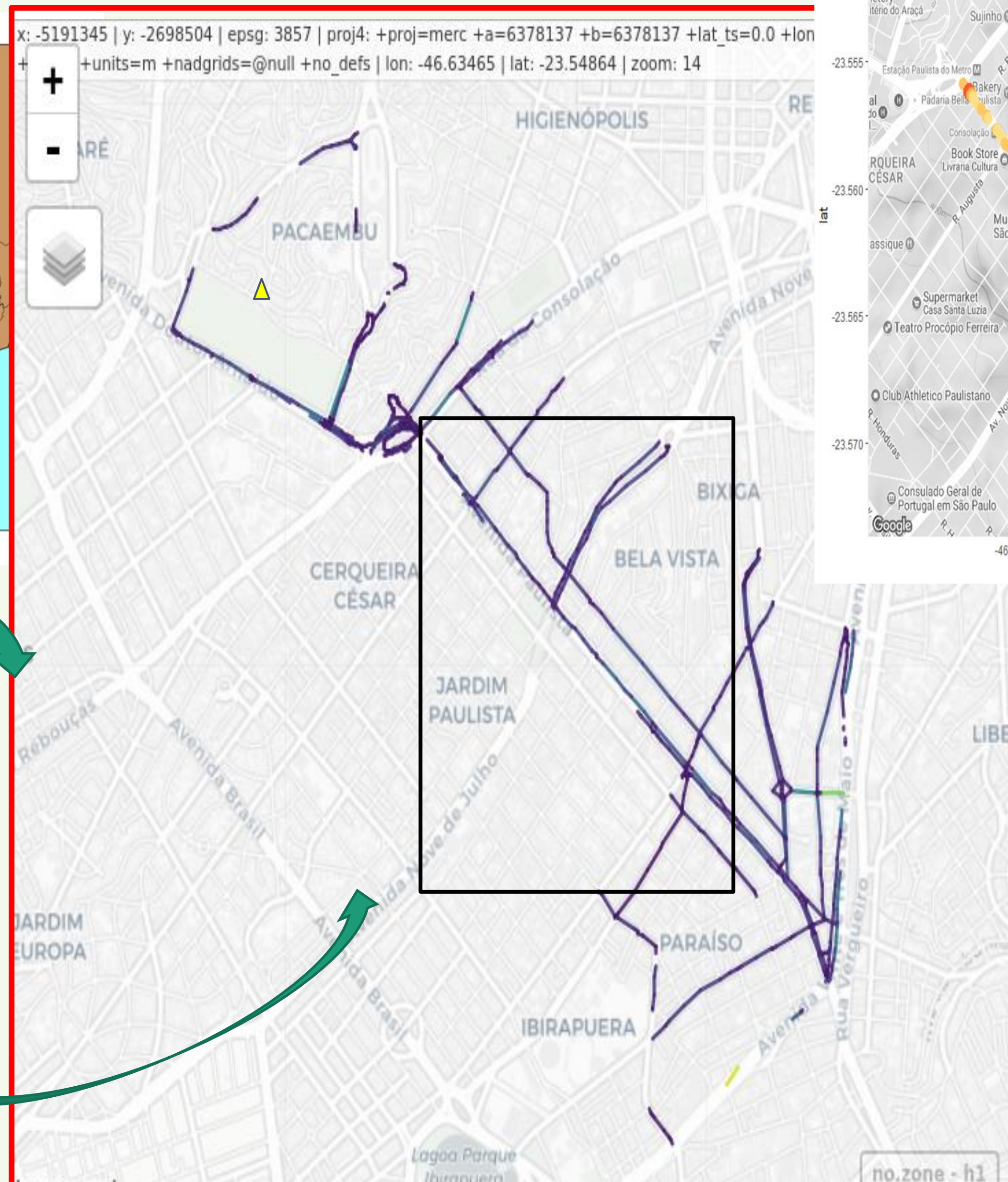
(Kim et al., 2018)

http://cerea.enpc.fr/munich/index.html

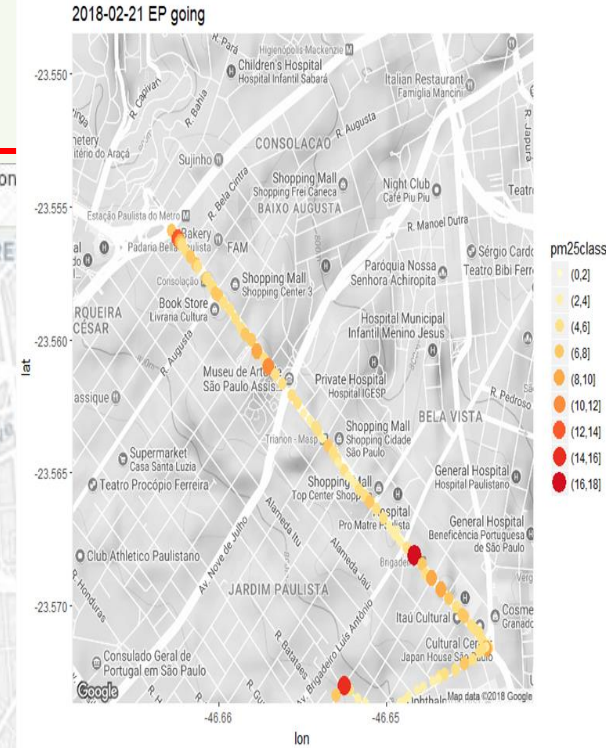

Av. Paulista
São Paulo, State of São Paulo
Google, Inc.
Street View - Nov 2017
Shopping Mall
Center Shopping
Alameda Jaú
Brigade
STA
Av. Paulista
Google
Image capture: Nov 2017
© 2018 Google
Brazil
Terms
Report a problem

MUNICH Domain





Gavidia-Calderon et al., 2019

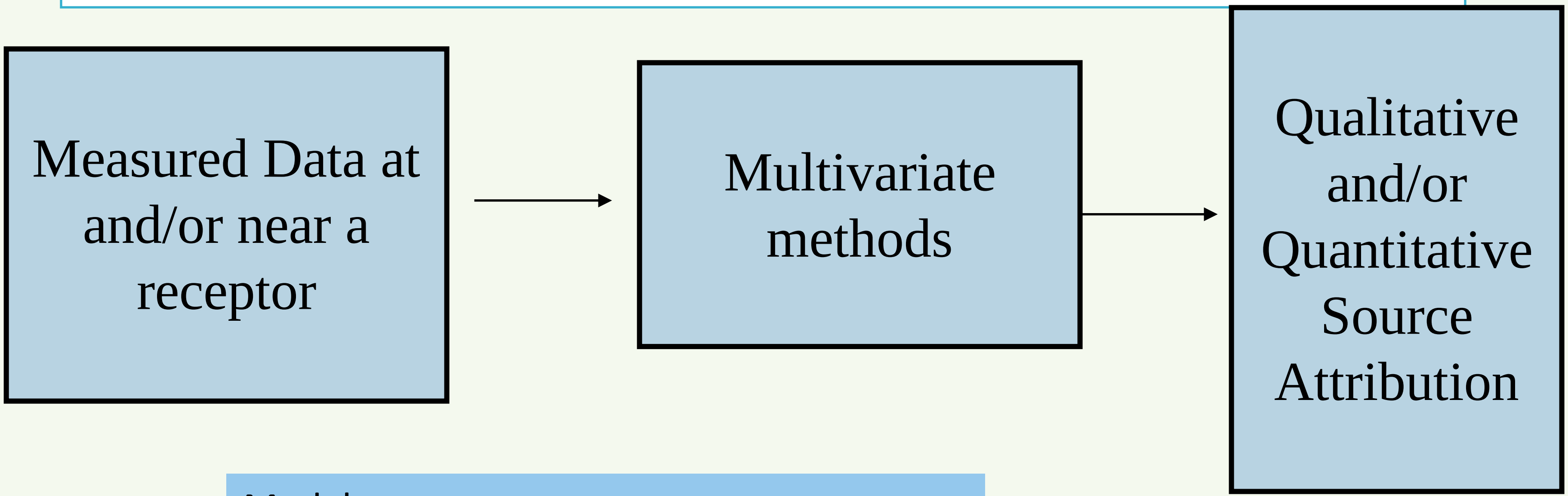


Red square: MUNICH domain: 837 links, ~ 5 km²

Black square: the area with obs. from ASTRID project

Ibirapuera AQS
Cerqueira Cesar AQS

Receptor Models



Models:

CMB, Chemical Mass Balance

PCA, Principal Component Analysis

PMF, Positive Matrix Factorization

Advantages of Receptor Models

— derives information about sources from measured data

— estimate the contribution of sources for most of the PM chemical components

— does not require an extensive input data set (e.g. 3D meteorological data, 3D emission data, air concentrations at boundaries)

— does not require significant computing resources and data storage is negligible

— the uncertainty of the output is estimated.

Experimental design

- Site selection
- Species selection
- Number and frequency of samples

Receptor models (RMs)

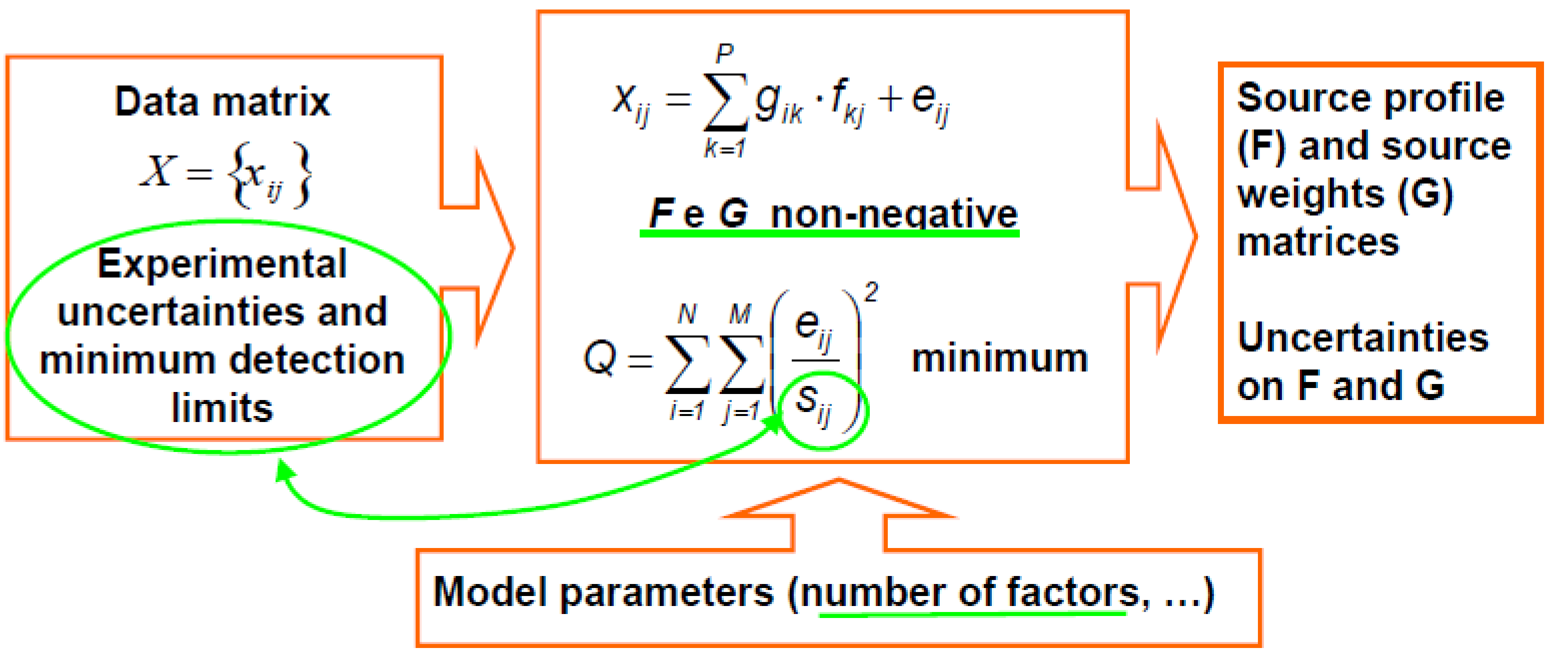
RMs are based on a chemical mass balance equation associating the concentration of each PM chemical component (x_{ij}) with the chemical profiles of all major sources and their contributions to PM mass:

$$x_{ij} = \sum_{k=1}^{N} g_{ik} \cdot f_{kj} + e_{ij} \quad (1)$$

where: N is the assumed number of sources, g_{ik} is the contribution of source k to sample i, f_{kj} is the relative concentration of species j to the chemical profile of source k, and e_{ij} is the residual for sample i of species j.

Basic principles of PMF (Positive Matrix Factorization)

PMF solves the factor analysis problem X = GF + E by an explicit **least-square approach** with **individual data point weights**: G and F are determined so that the residual matrix E, weighted with experimental uncertainties, is minimised; furthermore the solution is constrained so that all the elements of G and F are required to be **non-negative**



[Paatero and Tapper, Environmetrics, 1994]

Possible input data

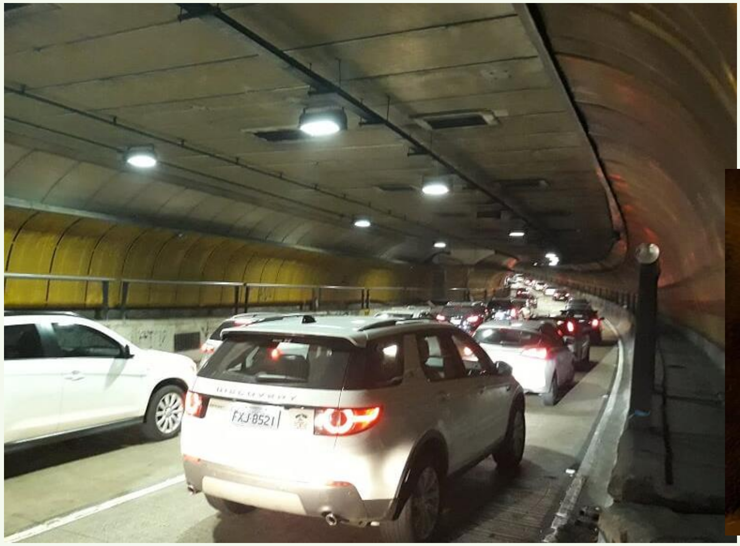
Ions	sulphate, nitrate, ammonium, chloride, Na+, Mg^{++}, K^{+}, Ca^{++}
Carbonaceous fractions	Total carbon (TC), elemental carbon (EC)/organic carbon (OC) total or fractions obtained in every analytical step
Elements	Na, Mg, Al, Si, P, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Zr, Mo, Rh, Pd, Ag, Cd, Sn, Sb, Te, I, Cs, Ba, La, W, Au, Hg, Pb
Organic markers	n-alkanes, alkanoic (carboxylic) acids (especially fatty acids), aromatic carboxilic acids, levoglucosan/mannosan, PAHs, hopanes, resin acids, syringols, cholesterol
Aerosol size distribution	scanning mobility particle sizer (SMPS), optical particle counter (OPC), aerodynamic particle sizer (APS), cascade impactors, streakers, Davis rotating-drum Universal-size-cut Monitoring impactor (DRUM/RDI)
Mass fragments (m/z) concentrations	obtained with aerosol mass spectrometer (AMS) or aerosol chemical speciation monitor (ACSM) techniques and used to apportion the organic fraction (see section 13).
Optical properties	absorption coefficients to apportion C_{ff} * and C_{wb} *, light scattering at multiple wavelengths (see section 14).
Isotopic ratios	$^{14}C/^{12}C$ ratios to apportion fossil and modern C fractions (see section 15)
Radon	indicator of planetary boundary layer (PBL) mixing and long-range pollution transport

Tunnel Measurements for evaluation of vehicular emissions factors

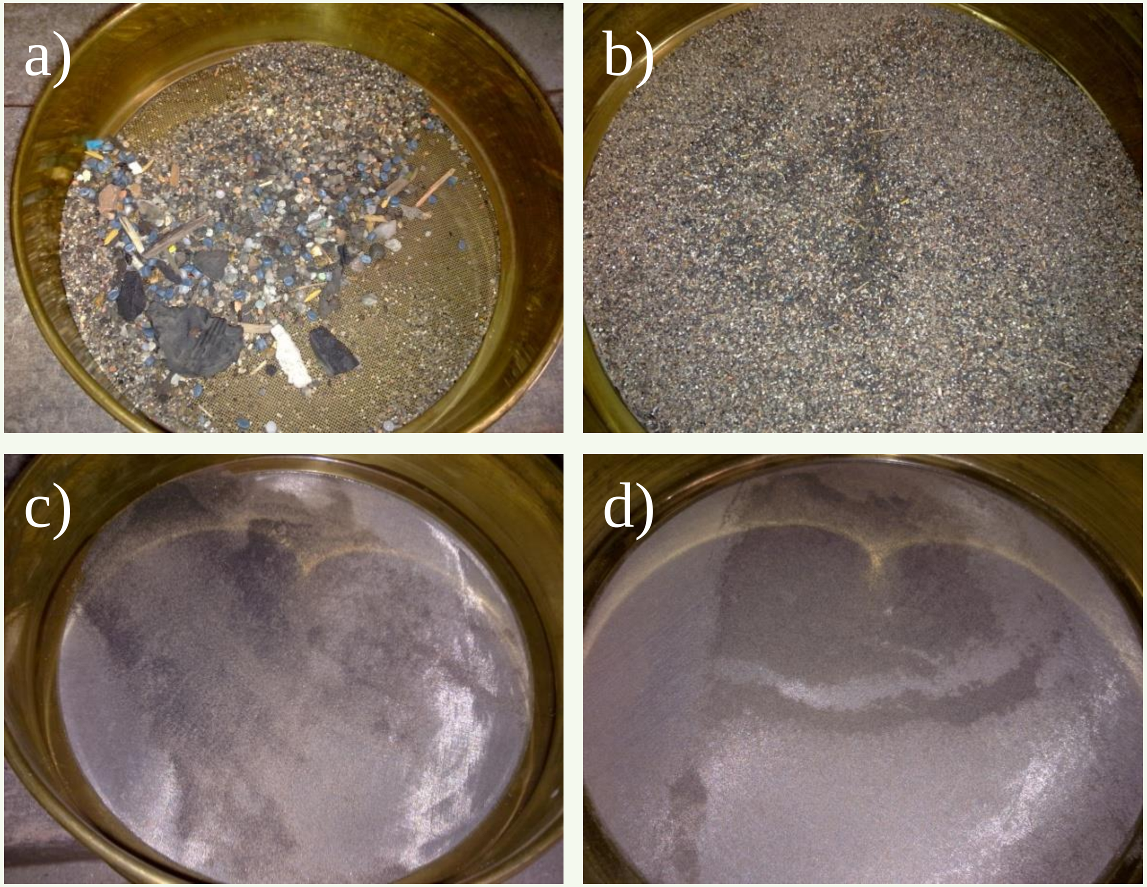
Experiments performed in 2001, 2004, 2011, 2018

Sanchez-Ccoyllo et al., 2006
Martins et al., 2008
Perez-Martinez et al., 2015
Brito et al., 2016
Nogueira et al., 2017
etc

2018



Road Dust Emission



Hetem & Andrade, 2016

Review on recent progress in observations, source identifications and countermeasures of $PM_{2.5}$

Chun-Sheng Liang [a,c], Feng-Kui Duan [a,**], Ke-Bin He [a,b,*], Yong-Liang Ma [a,b]

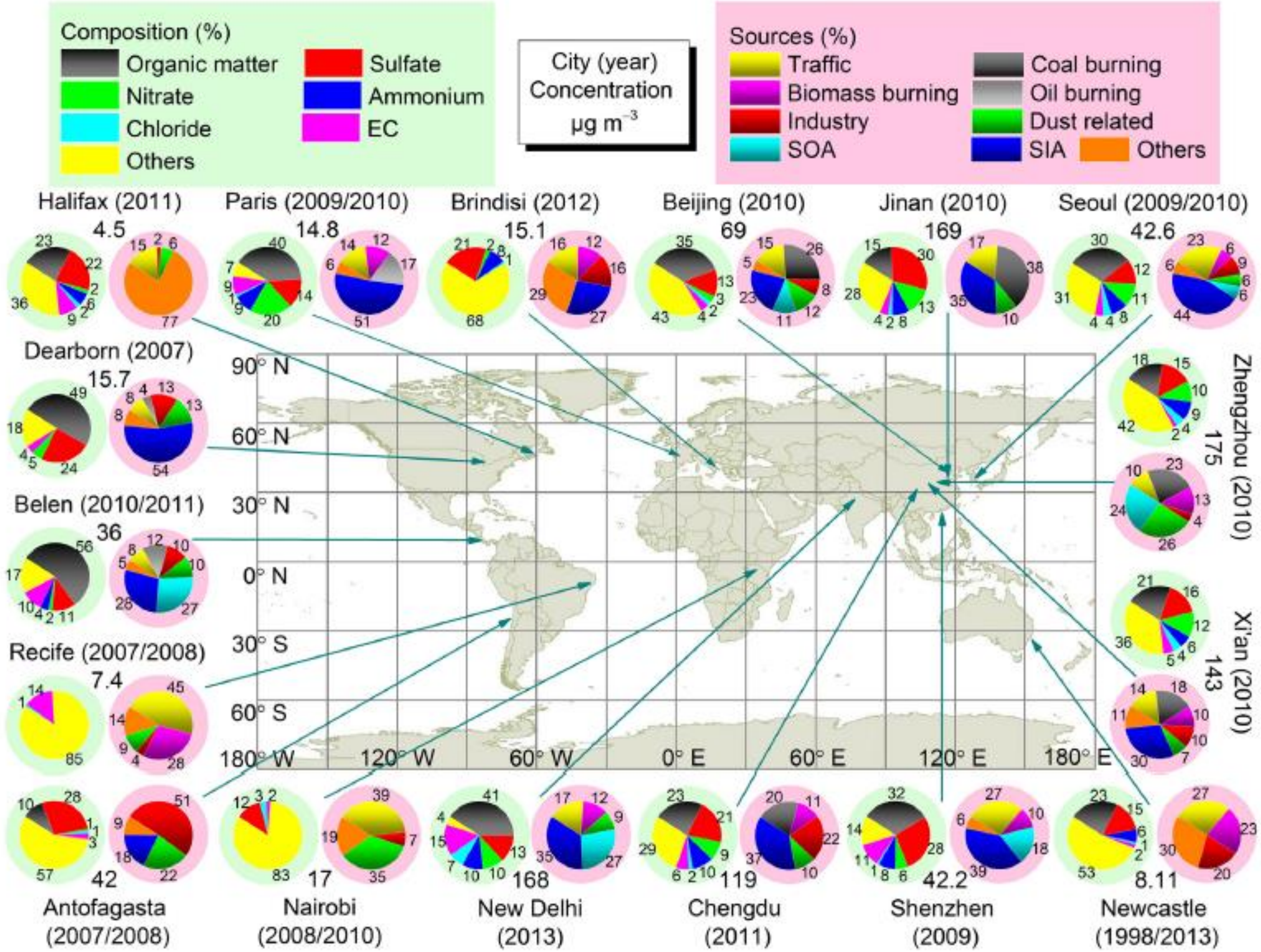
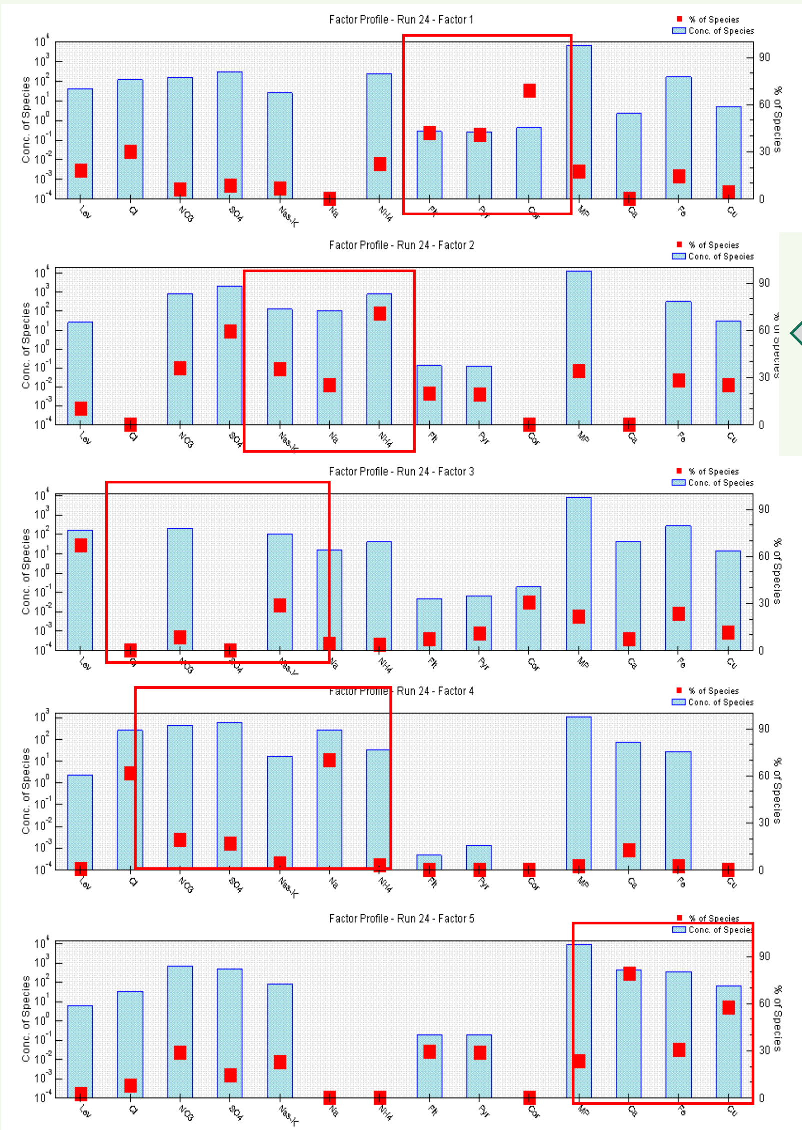


Fig. 2. Concentrations, composition and sources of $PM_{2.5}$ in different continents according to the recently reported results. Results were based on PMF, except in New Delhi (pragmatic mass closure). Data taken from references: Seoul (Choi et al., 2013), Beijing (Wu et al., 2014b), Jinan (Gu et al., 2014), Zhengzhou (Geng et al., 2013), Xi'an (Wang et al., 2015c), Chengdu (Tao et al., 2014a), Shenzhen (Huang et al., 2014b), New Delhi (Pant et al., 2015), Paris (Bressi et al., 2013; Bressi et al., 2014), Brindisi (Cesari et al., 2014), Halifax (Gibson et al., 2013), Dearborn (Pancras et al., 2013), Costa Rica (Murillo et al., 2013b), North Chile (Jorquera and Barraza, 2013), Recife (dos Santos et al., 2014), Nairobi (Gaita et al., 2014), Newcastle (Stelcer et al., 2014). See Table S3 for details.

$PM_{2.5}$ source identification with PMF - 2014



Coroneno – HPA associado com emissões veiculares

NO_3^-, SO_4^{2-} and NH_4^+ – aerossol inorgânico secundário

Levoglucosan e Nss-K^+ - queima de biomassa

Na^+ e Cl^- - aerossol marinho

Ca e Fe – ressuspensão do solo

Pereira et al., 2017. ACP

Some points:

- The importance of having measurements, even with low-cost sensors
- The necessity of having an emission model
- The knowledge of the emissions of the region
- The use of modeling approaches: receptor or dispersion
- Evaluation of risks impact

Current uncertainties in urban emissions must be tracked

- Estimates of Pollutants emissions from many cities are either not available or are generated using "bottom-up" accounting methods.
- Where such estimates are available agencies collect data from different sectors and use emission-factors to calculate the emissions associated with a given activity. The results are then tabulated in an emission inventory for the city (typically annually).
- The degree of uncertainty in these emission inventories depends on the quality and completeness of the emission activity data, accuracy of the emission factors, and the estimation, quality control, error quantification, and verification processes applied to them.
- These uncertainties and errors represent a risk to decision makers in terms of drawing the wrong conclusions when trying to answer the following questions: are policies having the intended impact and if not, why and how should they be change? are the policies being implemented cost-effective or could they be made more efficient?

Gracias!
Thank You!
Obrigada!

Foto: Rosana Astolfo, outubro 2019