Vers un système intégré pour l’observation et la prévision de la qualité de l’air et l’attribution des sources

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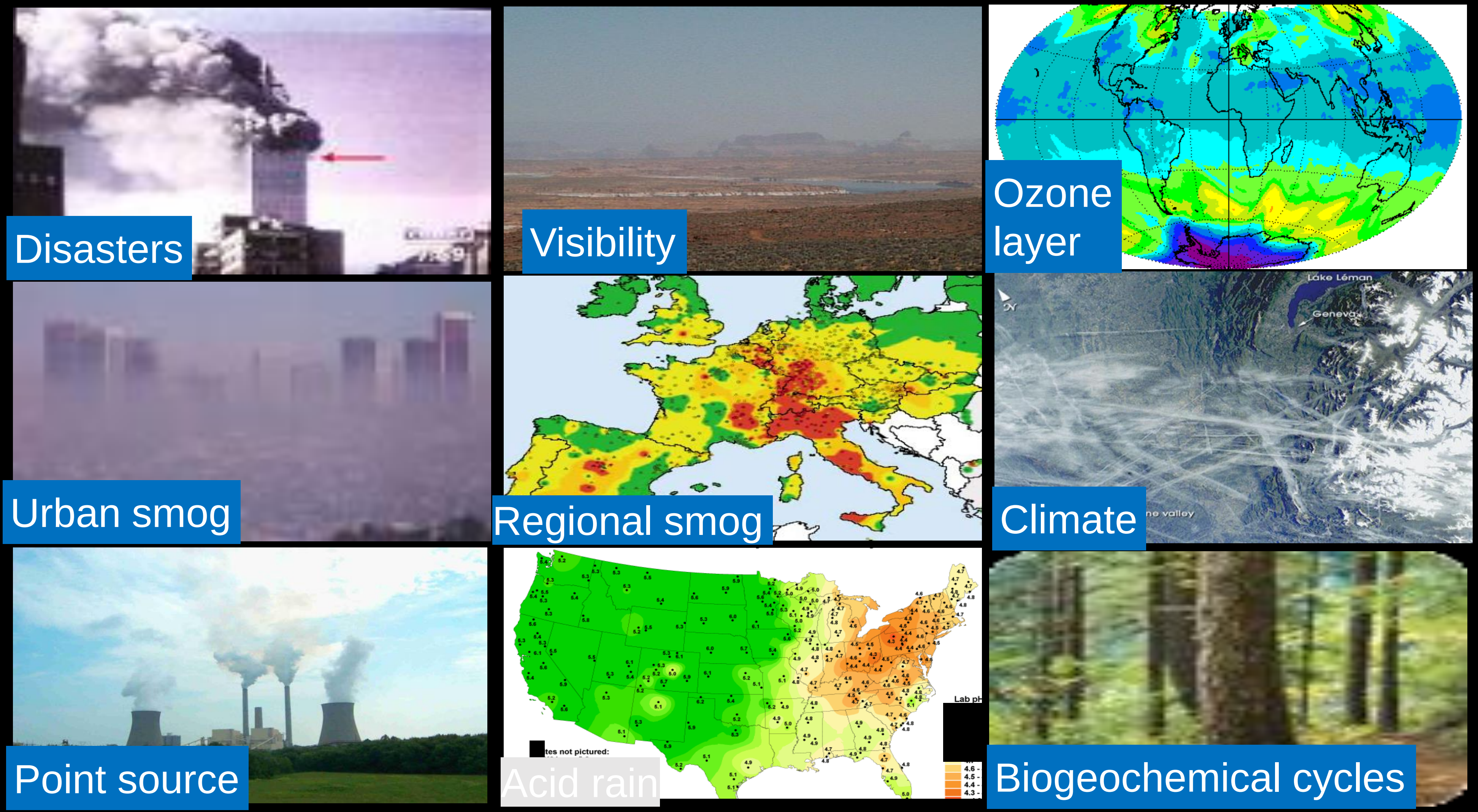
and
National Center for Atmospheric Research, Boulder, CO, USA

SCALES OF ATMOSPHERIC CHEMISTRY PROBLEMS



LOCAL
< 100 km

REGIONAL
100-1000 km

GLOBAL
> 1000 km

Air pollution has become a global problem

- $ 7 million premature deaths [WHO, 2018]
- US $ 5 trillion economic loss [World Bank, 2015]
- 79-121 million tons of lost crop produces globally [Avnery et al., 2011]
- 94 million people could be fed in India by saving crops from ozone damage [Ghude et al., 2014]

People are directly affected by air pollution

London fog

Particulate matter (PM) from domestic+industrial coal combustion

“Killer fog” of December 1952 resulted in 10,000 excess deaths

Altitude

inversion

< 1km

Sulfur dioxide (SO_2) → **particles** { **sulfate**, **organic carbon**, **black carbon** }

Temperature

Coal combustion

Daniel Jacob

Los Angeles smog

Respiratory problems, vegetation damage due to high surface ozone

altitude

produced by photolysis of oxygen (O_2)

stratosphere

~ 10 km

troposphere

temperature

ozone

inversion

~ 1 km

Nitrogen oxides ($NO_x \equiv NO + NO_2$)
Volatile organic compounds (VOCs)

Sunlight

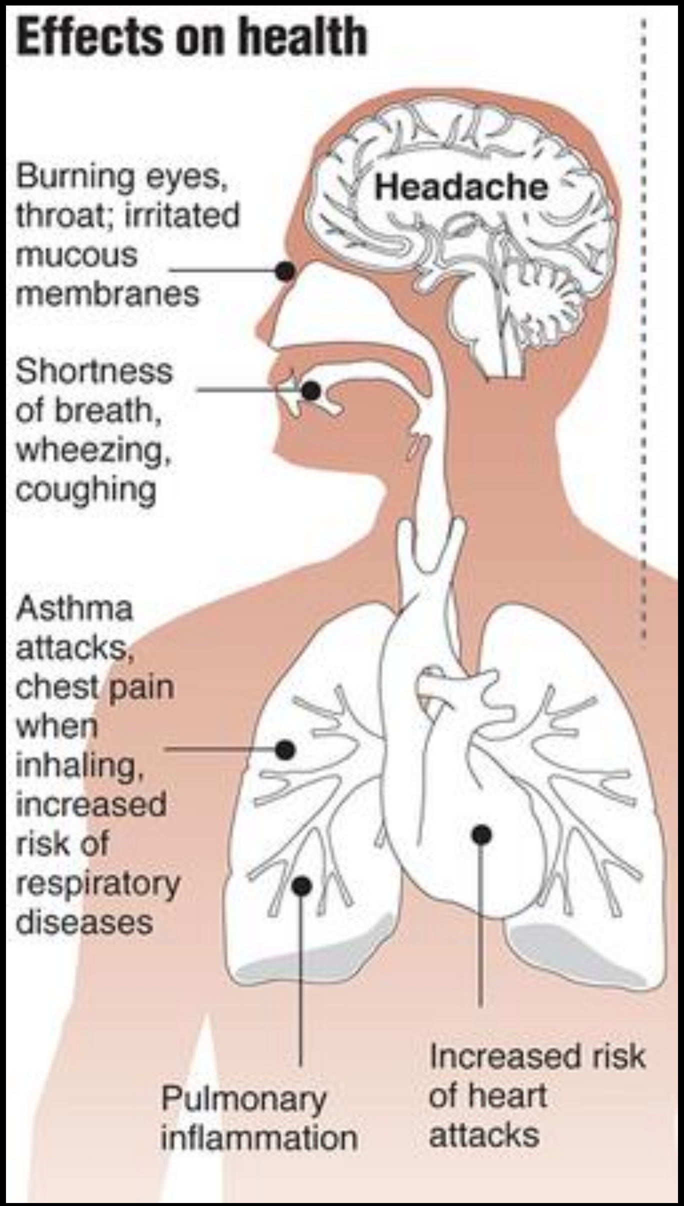
Ozone (O_3)

PM

vehicles, industry, vegetation

Daniel Jacob


Ground Level Ozone Formation
Sunlight
Nitrogen Oxides
NOx
Mobile and Combustion Sources
Volatile Organic Compounds
VOCs
Vegetation, Mobile Sources and Industry
Ozone
O3
Pollutants "bake" together in direct sunlight forming ozone.


Effects on health
Headache
Burning eyes, throat; irritated mucous membranes
Shortness of breath, wheezing, coughing
Asthma attacks, chest pain when inhaling, increased risk of respiratory diseases
Pulmonary inflammation
Increased risk of heart attacks

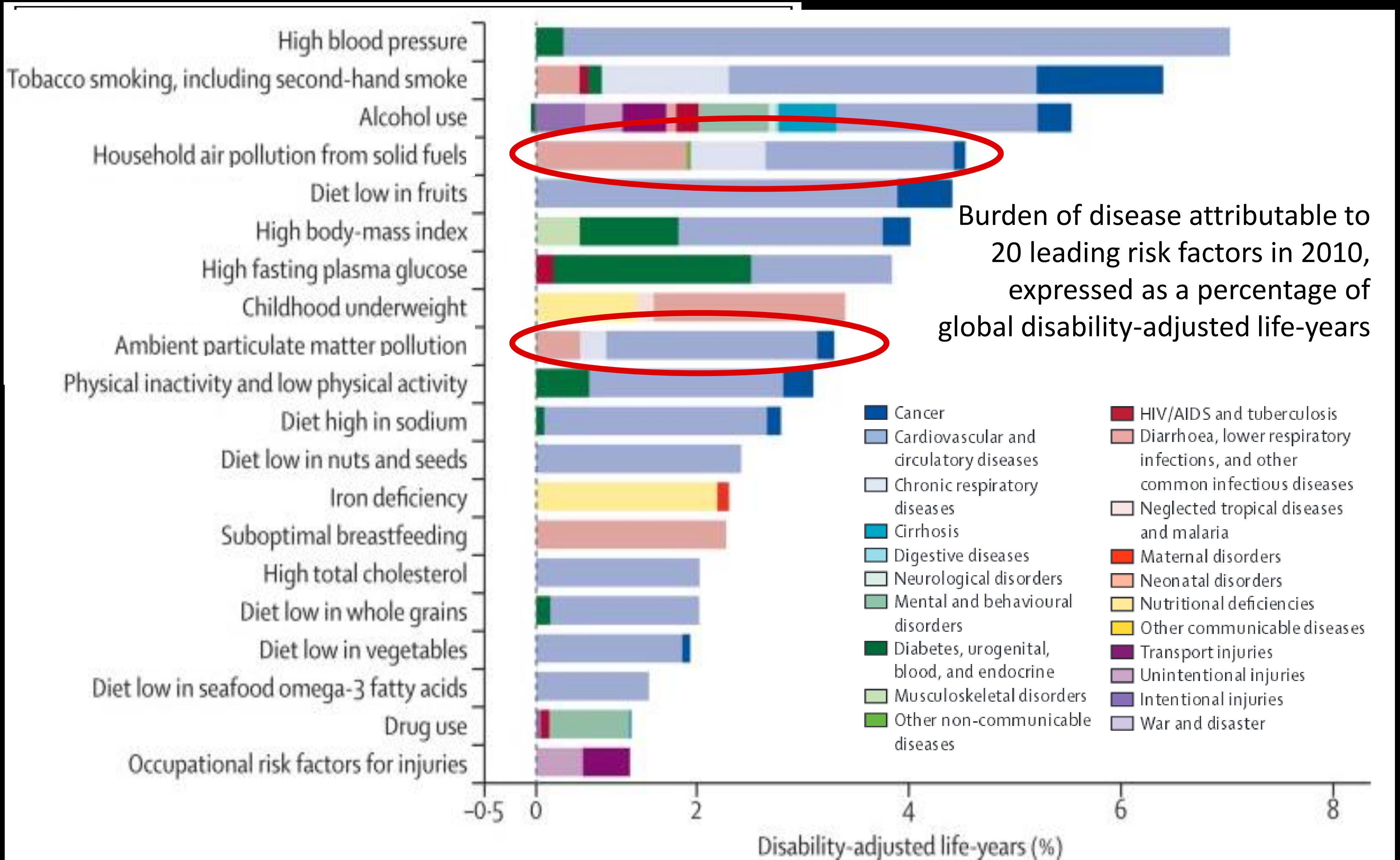
Los Angeles Times:

"Los Angeles' smoggiest day occurred on Sept. 13, 1955, when ozone levels reached 850 parts per billion in downtown Los Angeles and 900 ppb in Vernon."

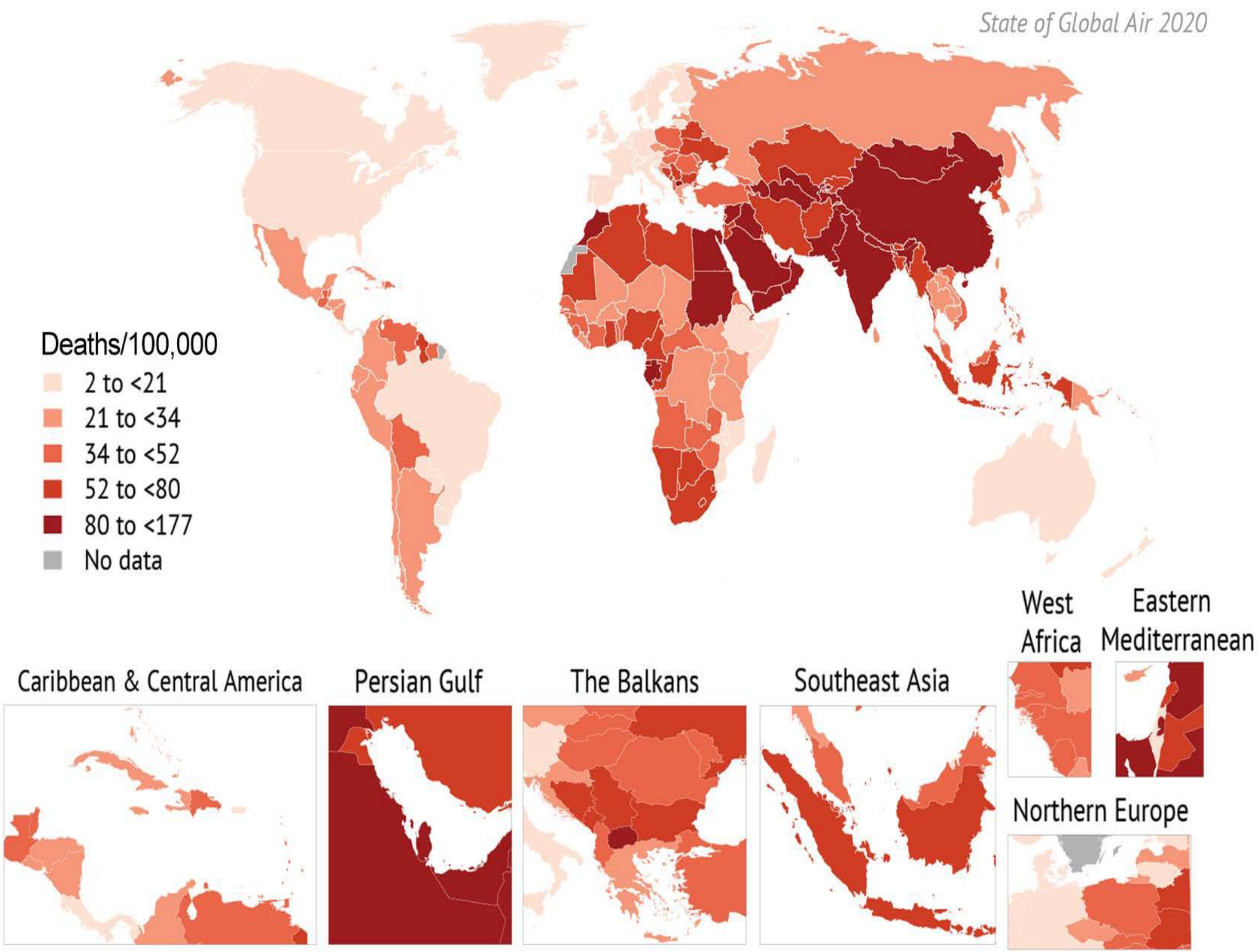
Photo from front page of the 15 September 1955, Los Angeles Times.

L’impact de la pollution de l’air sur la santé est énorme

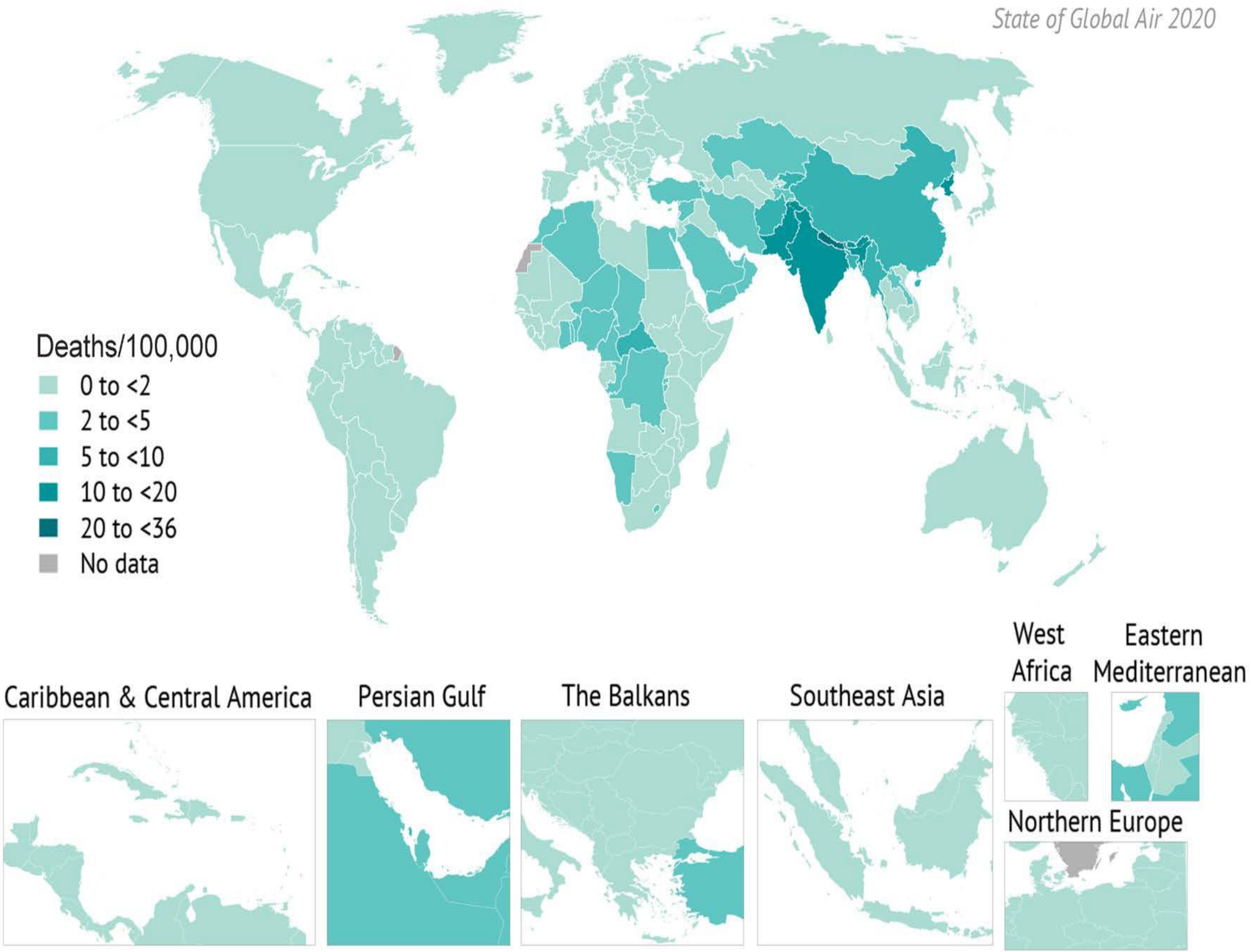
(7 million de morts chaque année due à la pollution de l’air !!)



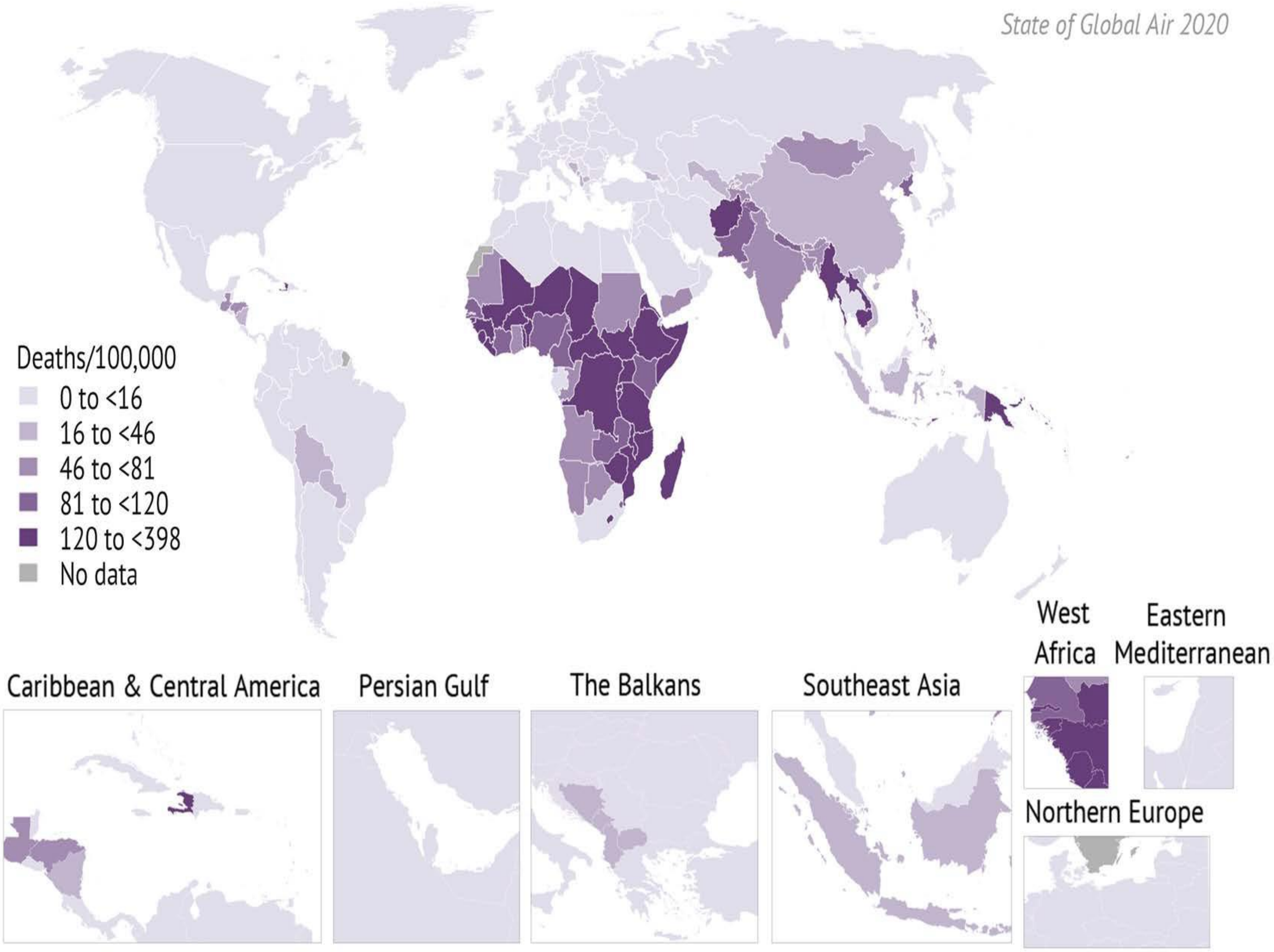
Age standardized rates of death attributable to PM2.5 in 2019



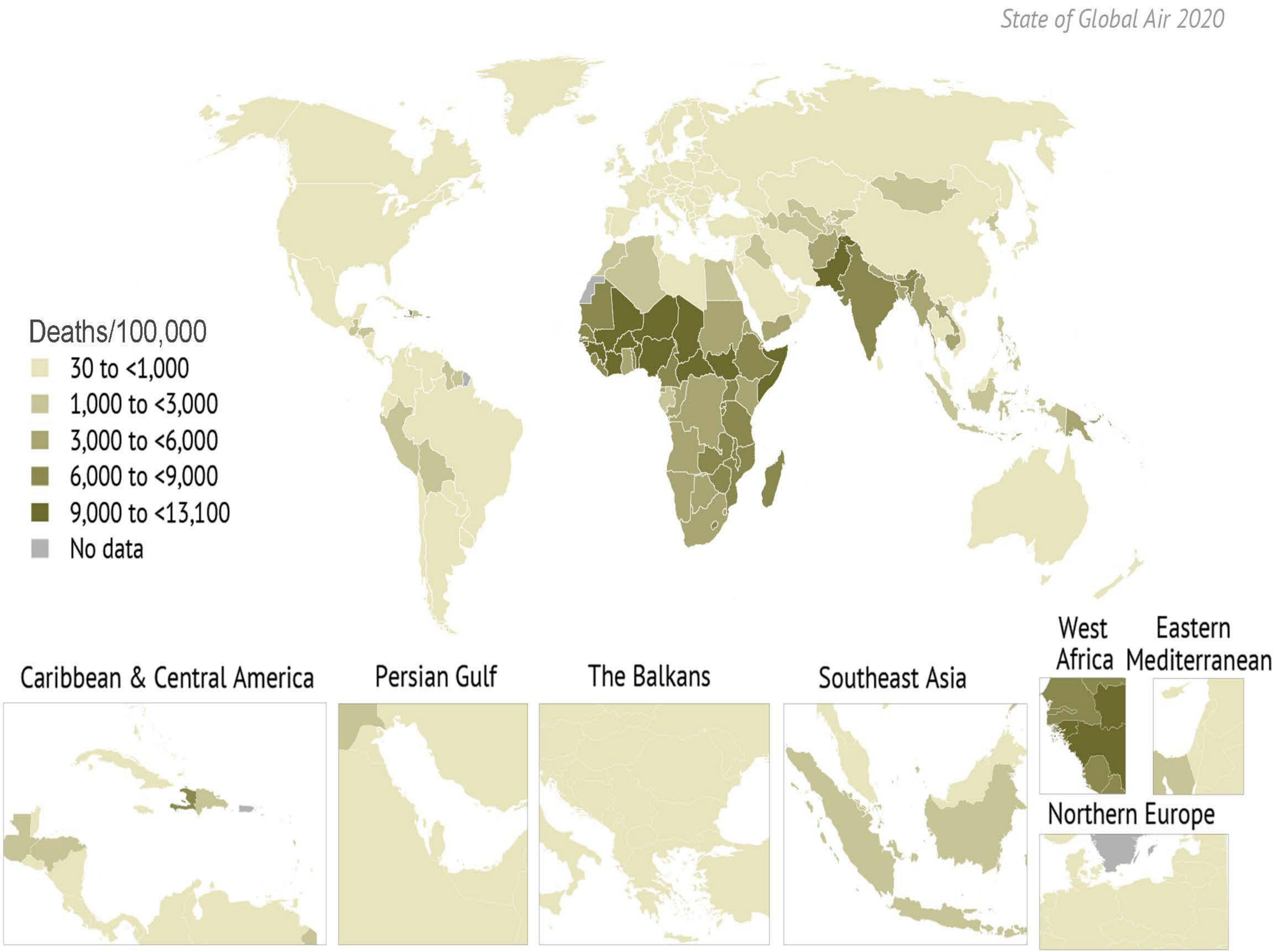
Age standardized rates of death attributable to ozone in 2019



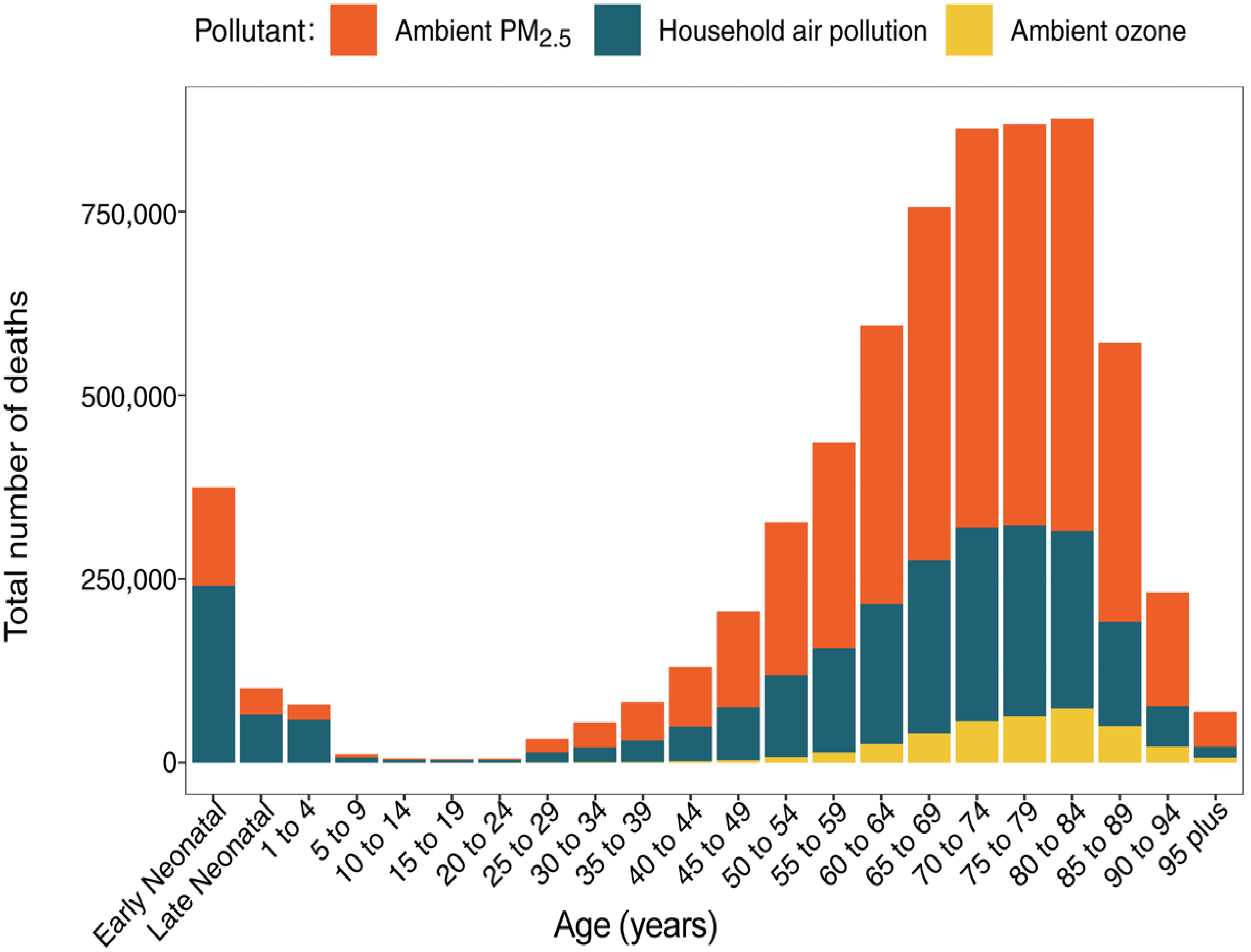
Age-standardized rates of death attributable to household air pollution in 2019



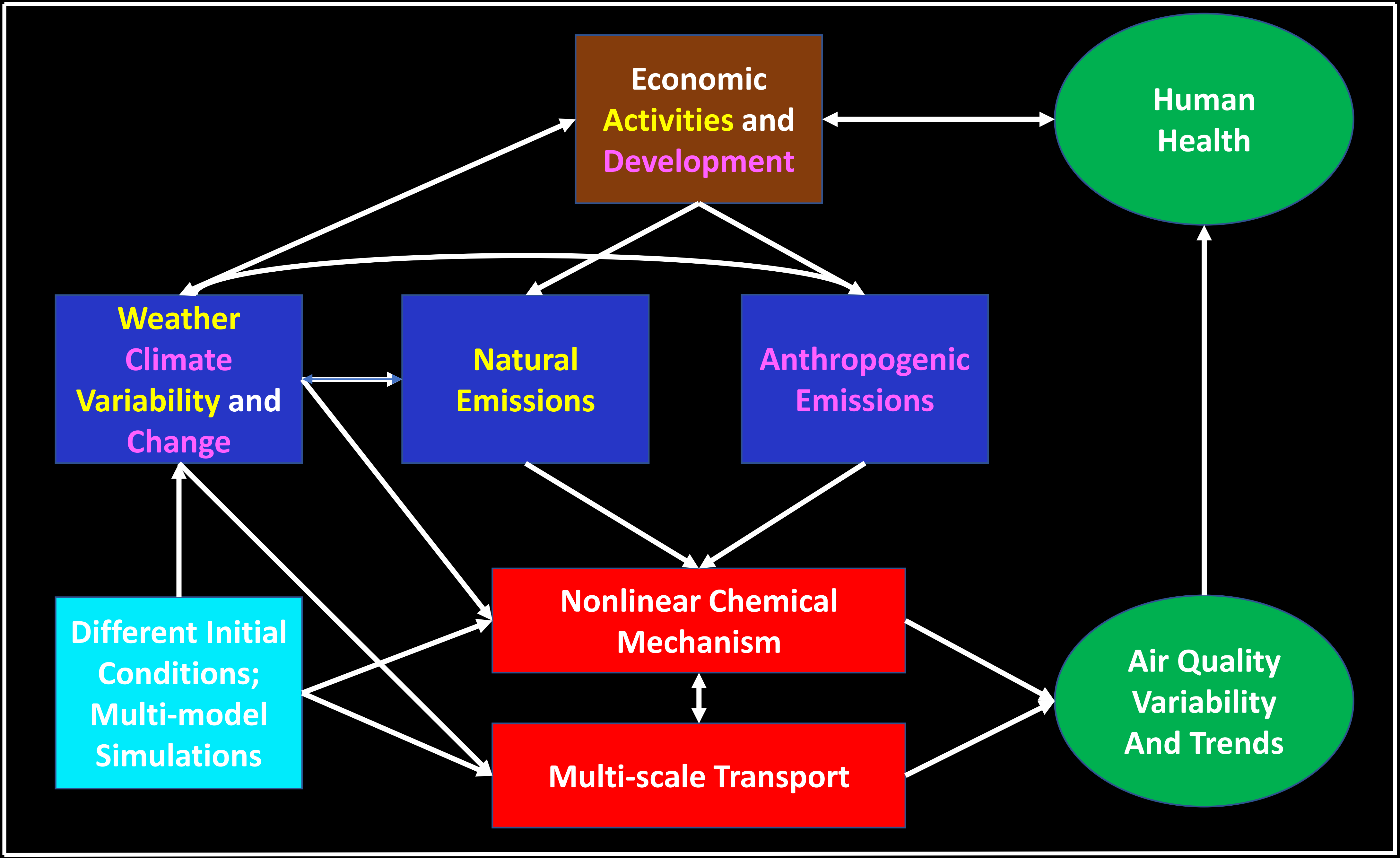
Neonatal death rates attributable to air pollution in 2019



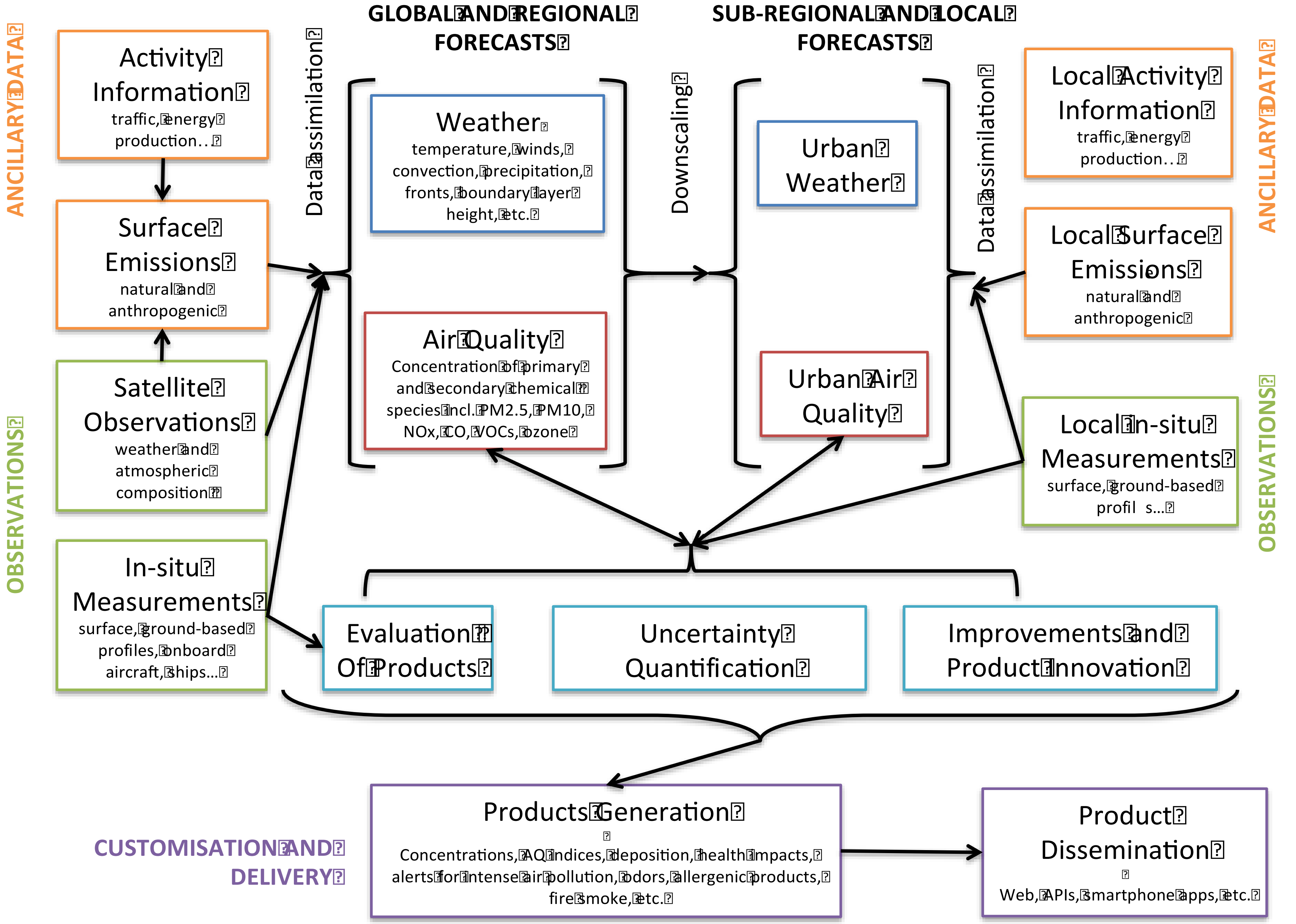
Distribution by age of global deaths in 2019 attributable to PM2.5, ozone and household air pollution



Un système intégré pour l’observation, l’analyse et la prévision de la qualité de l’air

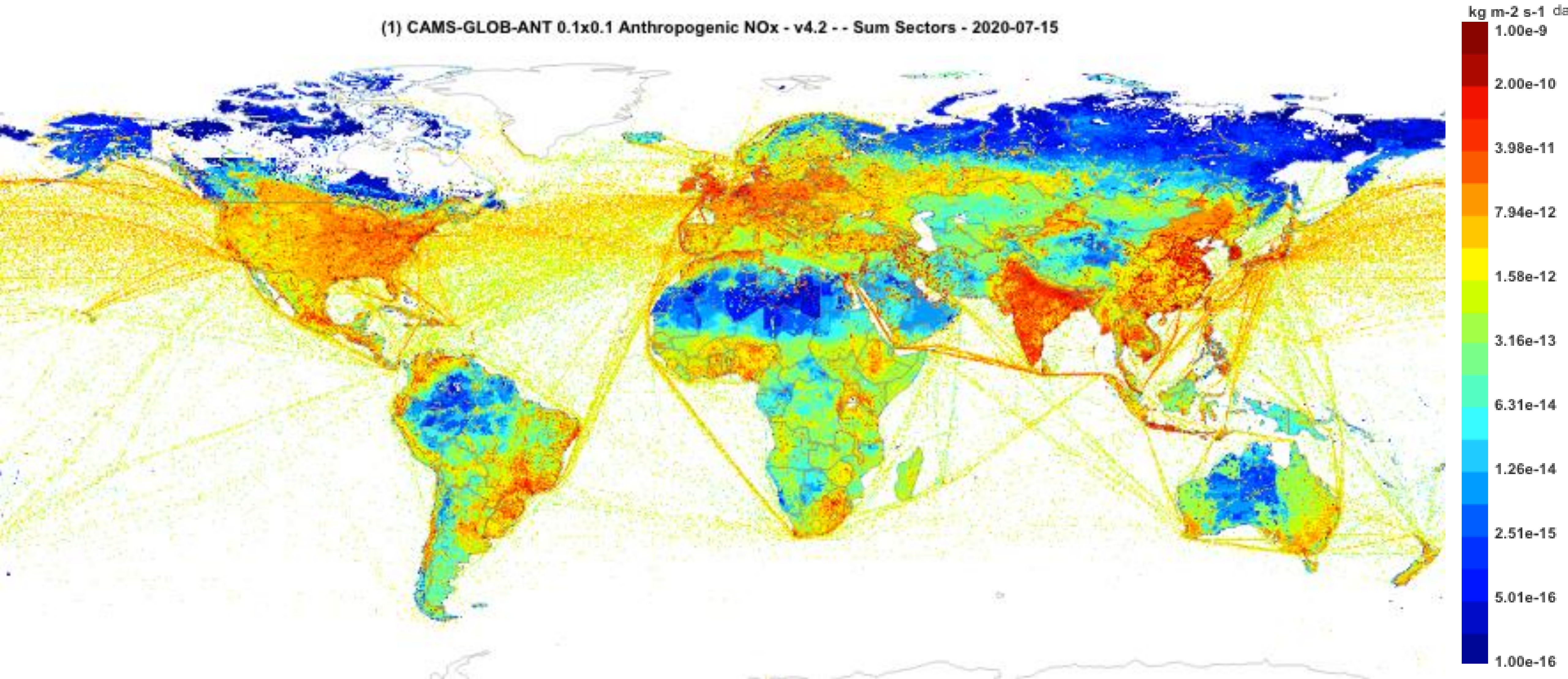

Economic Activities and Development
Human Health
Weather Climate Variability and Change
Natural Emissions
Anthropogenic Emissions
Nonlinear Chemical Mechanism
Different Initial Conditions; Multi-model Simulations
Multi-scale Transport
Air Quality Variability And Trends

Un système intégré pour la prévision de la qualité de l'air à multi-échelles.

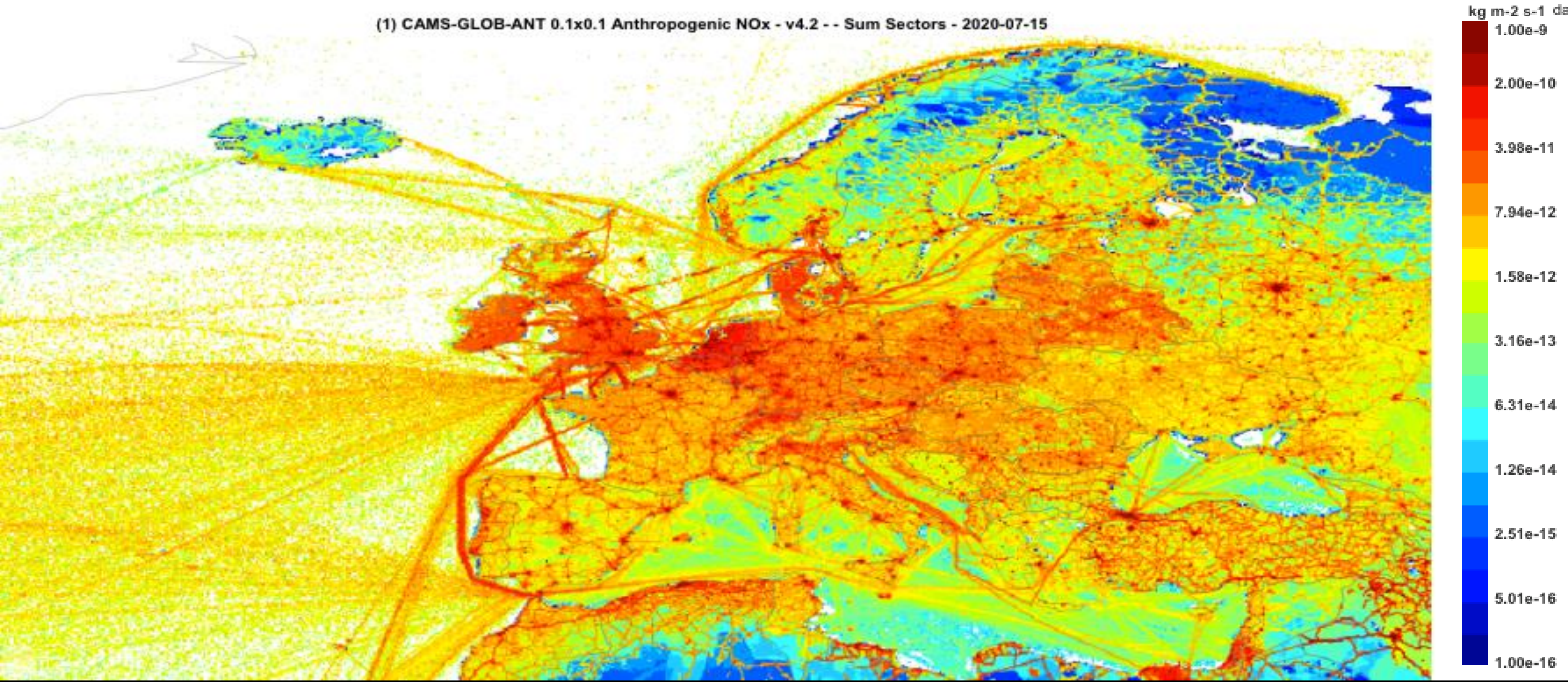


Emissions

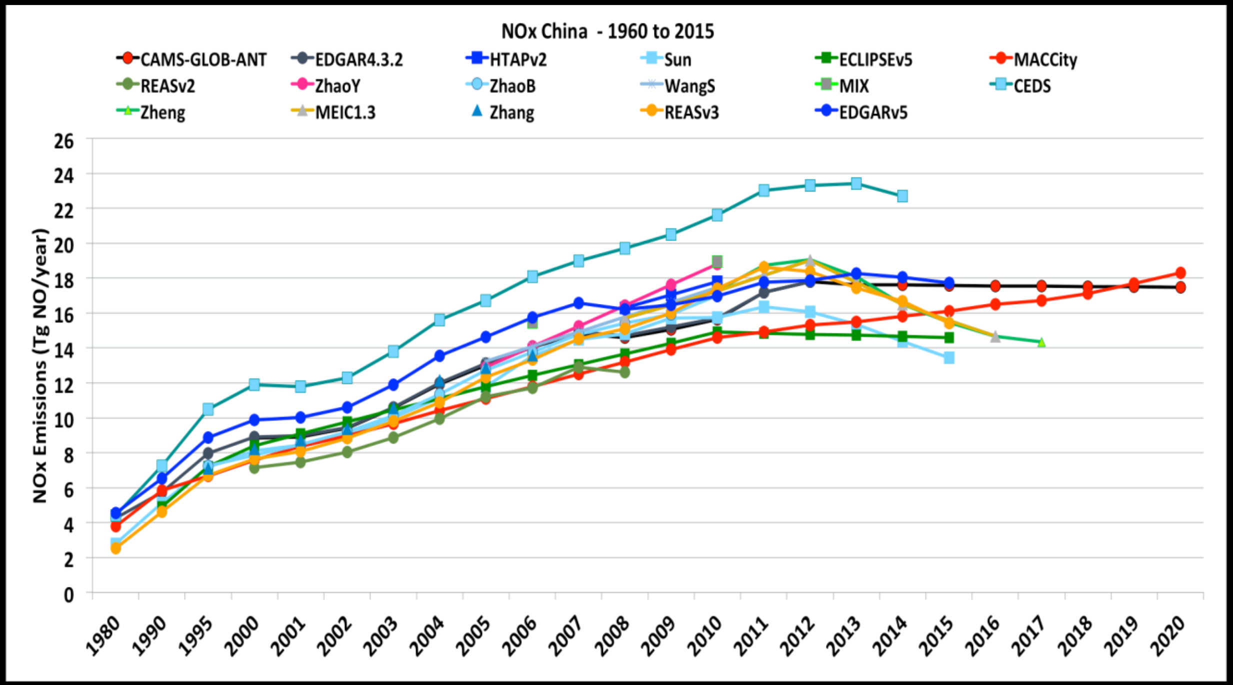
Emissions globales de NOx Juillet 2015 (CAMS)

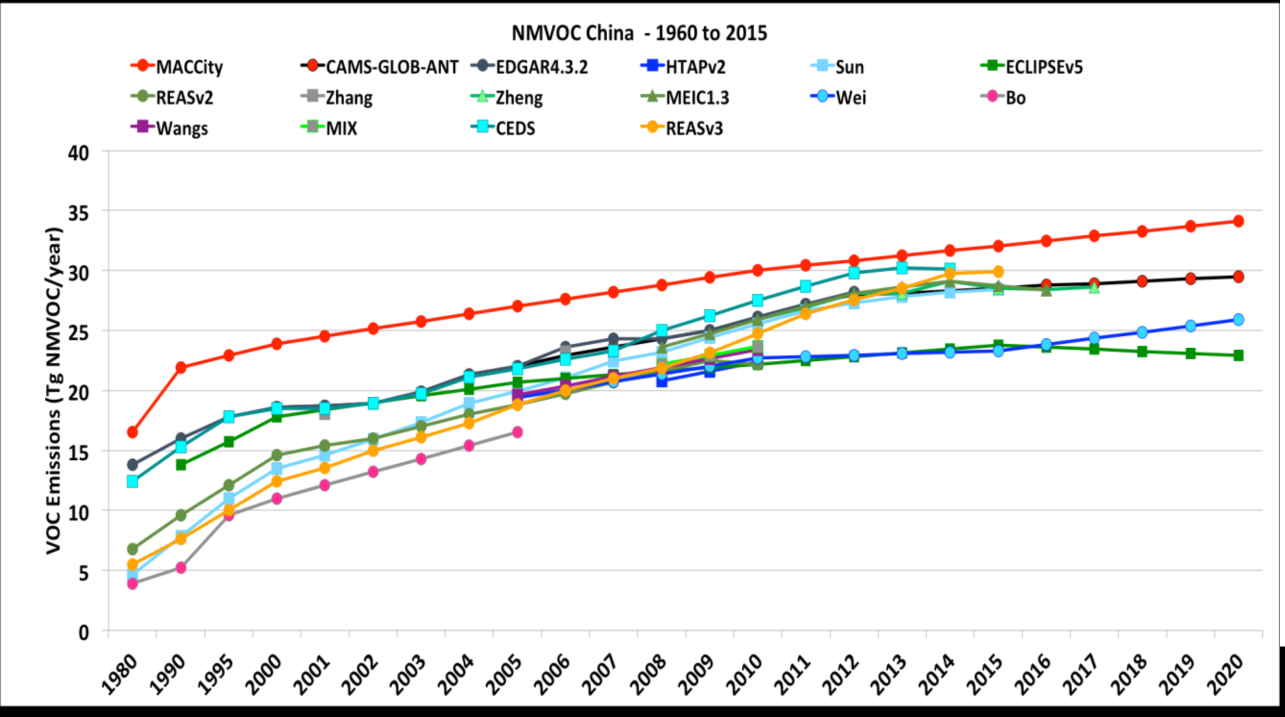


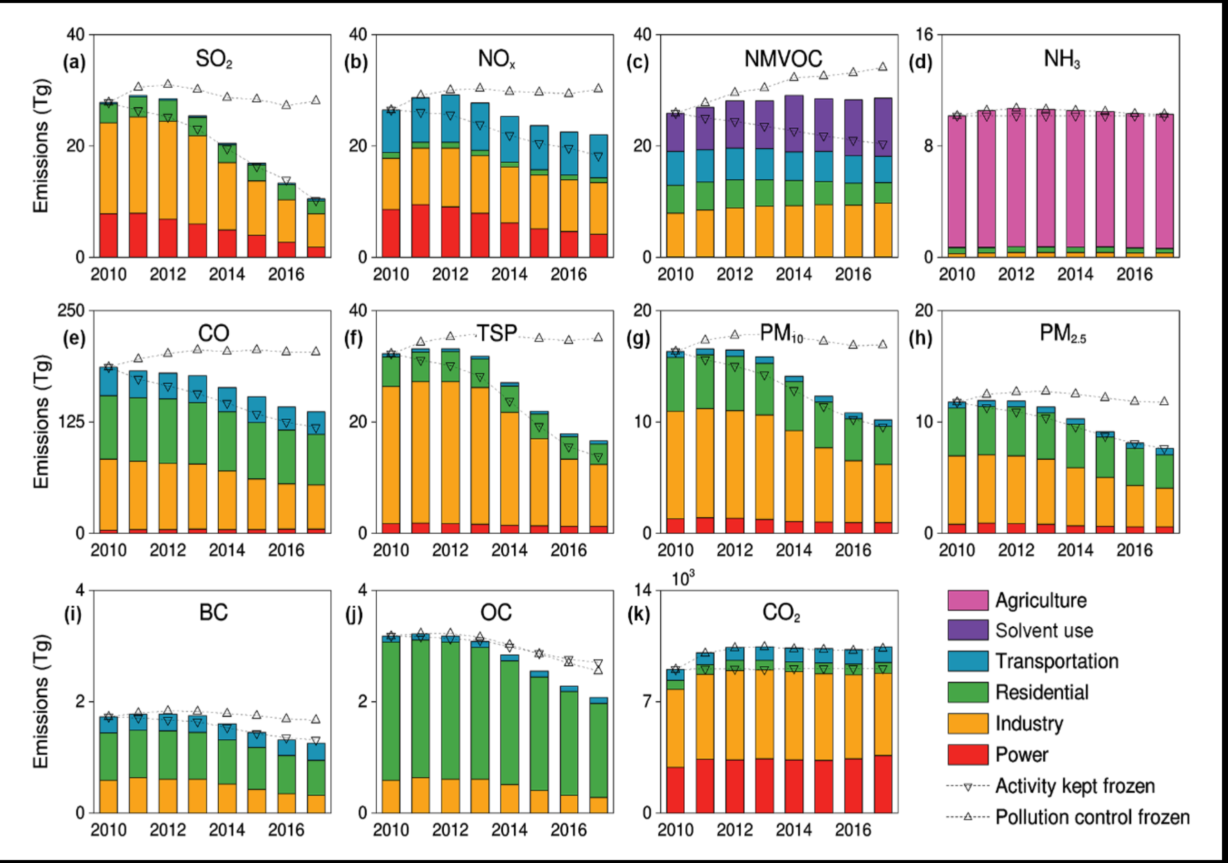
Emissions Européennes de NOx Juillet 2015 (CAMS)



Evolution in surface emissions in China



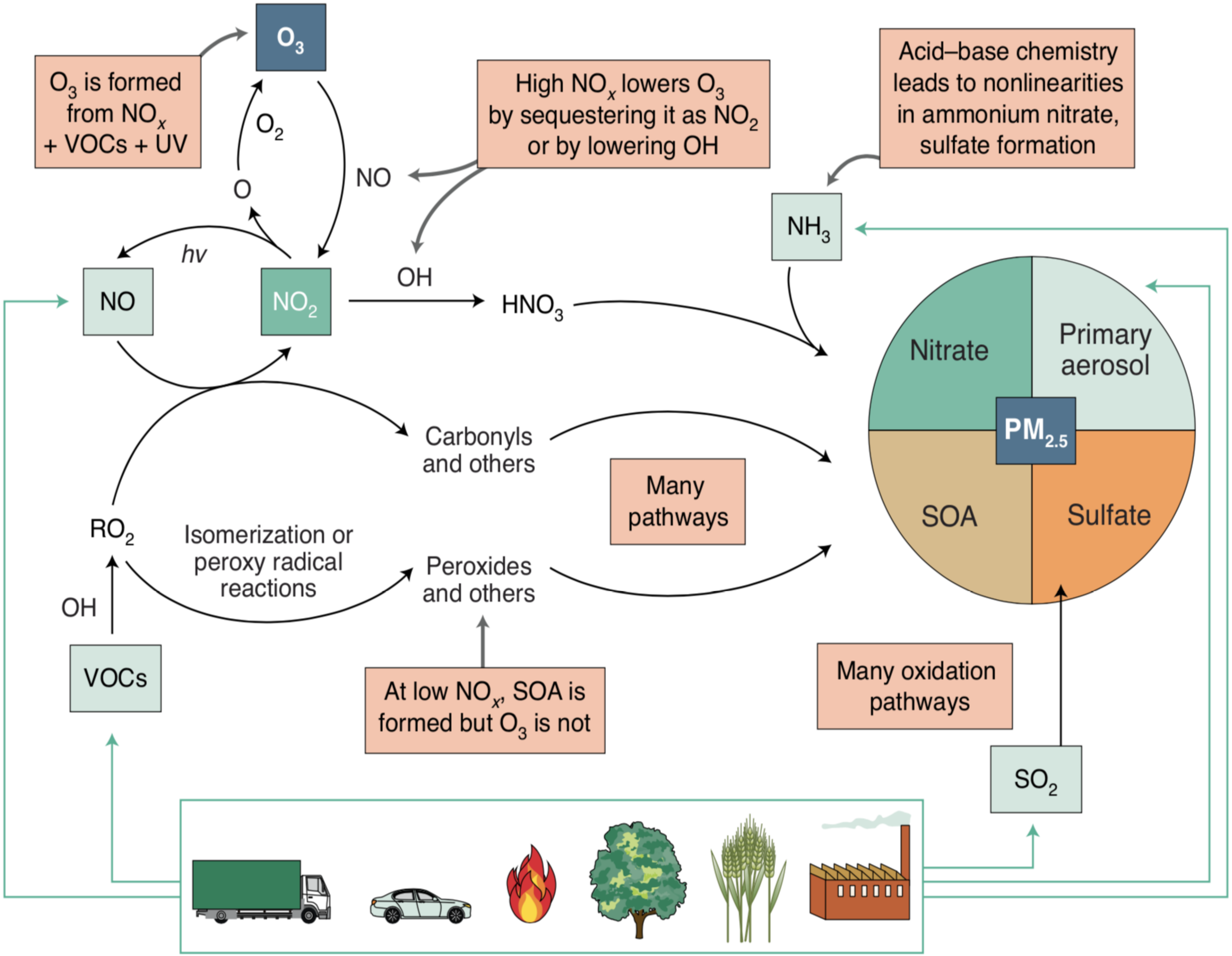




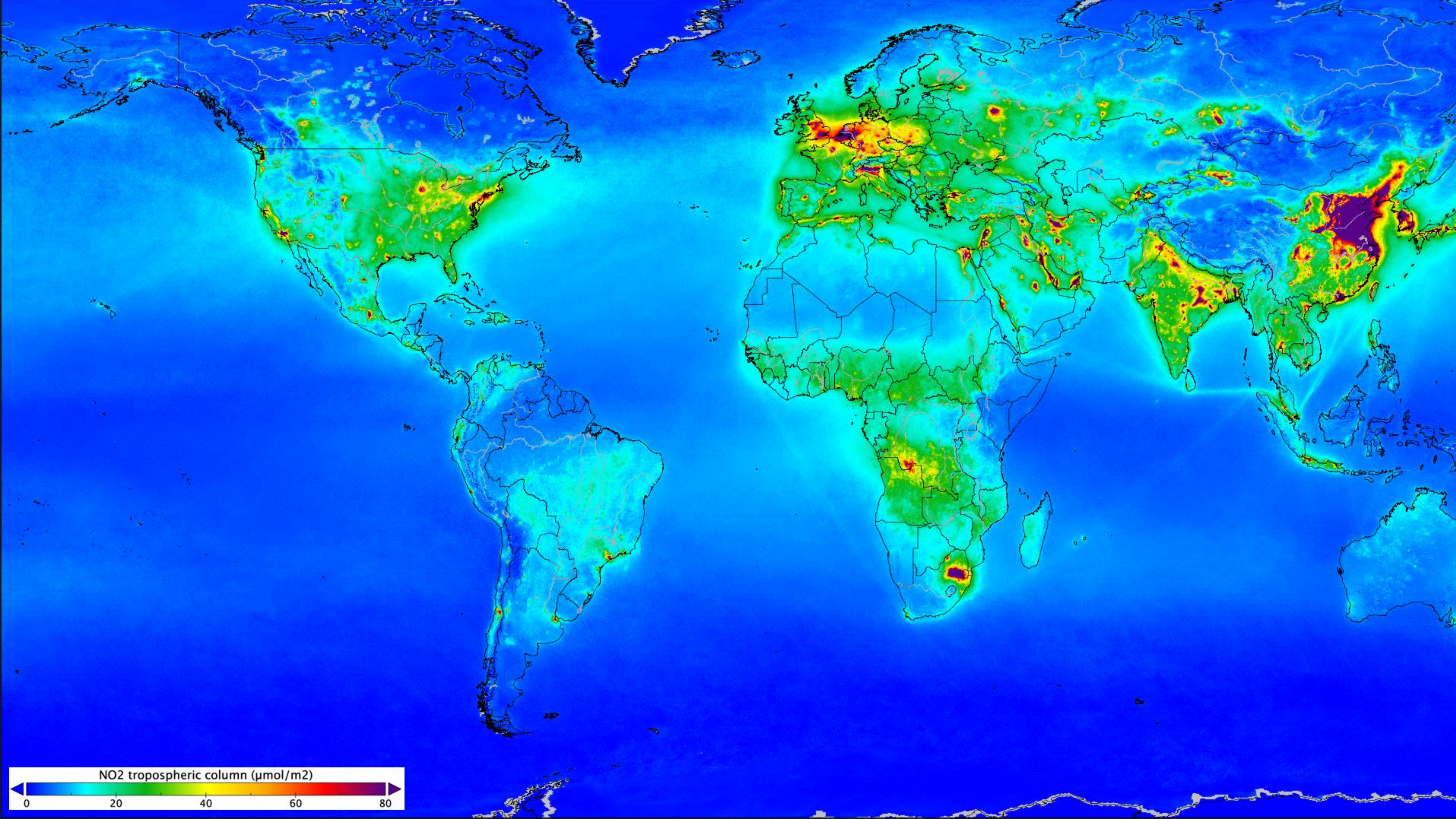
Chemical Mechanisms

Simplified overview of the atmospheric chemistry of ozone and PM2.5.

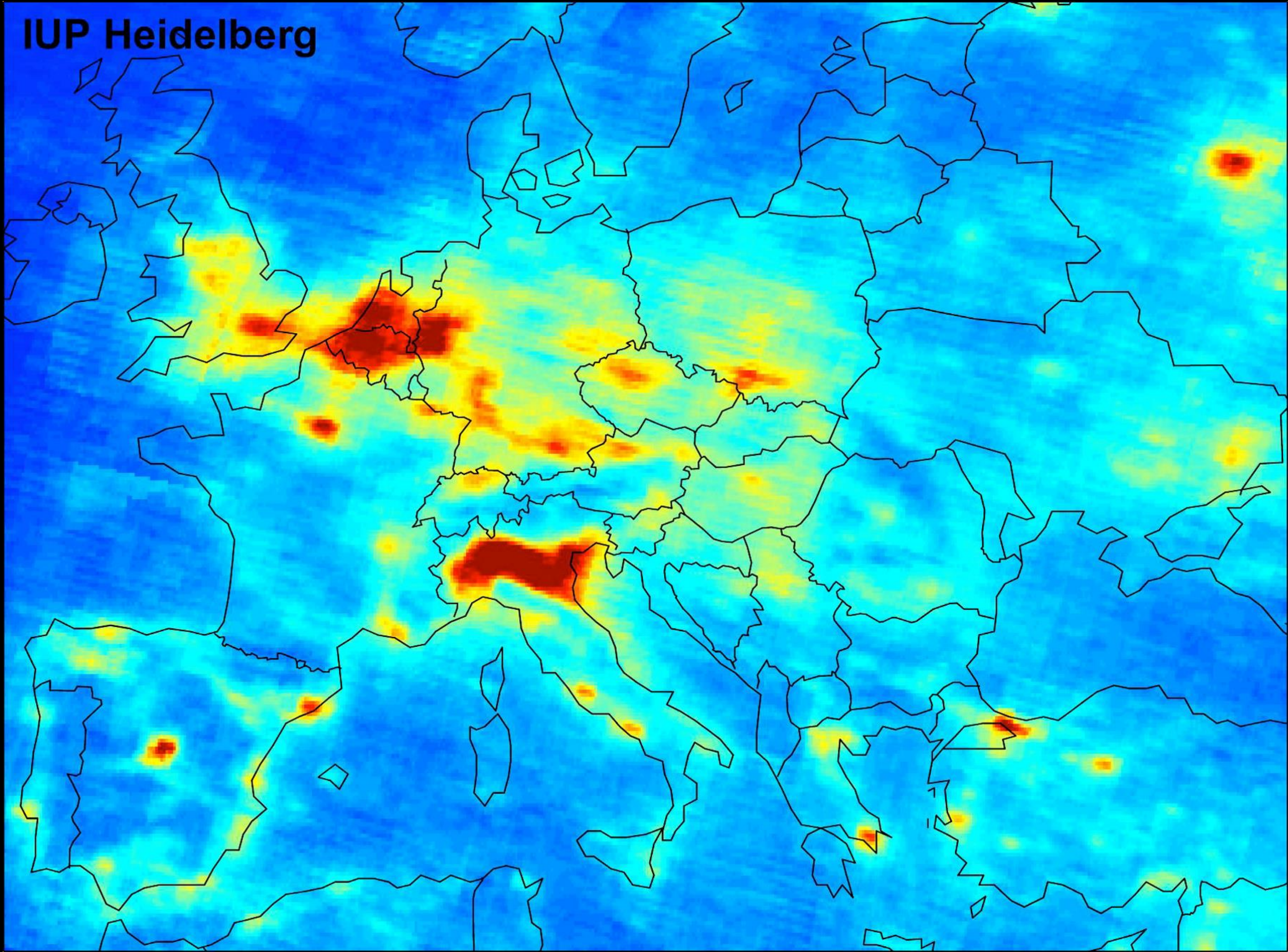
Kroll et al., Nature Chemistry September 2020



Space Observations

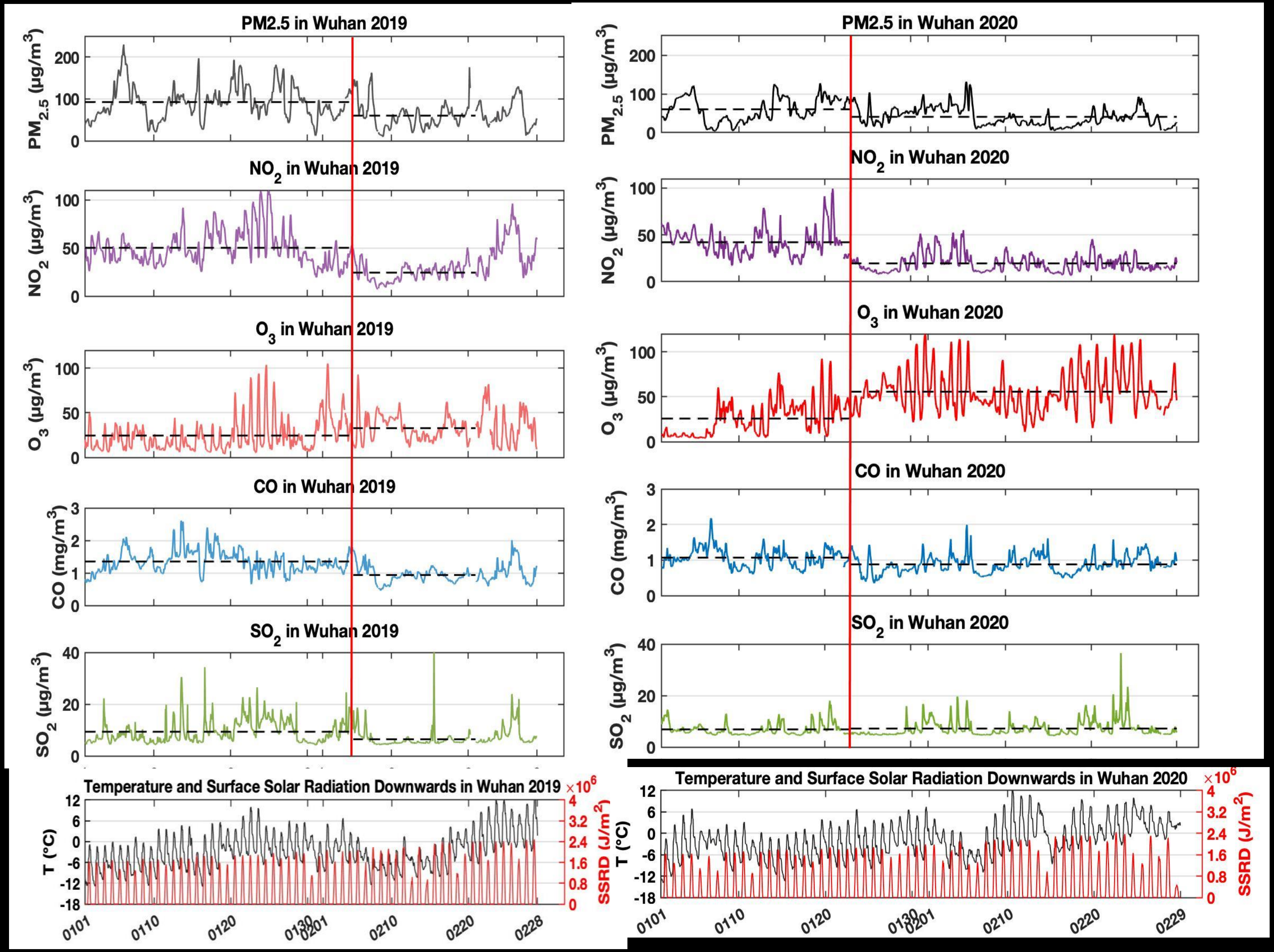

NO2 tropospheric column (µmol/m2)
0
20
40
60
80

Oxydes d’azote mesurés de l’espace en Europe



Surface Measurements

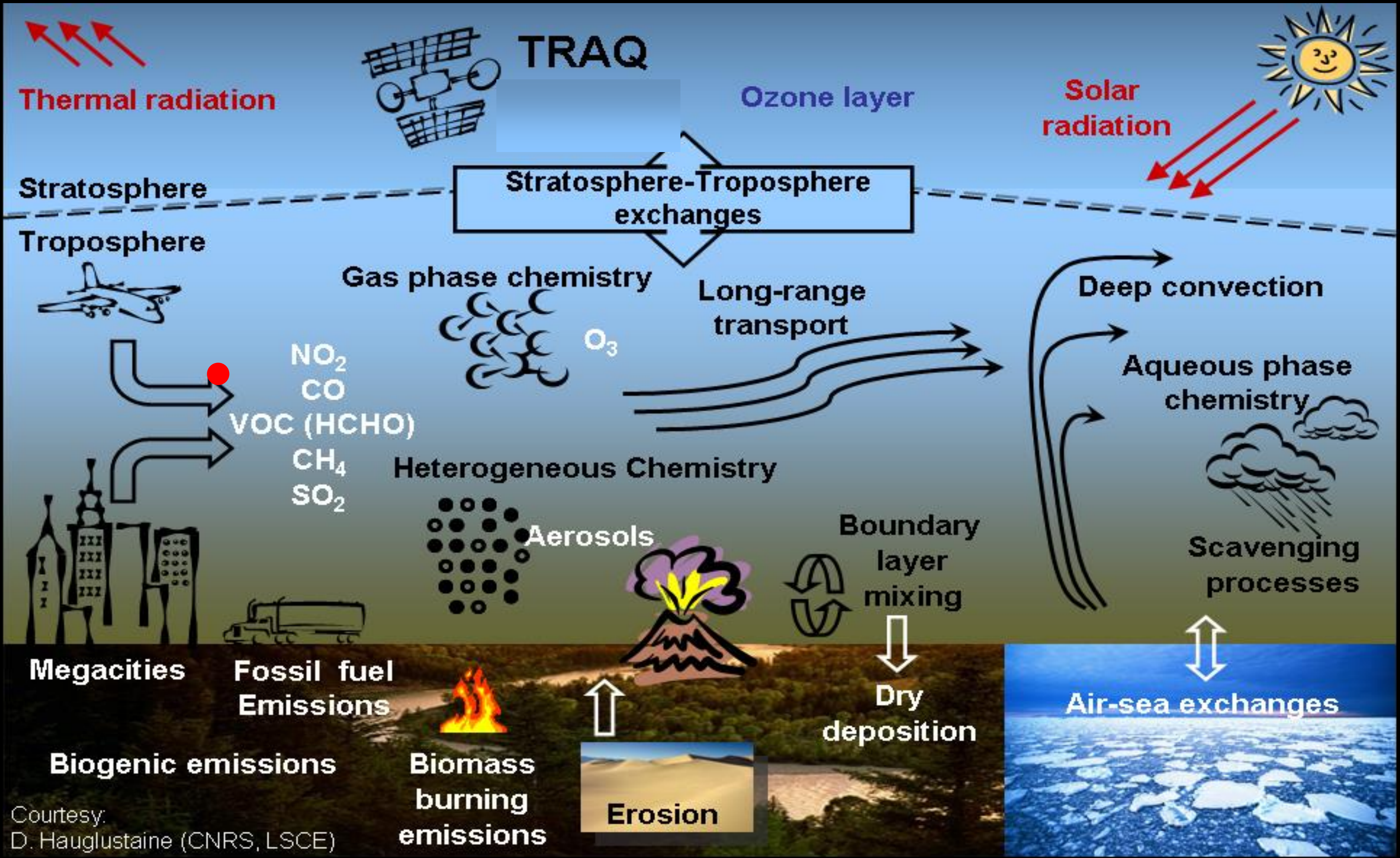
Observations in Wuhan



Shi and Brasseur, GRL, 2020

Multi-scale Modeling

Developing a Predictive Understanding of the Complex Atmospheric System and its Interactions with the Whole Earth System

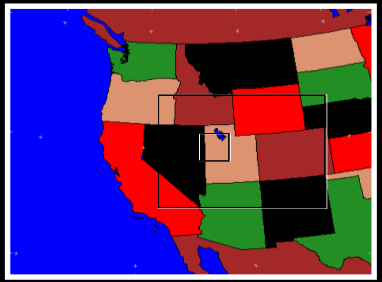


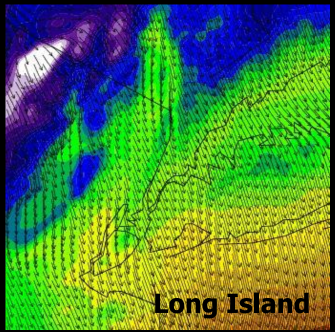
A Spectrum of Coupled Scales

How do global and hemispheric patterns influence regional and local events?

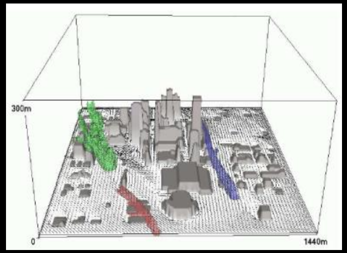

Global Scales

Continental Scales


Regional Scales



Local Scales


Urban Scales

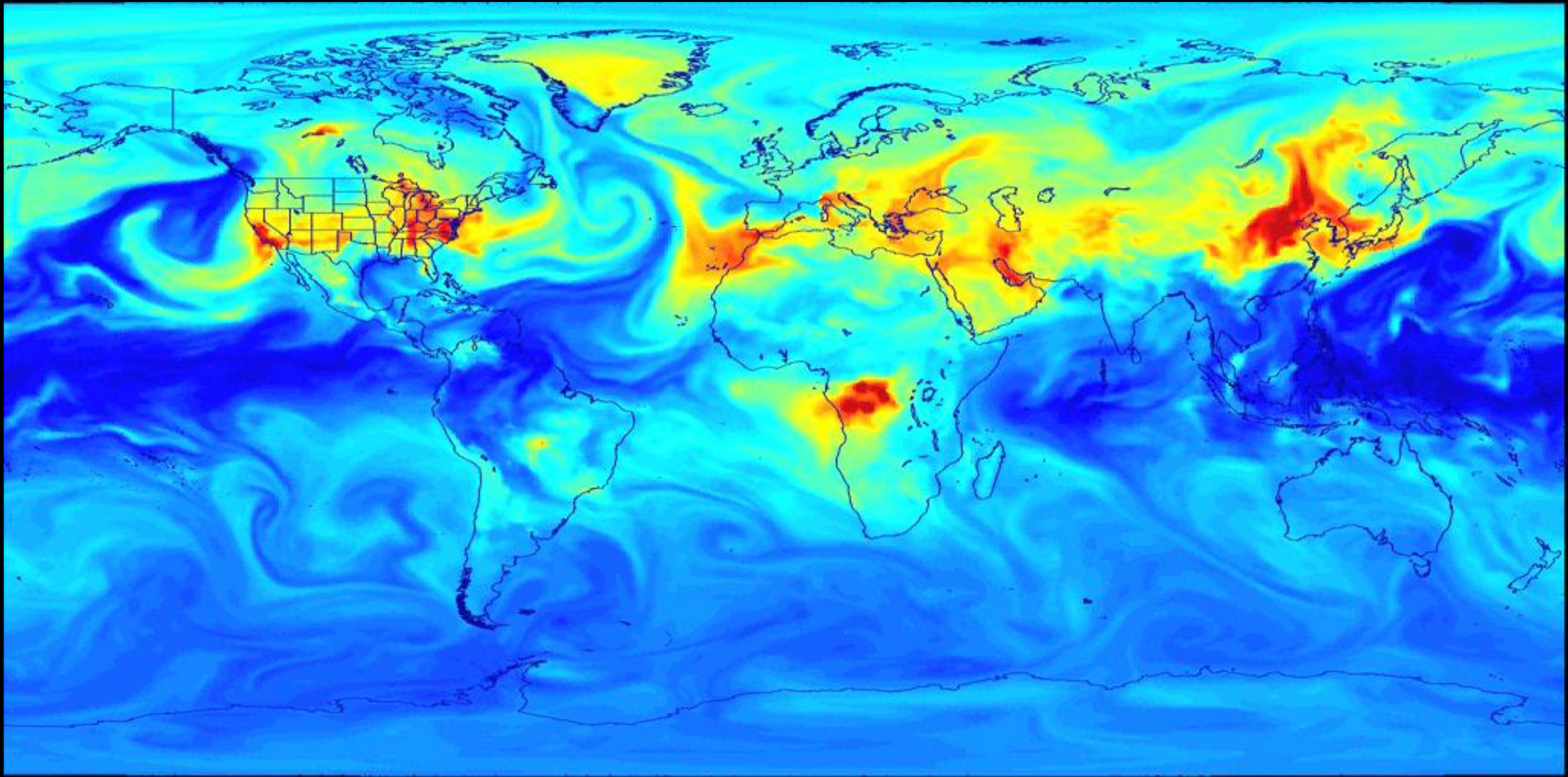
Influences of local pollution sources on the regional and global scales

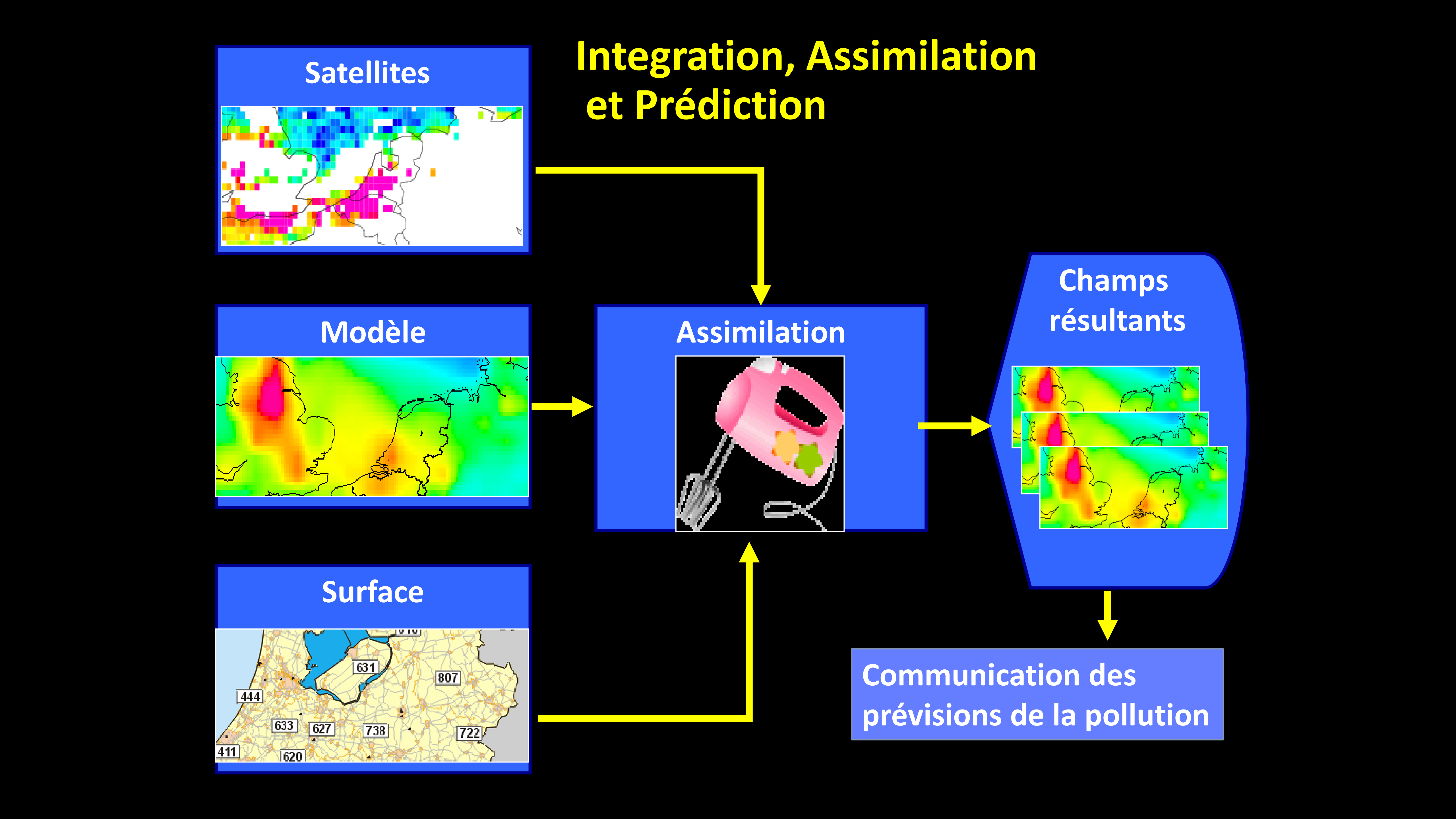
From Xuemei Wang

Les modèles globaux de la qualité de l’air

CAM-chem at 0.5° - Surface Ozone

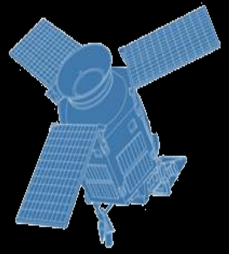
From *Louisa Emmons, NCAR*





Integration, Assimilation
et Prédiction
Satellites
Modèle
Surface
631
807
444
633
627
738
722
411
620
Assimilation
Champs
résultants
Communication des
prévisions de la pollution

The Copernicus Atmosphere Monitoring Service (CAMS)



Forecasts and informs on impacts

Detects emissions and estimate surface fluxes

Quantifies transport, removal and transformations of atmospheric constituents

CAMS en trois chiffres:

280 millions d'observations analysées toutes les 12 heures

Donées de **70 instruments spatiaux** are reçus et utilisés

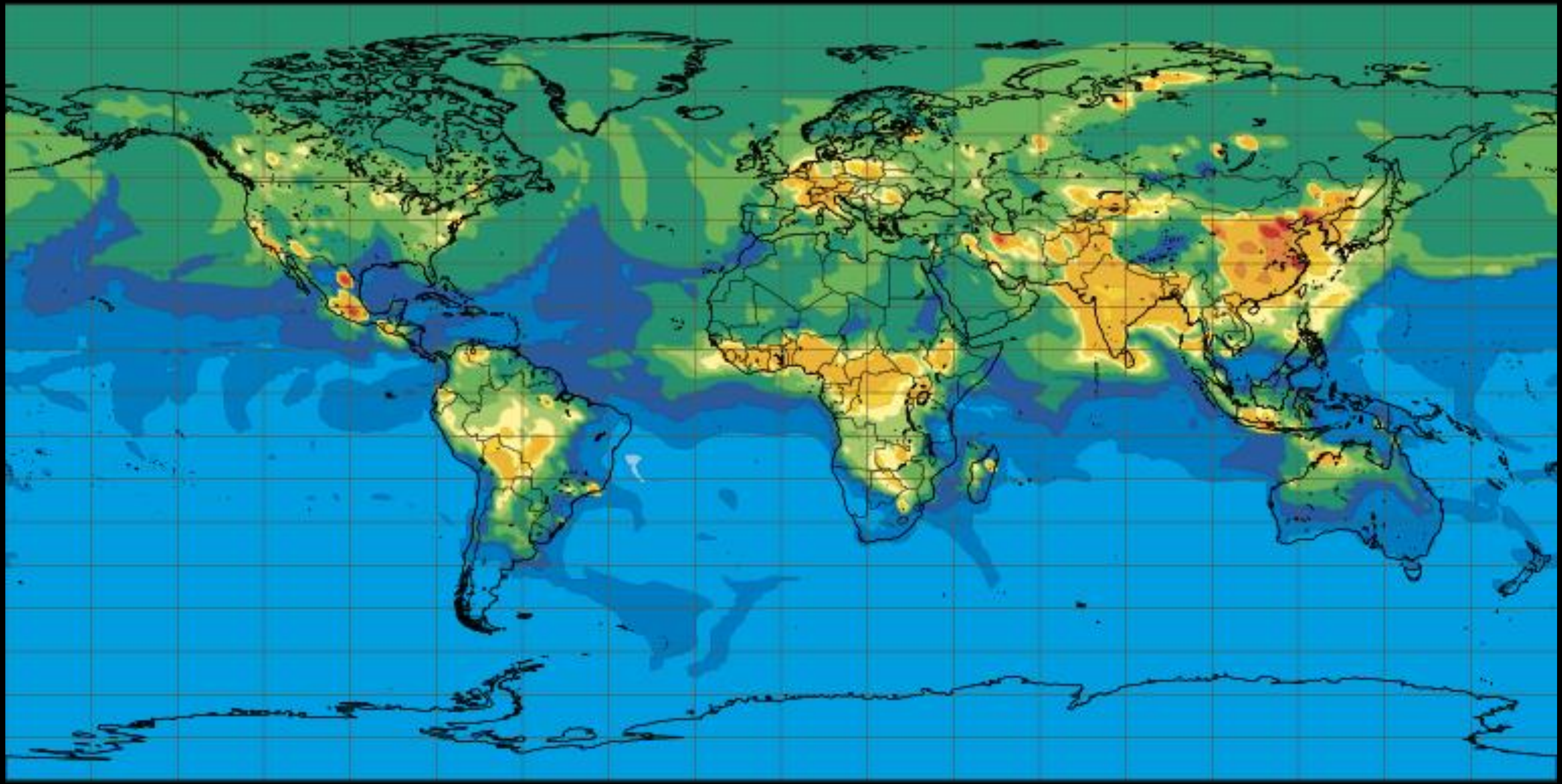
Produit chaque jour **14,000 cartes qui sont en ligne.**

From "Meteorological Weather" to "Chemical Weather" Environmental Forecasts

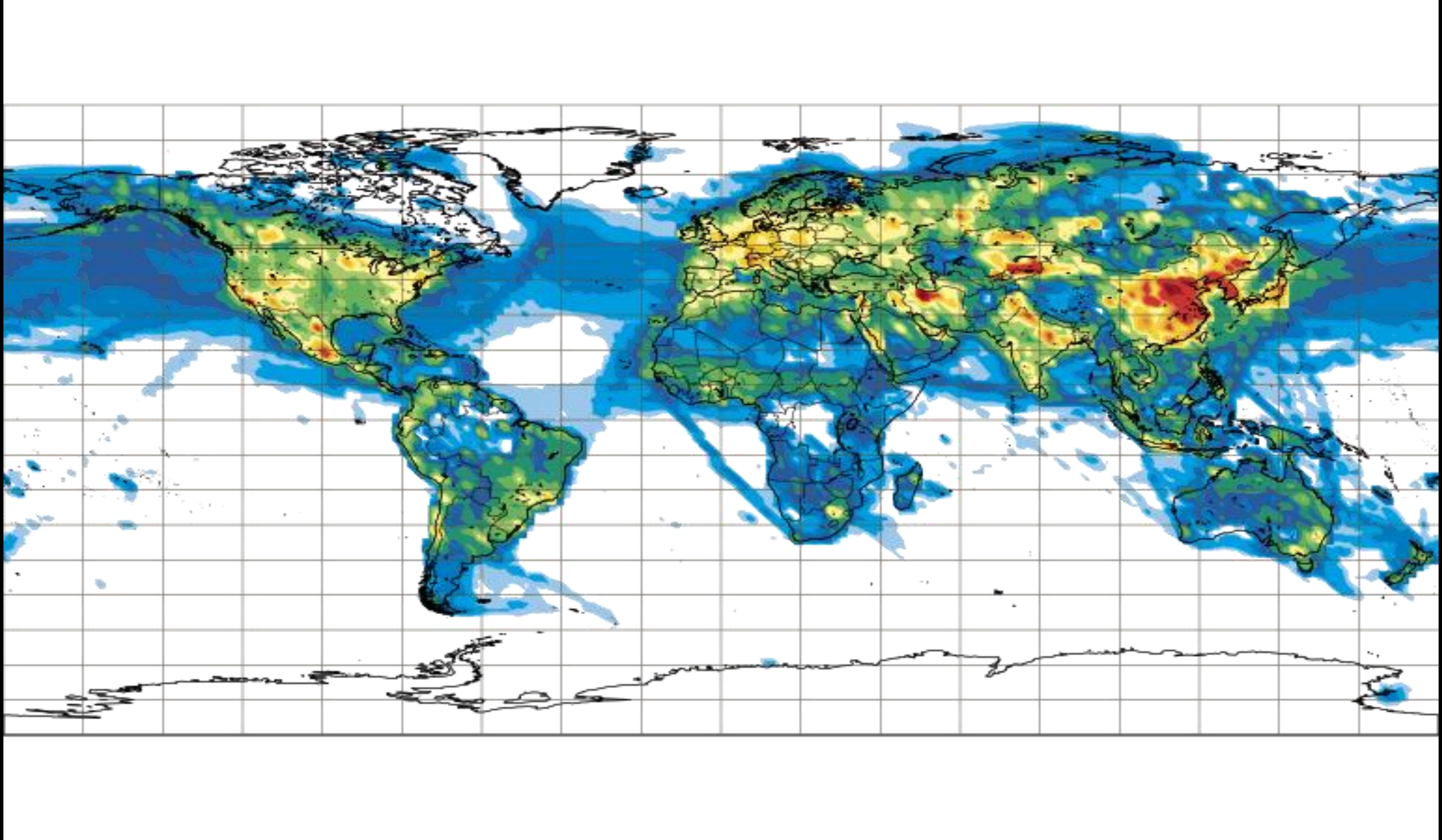
Chemical Weather forecasts are fundamentally based upon similar methodologies and tools as the ones successfully used for today's numerical weather predictions.

"The quiet revolution of Numerical Weather Prediction"
Sept. 2015

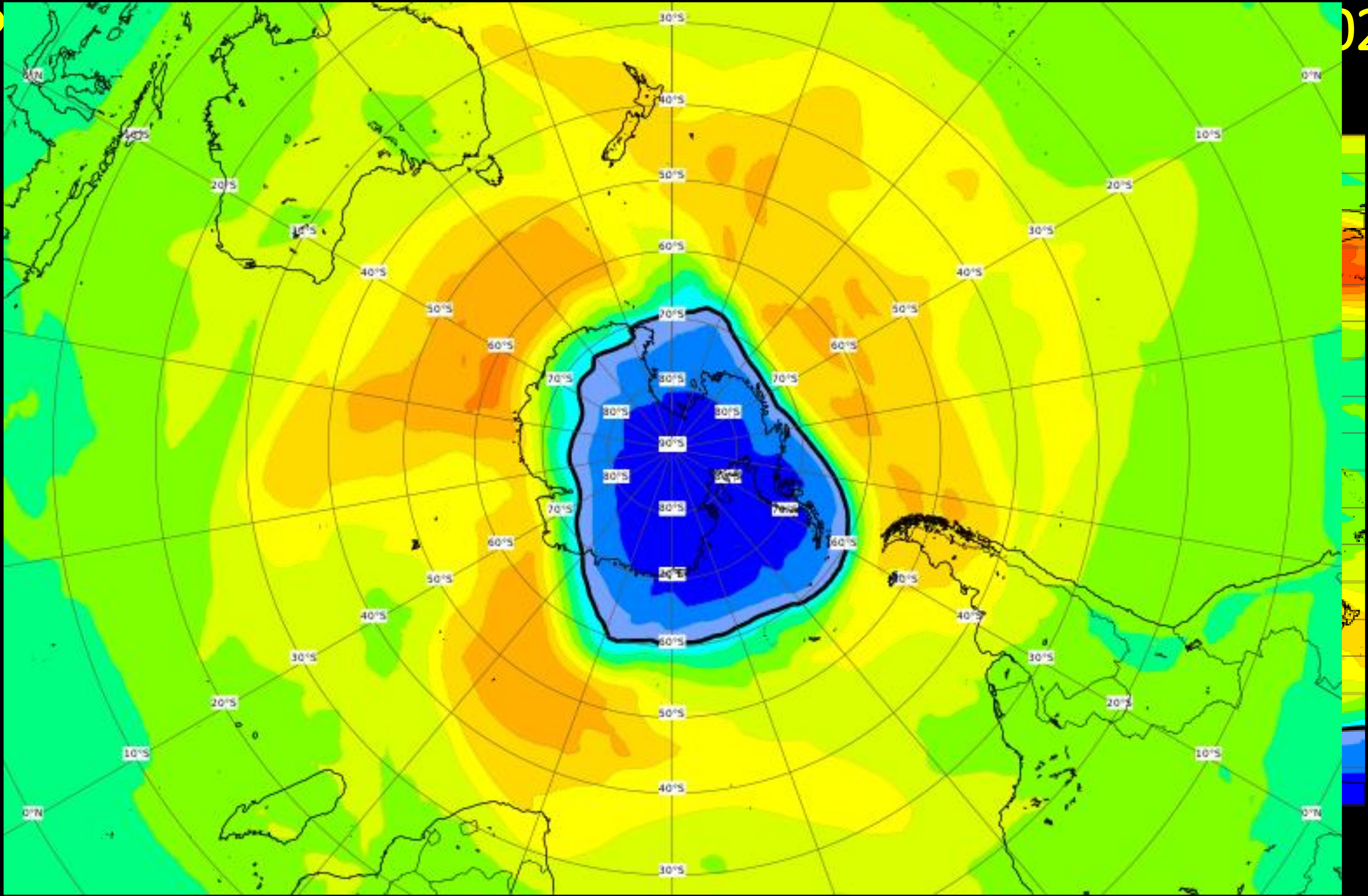
Prévision de CO à la surface pour le 25 novembre 2020



Prévision de NO2 à la surface pour le 25 novembre 2020



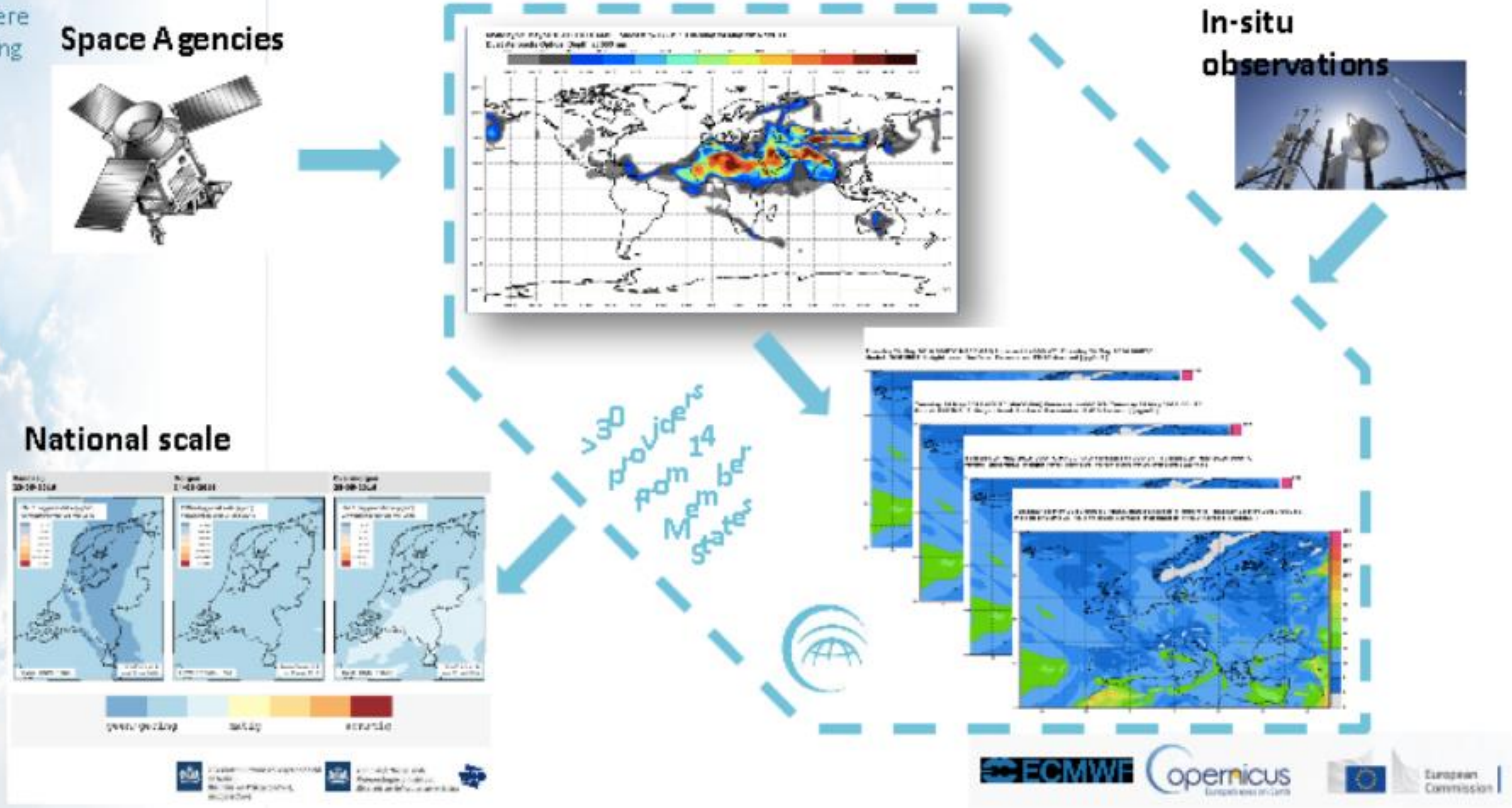
P … 020



Regional Air Quality Models

Atmosphere Monitoring

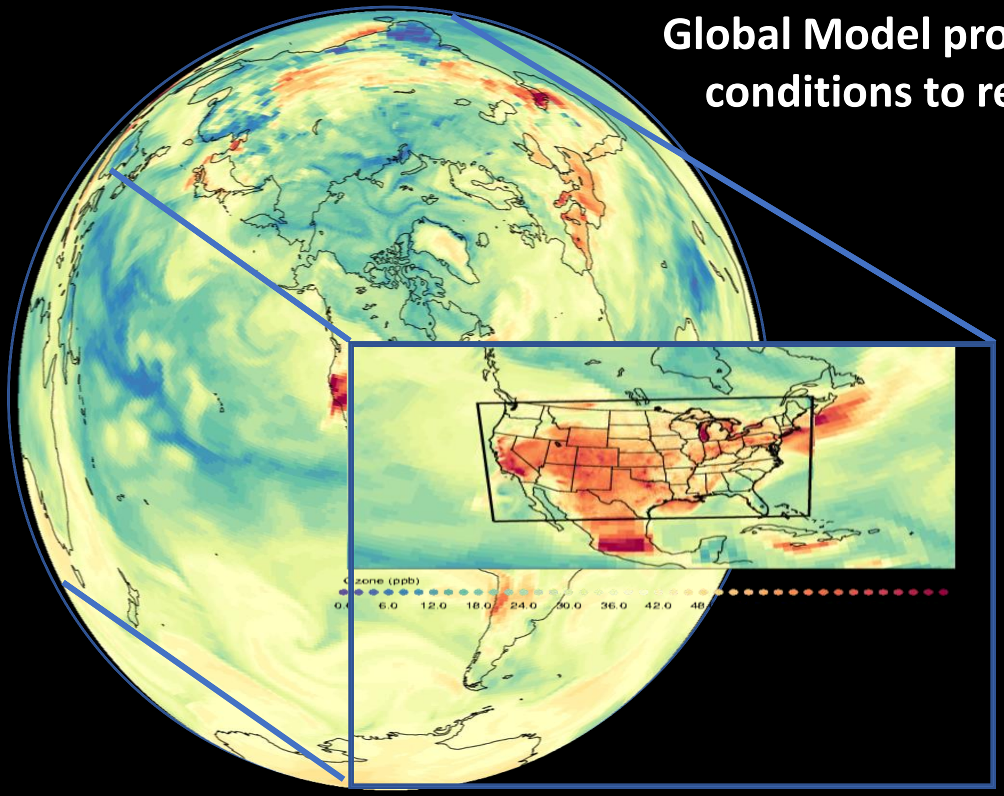
CAMS SERVICE CHAIN



NCAR Air Quality Predictions

- **Daily Global Air Quality Predictions**: 10-day forecast with WACCM
- **U.S. Air Quality Predictions**: 2-day forecasts with WRF-Chem driven by WACMM boundary conditions. 12 km over CONUS, 4 km over Colorado.

Global Model provides boundary conditions to regional model



- Test model performance in near real-time
- Support field campaign design and forecast
- Provide information for stakeholders & public

https://www2.acom.ucar.edu/acresp/forecasts-and-near-real-time-nrt-products

Operational Forecasting System at MPI-M with WRF-Chem
(DKRZ, Hamburg, Germany)

6pm (LT)

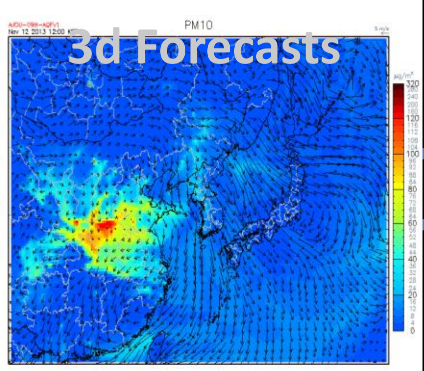
NCEP GFS

Meteorol. Forecasts

10pm (LT)

WRF Meteo spinup

00:00 (LT):



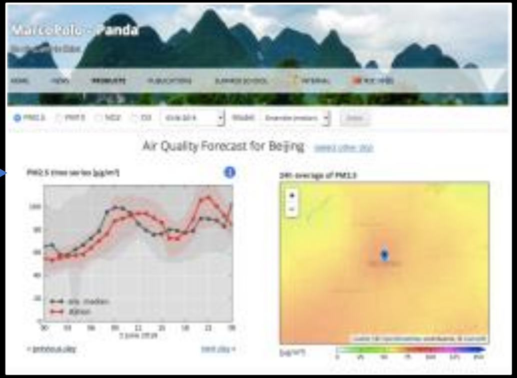
10pm (LT)

Chem. BC: ECMWF CAMS

Chem. IC: Day -1 Forecast

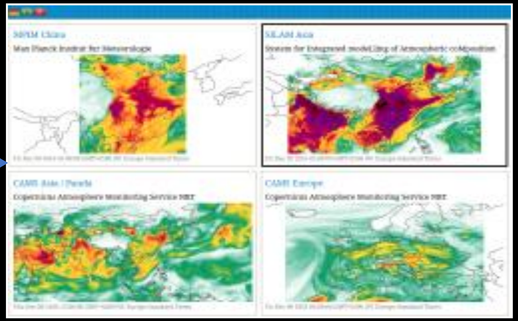
HTAPv2 FINN Emissions

KNMI
www.marcopolo-penda.eu

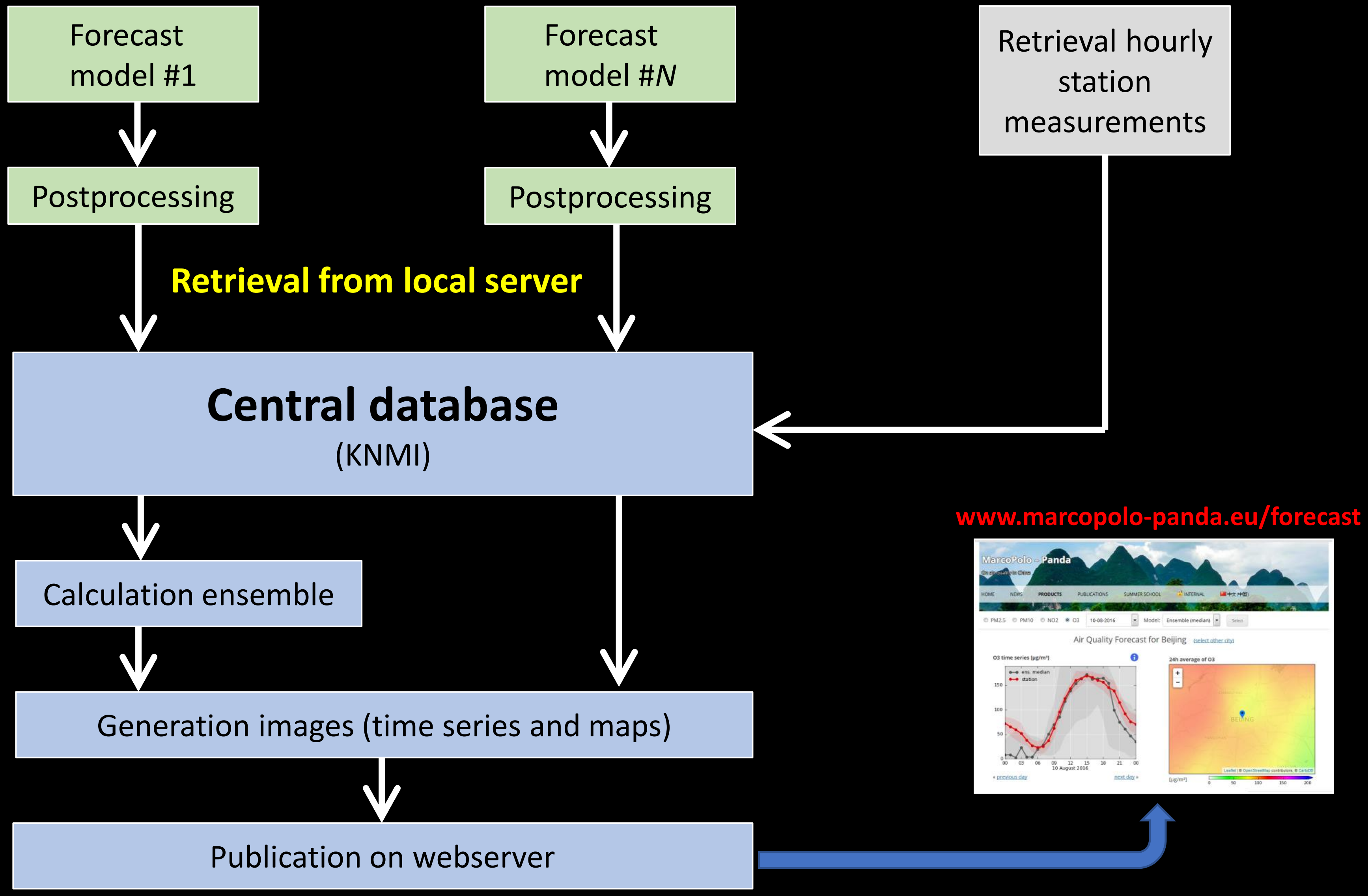


Dissemination

aqicn.org/forecast

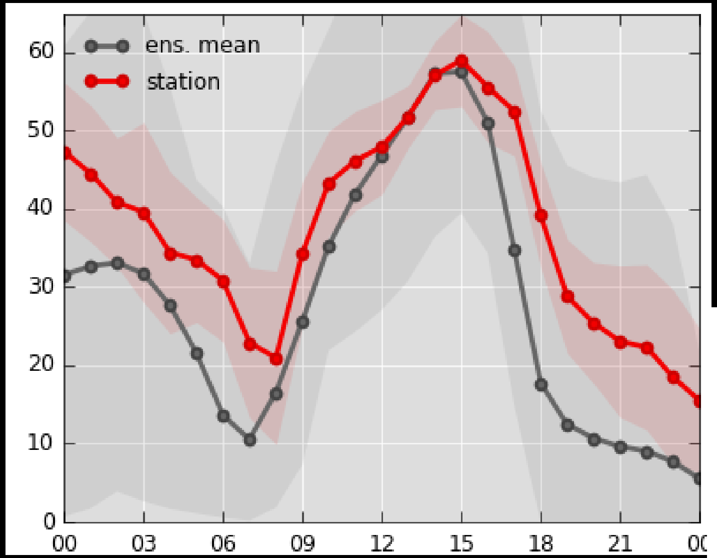


Schematic Overview Data Flow



Ensemble Ozone Forecasts
Beijing 12 October 2020
[micrograms/m^3]

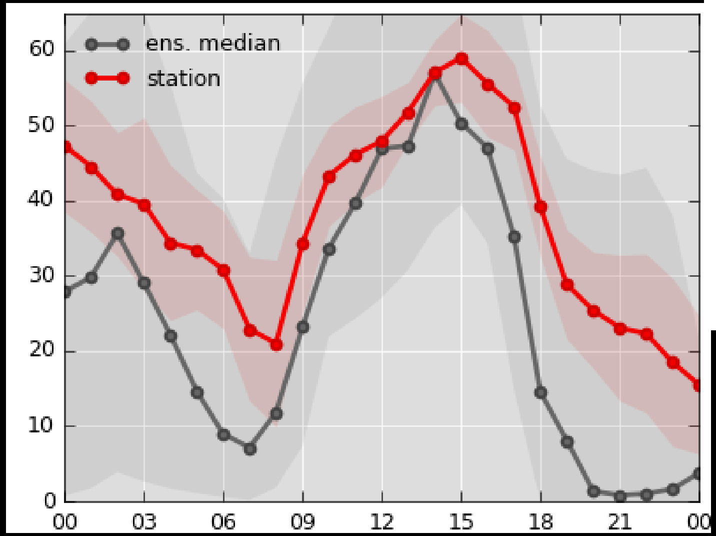
Mean

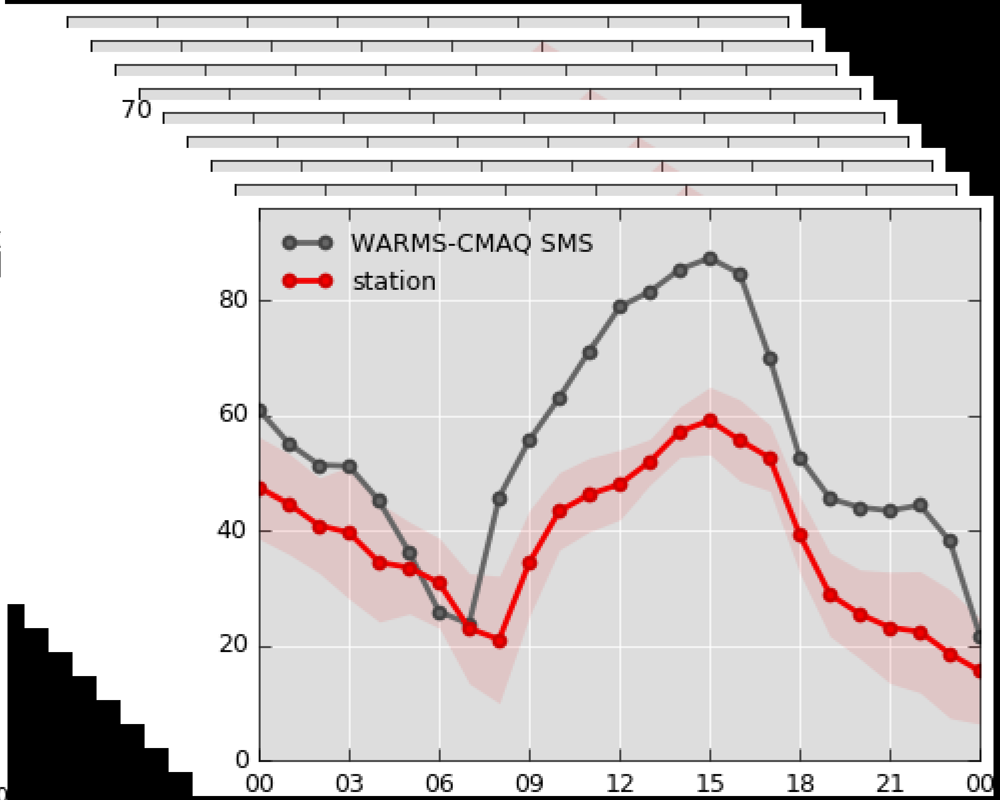


马可·波罗
MARCOPOLO

PANDA 熊貓
PArtnership with ChiNa on space DAta

Median

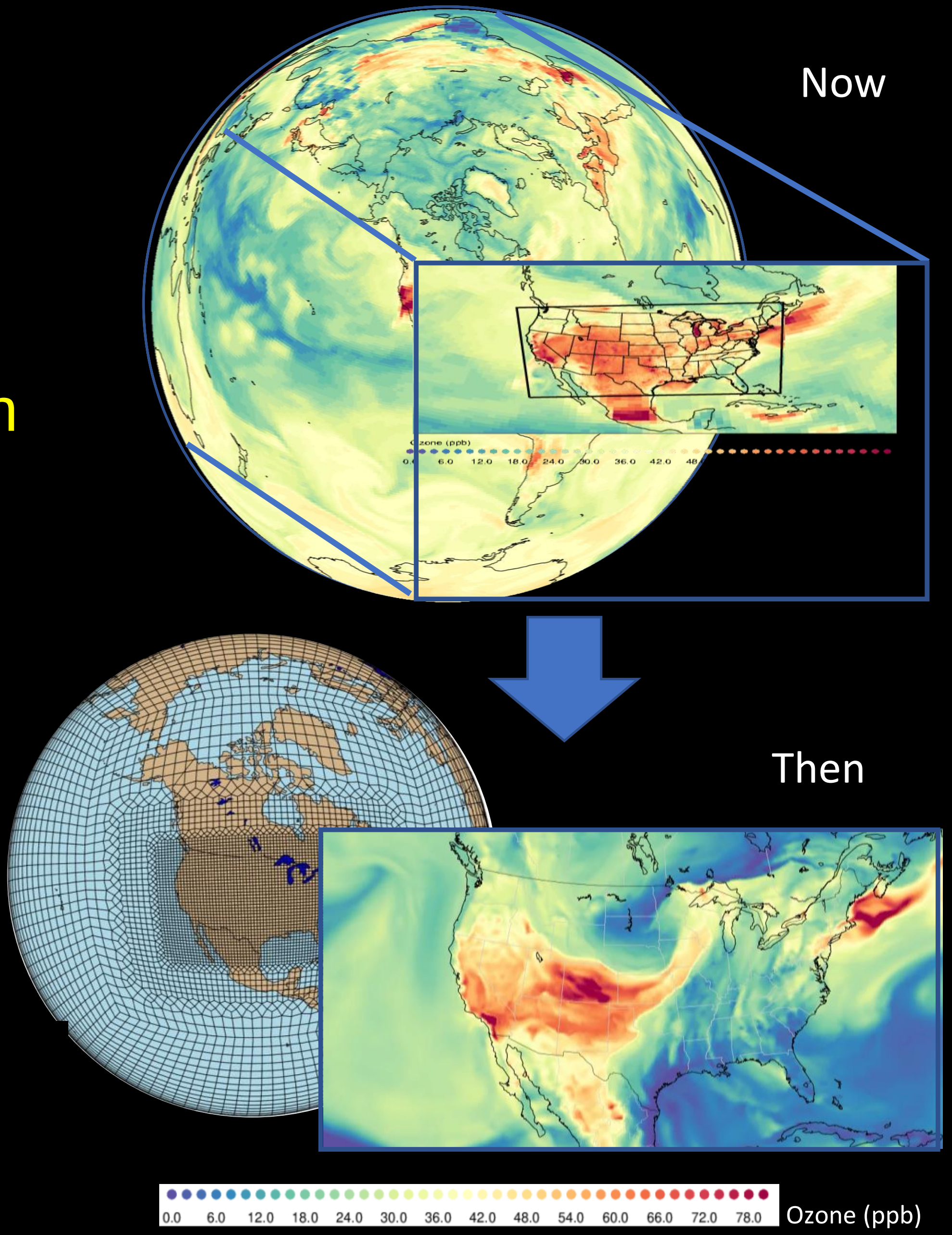




MUSICA

A new *community* model-independent infrastructure, which will enable chemistry and aerosols to be simulated at different resolutions in a coherent fashion

- Fully coupled Earth System Framework
- Whole atmosphere representation: Surface to thermosphere
- Facilitate use of a variety of chemistry & physics schemes, and atmospheric models in a flexible modular way
- Modern Software Design



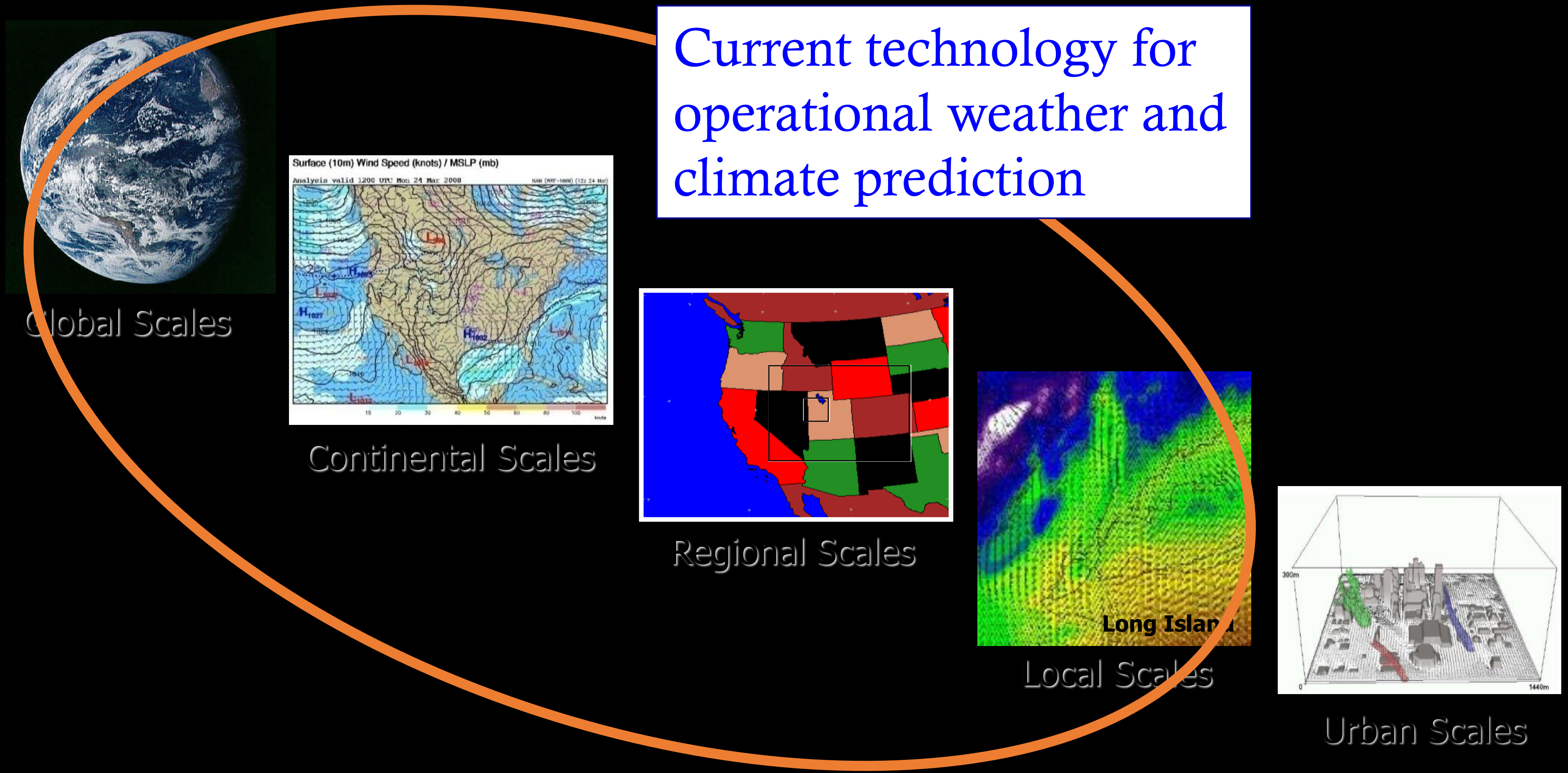
https://www2.acom.ucar.edu/sections/multi-scale-chemistry-modeling-musica
Visit the website to join Working Groups, get information about upcoming tutorials and more.

MUSICA Vision paper published in BAMS
(Pfister et al., 2020: https://doi.org/10.1175/BAMS-D-19-0331.1)

Les modèles locaux de la qualité de l’air

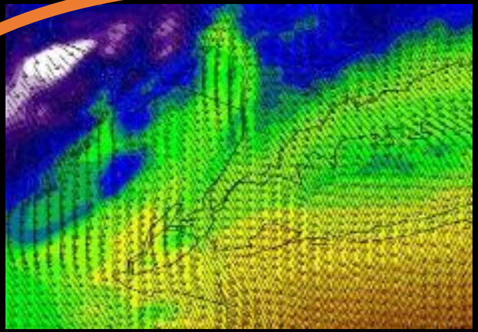
Modélisation Aria - Mozilla Firefox
Modélisation Aria
Champs-Elysées
Tour Eiffel - Parc du Champ-de-Mars
Google earth
NO
Déconnexion

The physical modeling system:
----A spectrum of coupled scales

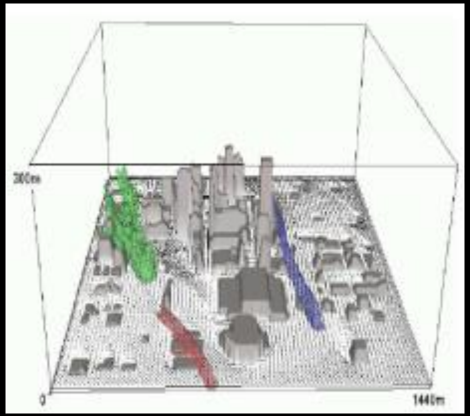


Challenge in representing multi-scale urban microclimate

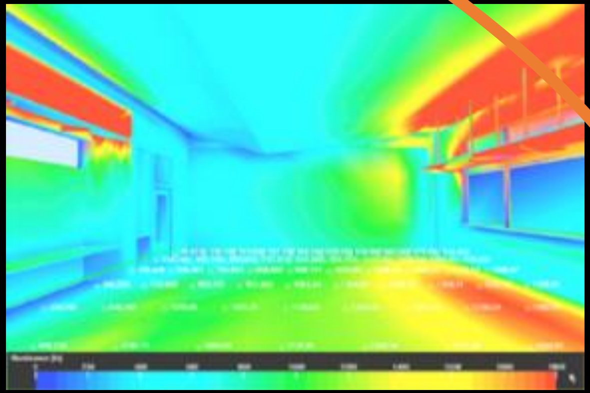
New technology for coupling fine-scale models



Mesoscale models



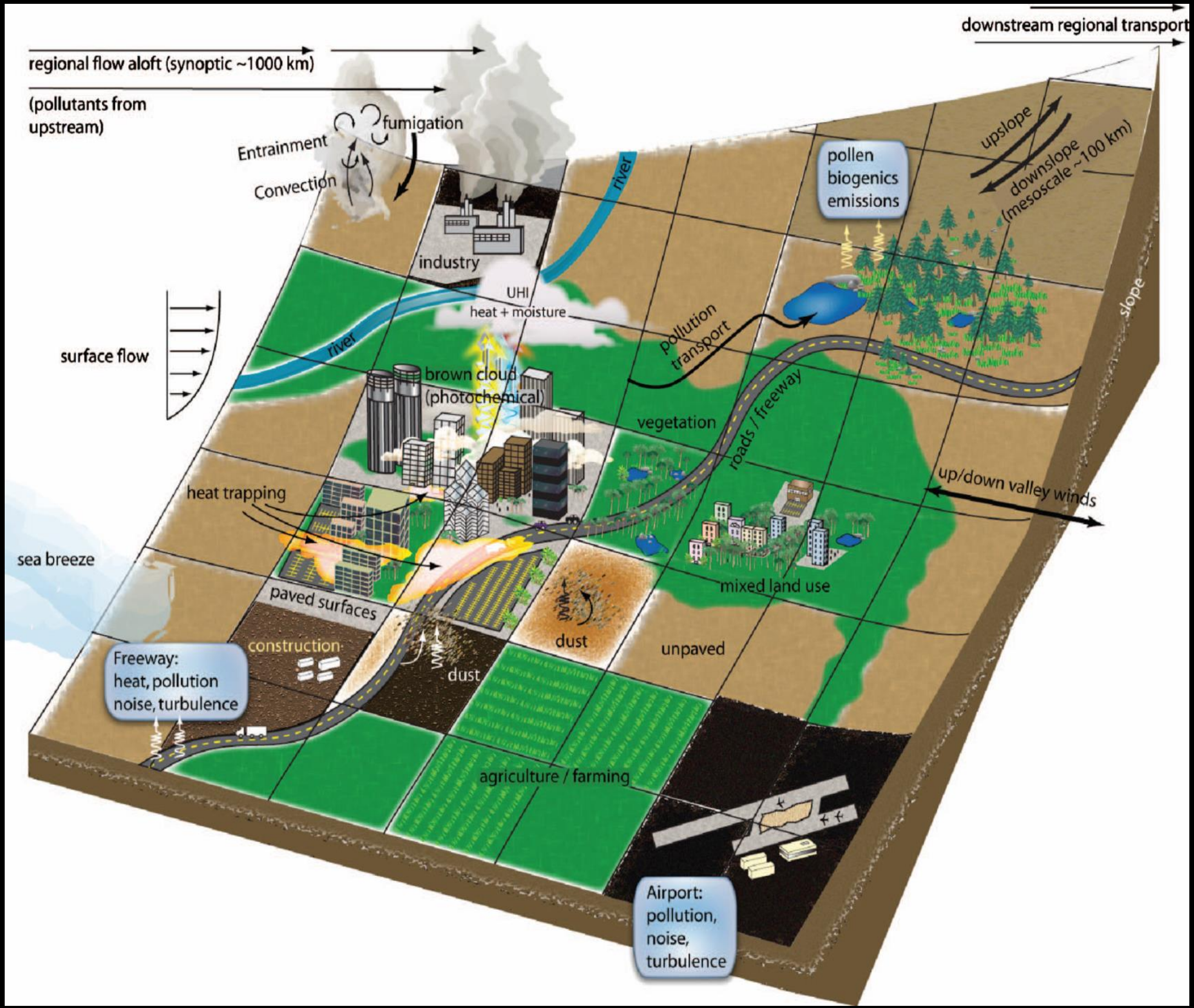
Urban Scale models (CFD, LES)



Building energy models
Indoor-outdoor exchange

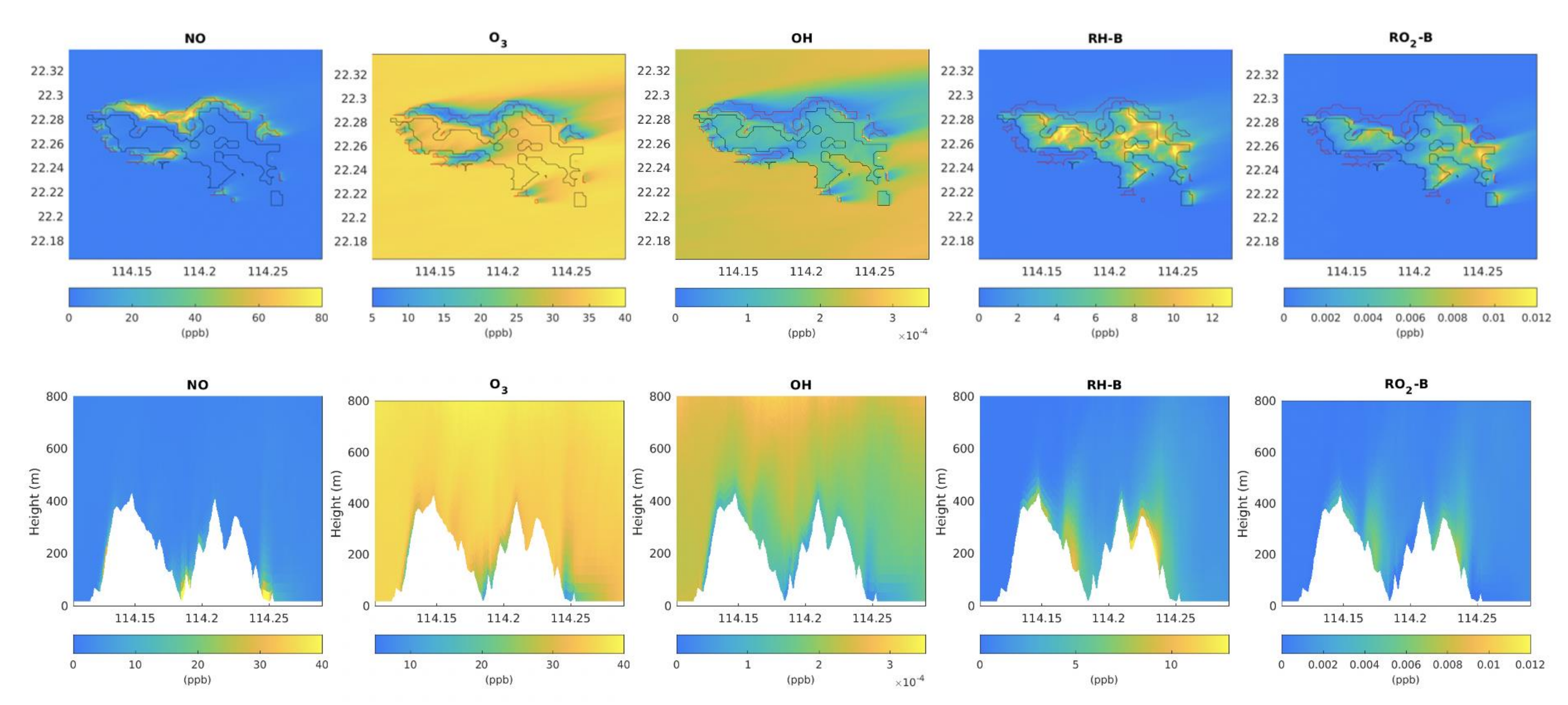
Chemical Transport Models (CTMs)

Flow, turbulence, and pollutant dispersion in urban atmospheres



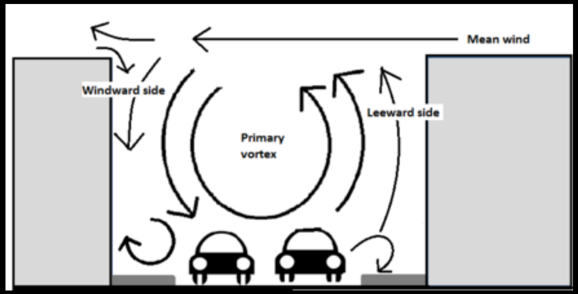
From
Fernando et al.
(2010)

Distribution of chemical species in and along the Hong-Kong Island calculated by a Large Eddy Simulation (LES) model at 100 m resolution



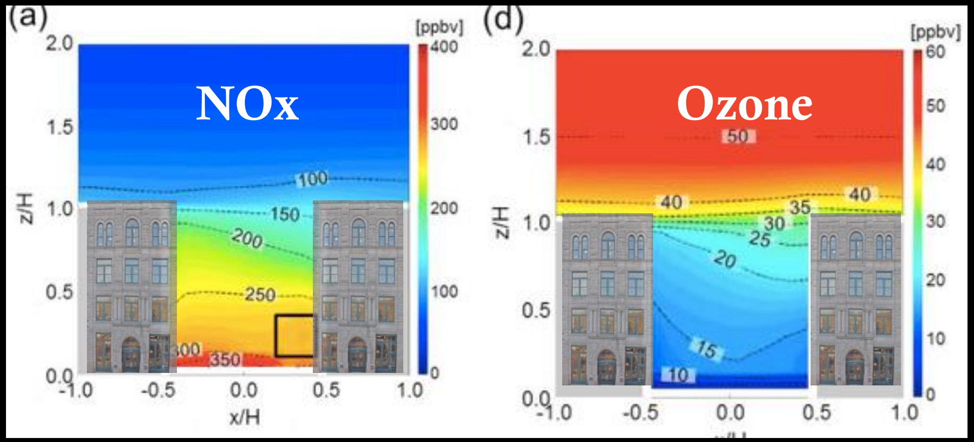
Application to the the urban area of Hong Kong

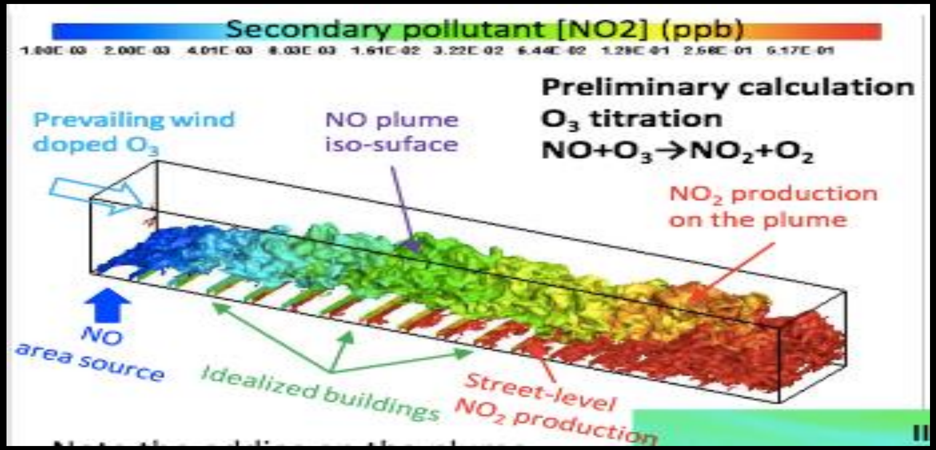
- Hong Kong is characterized by a complex topography and canopy:
  - Mountains surrounding a complex coast line
  - Dense urban canopy with many high-rise buildings and street canyons



Downscaling Chemical Concentrations to sub-urban Scales

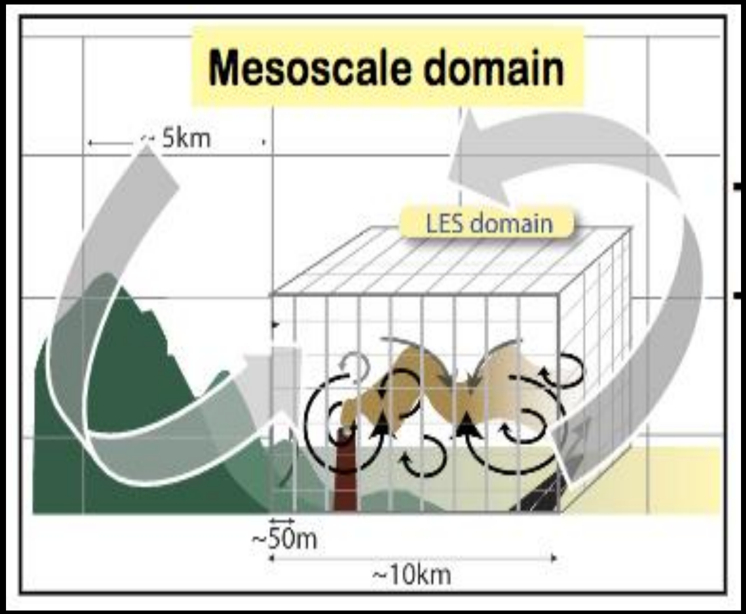
Large Eddy Simulations

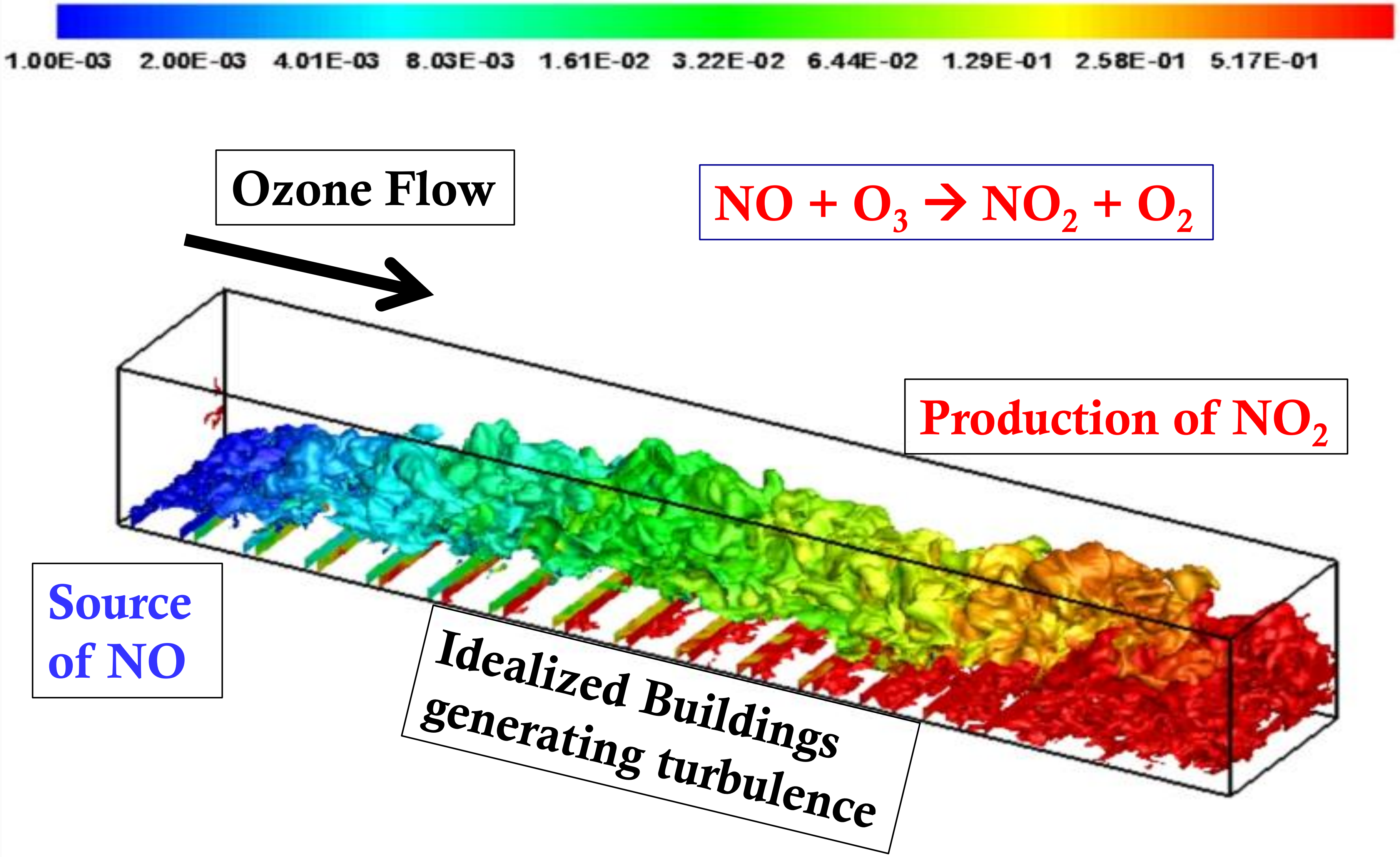




Locally emitted pollutants (e.g., NOx, VOCs) in street canyons interact chemically with background atmospheric species (e.g., ozone). Reaction rates are affected by **turbulence** mechanically and thermally generated in the urban canopy

Large eddy simulation (LES) models coupled to regional mesoscale models (e.g., WRF) will be used to simulate the turbulent transport and chemical transformations of pollutants in the urban environment.

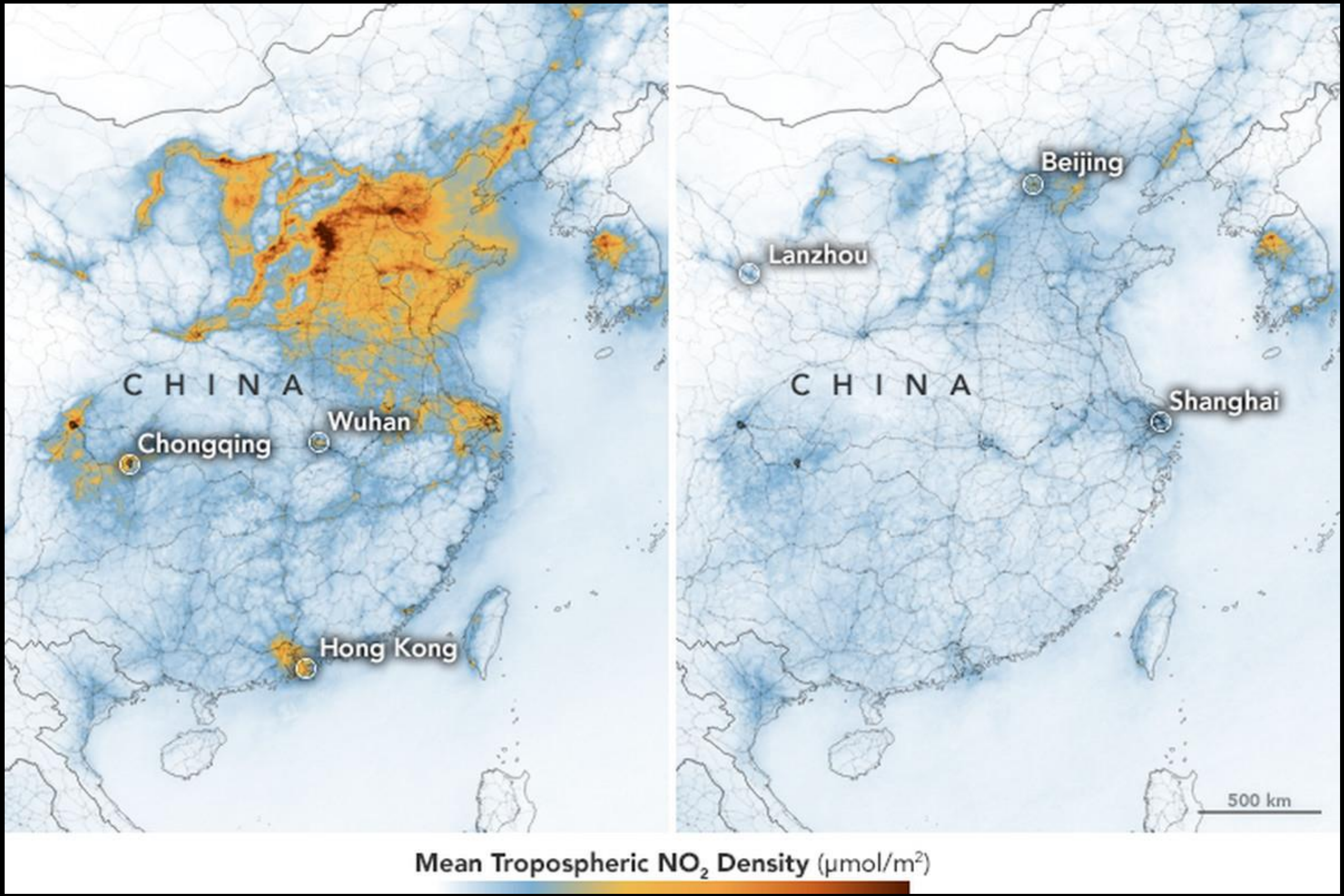




Model of Chun-Ho Liu
Hong Kong University

La Qualité de l'air pendant la COVID-19

NO_2

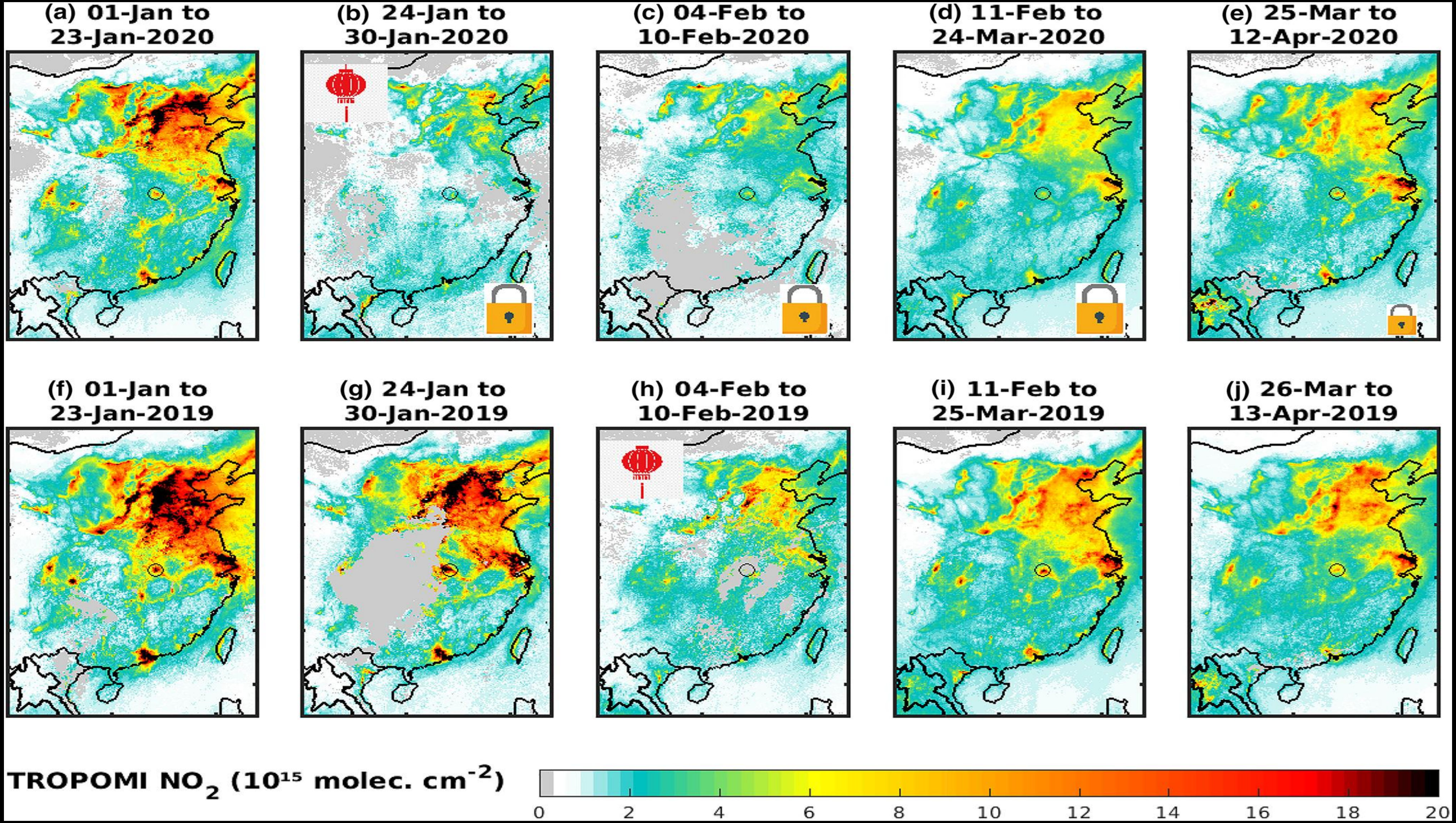


- Sharp reduction of NO_2 during the covid-event in China

Impact of Coronavirus Outbreak on NO2 Pollution Assessed Using TROPOMI and OMI Observations

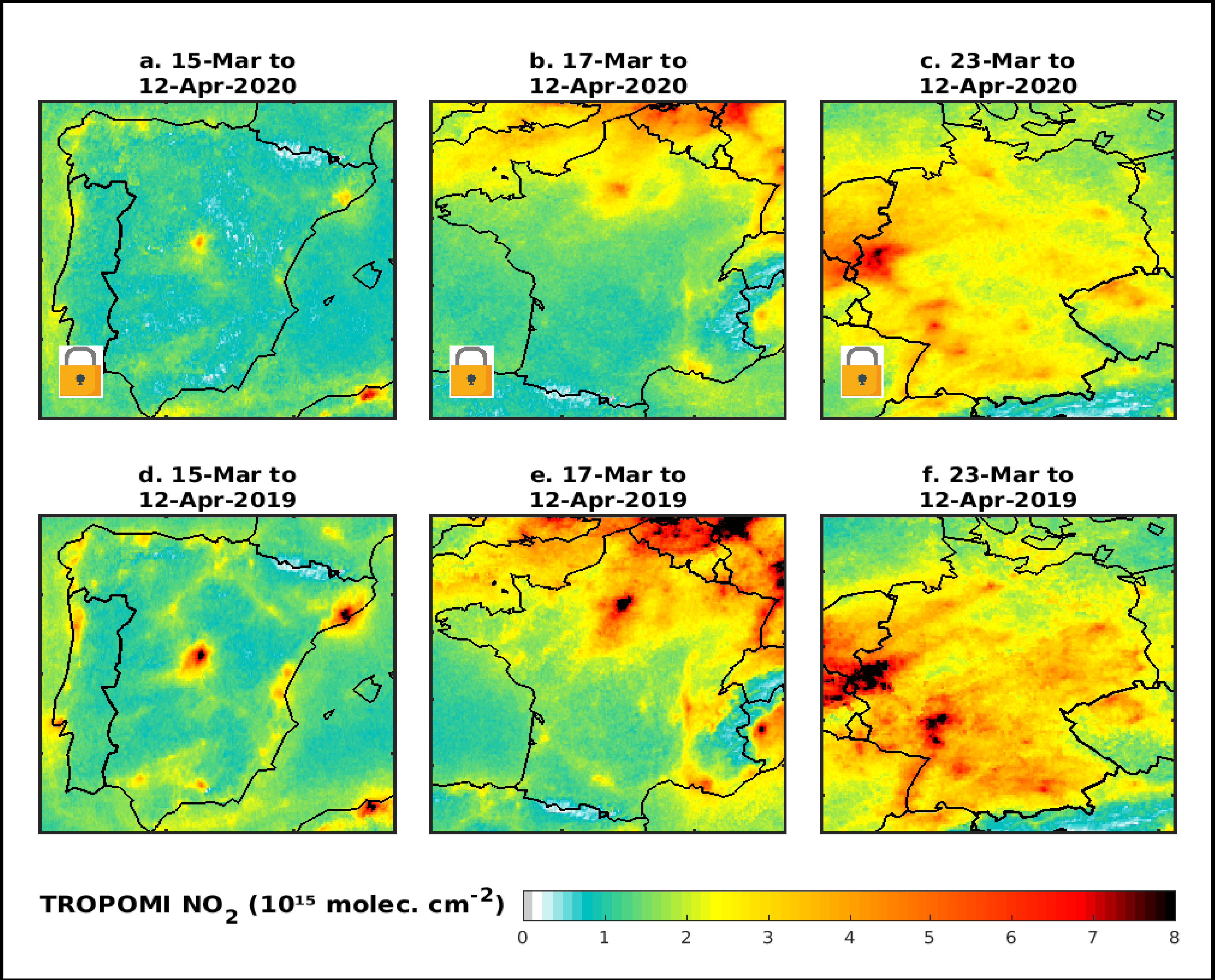
2020

2019



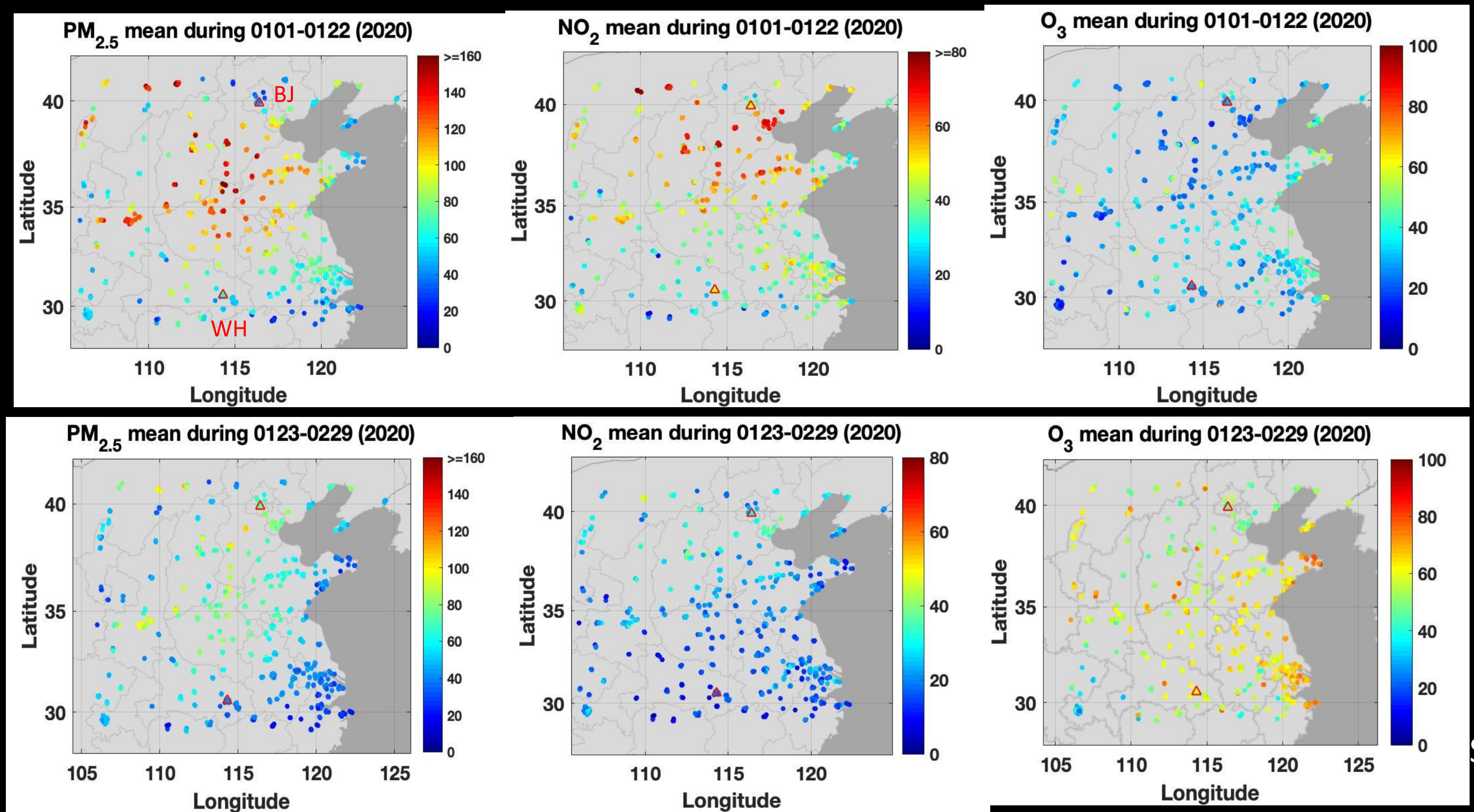
Geophysical Research Letters, Volume: 47, Issue: 11, First published: 08 May 2020, DOI: (10.1029/2020GL087978)

Reduction in NO2 during COVID-19 observed by TROPOMI and OMI



$PM_{2.5}$, NO_2 and O_3 in 2020 before and after the lockdown in China

PM2.5 **NO2** **ozone**



Before

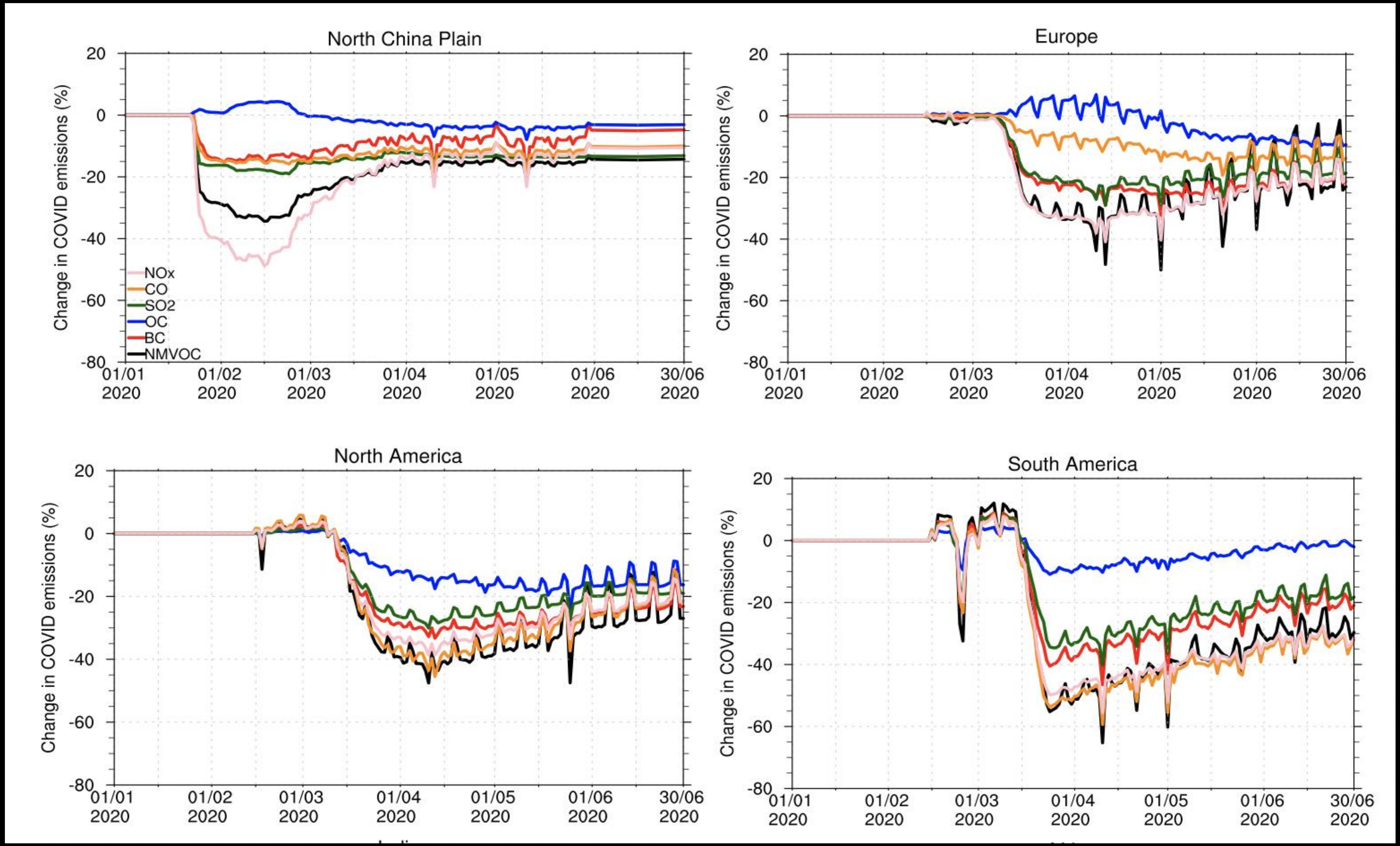
1-22 January 2020

After

23 January to 29 February 2020

Shi and Brasseur, GRL, 2020

Adjustment of the emissions during the pandemic in different regions of the world

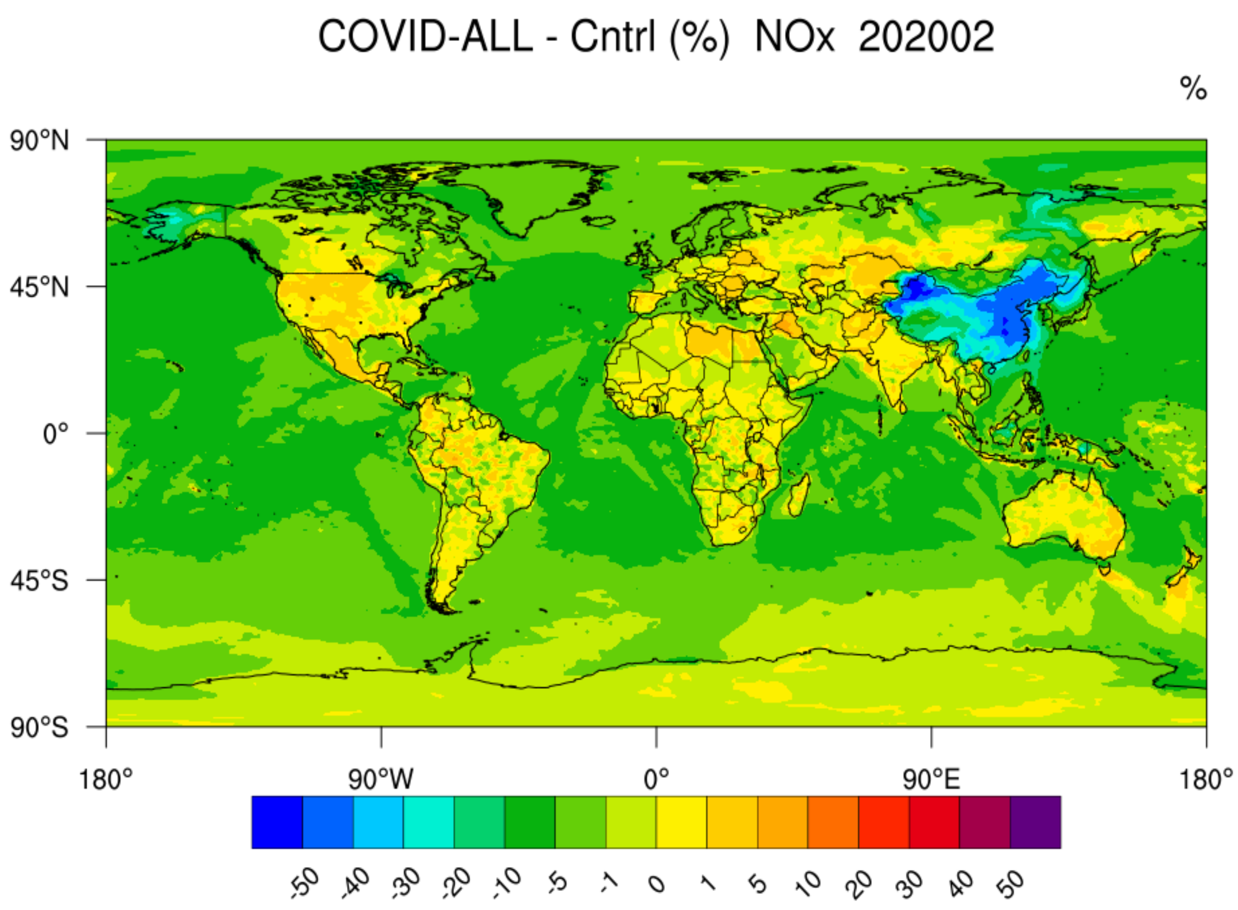


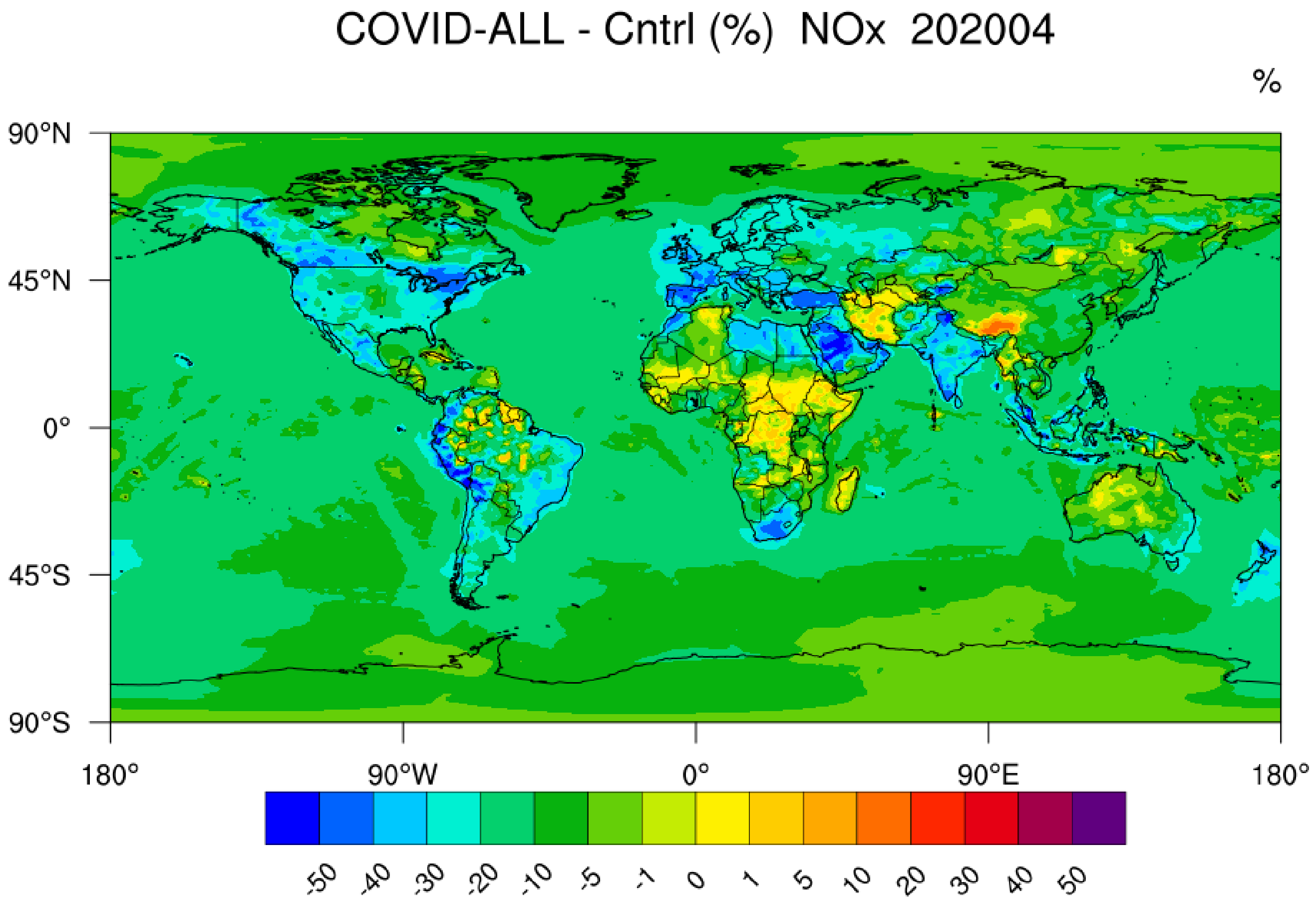
- China: Reduction starts in February 2020 (40% for NOx, 25% for VOCs)
- Rest of the world: Reduction is highest on March-April 2020.

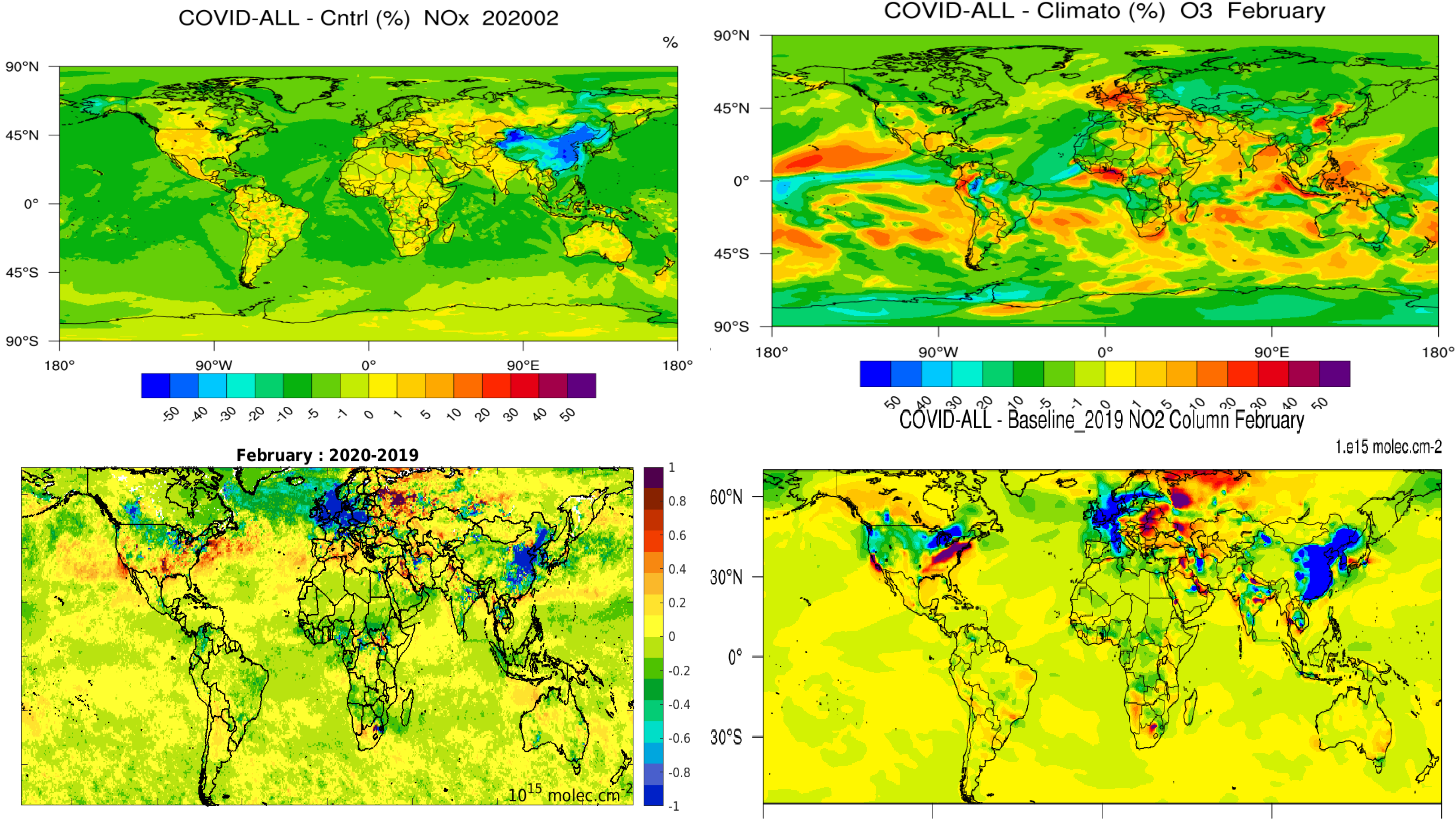
Based on Doumbia et al. 2020

Reduction in NO_2: From China in February to the rest of the world in April 2020

February **April**






COVID-ALL - Cntrl (%) NOx 202002
%
90°N
45°N
0°
45°S
90°S
180°
90°W
0°
90°E
180°
-50 -40 -30 -20 -10 -5 -1 0 1 5 10 20 30 40 50
COVID-ALL - Climato (%) O3 February
90°N
45°N
0°
45°S
90°S
180°
90°W
0°
90°E
180°
50 40 30 20 10 5 1 0 1 5 10 20 30 40 50
February : 2020-2019
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
10^{15} molec.cm^{-2}
COVID-ALL - Baseline_2019 NO2 Column February
1.e15 molec.cm-2
60°N
30°N
0°
30°S

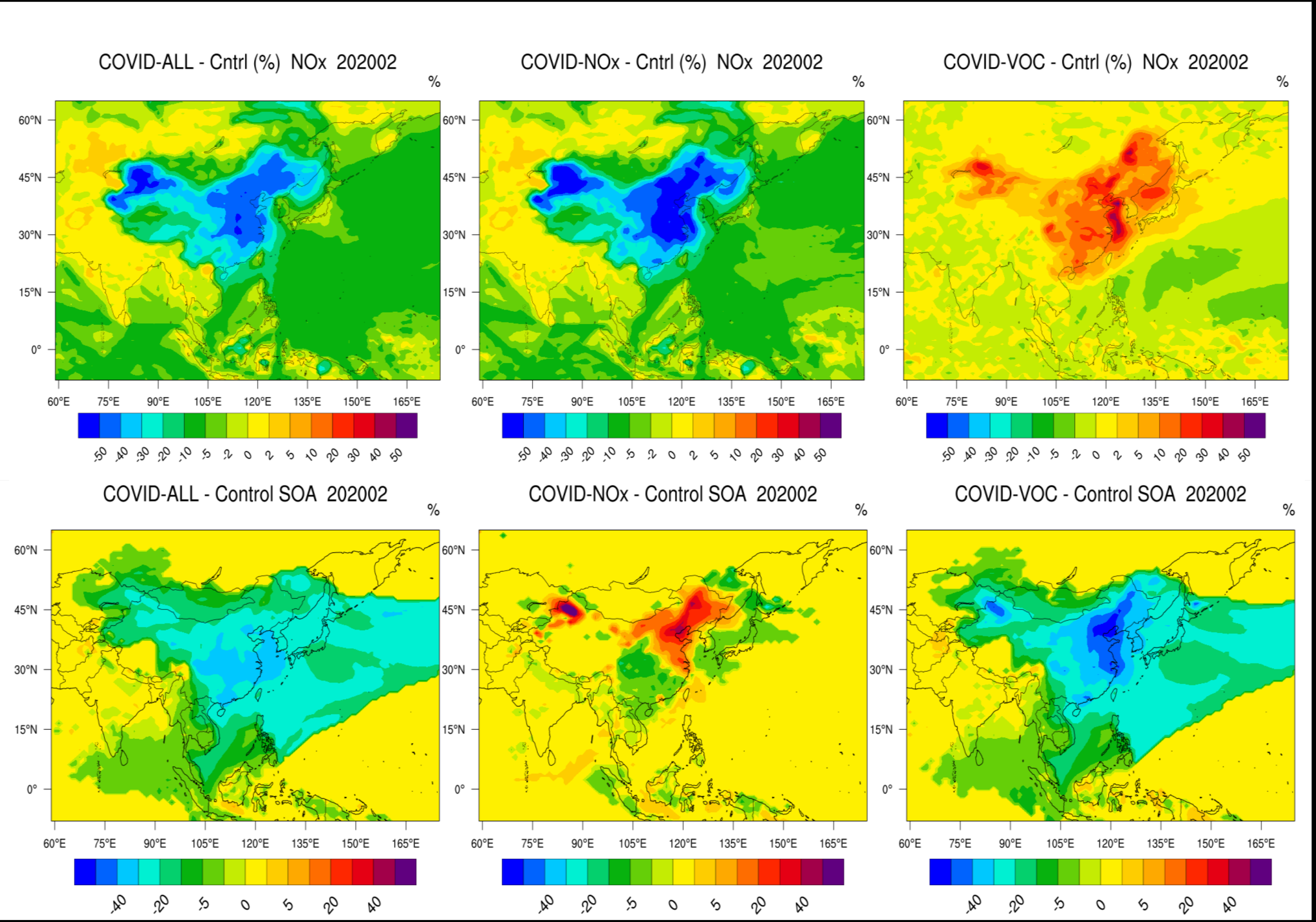
In China:

Reduction in: All emissions. NOx emissions. VOC and CO emissions

The response of NO_2 and secondary pollutants to reduced emissions during February 2020

NO_2

SOA



During the pandemic: Reduction in ozone titration in northern China (NOx saturated)

In Europe:

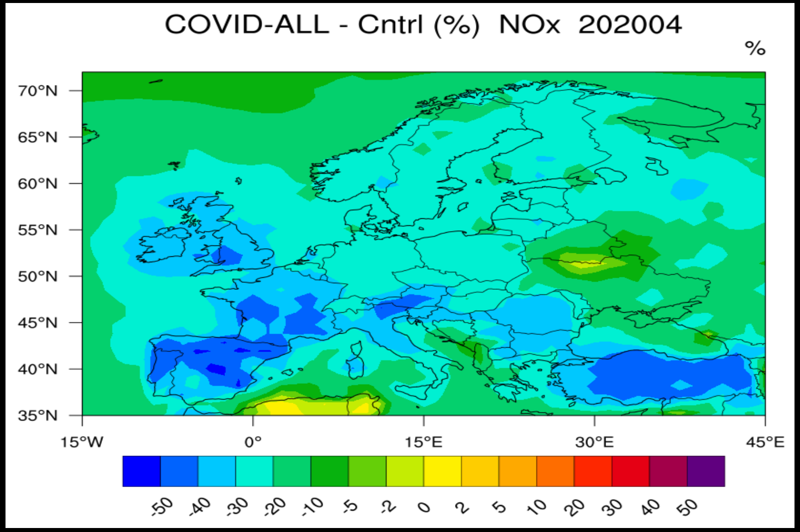
The response of NO_2 and ozone in reduced emissions during April 2020. Importance of weather anamalies

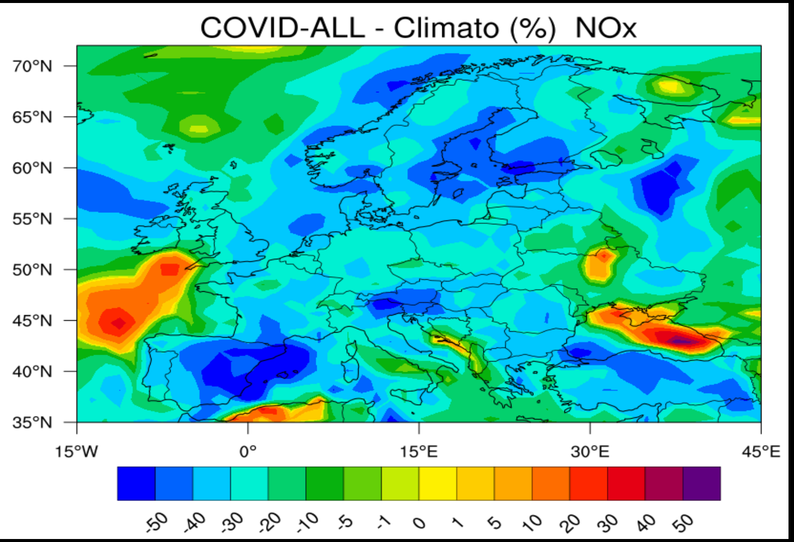
During the pandemic: most of the ozone increase is attributed to weather anomaly (except in the UK, Benelux, Germany)

Emissions reduction only
No meteorological effect

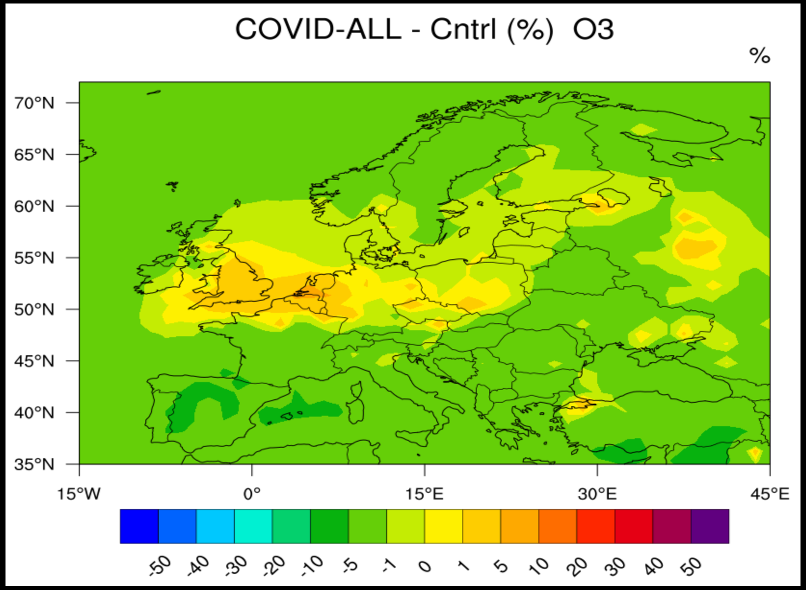
Emissions reduction
With meteorological effects

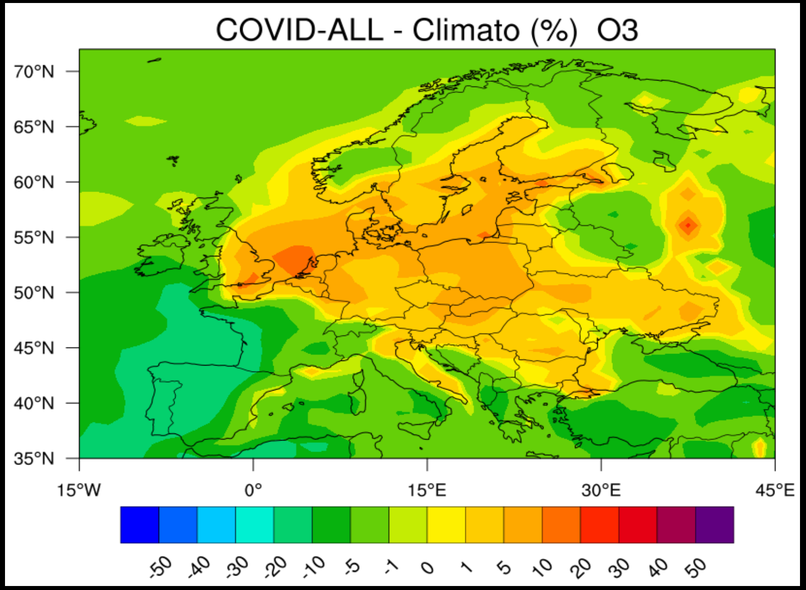
NO_2





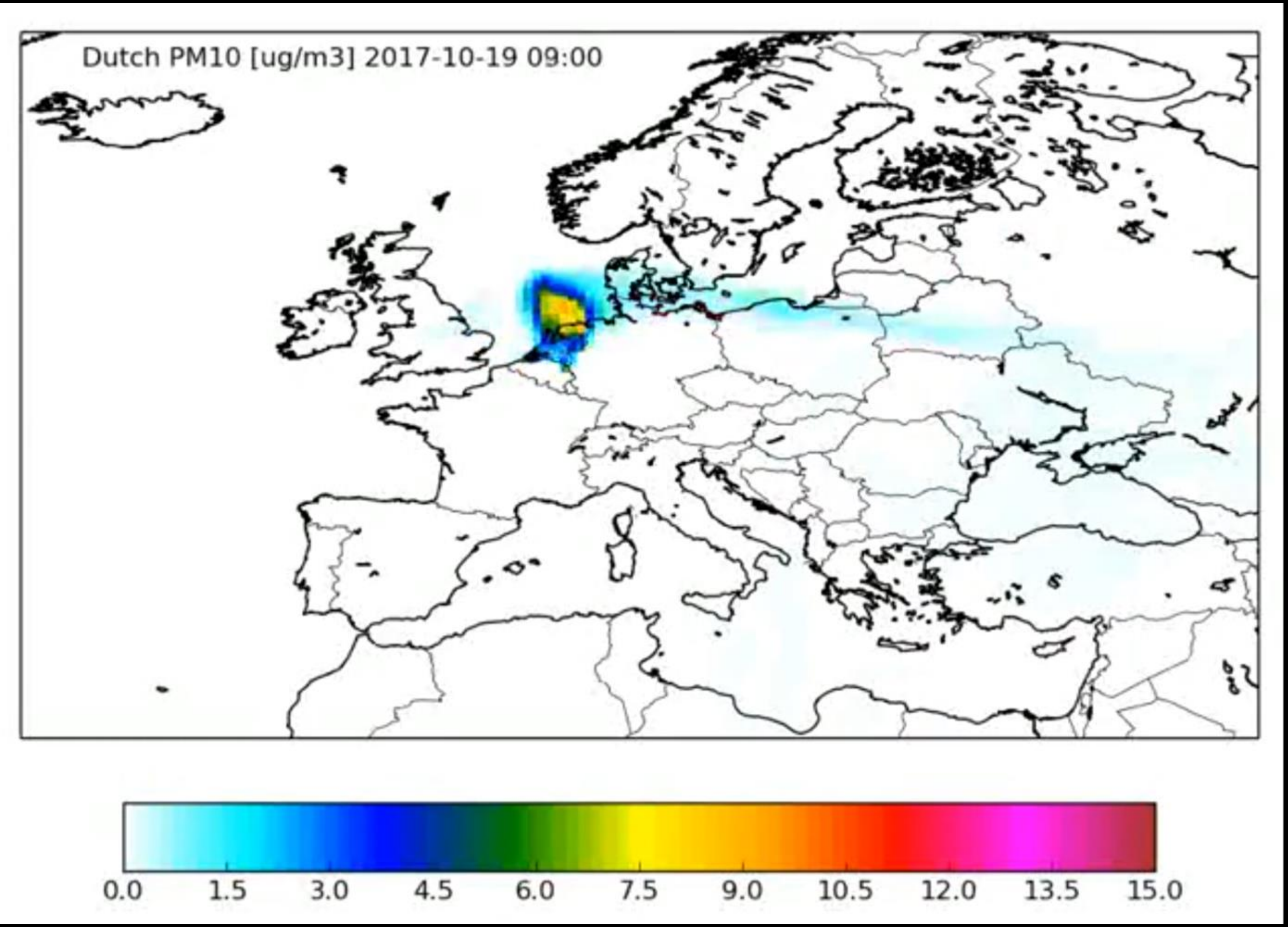
O_3

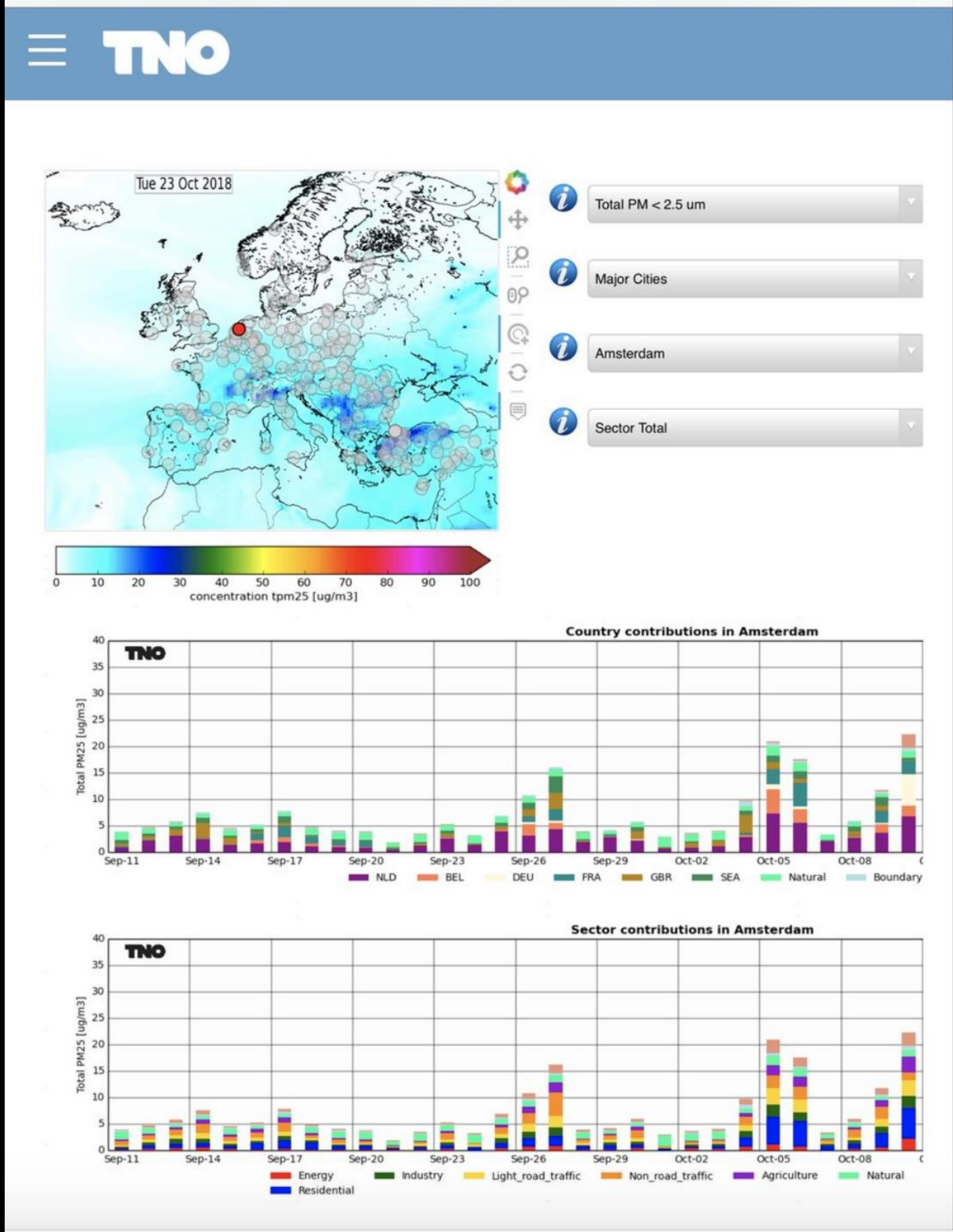




Attribution des sources de pollution

Attribution des sources de pollution



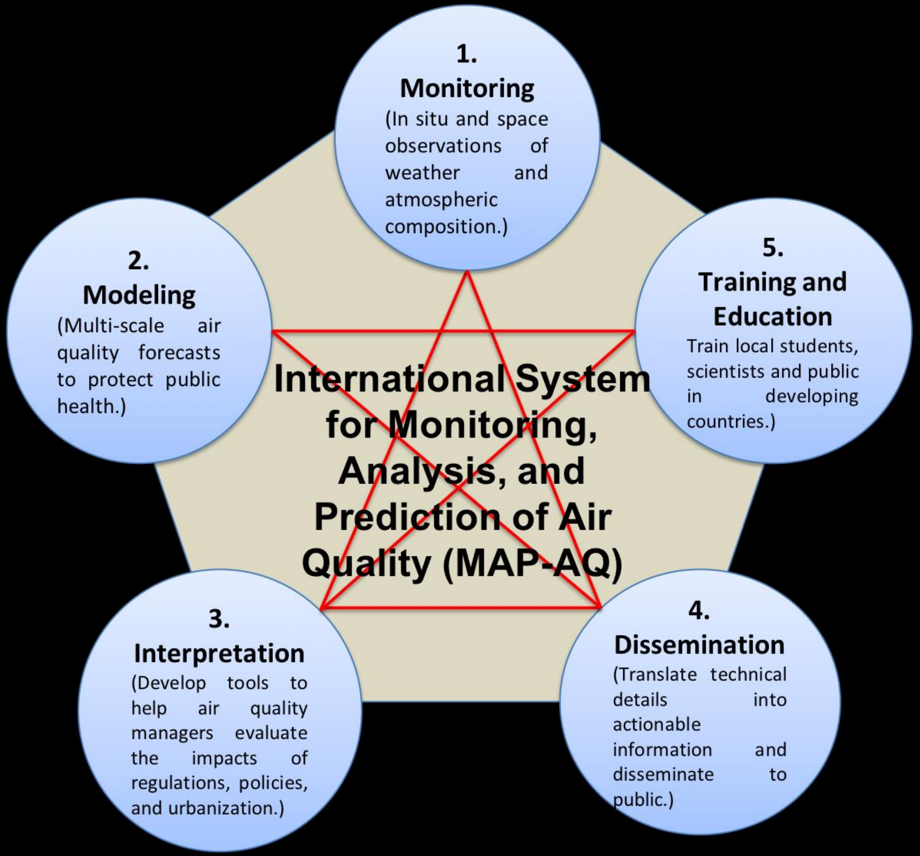


An International Initiative

MAP-AQ:

Monitoring, Analysis and Prediction of Air Quality

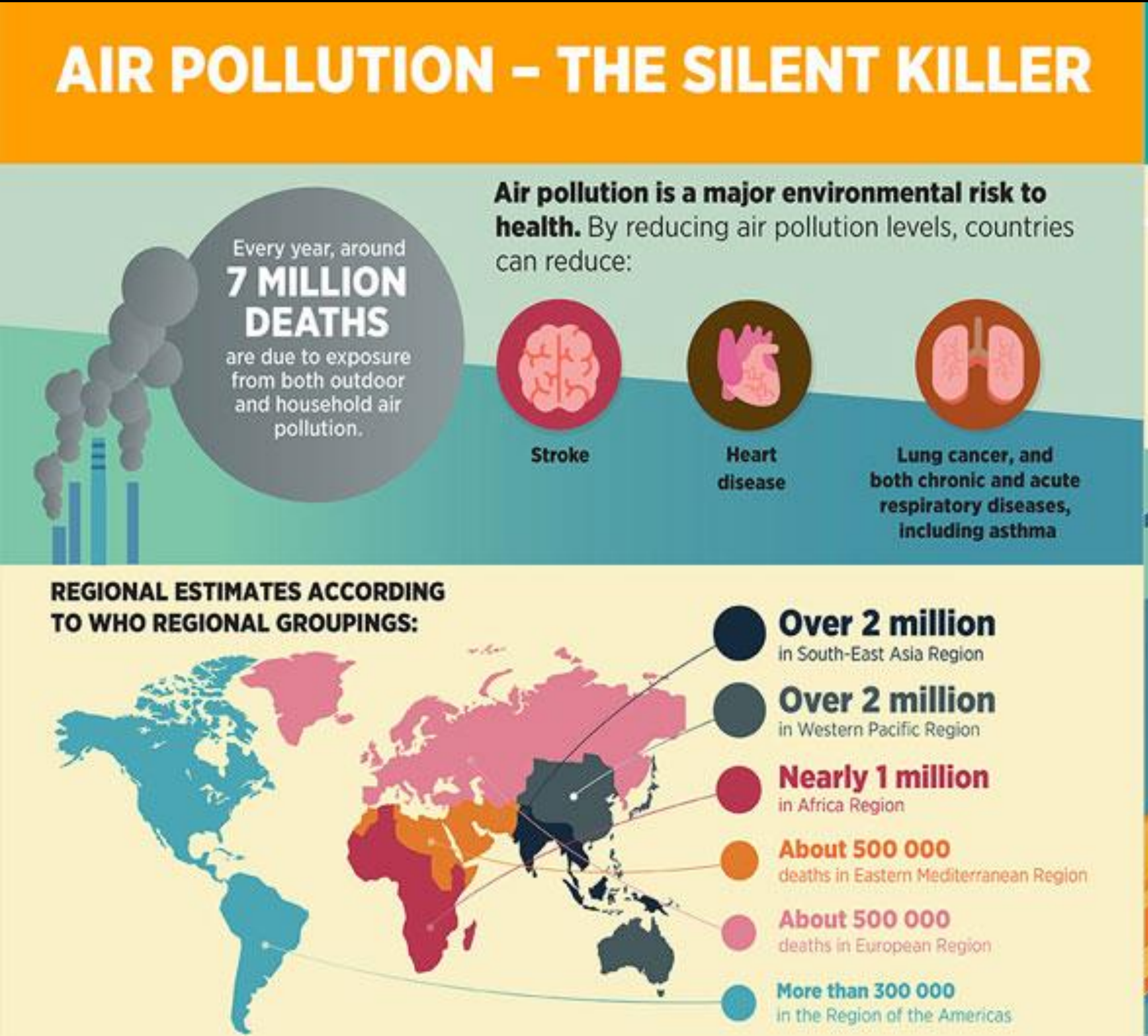
MAP-AQ: Five Components



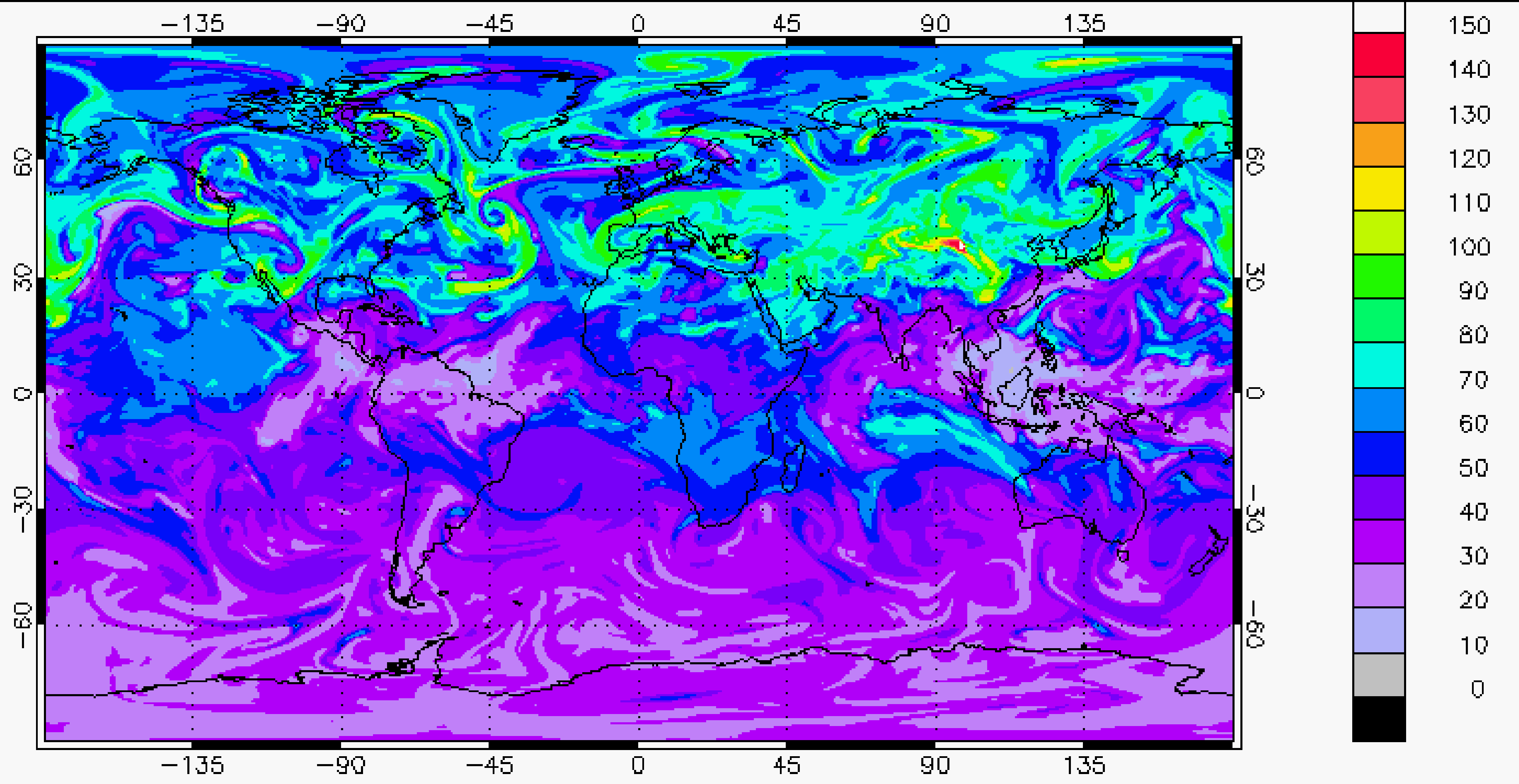
1. Multi-platform observations of weather and atmospheric composition
2. Multi-scale air quality forecasts
3. Develop tools to help AQ managers evaluate impacts of regulations, policies and urbanization
4. Translate technical details into actionable information and disseminate to public
5. Train local students, scientists, and public in developing countries

[Kumar et al., Nature, 2018]

Développer des solutions



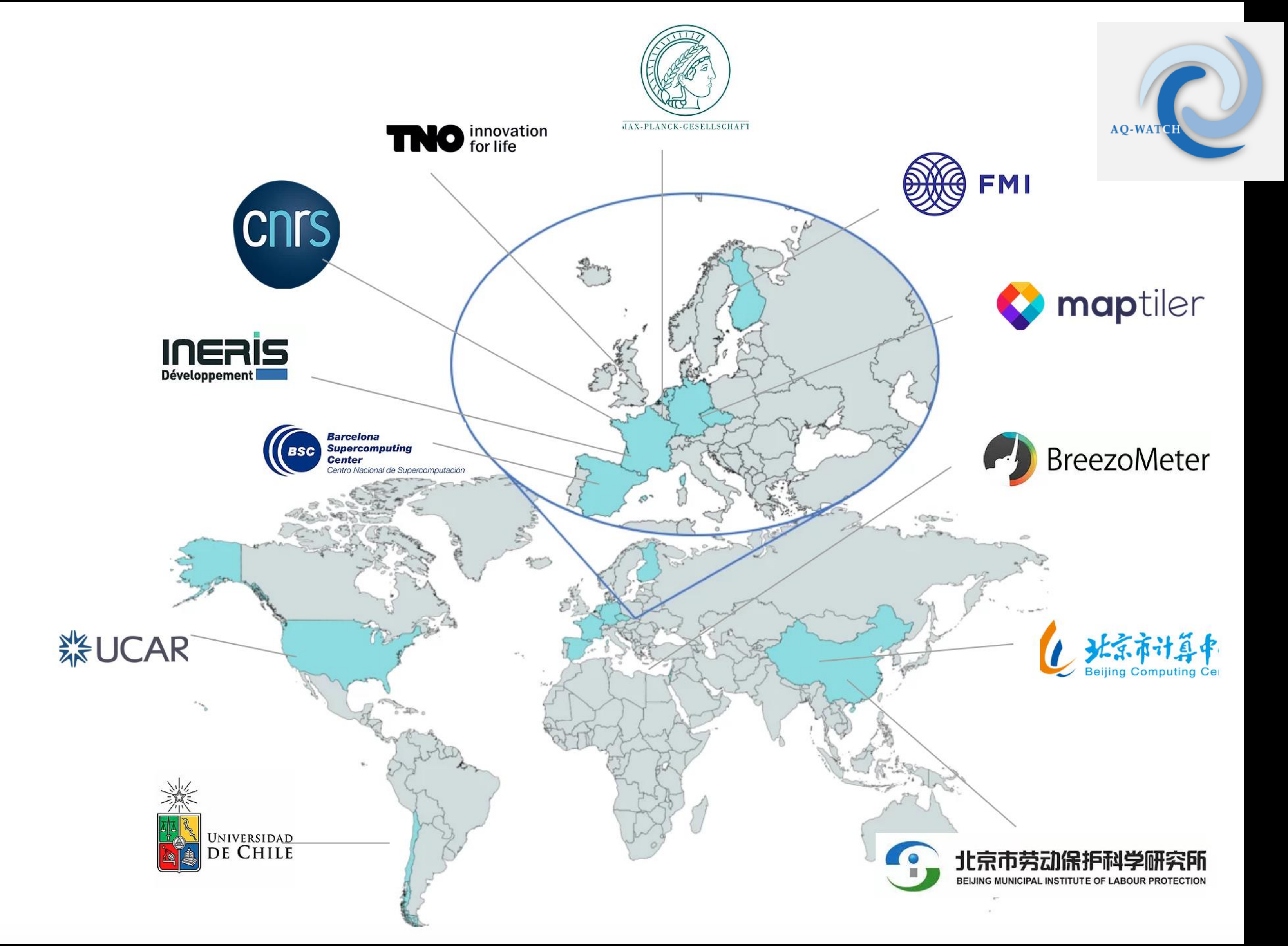
Thank You

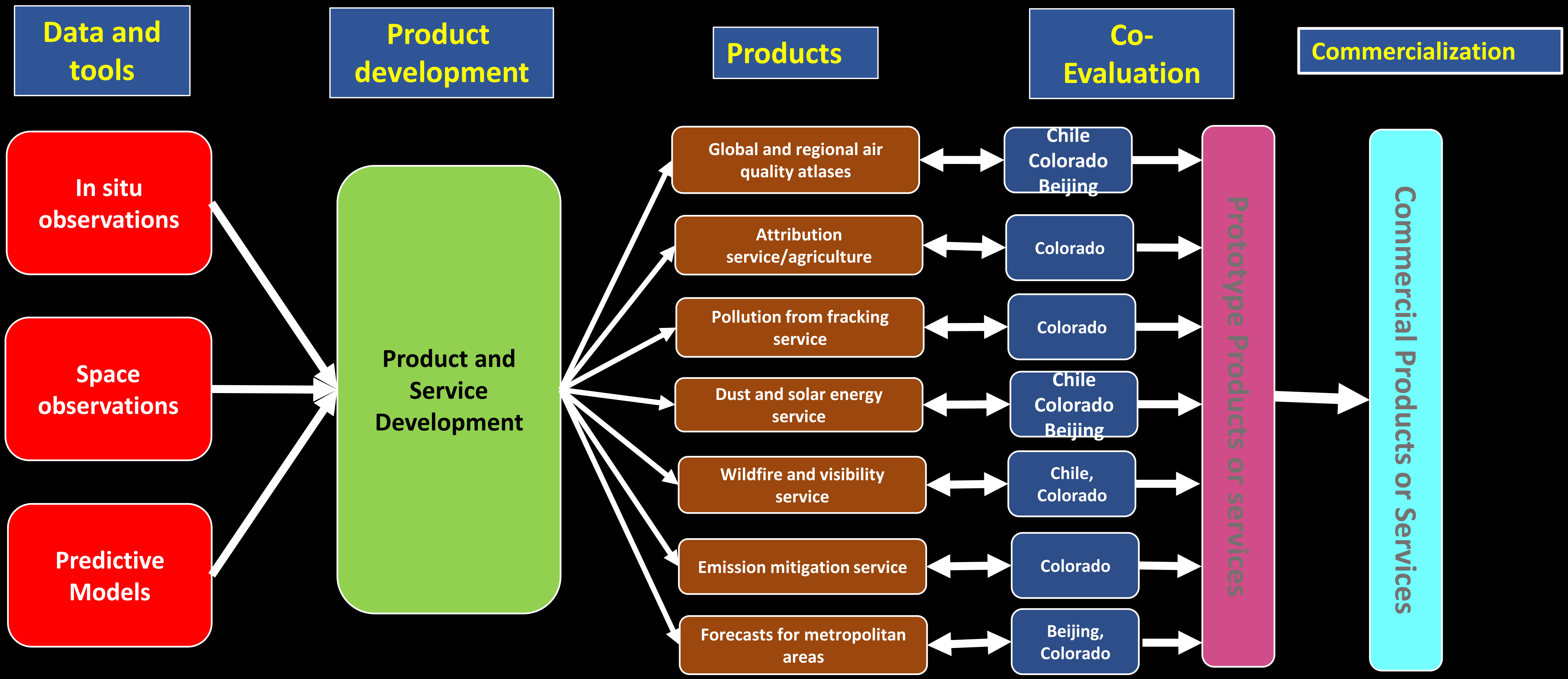


-135
-90
-45
0
45
90
135
60
30
0
-30
-60
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0

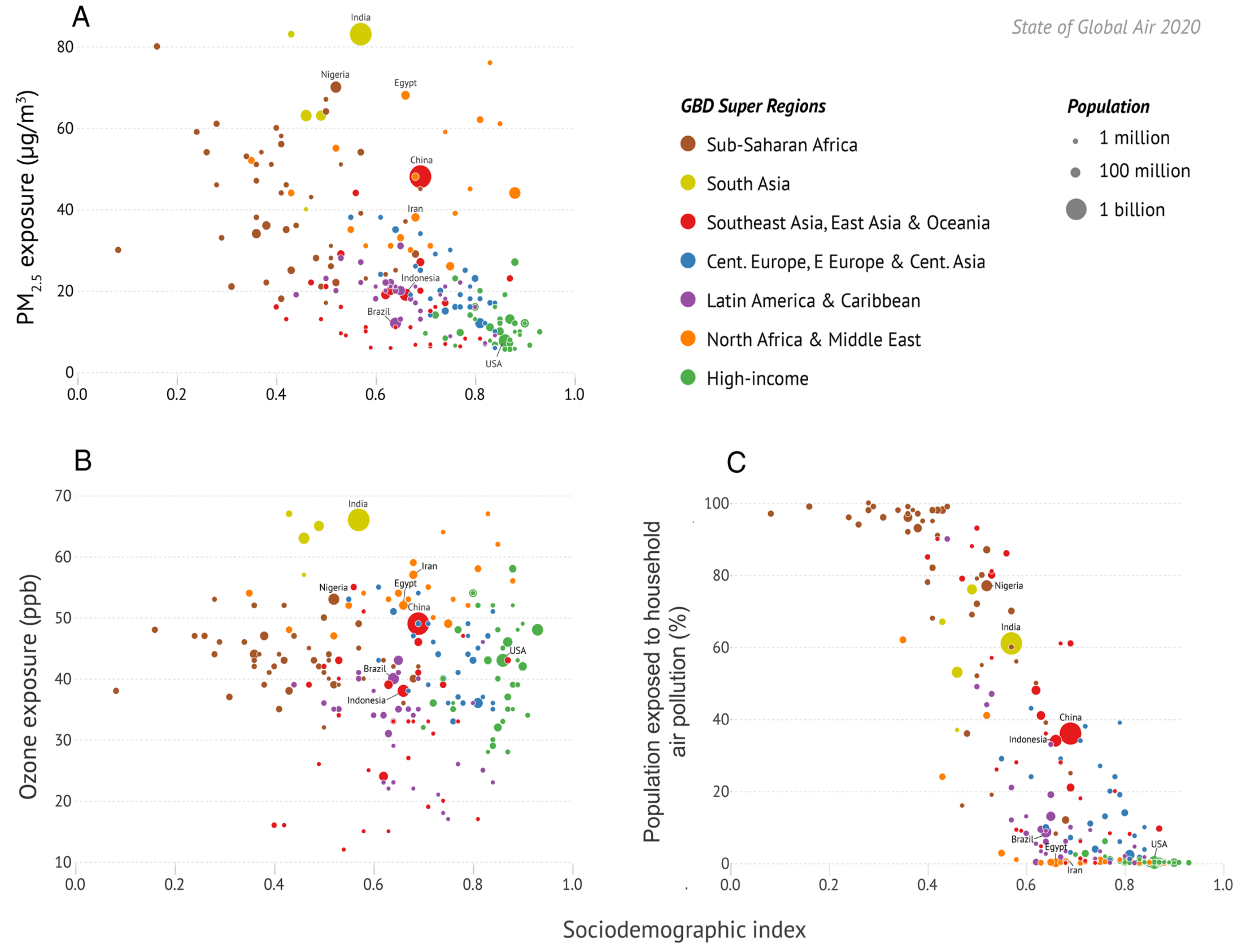
Developing Products and Services to Reduce Air Pollution:

The AQ-Watch Project

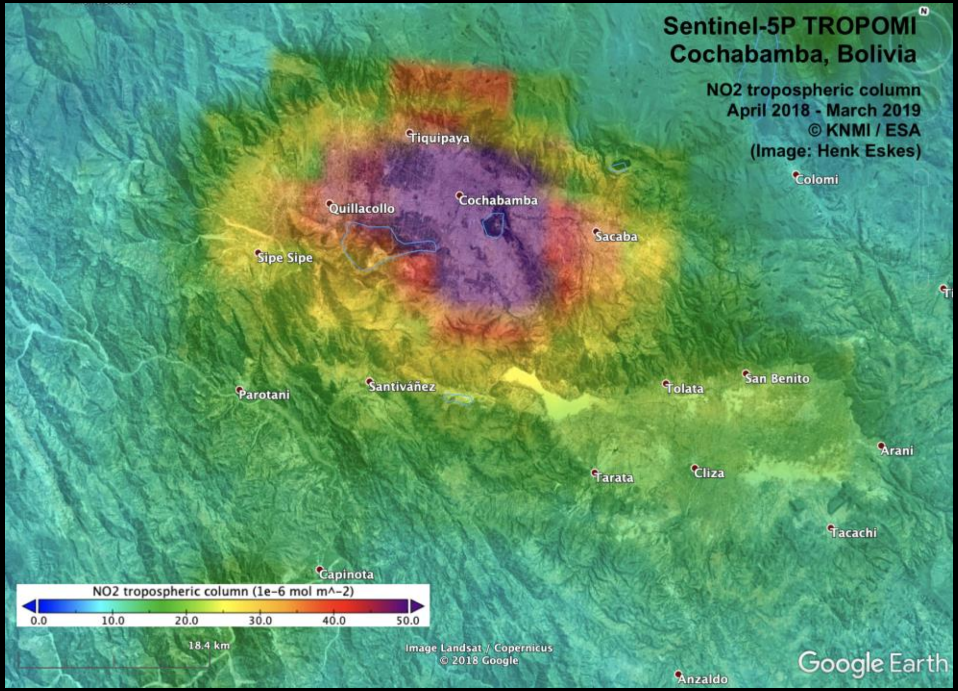


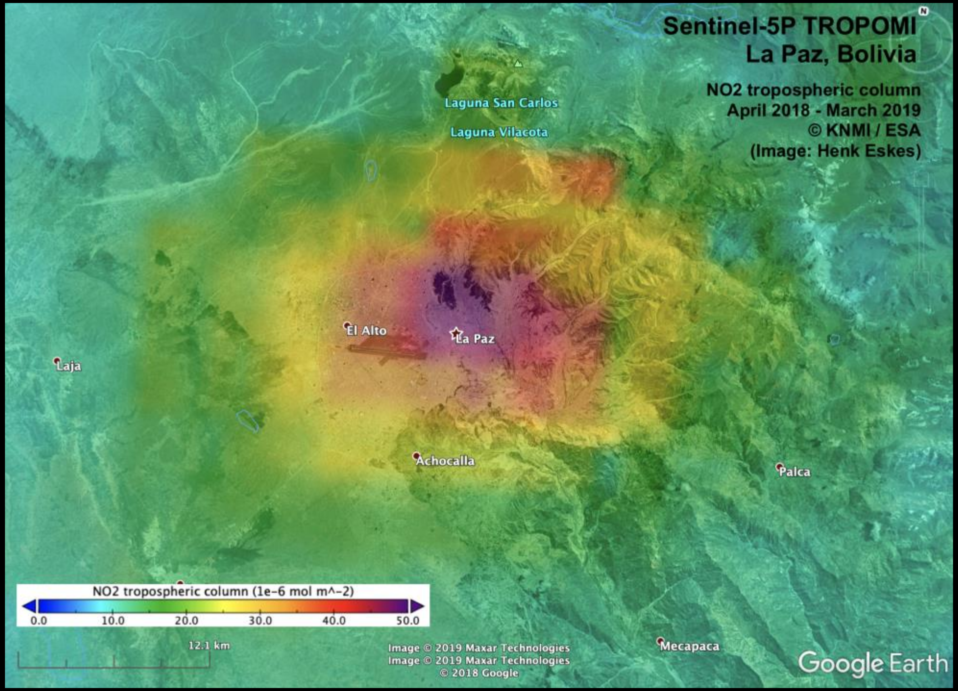


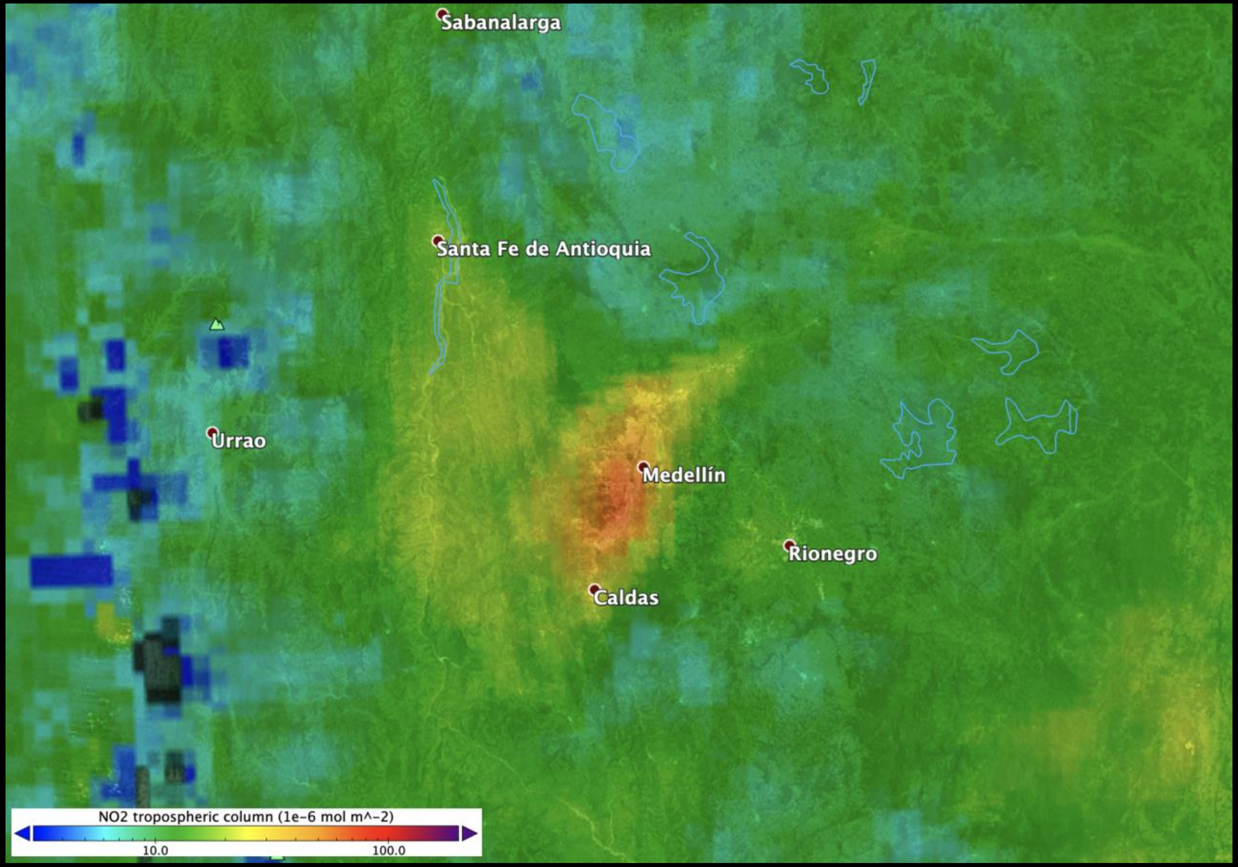
Data and tools
Product development
Products
Co-Evaluation
Commercialization
In situ observations
Space observations
Predictive Models
Product and Service Development
Global and regional air quality atlases
Attribution service/agriculture
Pollution from fracking service
Dust and solar energy service
Wildfire and visibility service
Emission mitigation service
Forecasts for metropolitan areas
Chile Colorado Beijing
Colorado
Colorado
Chile Colorado Beijing
Chile, Colorado
Colorado
Beijing, Colorado
Prototype Products or services
Commercial Products or Services



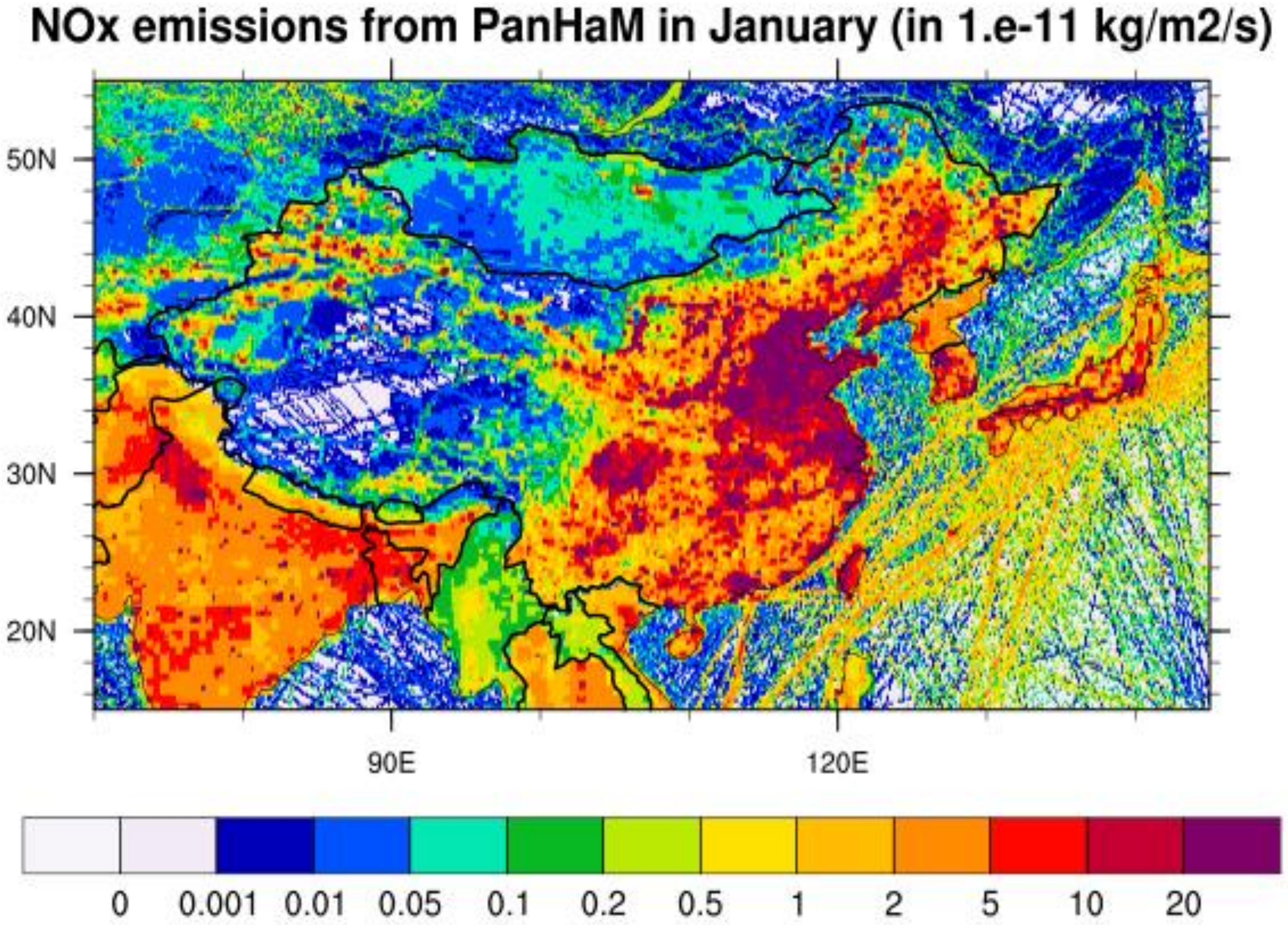
Exposure in different countries to PM2.5, ozone and household air pollution in 2019


Sentinel-5P TROPOMI
Cochabamba, Bolivia
NO2 tropospheric column
April 2018 - March 2019
© KNMI / ESA
(Image: Henk Eskes)
Tiquipaya
Colomi
Quillacollo
Cochabamba
Sacaba
Sipe Sipe
Santivañez
Parotani
Tolata
San Benito
Arani
Tarata
Cliza
Tacachi
Capinota
Anzaldo
NO2 tropospheric column (1e-6 mol m^-2)
0.0
10.0
20.0
30.0
40.0
50.0
18.4 km
Image Landsat / Copernicus
© 2018 Google
Google Earth


Sentinel-5P TROPOMI
La Paz, Bolivia
NO2 tropospheric column
April 2018 - March 2019
© KNMI / ESA
(Image: Henk Eskes)
Laguna San Carlos
Laguna Vilacota
El Alto
La Paz
Laja
Achocalla
Palca
Mecapaca
NO2 tropospheric column (1e-6 mol m^-2)
0.0
10.0
20.0
30.0
40.0
50.0
12.1 km
Image © 2019 Maxar Technologies
Image © 2019 Maxar Technologies
© 2018 Google
Google Earth


Sabanalarga
Santa Fe de Antioquia
Urrao
Medellín
Rionegro
Caldas
NO2 tropospheric column (1e-6 mol m^-2)
10.0
100.0

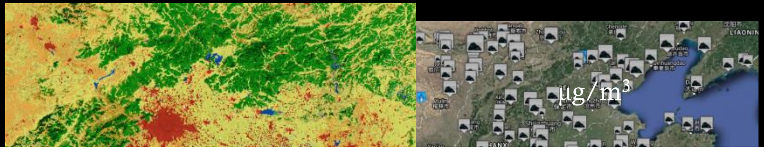
Emissions de NOx en Asie

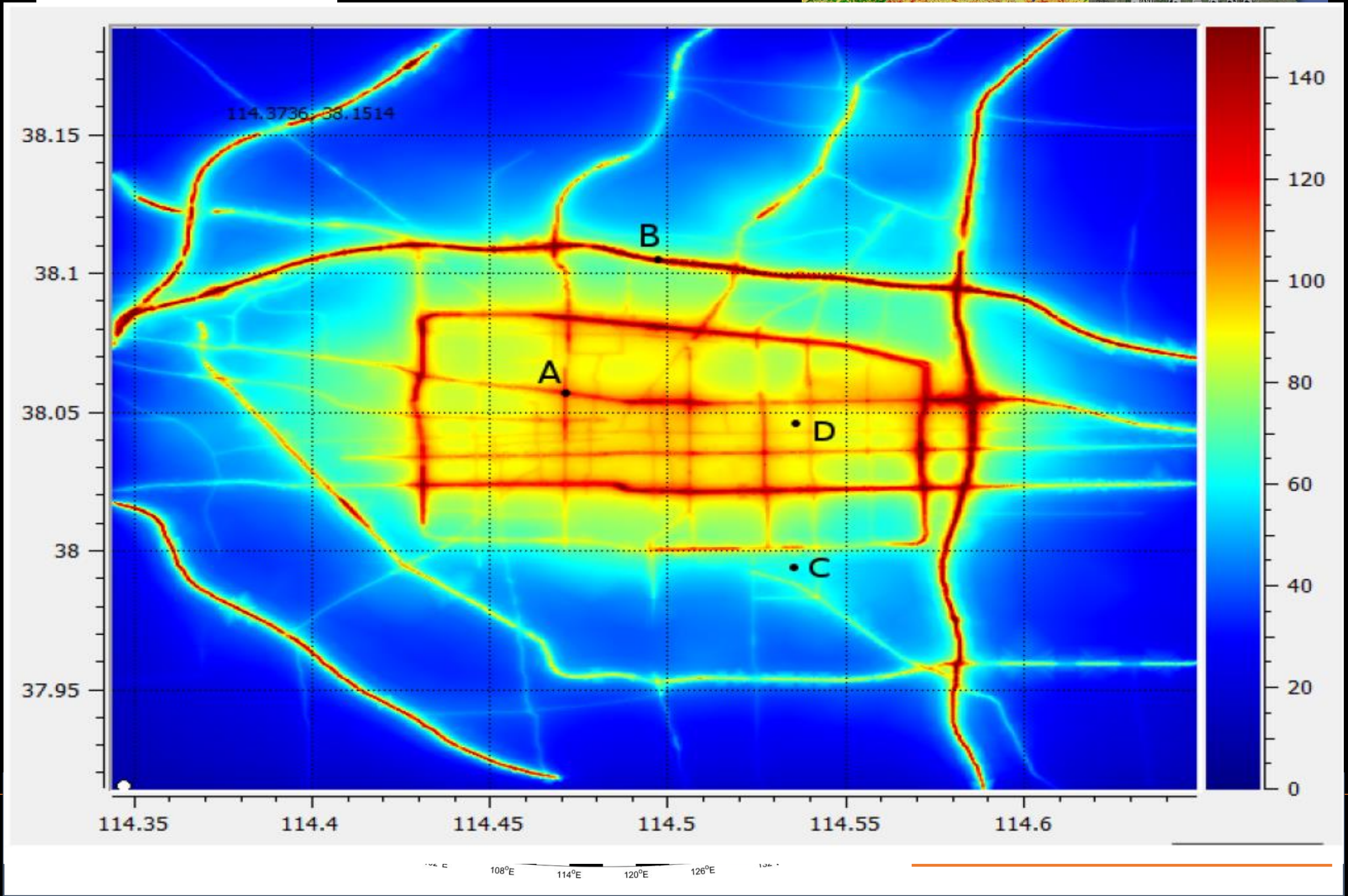


Claire Granier, NOAA

MEIC inventory

Downscaling Emissions (VITO)





马可·波罗
MARCOPOLO