Anthropogenic emissions

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CIRES, University of Colorado, USA

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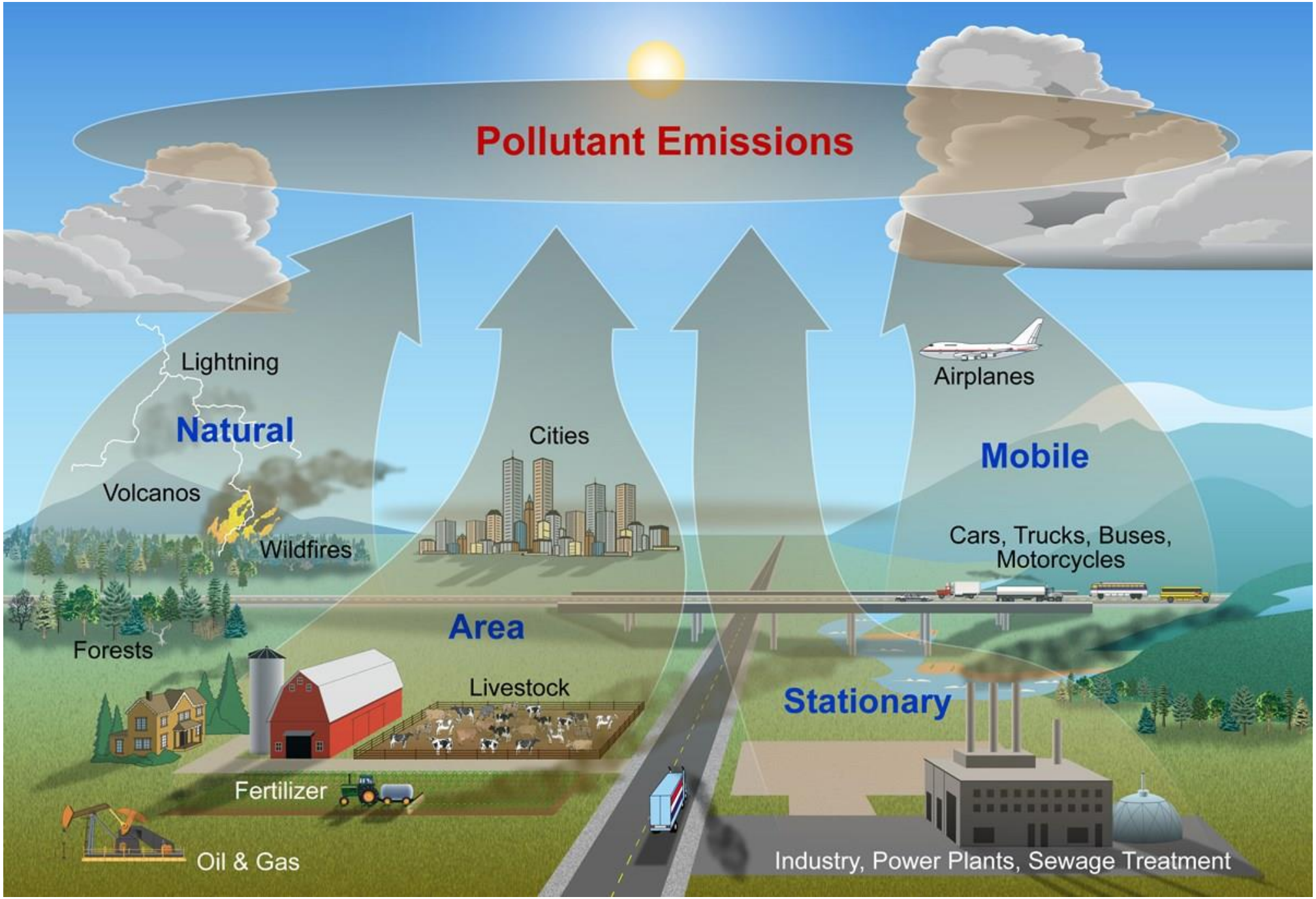
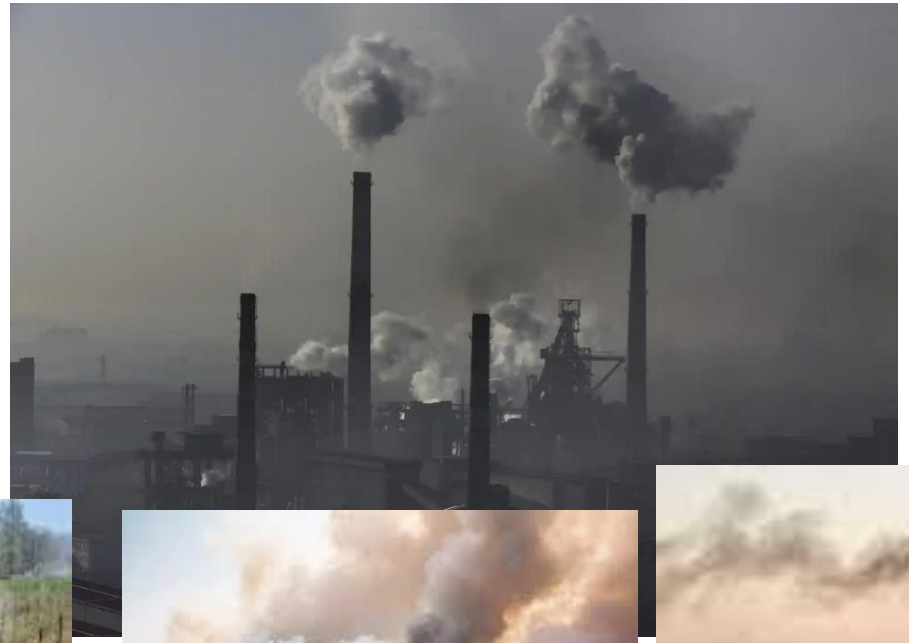
(Note: amigo email closed at the end of the week)


Pollutant Emissions
Lightning
Natural
Volcanos
Wildfires
Forests
Cities
Airplanes
Mobile
Cars, Trucks, Buses,
Motorcycles
Area
Livestock
Fertilizer
Stationary
Oil & Gas
Industry, Power Plants, Sewage Treatment


Germany 1860s



Motivation for Understanding Emissions

Actions and decisions about the atmosphere focus on emissions

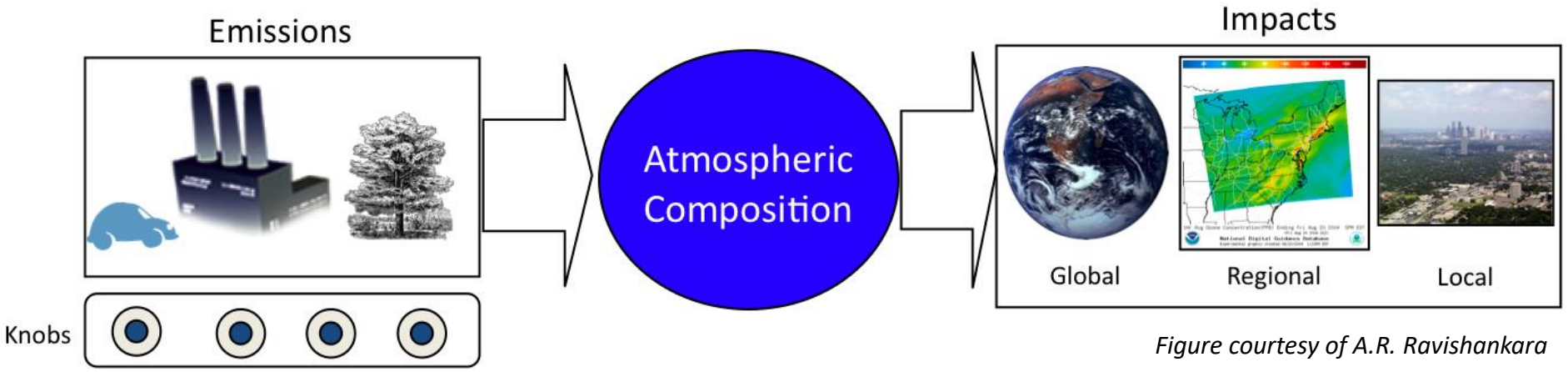


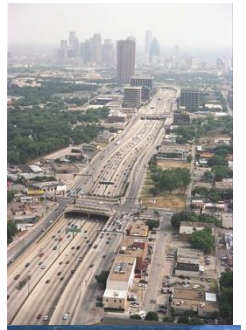
Figure courtesy of A.R. Ravishankara

Accurate emission information is needed to:

- Quantify and predict atmospheric composition
- Understand changes in air quality and climate
- Make choices about emission controls

Quantification of missions are tools of regulation, economics, foreign policy, & international diplomacy

Emissions Information Challenges



Many emissions data requirements are common to air quality and climate research, regulation, & policy

- Transparency
- Consistency
- Accuracy
- Timeliness
- Uncertainty

At the same time, there are many issues and needs associated with emissions data

Complexity

- Spatial/temporal scales
- Source types
- Interdisciplinary

Development

- Inconsistencies
- Timeliness
- Traceability

Analysis

- Evaluations
- Uncertainties
- Impacts

Communication

- Data access and sharing
- Literature access
- Producer – user feedbacks

Frost et al., Atmos. Environ., 2012

Emissions Needs in Atmospheric Research

- **Analysis and forecasting of atmospheric composition, observations from campaigns**
  - wide range of chemical species
  - high spatial and temporal resolution

- **Global scale, long-range transport**
  - limited number of chemical species
  - moderate spatial and temporal resolution
  - long-term variation (a few decades)
  - need some coupling emissions/meteorological conditions

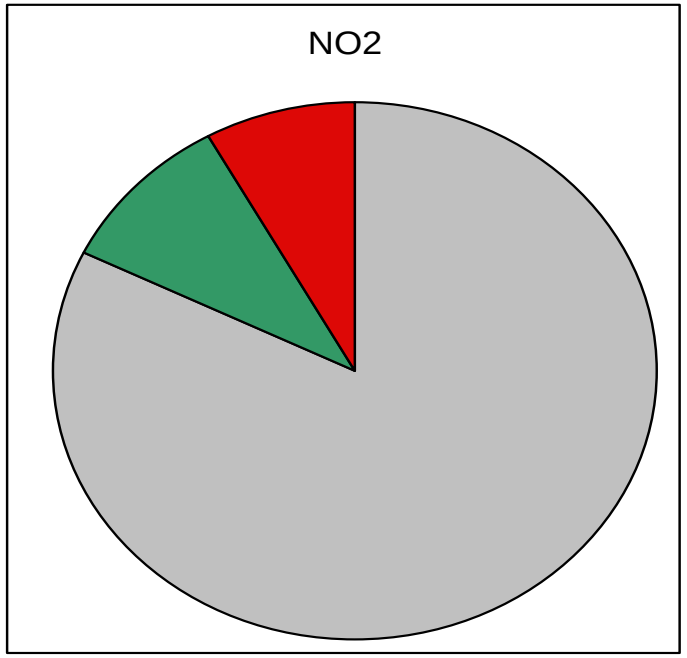
- **Climate studies: impact of climate on emissions and of emissions on climate**
  - long-lived species, aerosols and a few ozone precursors
  - emissions models or algorithms to take into account land-use and human-related changes
  - past/future realistic scenarios (decades-century)

Large diversity of sources for atmospheric pollutants

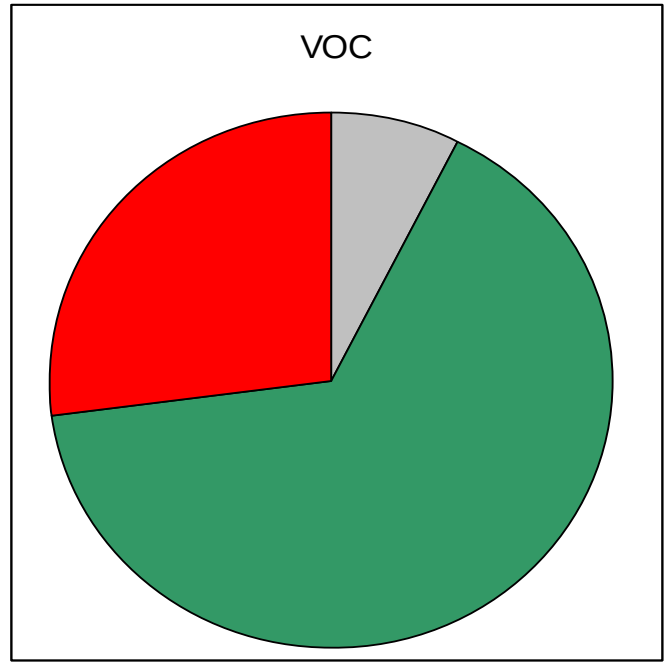
	Anthro-pogenic	Biomass burning	Biogenic/ continental	Oceanic	Photo-chemistry
CH4	Major	Significant	Major	Minor	No
CO	Major	Major	Significant	Minor	Major
NOx	Major	Significant	Major	No	Minor
VOCs	Major	Major/Sign.	Major	Minor	Major/Sign.
SO2	Major	Minor	Major	No	Minor
BC/OC	Major	Major	No	No	Minor
NH3	Major	Minor	Minor	No	No
PMs	Major	Major	Major (dust)	No	Major

NOx = nitrogen oxides ; VOCs = Volatile Organic Compounds ; BC = black carbon (soot)
OC = organic carbon ; NH3 = ammonia ; PMs = particulate matter

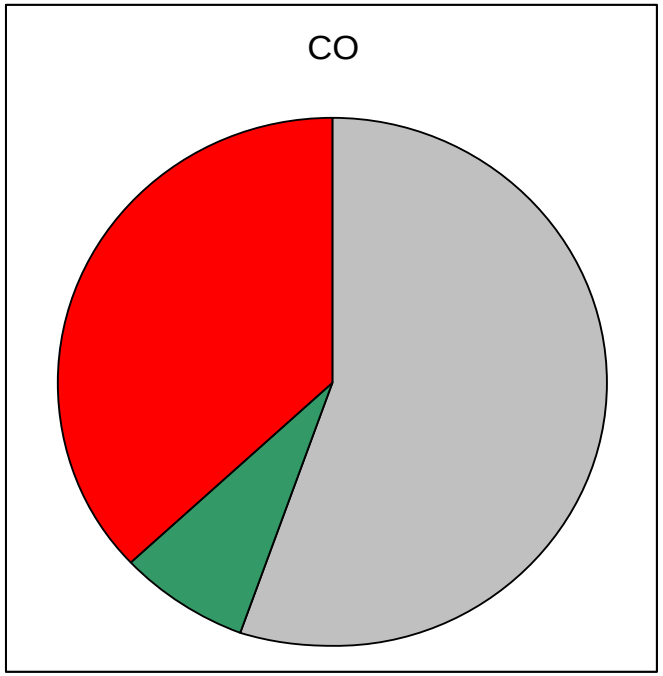
Global Emission Estimates: Trace Gases



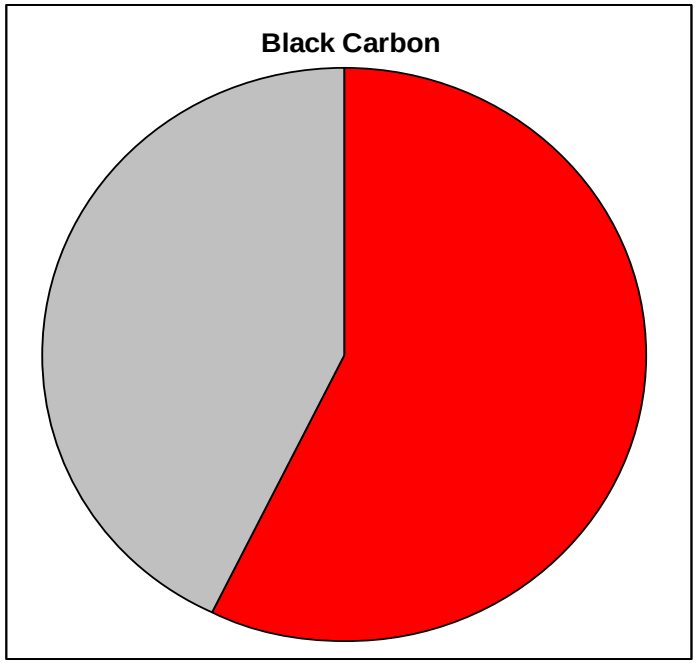
NO2



VOC



CO



BC

Yokelson et al., ACP, 2008

Anthropogenic emissions

Outline

1. General methodology to calculate emissions
2. Activity data
3. Emission factors
4. Spatial/temporal variations and VOCs speciation
5. Current public global inventories
6. A few current public regional inventories
7. Evaluation of anthropogenic emissions
8. Conclusions

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Emissions Calculation General Methodology

Total mass emissions of compound X

$$E_X = \sum_S [EF_{X,S} \bullet A_S \bullet (1 - CE_{X,S})]$$

Sum up all sources S

Emissions factor = mass of compound X emitted by source S per unit activity; "representative"

Activity of source S, e.g., amount of fuel burned, vehicle miles driven, etc.;

Effectiveness of control measures for compound X at source S;

Emissions from fires: $E_X = \sum_S [EF_X \bullet BA \bullet BD \bullet BE]$

BA = Burnt Area ; BD = Biomass Density; BE = Burning Efficiency

Emissions of biogenic hydrocarbons from the vegetation:

$$E_X = \sum_S [EF_X \bullet EA \bullet EE]$$

EE = Escape efficiency; EA = Emission activity (depends on light, temperature, leaf age, leaf area index, soil moisture, etc.

Bottom-Up Inventory Methods

Total mass of compound X emitted

$$E_X = \sum_S [EF_{X,S} \bullet A_S \bullet (1 - CE_{X,S})]$$

Sum up all sources S

Emissions factor = mass of compound X emitted by source S per unit activity

Activity of source S, e.g., amount of fuel burned

Effectiveness of control measures for compound X at source S

Calculated for…
Specific region
Specific time
Also need…
Spatial allocation
Temporal variation
Speciation

Example: On-road motor vehicles

Vehicle fleet

Fuel type

Control technology

Emissions source

Fuel economy

Vehicle condition

Road type

Distance driven

Vehicle load

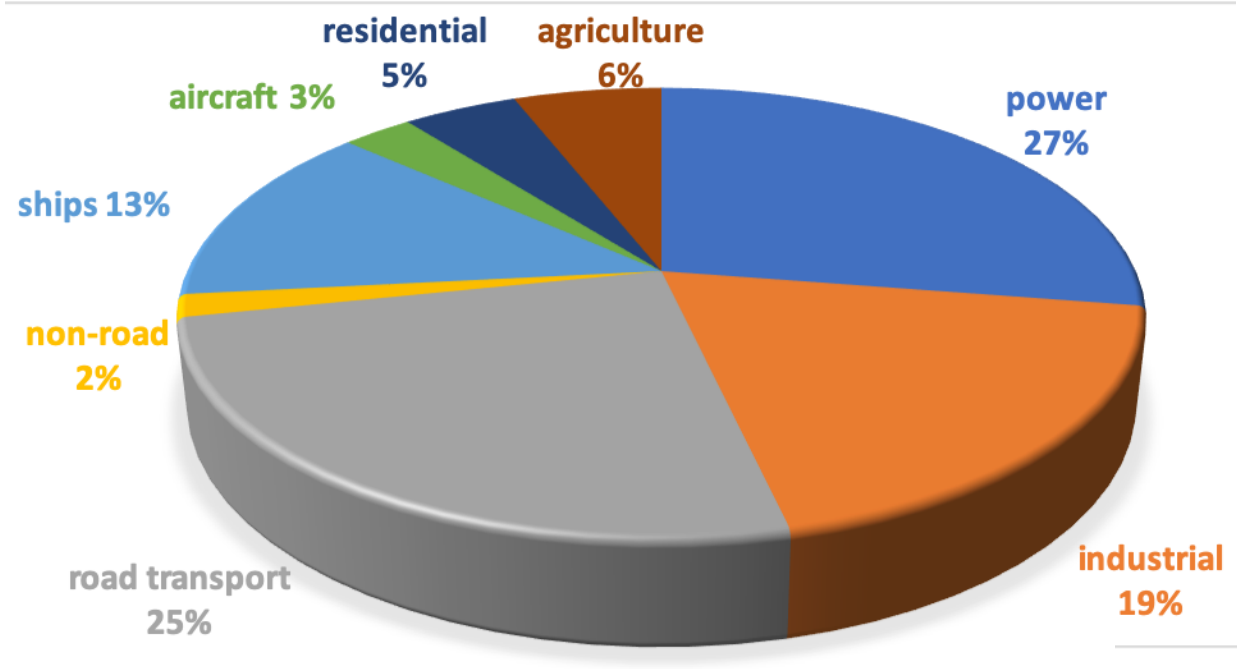
Which sectors are the most important? It depends on the species

	Energy	Industry	Transport	Buildings	Solvents	Agriculture	Ag Wst Brn	Waste
CO2	43%	24%	18%	15%	0%	0%	0%	0%
NOx	27%	18%	41%	10%	0%	2%	1%	0%
SO2	57%	29%	5%	9%	0%	0%	0%	0%
CO	3%	16%	37%	41%	0%	0%	3%	1%
NMVOC	21%	7%	25%	28%	16%	1%	2%	1%
BC	1%	30%	27%	39%	0%	0%	3%	1%
OC	3%	18%	12%	62%	0%	0%	6%	0%
NH3	0%	0%	1%	1%	0%	96%	2%	0%
CH4	26%	0%	0%	5%	0%	46%	1%	23%

What is important for SLCFs is often different than what is important for GHGs.

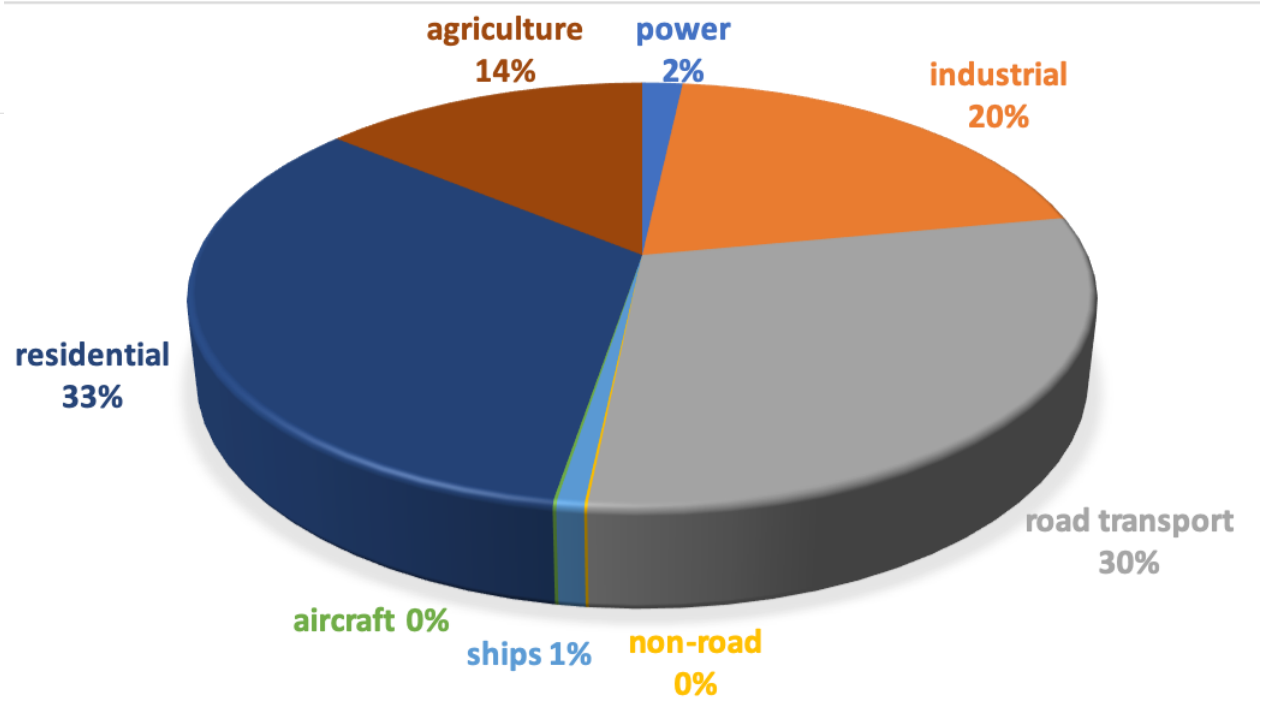
- Buildings and transport are particularly important.
- Energy sector, which is a major focus of IAMs, is very important for SO_2, but only moderately or not important for other emissions.

Data: Lamarque, et al. (2010) Historical (1850-2000) gridded anthropogenic and biomass burning emissions of reactive gase and aerosols: methodology and application *Atmospheric Chemistry and Physics* **10** pp. 7017–7039



NOx

Emissions have to be quantified for many different sectors:
example = CO and NO_x in 2010



CO

Comparisons for different sectors

→ **Most global inventories use the IPCC sectors**
→ **Regional inventories developed by regulatory agencies use SNAP/ GNFR or other sectors**

Sector number	Sector name
1	Energy production and distribution
2	Industry (combustion and non-combustion)
3	Land transport
4	Maritime transport
5	Aviation
6	Residential and commercial
7	Solvents
8	Agriculture
9	Agricultural waste burning on fields
10	Waste
11	Open vegetation fires in forests
12	Open vegetation fires in savanna and grasslands
13	Natural emissions

IPCC sectors

A	A_PublicPower
B	B_Industry
C	C_OtherStationaryComb
D	D_Fugitives
E	E_Solvents
F	F_RoadTransport
F1	F_RoadTransport_exhaust_gasoline
F2	F_RoadTransport_exhaust_diesel
F3	F_RoadTransport_exhaust_LPG_gas
F4	F_RoadTransport_non-exhaust
G	G_Shipping
H	H_Aviation
I	I_OffRoad
J	J_Waste
K	K_AgriLivestock
L	L_AgriOther

Overview of aggregated NFR (GNFR) sectors distin- guished in the emission inventory.

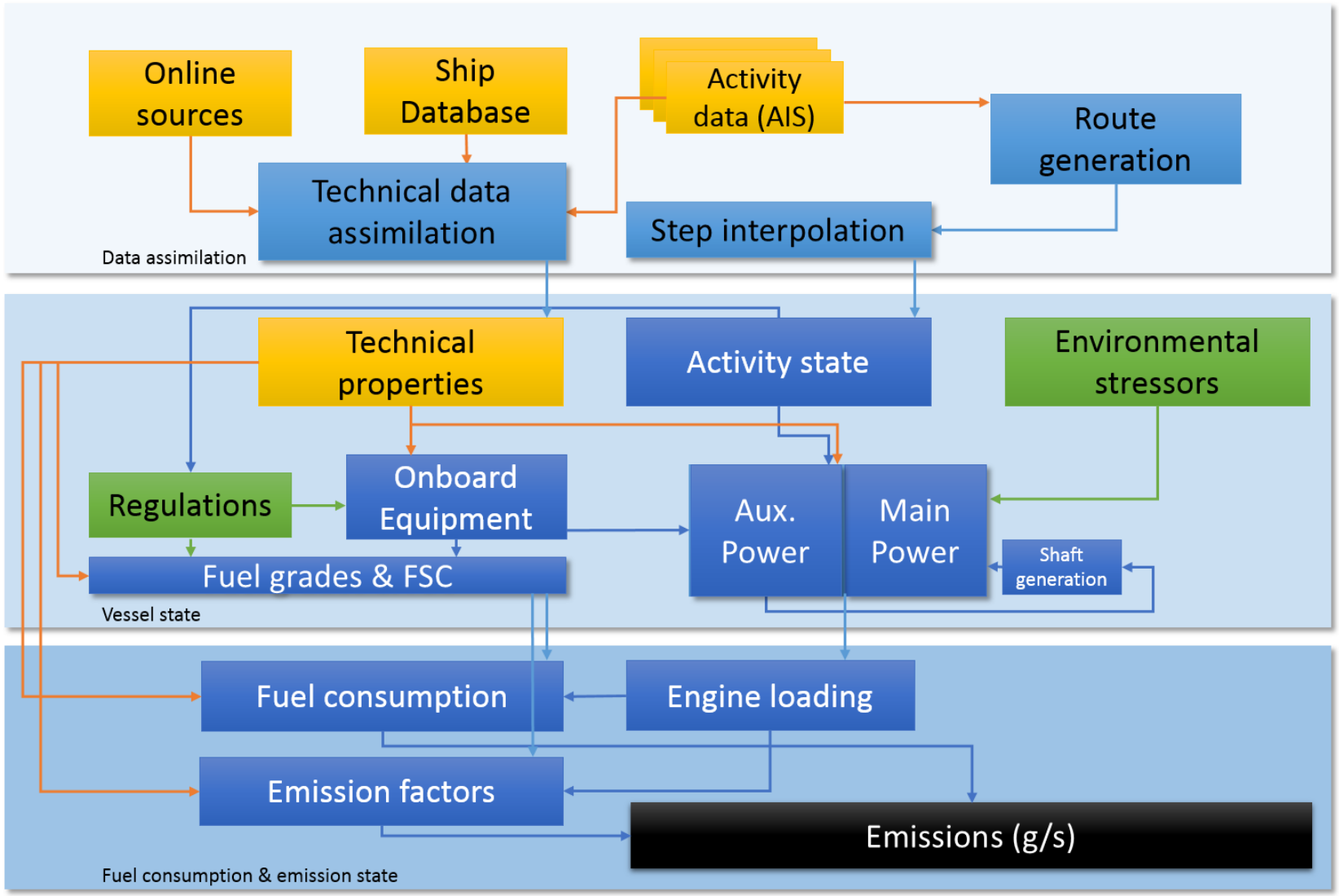
GNFR sectors

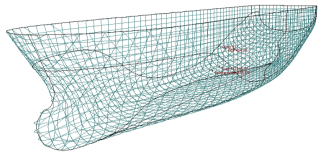
SNAP	Description
1	Public electricity and other energy transformation
2	Small combustion plants
3	Industrial combustion and processes with contact
4	Industrial process emission
5	Fossil fuel production
6	Solvent and product use
7	Road Transport
8	Other (non-road) transport and mobile machinery
9	Waste disposal
10	Agriculture
11*	Nature

SNAP sectors

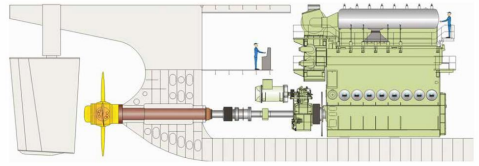
Example of emissions calculation: emissions from ships

From Jukka-Pekka Jalkanen, FMI





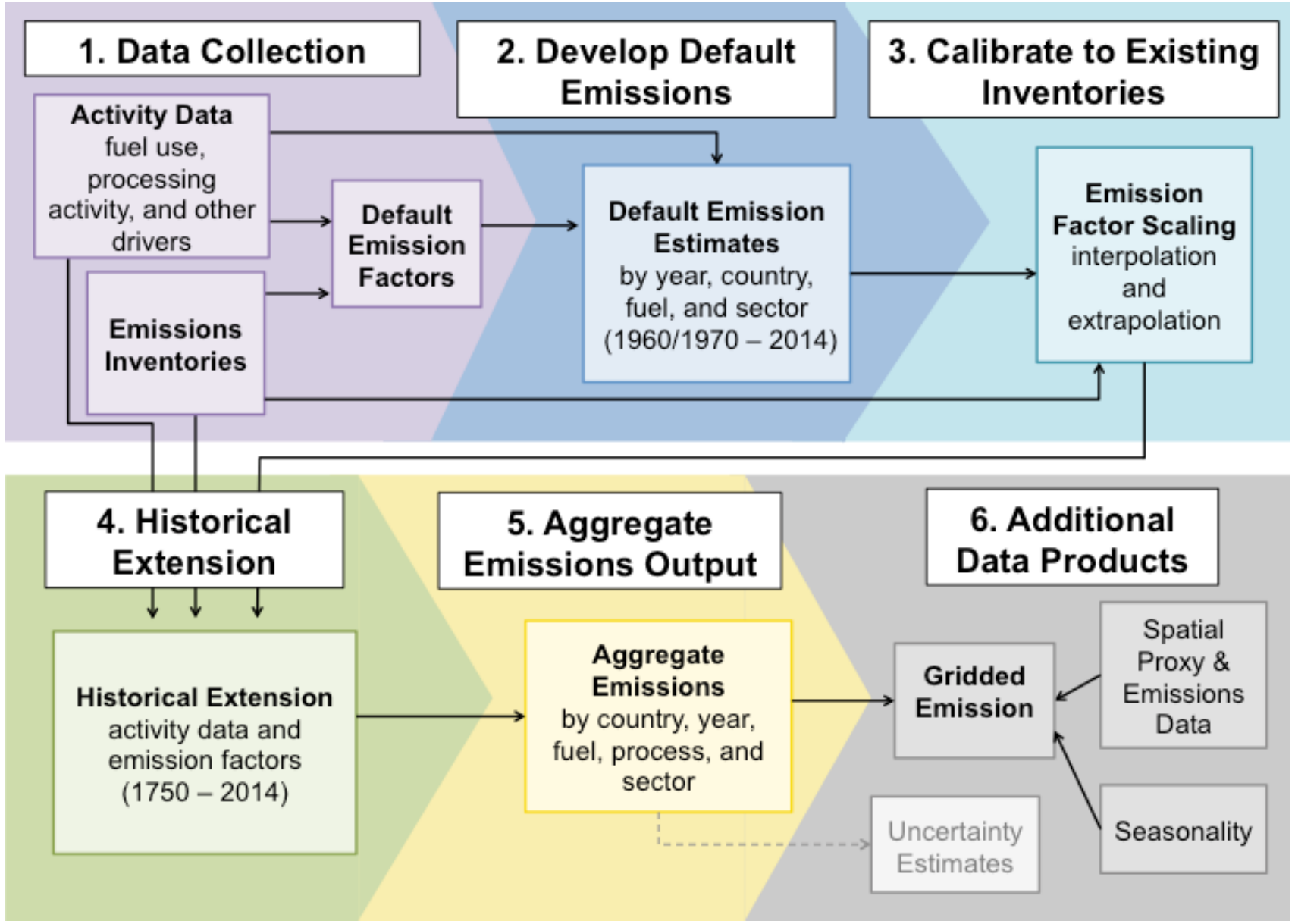
Activity



Emission factors

Gridding

System Diagram: CEDS inventory



Anthropogenic emissions

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1. General methodology to calculate emissions
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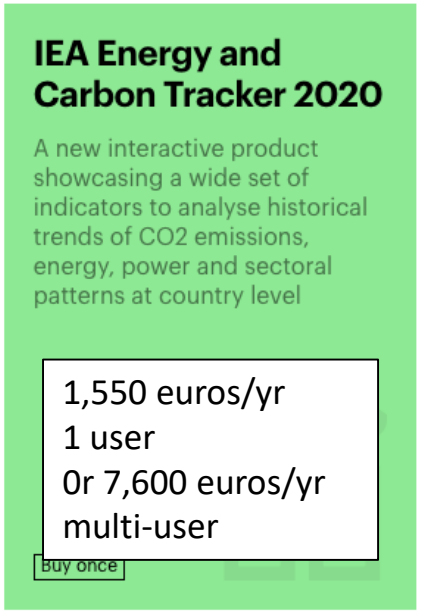
Acces to activity data

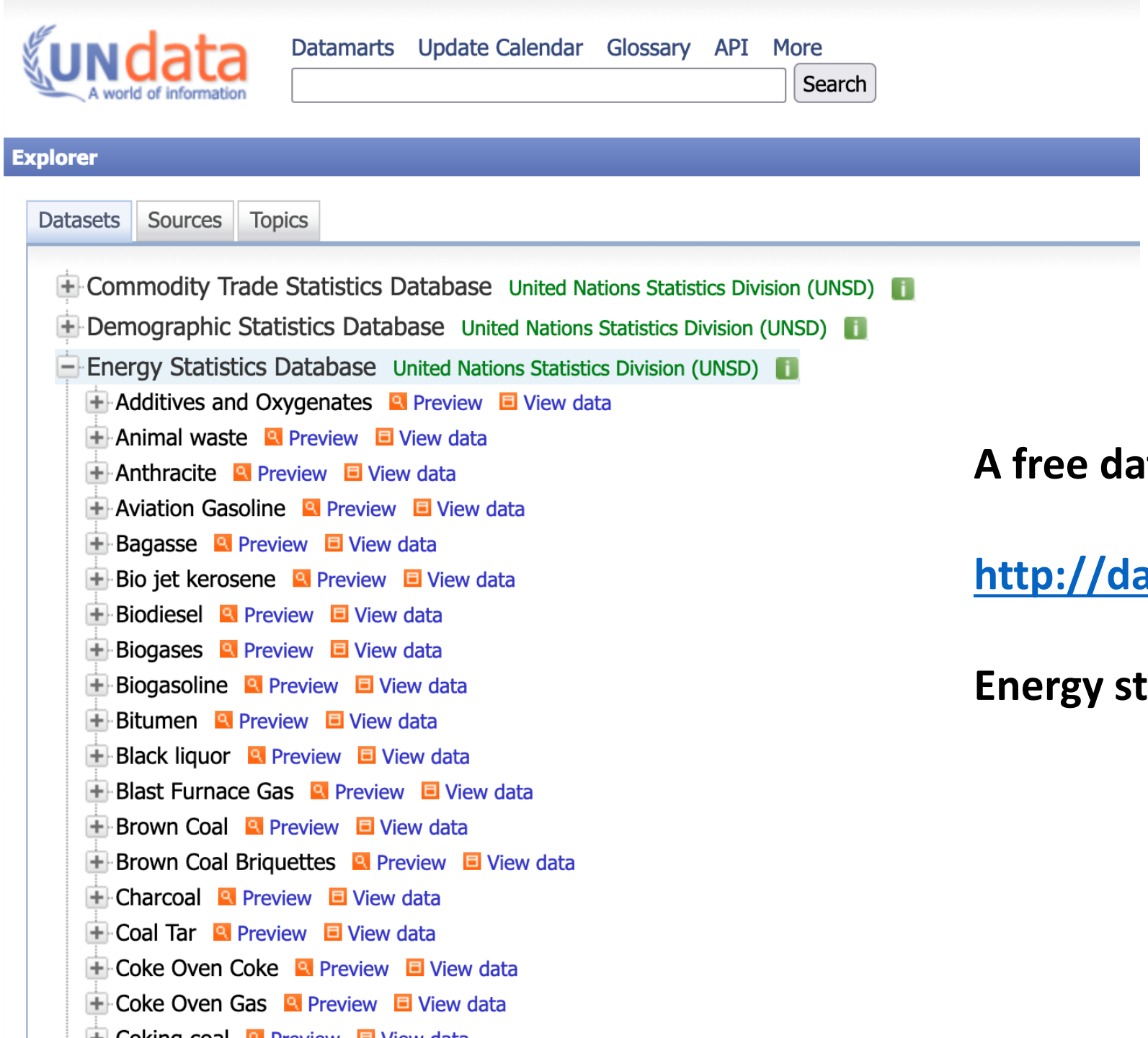
The dataset used by many groups: International Energy Agency = IEA

IEA: iea.org

Data are not free ➔ cannot be put directly on a website and cannot be shared



Emission factors one year, one user: 610 euros, or 2,990 for multi-users



A free dataset: Undata

http://data.un.org/Explorer.aspx

Energy statistics database

- Falling Water Preview View data
- Fuel Oil Preview View data
  - Fuel oil - Consumption by chemical and petrochemical Preview View data
  - Fuel oil - Consumption by commerce and public services Preview View data
  - Fuel oil - Consumption by construction Preview View data
  - Fuel oil - Consumption by domestic aviation Preview View data
  - Fuel oil - Consumption by domestic navigation Preview View data
  - Fuel oil - Consumption by food and tobacco Preview View data
  - Fuel oil - Consumption by households Preview View data
  - Fuel oil - Consumption by iron and steel Preview View data
  - Fuel oil - Consumption by machinery Preview View data
  - Fuel oil - Consumption by manufacturing, construction and non-fuel industry Preview View data
  - Fuel oil - Consumption by mining and quarrying Preview View data
  - Fuel oil - Consumption by non-ferrous metals Preview View data
  - Fuel oil - Consumption by non-metallic minerals Preview View data
  - Fuel oil - Consumption by other Preview View data
  - Fuel oil - Consumption by other manuf., const. and non-fuel ind. Preview View data
  - Fuel oil - Consumption by paper, pulp and print Preview View data
  - Fuel oil - Consumption by pipeline transport Preview View data
  - Fuel oil - Consumption by textile and leather Preview View data
  - Fuel oil - Consumption by transport Preview View data
  - Fuel oil - Consumption by transport equipment Preview View data
  - Fuel oil - Consumption by wood and wood products Preview View data
  - Fuel oil - Consumption in agriculture, forestry and fishing Preview View data
  - Fuel oil - Consumption in rail Preview View data
  - Fuel oil - Consumption in road Preview View data
  - Fuel oil - Consumption not elsewhere specified (industry) Preview View data
  - Fuel oil - Consumption not elsewhere specified (other) Preview View data
  - Fuel oil - Consumption not elsewhere specified (transport) Preview View data

http://data.un.org/Explorer.aspx

Details on consumption

Open to all ➔ can be shared

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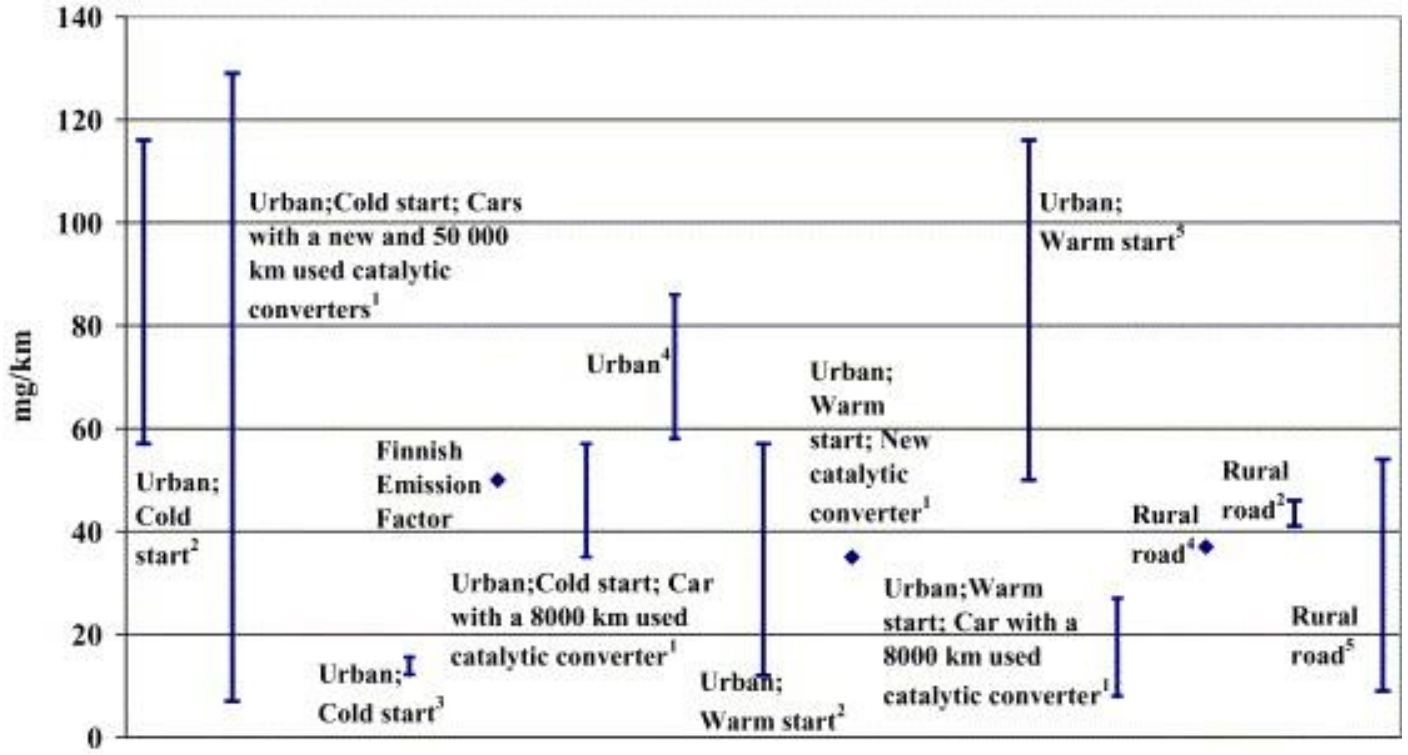
One of the main uncertainties: Emission Factors

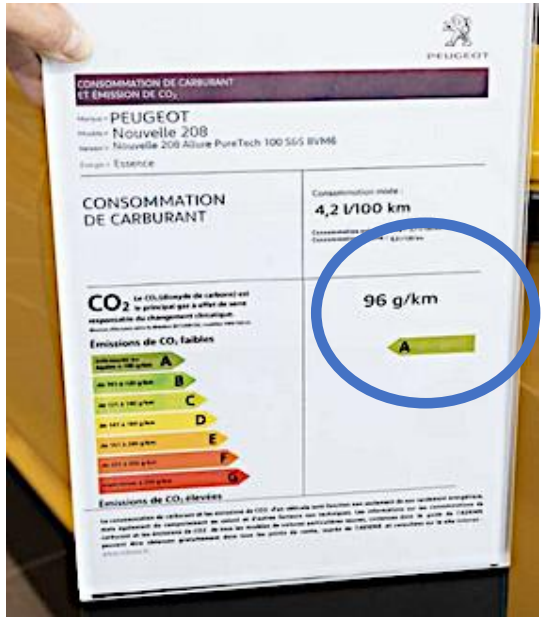
Main reasons:

- errors in definition / interpretation of definition
- difficulty in sampling because of a wide range of conditions
- vary widely among the different processes considered

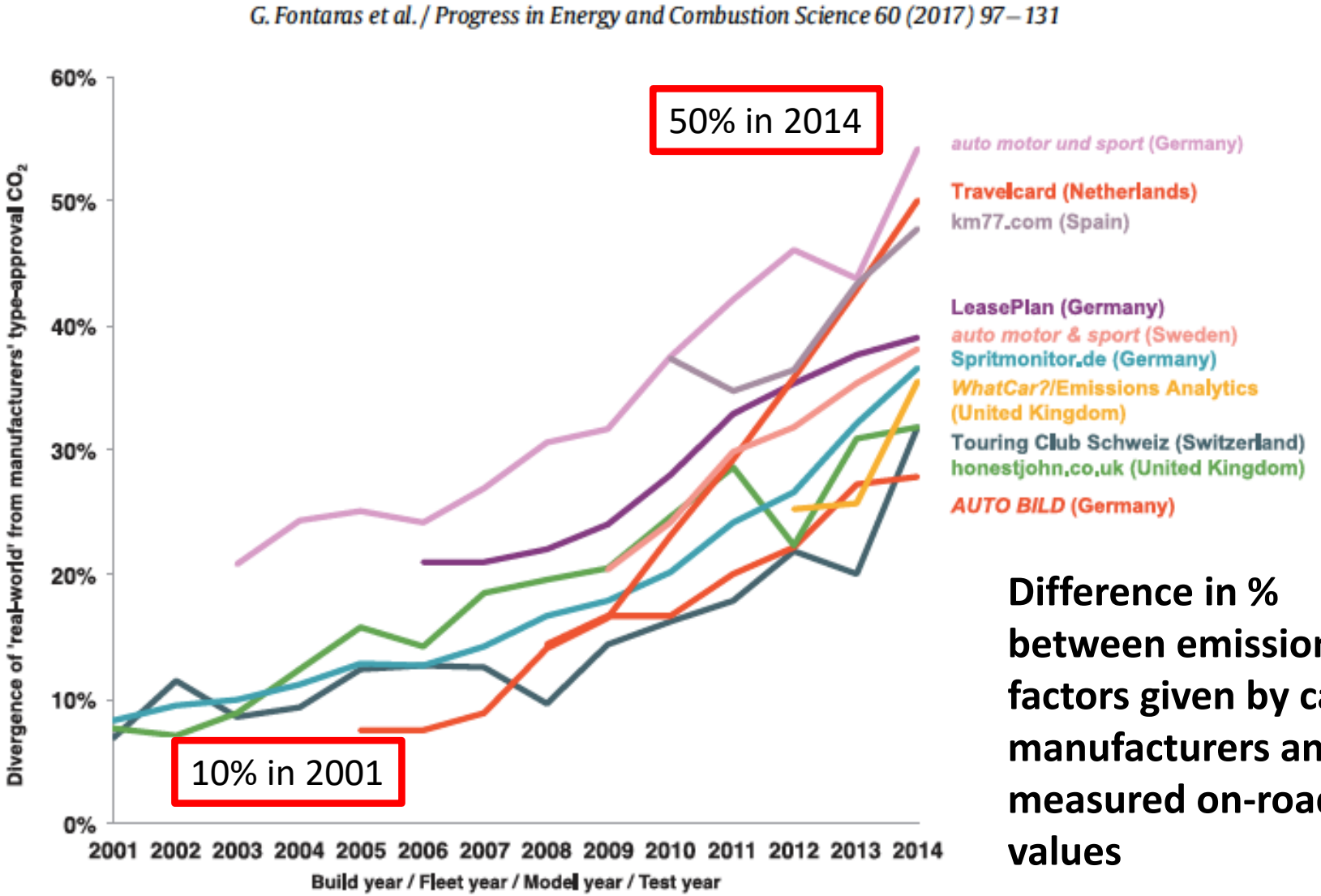


From Monni et al., 2004 (Measurement results of N_2O emission factors (mg/km) of cars with catalytic converters in different studies)

Automobiles emission factors: can we trust values provided by car companies?



What you can see when you buy a car



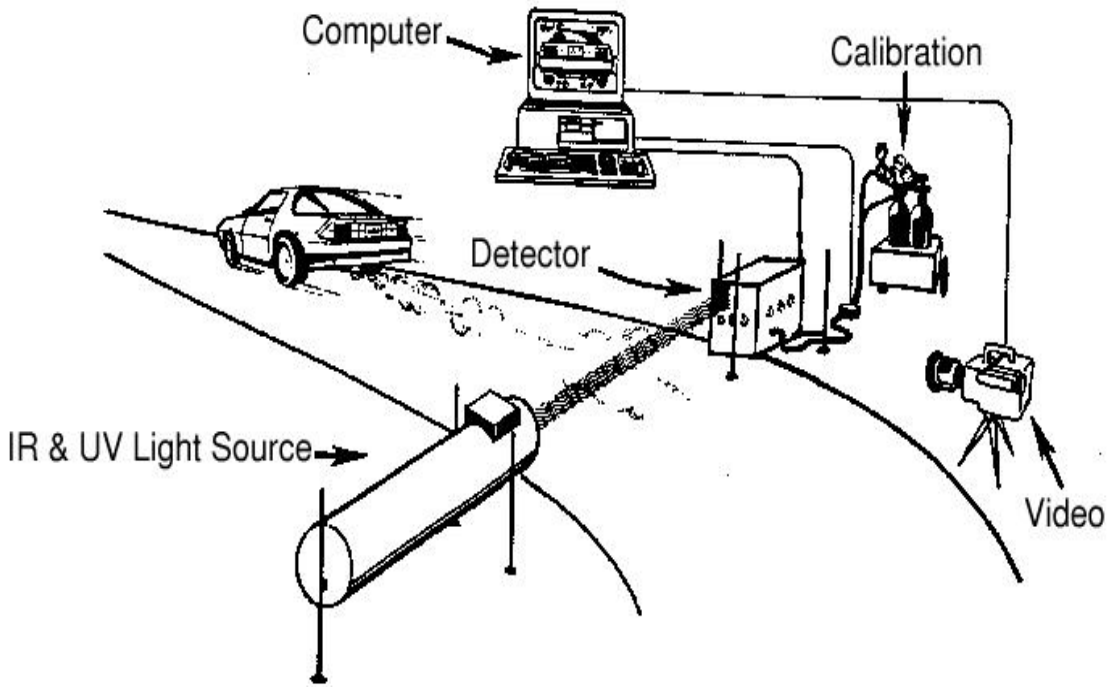
Difference in % between emission factors given by car manufacturers and measured on-road values

Measurement of emission factors related to traffic in different parts of the world

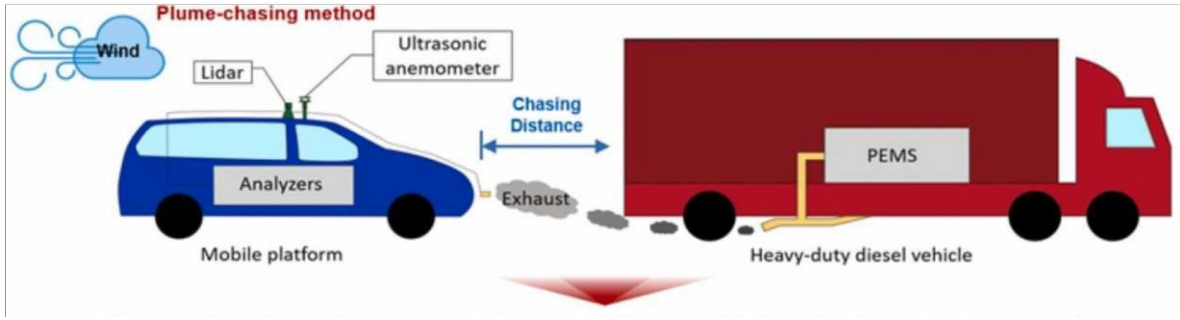
Measurement of emission factors for anthropogenic emissions

Sekou Keita

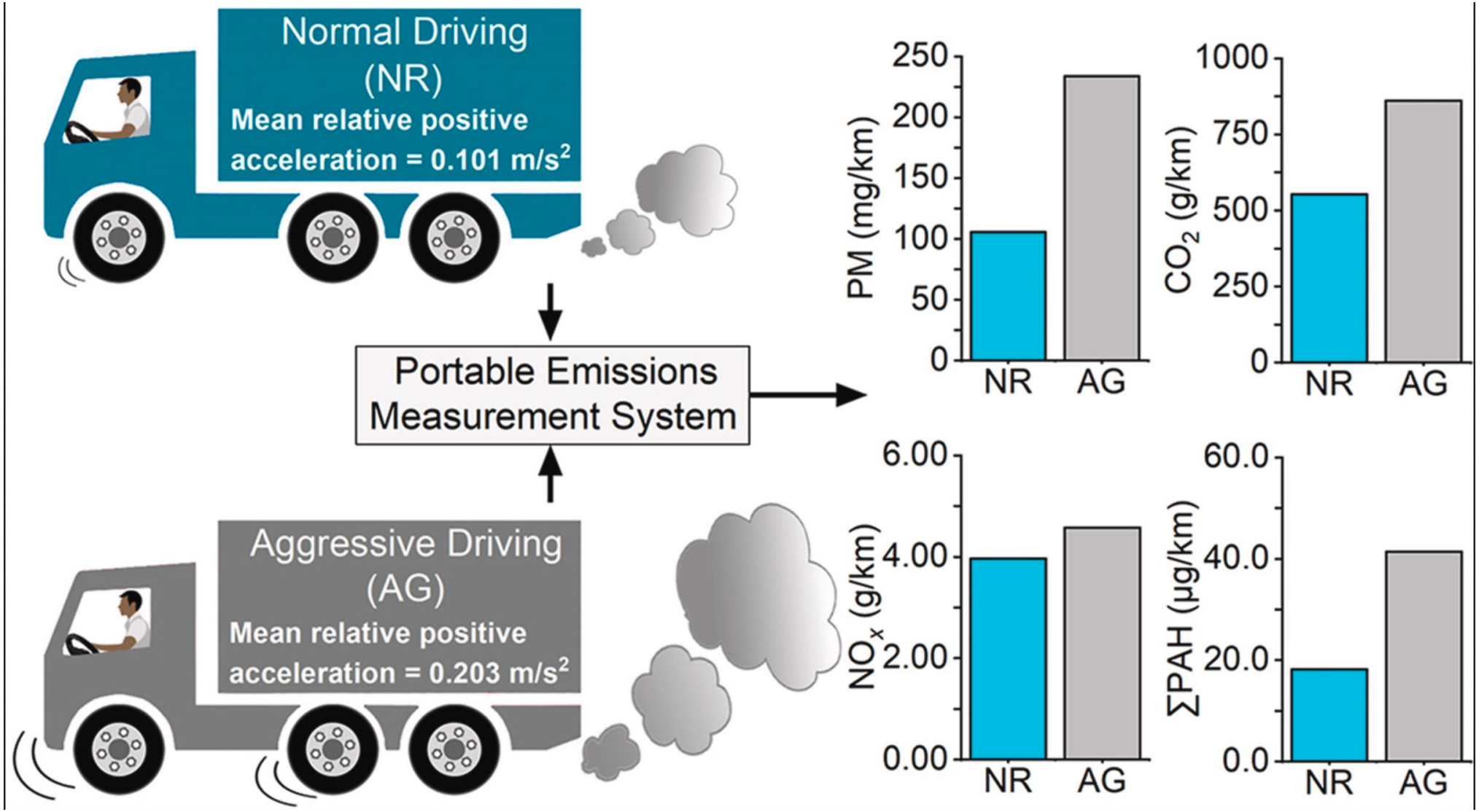
CO, HC and NO Remote Sensing



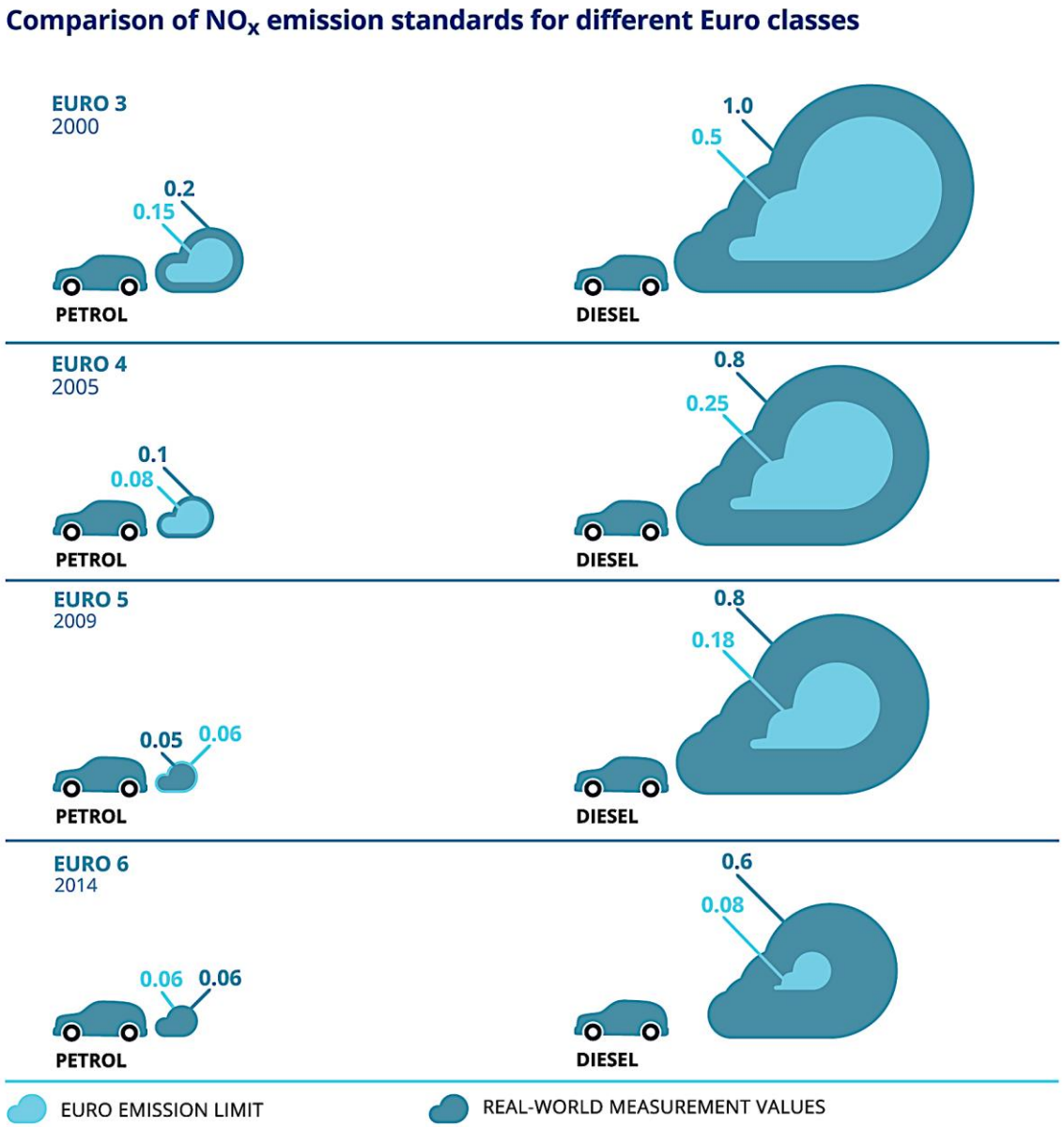
From Stedman, GEIA, 2014



From Tong et al. Journal Hazardous materials, 2021



From Dithal et al., Environmental Pollution, 2021



https://www.eea.europa.eu/media/infographics/comparison-of-nox-emission-standards/view

A database of emission factors

EFDB
emission factor database

ipcc
INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP

IPCC web sites

Home | Basic search | Fulltext search | Search by ID | Documents | Off-line version of EFDB | Help

Basic search

Select Gases | Select Fuels | IPCC Default Data | Other (non-default) Data

Choose table columns | Hide IPCC Category tree | Hide status

IPCC Guidelines: 2006

- IPCC 2006 Categories
  - 1 - Energy
  - 2 - Industrial Processes and Product Use
  - 3 - Agriculture, Forestry, and Other Land Use
  - 4 - Waste
  - 5 - Other

Status

- **IPCC 2006 Source/Sink Category:** (All)
- **Gases:** (All)
- **Fuels:** (All + NA)
- **Type of parameter:** (All)

Displayed records: 1 - 20 / 19663. Export to XLS

Filter			Select Gases	Select Fuels												Apply filter
Active Filters																
EF ID	IPCC 1996	IPCC 2006	Gas	Fuel	Type of parameter	Description	Technologies / Practices	Parameters / Conditions	Region / Regional Conditions	Abatement / Control Technologies	Other properties	Value	Unit	Source of data	Action
62639	6A - Solid Waste Disposal on Land	4.A - Solid Waste Disposal	METHANE		1996 IPCC default	Municipal Solid Waste (MSW) Generation Rate			United States of America			2.0	kg/cap/day	Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 6-1 on Pages 6.6 - 6.7 of the Reference Manual)	Detail
62640	6A - Solid Waste Disposal on Land	4.A - Solid Waste Disposal	METHANE		1996 IPCC default	Municipal Solid Waste (MSW) Generation Rate			Canada			1.81	kg/cap/day	Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 6-1 on Pages 6.6 - 6.7 of the Reference Manual)	Detail
62641	6A - Solid Waste Disposal on Land	4.A - Solid Waste Disposal	METHANE		1996 IPCC default	Municipal Solid Waste (MSW) Generation Rate			Australia			1.26	kg/cap/day	Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 6-1 on Pages 6.6 - 6.7 of the Reference Manual)	Detail
62642	6A - Solid Waste Disposal on Land	4.A - Solid Waste Disposal	METHANE		1996 IPCC default	Municipal Solid Waste (MSW) Generation Rate			New Zealand			1.33	kg/cap/day	Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 6-1 on Pages 6.6 - 6.7 of the Reference Manual)	Detail
62643	6A - Solid Waste Disposal on Land	4.A - Solid Waste Disposal	METHANE		1996 IPCC default	Municipal Solid Waste (MSW) Generation Rate			United Kingdom of Great Britain and Northern Ireland.			1.9	kg/cap/day	Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 6-1 on Pages 6.6 - 6.7 of the Reference Manual)	Detail

https://www.ipcc-nggip.iges.or.jp/EFDB/main.php

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a. Gridded emissions 1992 (4.5° lat. X 7.5° lon.)

1989 paper

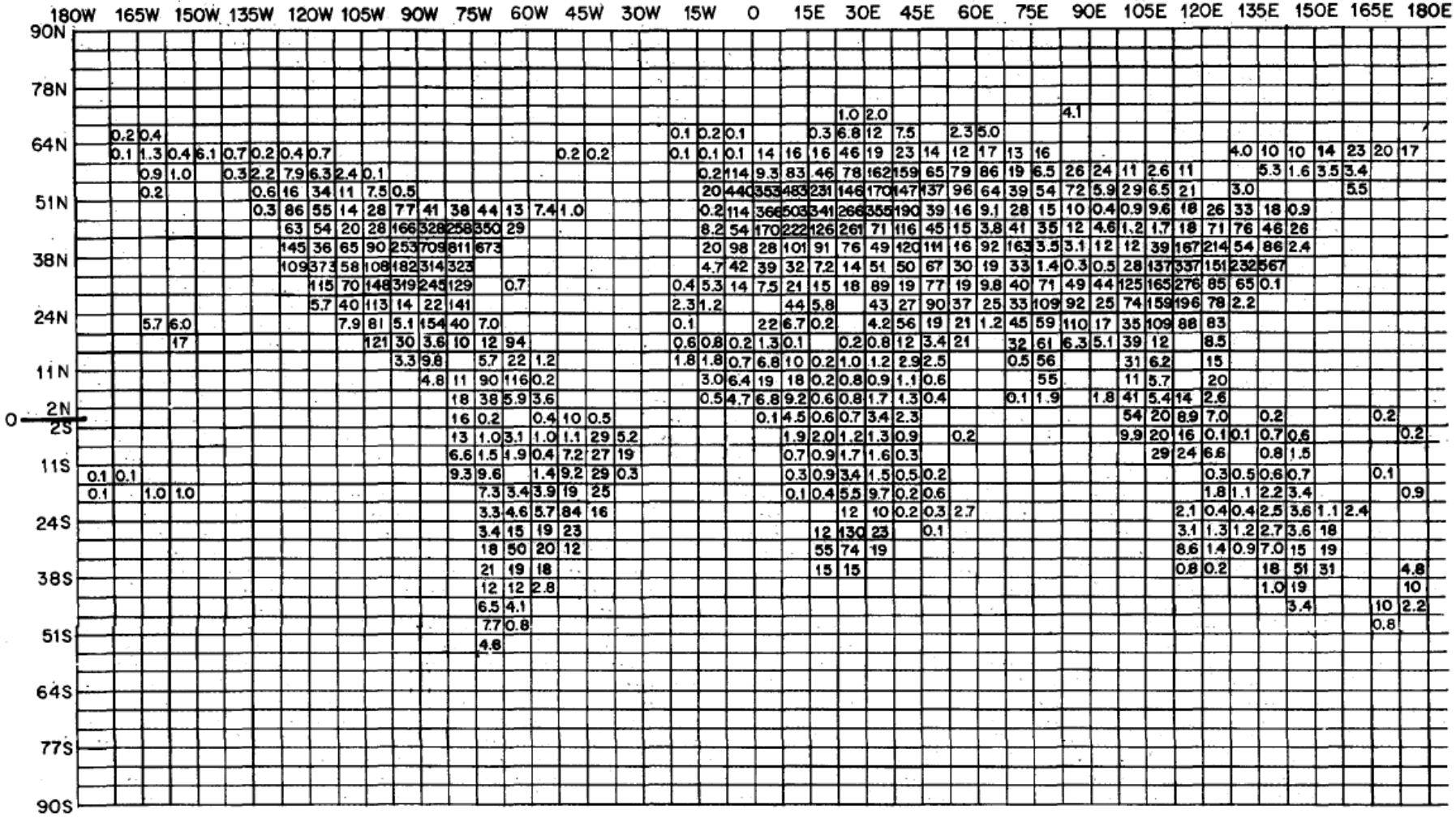
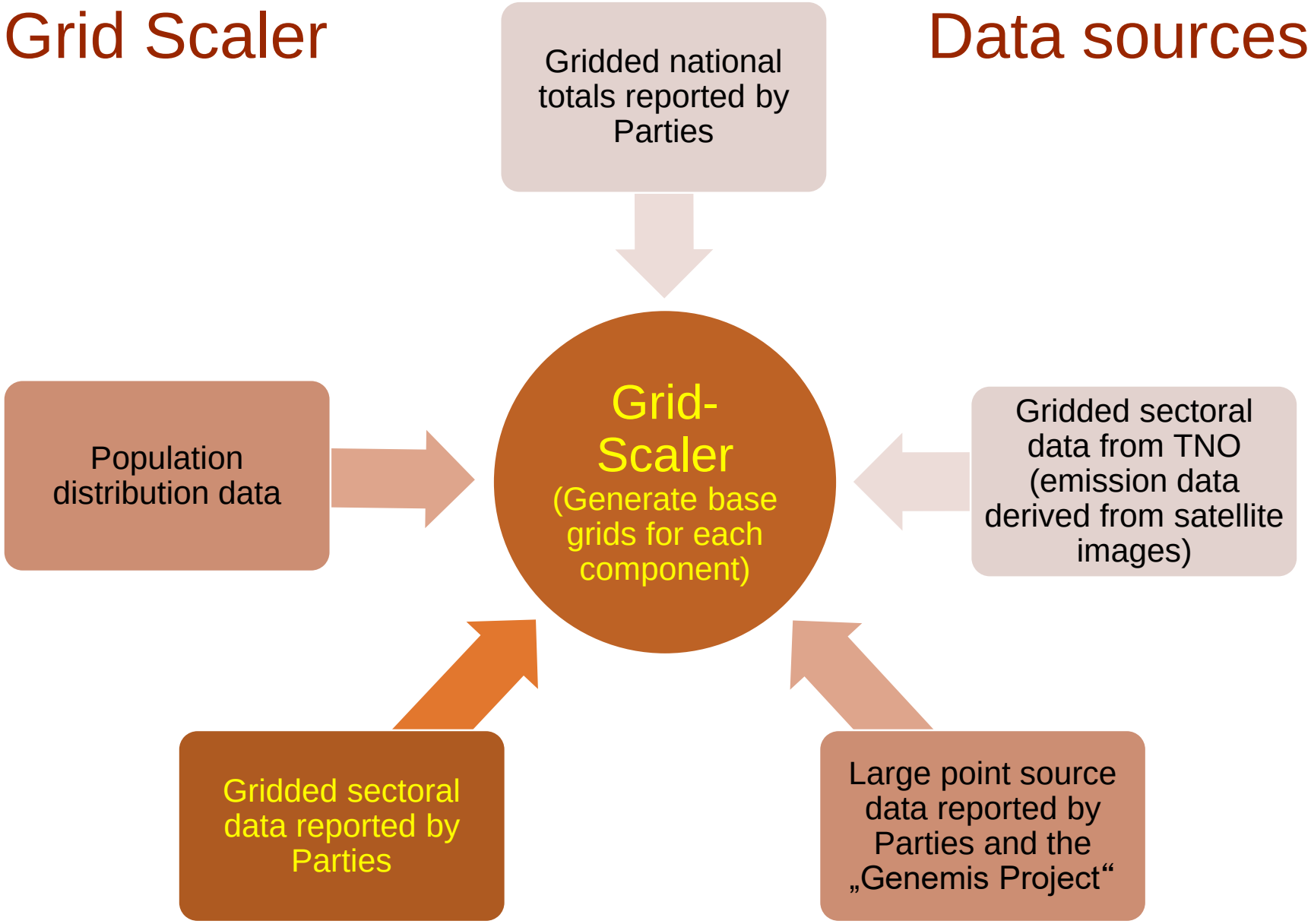


Figure 5. Geographical distribution of NO_x emissions from fossil fuel combustion for 1986.

Hameed and Dignon, Global Emissions of Nitrogen and Sulfur Oxides in Fossil Fuel Combustion 1970-1986. ISSN 1047-3289 J. Mr Waste Manage. Assoc. 42:159-163

European Environment Agency

Grid Scaler



Data sources

From TNO, The Netherlands

Road traffic data

Datasets commonly used:

- Geographical Information Systems (GIS): public versions exist

- Tomtom (tomtom.com): not all publicly available

- Google Community Mobility Reports

- Many national and cities datasets

Population data

- Data used by many groups: CIESIN

https://sedac.ciesin.columbia.edu/data/collection/gpw-v4

Population Density, v4.11 (2000, 2005, 2010, 2015, 2020)

Gridded Population of the World (GPW), *v4*

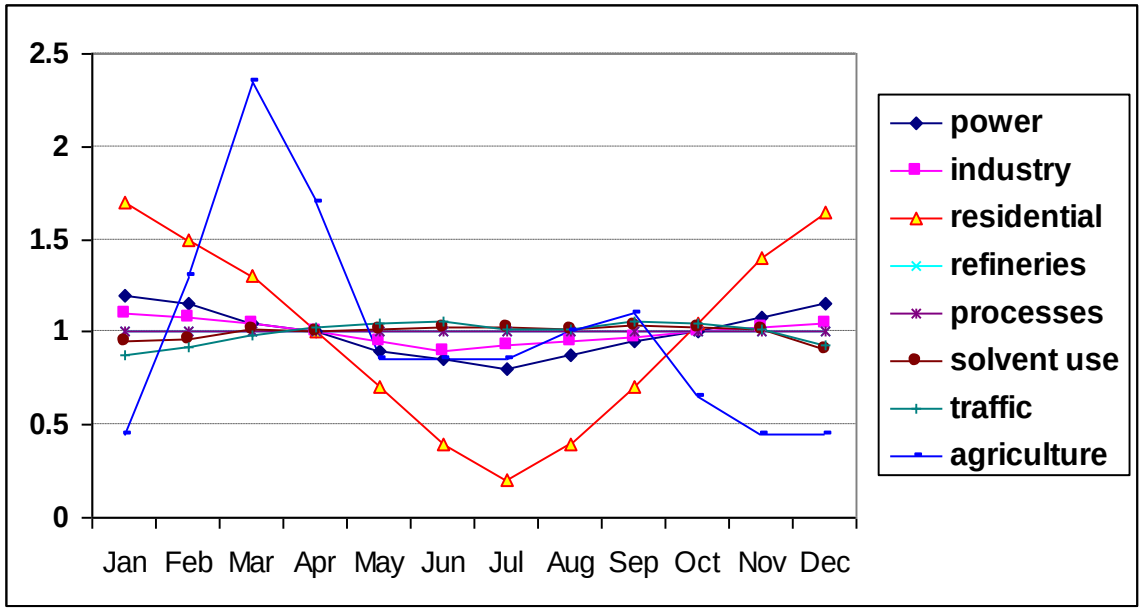
Overview
Download
Documents
(5) Maps
(5) WMS

To provide estimates of population density for the years 2000, 2005, 2010, 2015, and 2020, based on counts consistent with national censuses and population registers, as raster data to facilitate data integration.

The files for this data set are available as global rasters in GeoTIFF, ASCII, and netCDF-4 format. The ASCII and GeoTIFF data are available at the native 30 arc-second resolution and four lower resolutions: 2.5 arc-minute, 15 arc-minute, 30 arc-minute, and 1 degree. The netCDF-4 files are available at all resolutions except 30 arc-second. The data are stored in WGS84, geographic coordinate system (latitude/longitude).

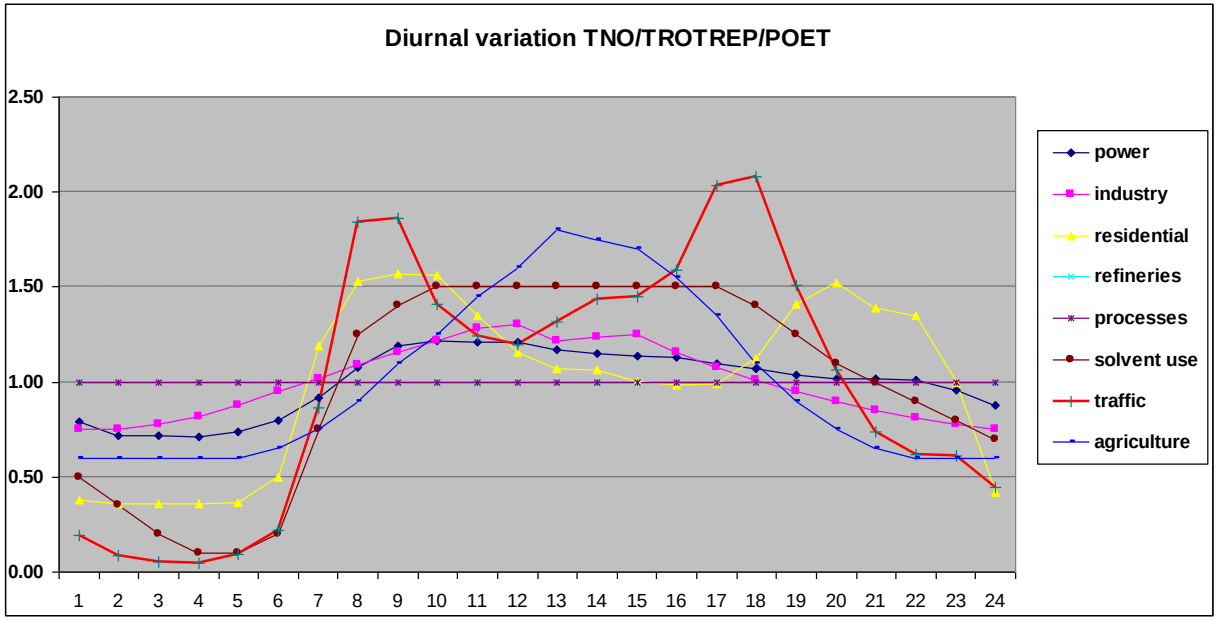
Temporal variations of the emissions: data used for a long time

Many datasets/models use old data from TNO in the Netherlands



Seasonal

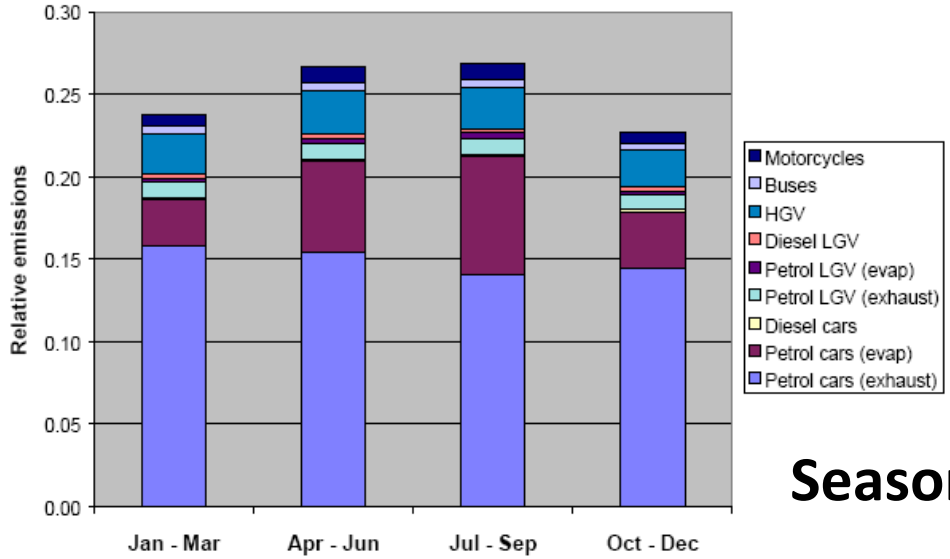
Not much details on differences between countries, species, etc.



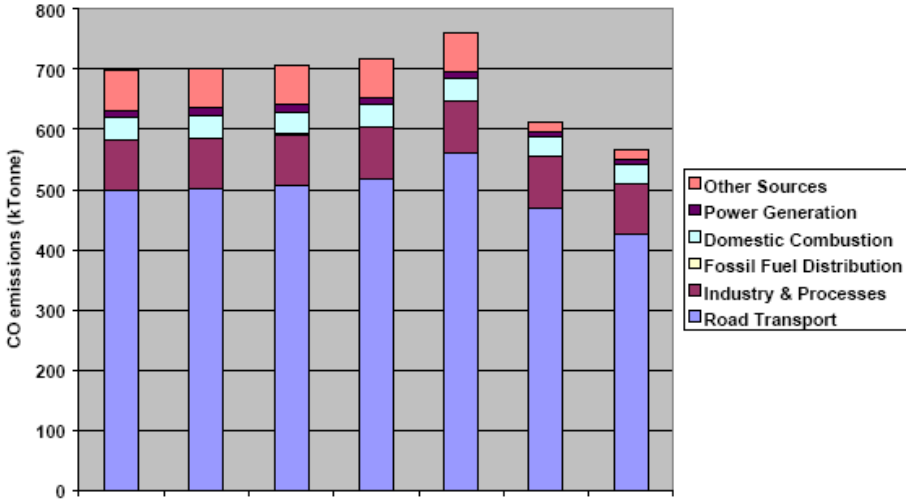
diurnal

From RIVM,
the Netherlands

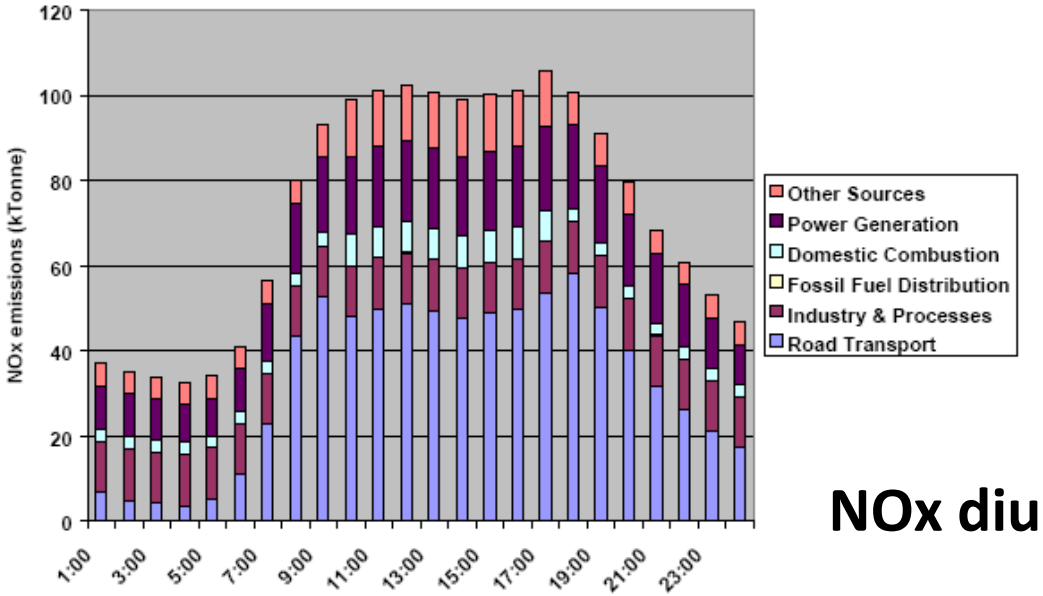
Temporal variation



Seasonal VOCs



CO weekly emissions



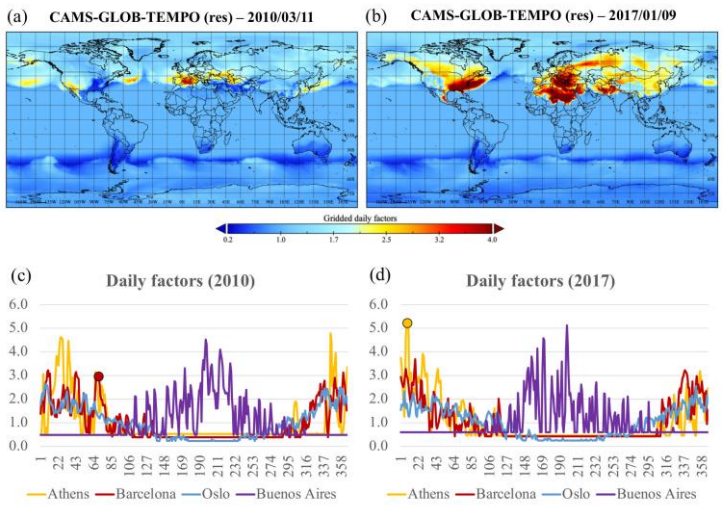
NOx diurnal emissions

New temporal profiles developed within the CAMS project (see later)

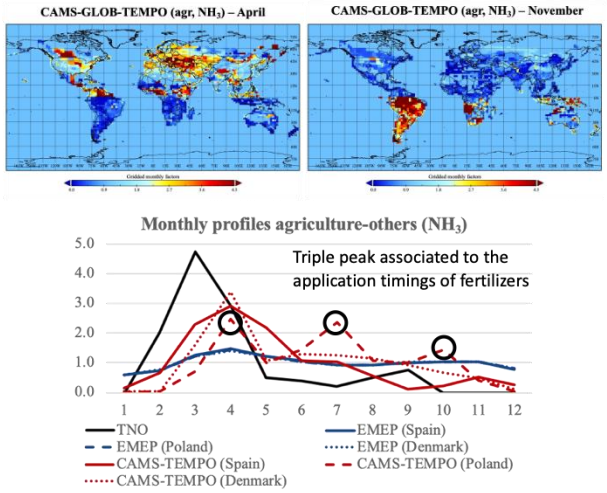
Much more recent: data developed as part of the CAMS (Copernicus Atmosphere Monitoring Service) → CAMS = atmosphere.copernicus.eu, developed at the Barcelona Supercomputer Center

- A collection of **gridded monthly, weekly, daily and hourly temporal profiles** to be combined with the CAMS-GLOB-ANT and CAMS-REG-AP/GHG emission inventories; considers **year & pollutant-dependency, sociodemographic and meteorological influences**
- **Temporal coverage:** 2000 - 2020
- **Sectoral coverage**: energy & manufacturing industry, residential/commercial combustion, road transport, agriculture (livestock, fertilizers and agricultural waste burning), aviation, shipping
- Methods and dataset documented in detail in **Guevara et al., Earth Syst. Sci. Data, 2021**

Residential combustion: Influence of temperature



Fertilizers: Influence of meteorology + crop calendars



Questions: ask Marc (Poster 3.07)

What VOCs speciation mean:

- **VOCs = volatile organic compounds ; Most inventories = emissions of total NMVOCs**

- **Atmospheric models include individual VOCs, such as ethane, propane, ethene, benzene, toluene, methanol, formaldehyde, etc.**

- **Most datasets provide surface emissions of total VOCs, without any indication of the emission of individual VOCs (speciation)**

- **Very few data available at the global scale. More data available at the country or city scale. Some regional models include a speciation, either based on reactivity, or just as a global percentage of total NMVOCs**

- **Gridded speciations: not many available public data**
  - **RETRO speciation: developed in 2000, never published, based on non-published EU data**
  - **Huang et al. 2017 (EDGAR group): 1970-2012 0.1x0.1 degree speciation**

Name	Real name	ENE	RCO	TRO	TNR	FEF	SLV	AGR	SHP	SWD
voc1	Alcohols	X	X	X	X	X	X		X	X
voc2	Ethane	X	X	X	X	X	X	X	X	X
voc3	Propane	X	X	X	X	X	X	X	X	X
voc4	Butanes	X	X	X		X	X	X		X
voc5	Pentanes	X	X	X	X	X	X	X	X	X
voc6	Hexanes	X	X	X	X	X	X	X	X	X
voc7	Ethene	X	X	X	X	X	X	X	X	X
voc8	Propene	X	X	X	X	X	X	X	X	X
voc9	Ethyne	X	X	X	X	X	X	X	X	X
voc10	Isoprenes	X	X	X	X	X	X	X	X	X
voc11	Monoterpenes	X	X	X	X		X	X	X	X
voc12	Other alkad.	X	X	X	X	X	X	X	X	X
voc13	Benzene	X	X	X	X	X	X	X	X	X
voc14	Methylbenzene	X	X	X	X	X	X	X	X	X
voc15	Dimethylbenzenes	X	X	X	X	X	X	X	X	X
voc16	Trimethylbenzenes	X	X	X	X	X	X	X	X	
voc17	Other aromatics	X	X	X	X	X	X	X	X	X
voc18	Esters	X	X	X	X	X	X		X	X
voc19	Ethers	X	X	X	X	X	X	X	X	X
voc20	Chlorinated	X	X	X	X	X	X		X	
voc21	Methanal	X	X	X	X	X	X	X	X	X
voc22	Other alkanals	X	X	X	X	X	X	X	X	X
voc23	Alkanones	X	X	X	X	X	X	X	X	
voc24	Acids	X	X	X	X		X		X	X
voc25	Others	X	X	X	X	X	X	X	X	X

VOCs speciation based on Huang et al. (2017), used in the CAMS-GLOB-ANT emissions

(From Soulie et al. to be submitted, 2023)

Speciation not adapted to most current models → redoing the speciation represents a large amount of work

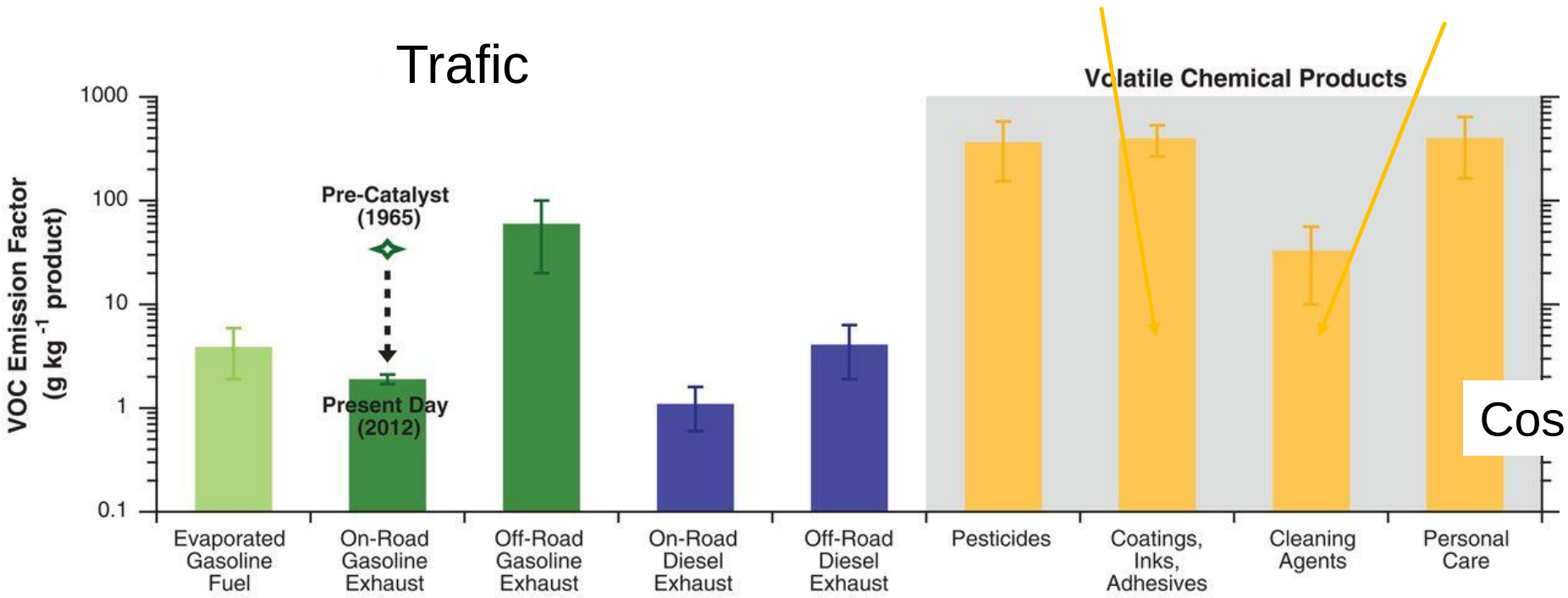
GEIA has a new VOCs working group → discussions planned during the conference

Recent work on the emissions of volatile chemical products: emissions from consumer and industrial products
→ not taken into account in many models

Adhesives

Cleaning agents

Trafic



Cosmetics

[McDonald et al., Science, 2018 → B. McDonald is the current IGAC co-chair]

Anthropogenic emissions

Outline

1. General methodology to calculate emissions
2. Activity data
3. Emission factors
4. Spatial/temporal variations and VOCs speciation
5. **Current public global inventories**
6. A few current public regional inventories
7. Evaluation of anthropogenic emissions
8. Conclusions

The first global inventory for 3-d tropospheric chemistry-transport models

Jean-François Müller at IASB-BIRA in a JGR paper in 1982

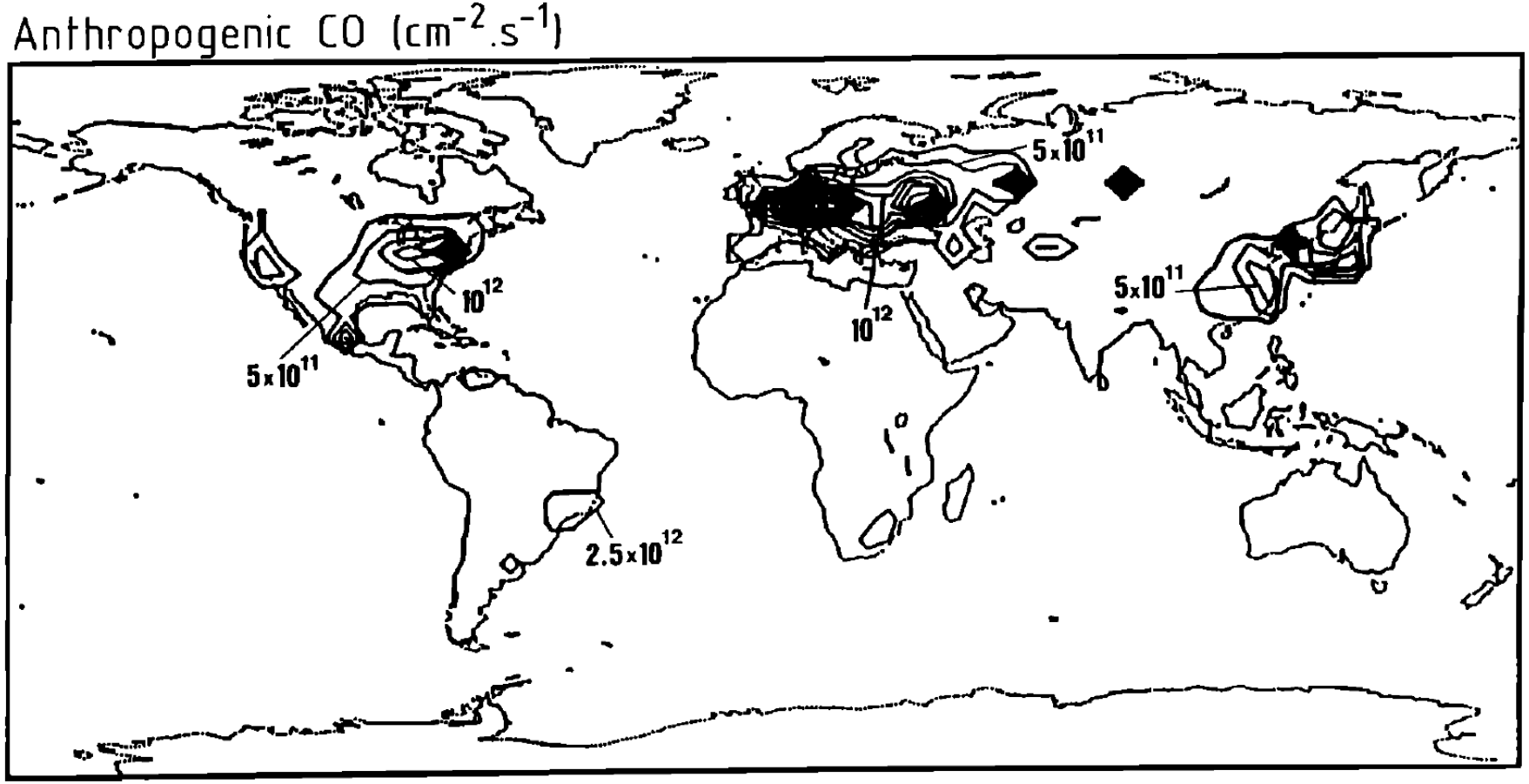


Fig. 2. Same as Figure 1, for carbon monoxide (molecules/cm^2/s).

5x5 degree

The global anthropogenic emissions inventories commonly used:

- EDGAR inventories (Joint Research Center, Italy) (including HTAP)
https://edgar.jrc.ec.europa.eu/

- CEDS inventory for IPCC AR6 (PNNL, Pacific Northwest National Laboratory):
http://www.globalchange.umd.edu/ceds/

- CAMS-GLOB-ANT, and CAMS-GLOB-SHIP, available from ECCAD
https://eccad.sedoo.fr/

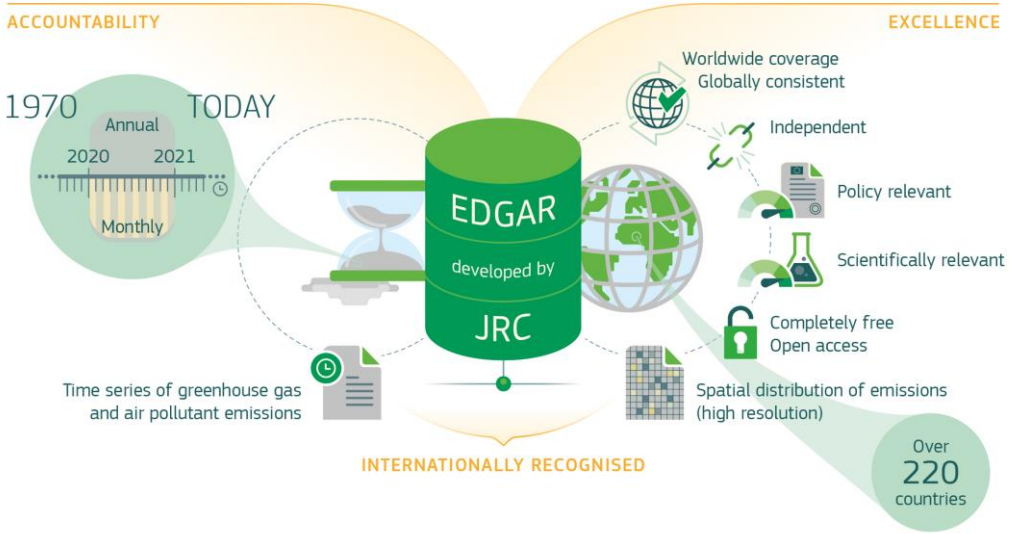
- ECLIPSE, developed at IIASA, Austria,
https://iiasa.ac.at/models-tools-data/global-emission-fields-of-air-pollutants-and-ghgs

EDGAR= Emissions Database for Global Atmospheric Research

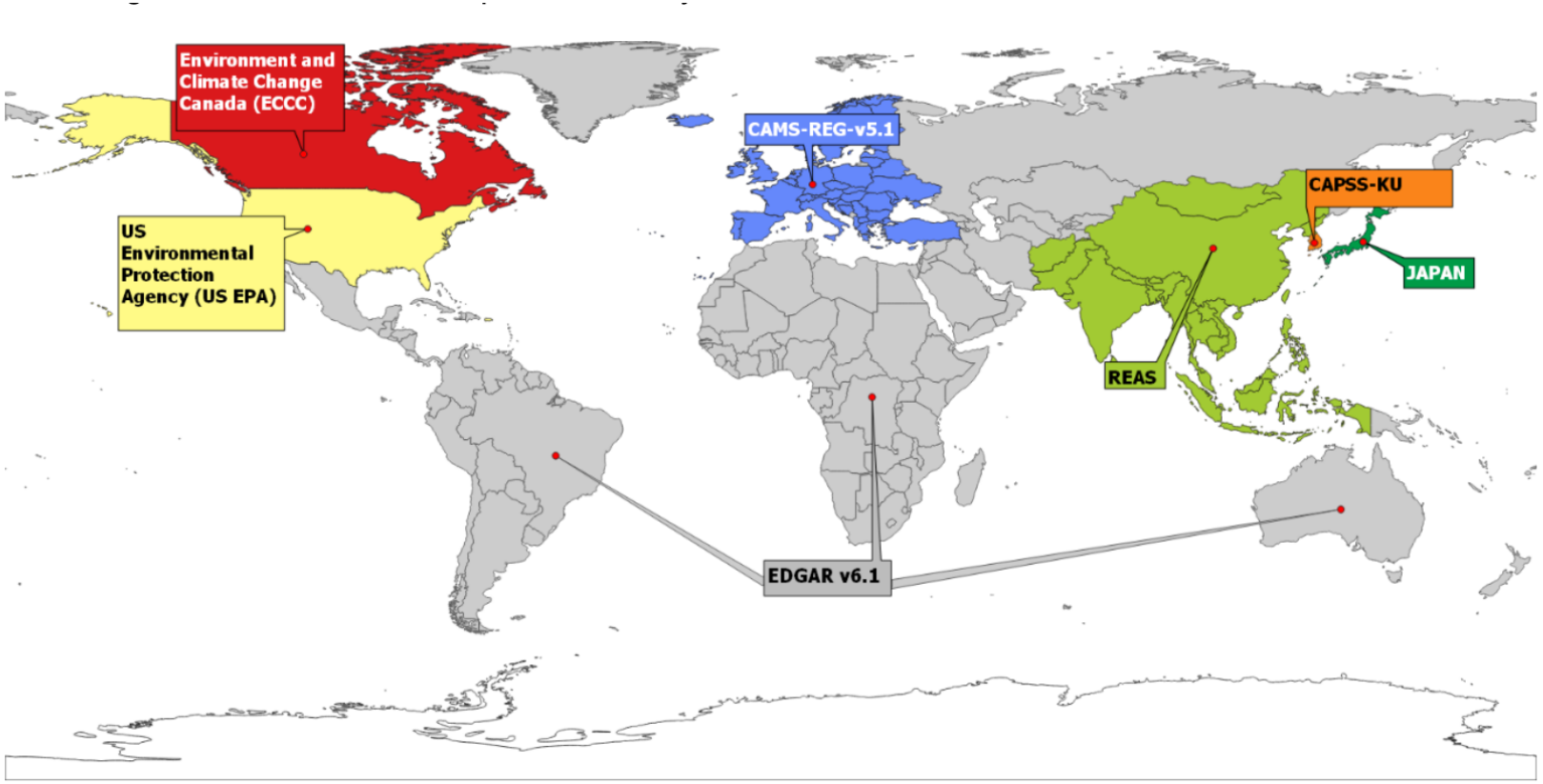
→ Developed in Ispra, Italy at the Joint Research Center. Site : https://edgar.jrc.ec.europa.eu/

→ Greenhouse gases and air pollutants

- Greenhouse gases: 1970 – 2021 with EDGARv7
- Pollutants: 1970-2018 with EDGARv6
- Monthly averages, spatial resolution : 0.1x0.1 degree
- 27 sectors
- VOCs speciation up to 2012



EDGAR/HTAP = An emission inventory in support to Hemisperic Transport of Air Pollution



Compared to the previous HTAP mosaics (HTAPv1, HTAPv2.2), HTAP_v3 aims at extending the temporal coverage of the air pollutant emissions, their sectoral breakdown and the geographical coverage of the official data. The overall purpose is to provide the scientific inventory and modelling communities a comprehensive tool to develop trend analysis, study the transboundary transport of air pollutants, and help policy makers in addressing and mitigating emissions for relevant sectors.

2010-2018

8 sectors

0.1x0.1 degree

All compounds, except greenhouse gases

HTAP discussion planned during a lunch at the GEIA conference, organized by Tim Butler (Germany)

CEDS – Community Emissions Data System

https://data.pnnl.gov/dataset/CEDS-4-21-21 = last version of the CEDS emissions

- **Emissions from 1750 to 2019**
- **Emissions used in the simulations of the last IPCC AR6 report**
- **Monthly emissions, spatial resolution : 0.5x0.5 degree**
- **Emissions per country and sector available at: https://zenodo.org/record/4741285**

CEDS – Community Emissions Data System

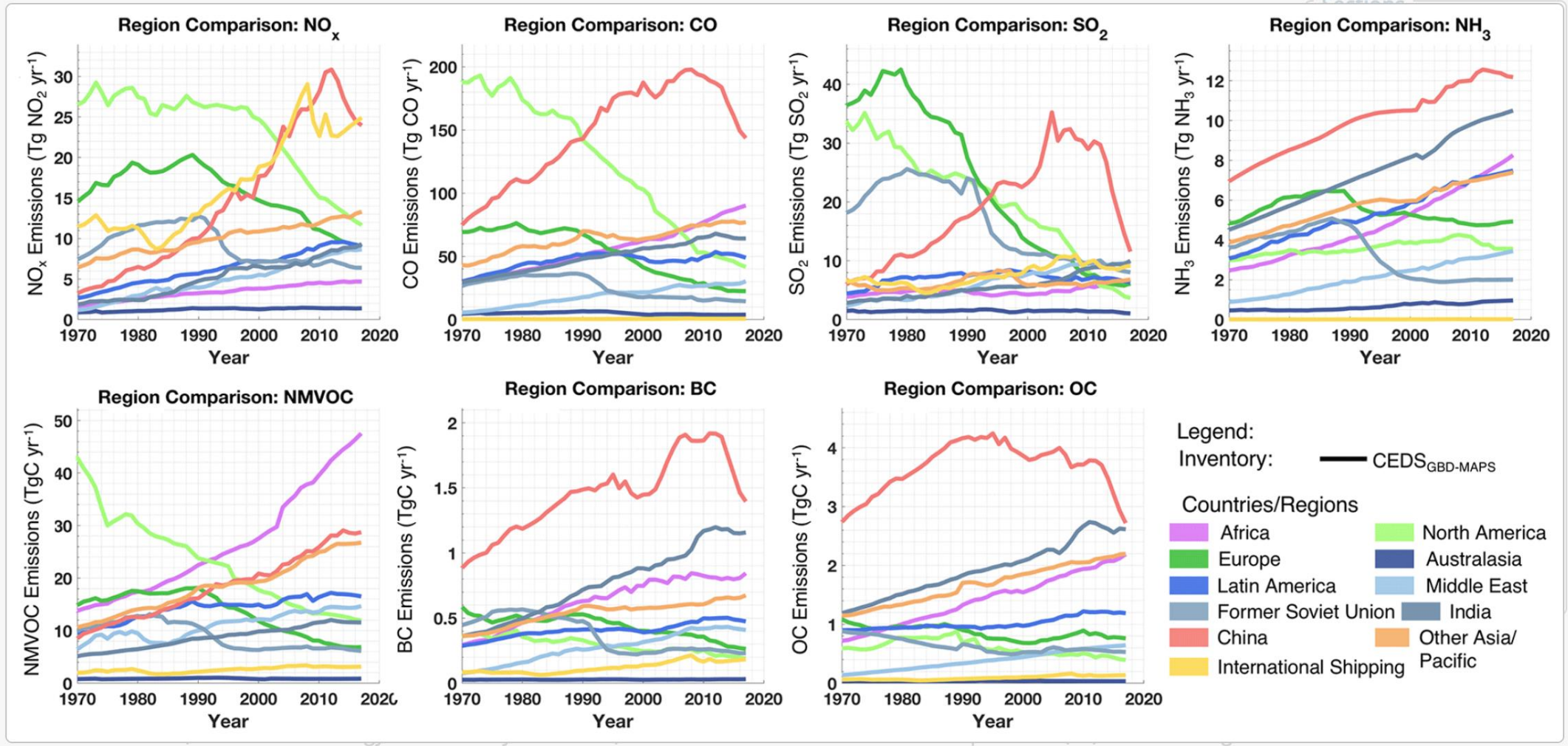
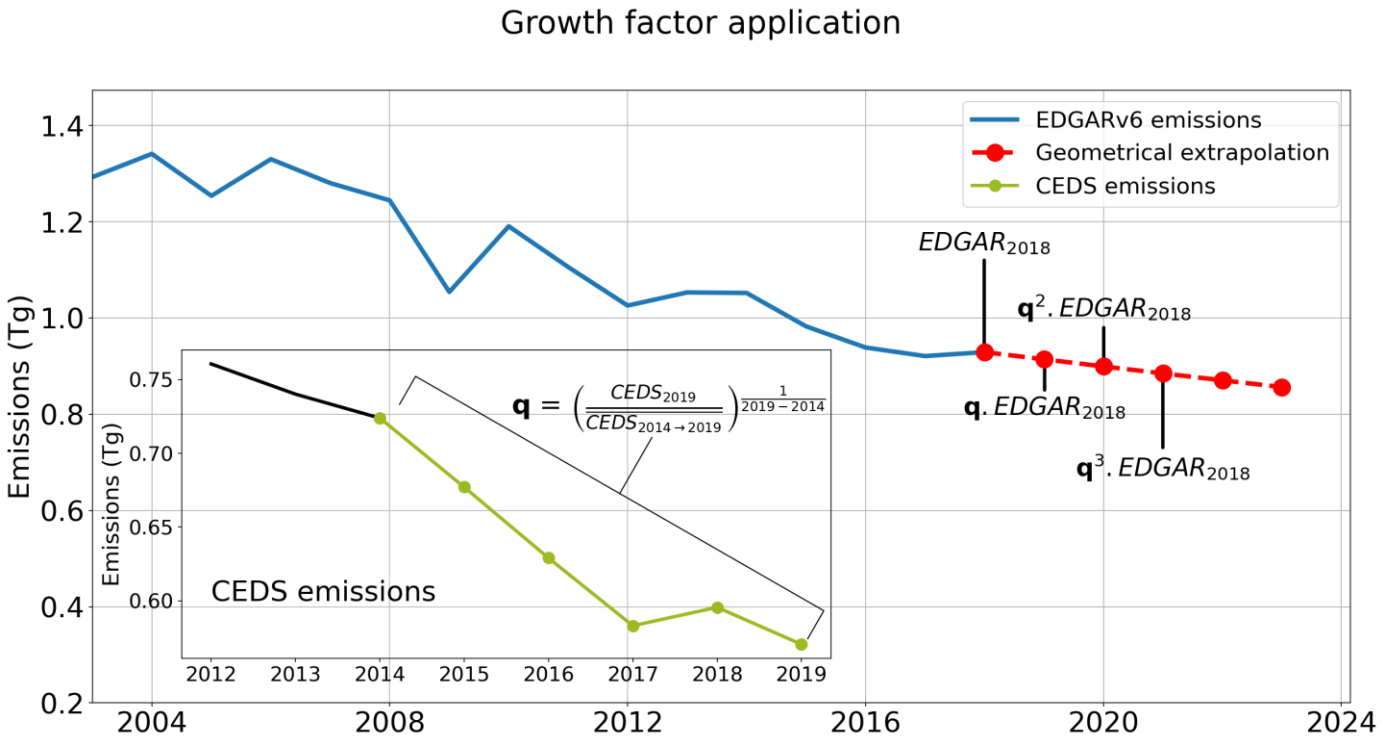


Figure 8 Time series of global annual $CEDS_{GBD\text{-}MAPS}$ emissions of NO_x, CO, SO_2, NH_3, NMVOCs, BC, and OC for all sectors and fuel types, split into 11 regions and countries (defined in Table S9).

McDuffie et al., ESSD, 2020

CAMS-GLOB-ANT_ version 5.3 developed as part of the European Copernicus Atmospheric Monitoring Service (CAMS)

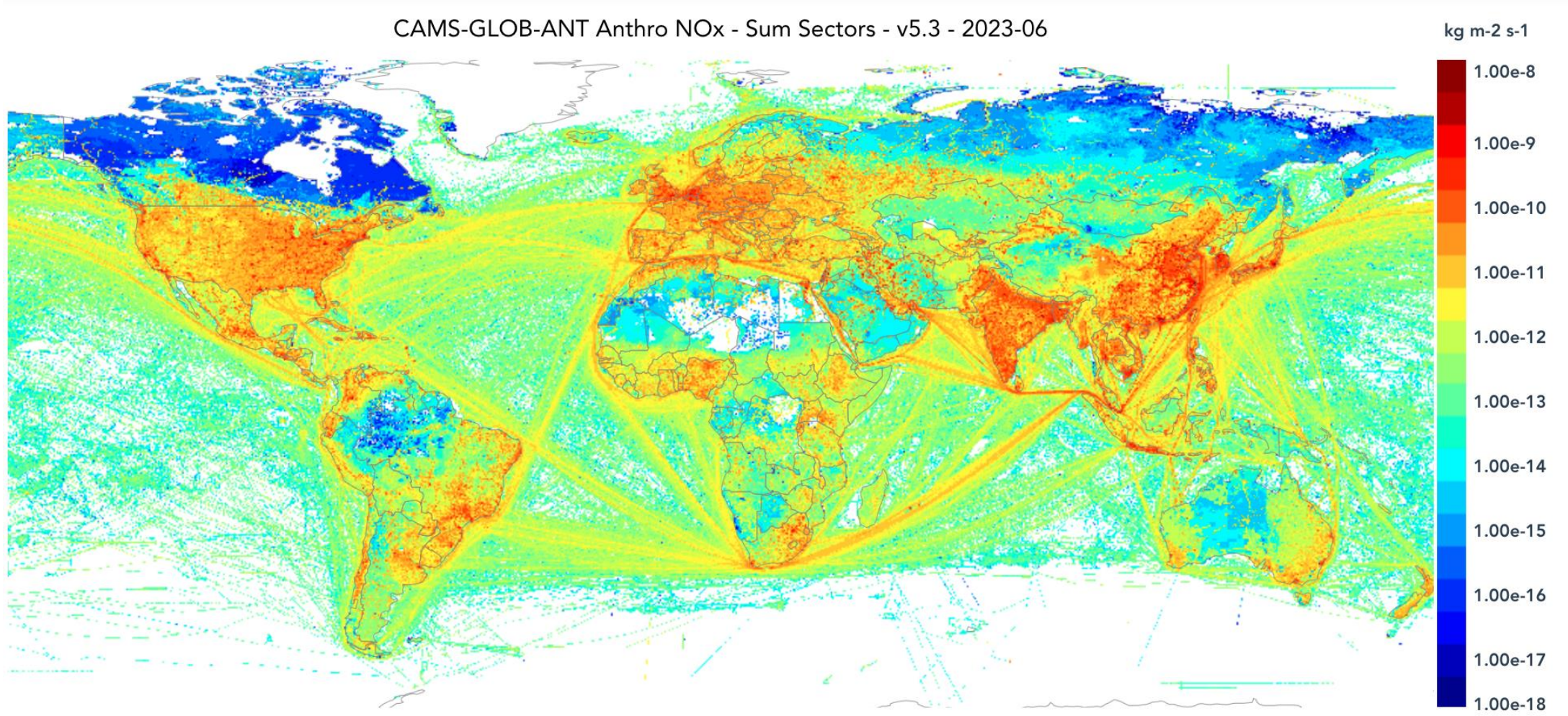
- **Required : 2000-2024 for forecasts and reanalyses (no other dataset available for such a period) → need extrapolation**
- **Based on EDGAR and CEDS + use of CAMS-GLOB-TEMPO and CAMS-GLOB-SHIP**



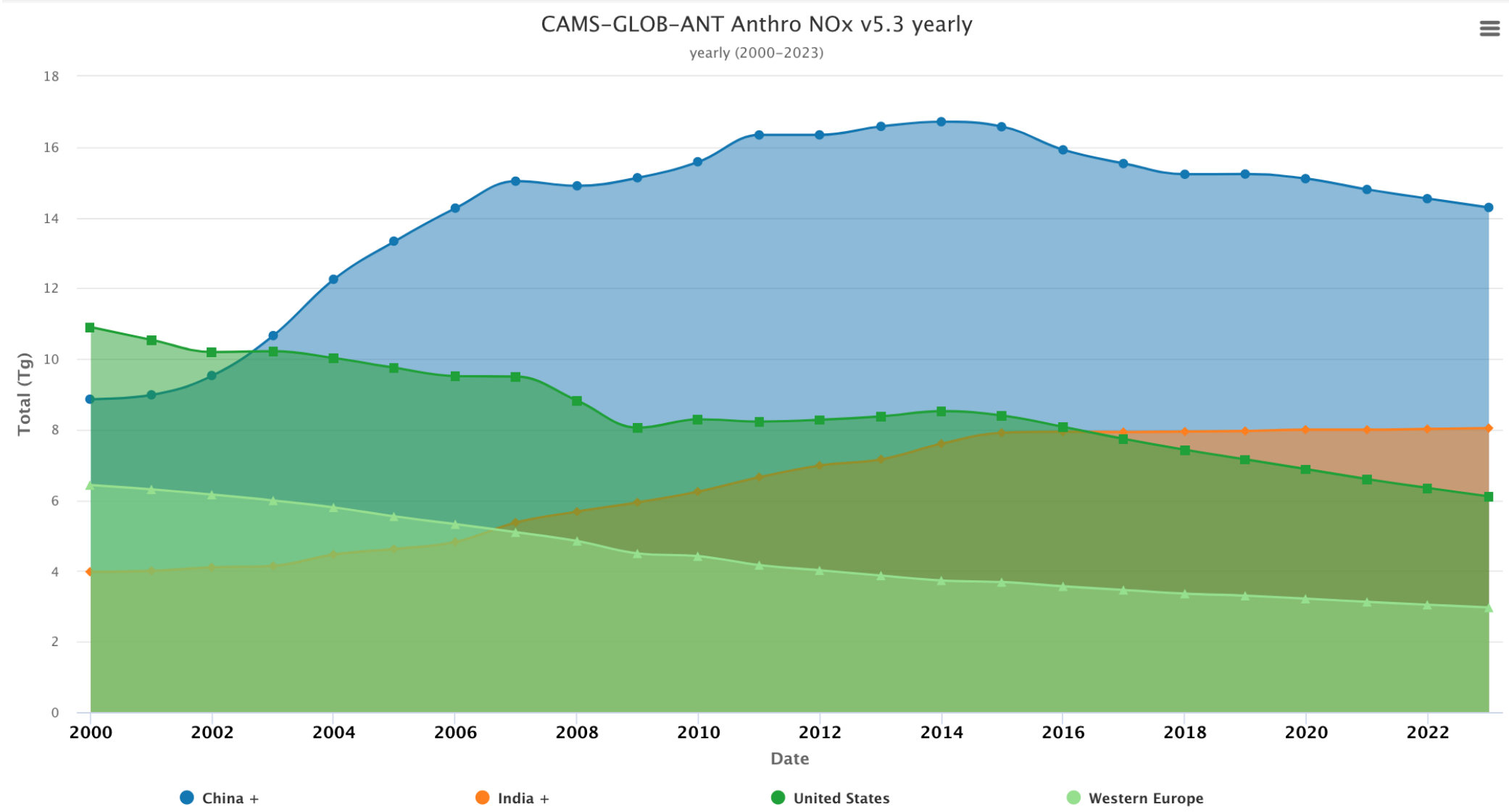
See the poster of Antonin Soulie for more details (#3.18)

From Soulie et al. (2023), to be submitted to ESSD

Example of CAMS emissions: version v5.3 – NOx in June 2023



Example of CAMS emissions: version v5.3 – NOx 2000-2023



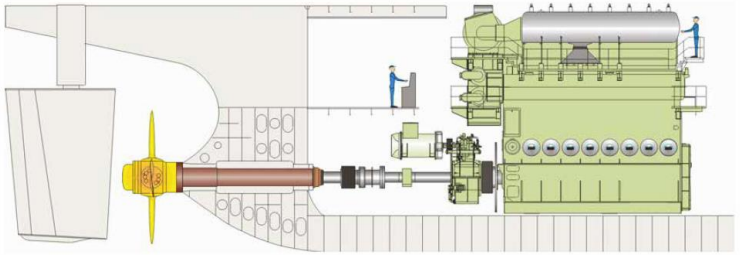
CAMS Global/European ship emissions: CAMS-GLOB-SHIP

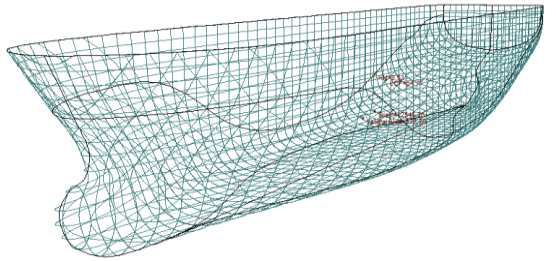
- **Ship emissions more and more important: in many countries, road emissions decreasing, and regulations in ship emissions are just starting (except in SECA countries in Nothern Europe which started a few years ago)**

- **FMI (Finland) has developed a very detailed model called STEAM, which calculate global and regional datasets based on realistic vessel traffic**

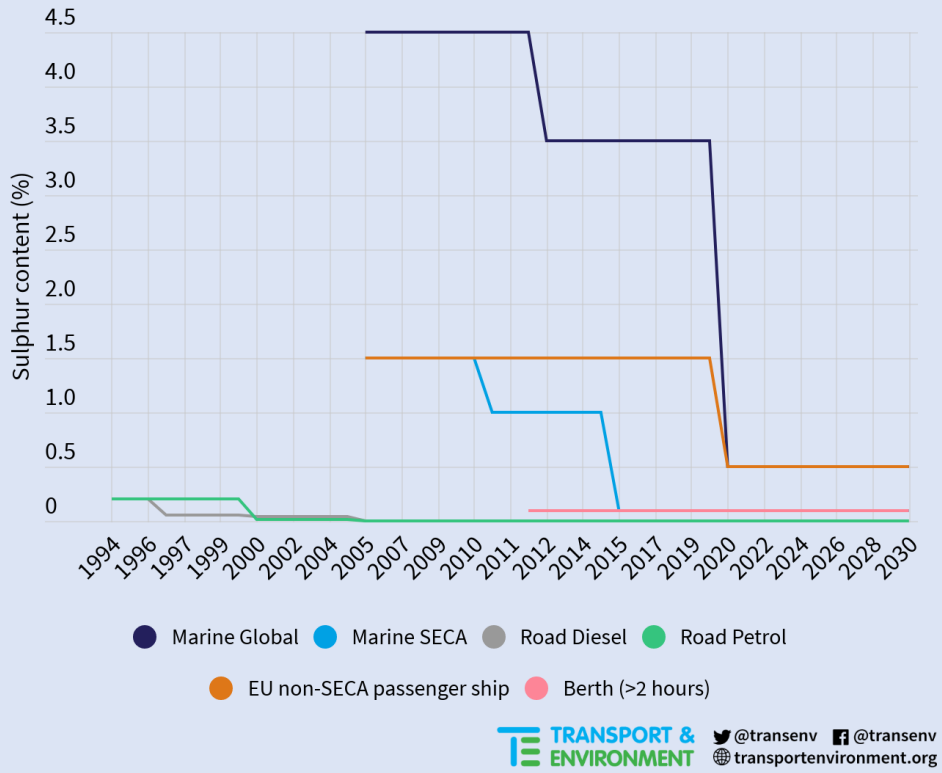
- **Localisation of ships with AIS (Automatic Identification System) + Technical description of the global fleet**

Developed at the Finnish Meteorological Office by Jukka-Pekka Jalkanen and colleagues



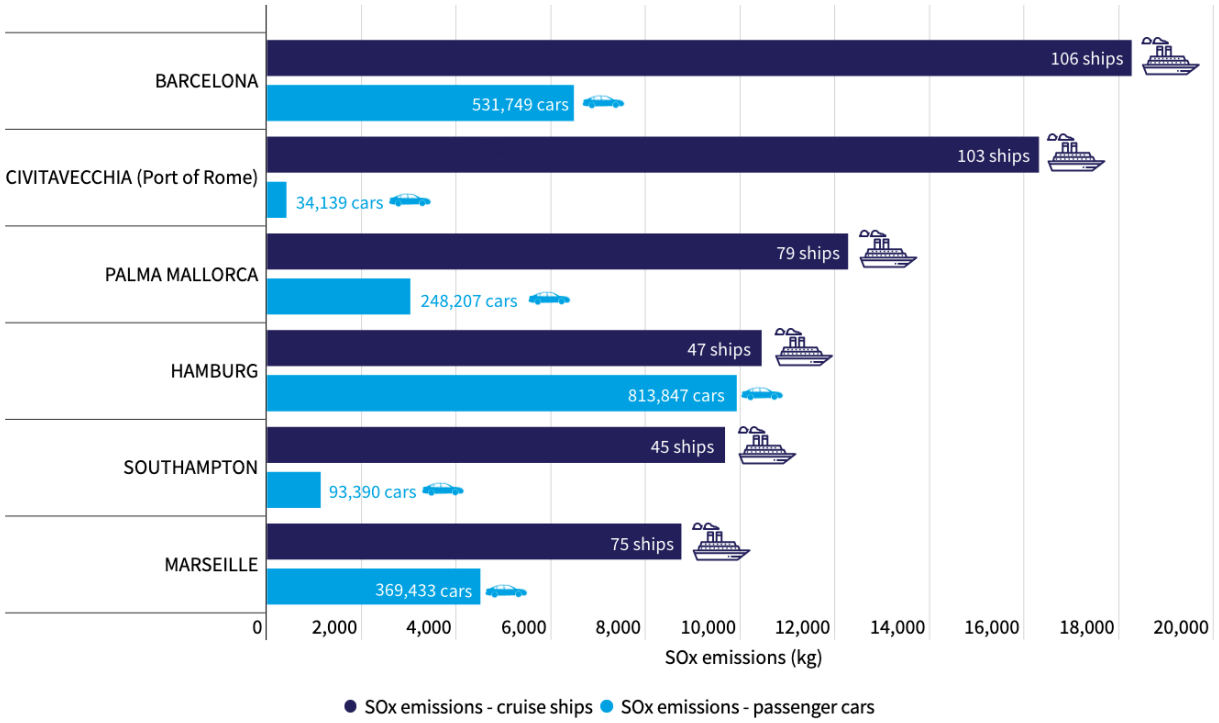


Marine and road fuel sulphur standards



SO2 emissions from ships

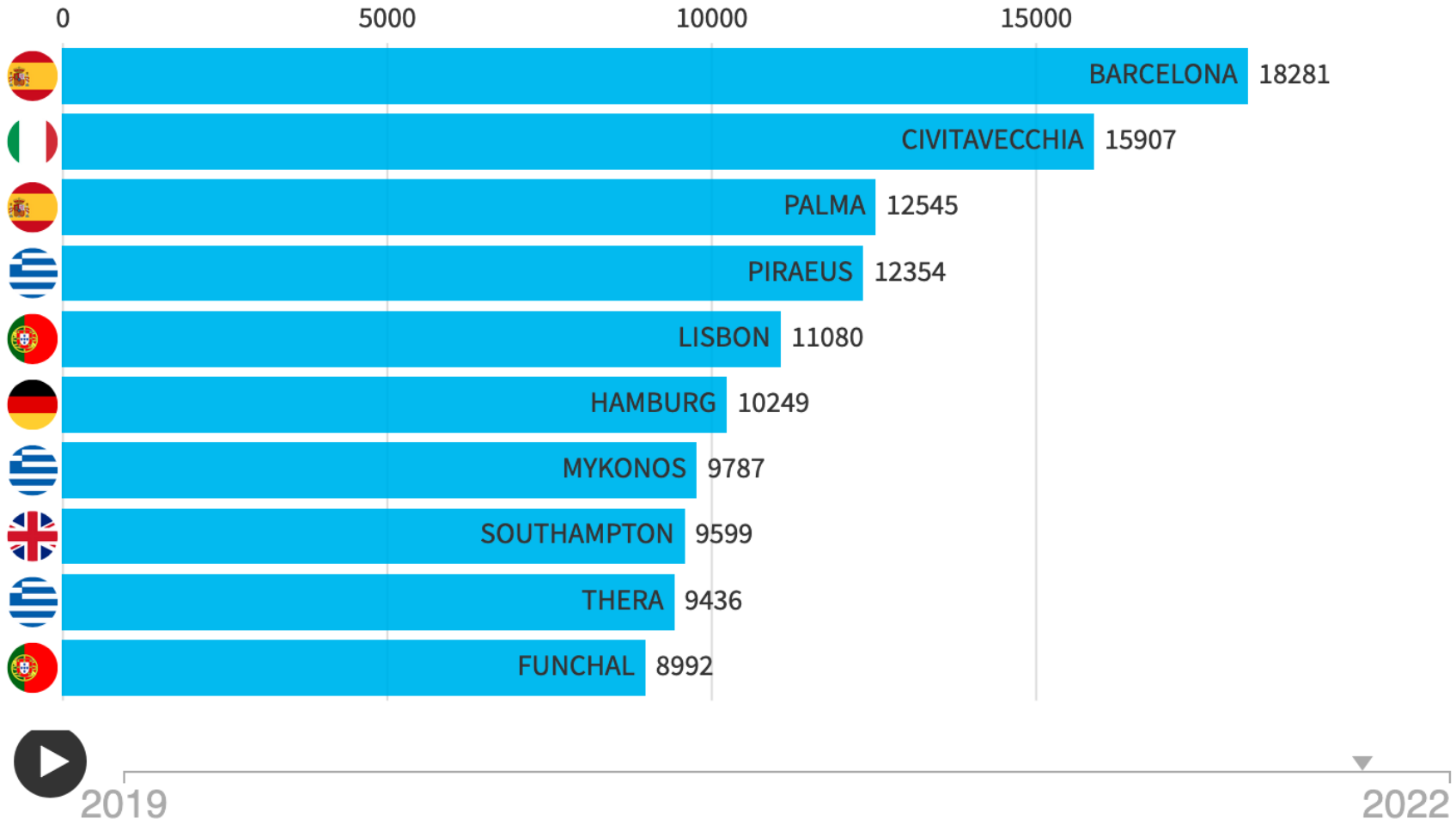
Cruise ships polluted more than all the cars circulating key port cities



Source: Transport & Environment (2023)

Europe's most polluted cruise ports

Barcelona suffers highest levels of toxic air pollution from cruise ships, while Venice drops off the list after cruise ship ban



Recent development in ship emissions

- International/Domestic split
- Import/Export emissions, country matrices
- Updated **emission factors and new pollutants**
- Updated method for **LNG engines and methane slip**
- Modelling of **auxiliary machinery**
- Impact of **weather and sea conditions**
  - **Wave resistance** (Townsin et al. 1993)
  - **Ice resistance** (Juva and Riska 2002)
  - **Wind resistance** (Blendermann 1993, 1996)
  - **Sea currents** (ship's velocity relative to water)
- Impact of **abatement systems**: scrubbers, SCR
- Local **regulations**
- Hires coastline determination

- To do:
- Metals, not decided which ones
  - Ni, V, Pb most probably (EMERGE project
- N_2O (SCIPPER project)
  - Added for ammonia fuelled ships, but not yet for all ships
  - NOx abatement (EMERGE project)
- New fuels
  - ULSFO, VLSFO, Hydrogen; Ammonia and methanol already in STEAM
  - Emission factors available?
    - Use emission factors for HFO, but remove S components accordingly, impact on BC?

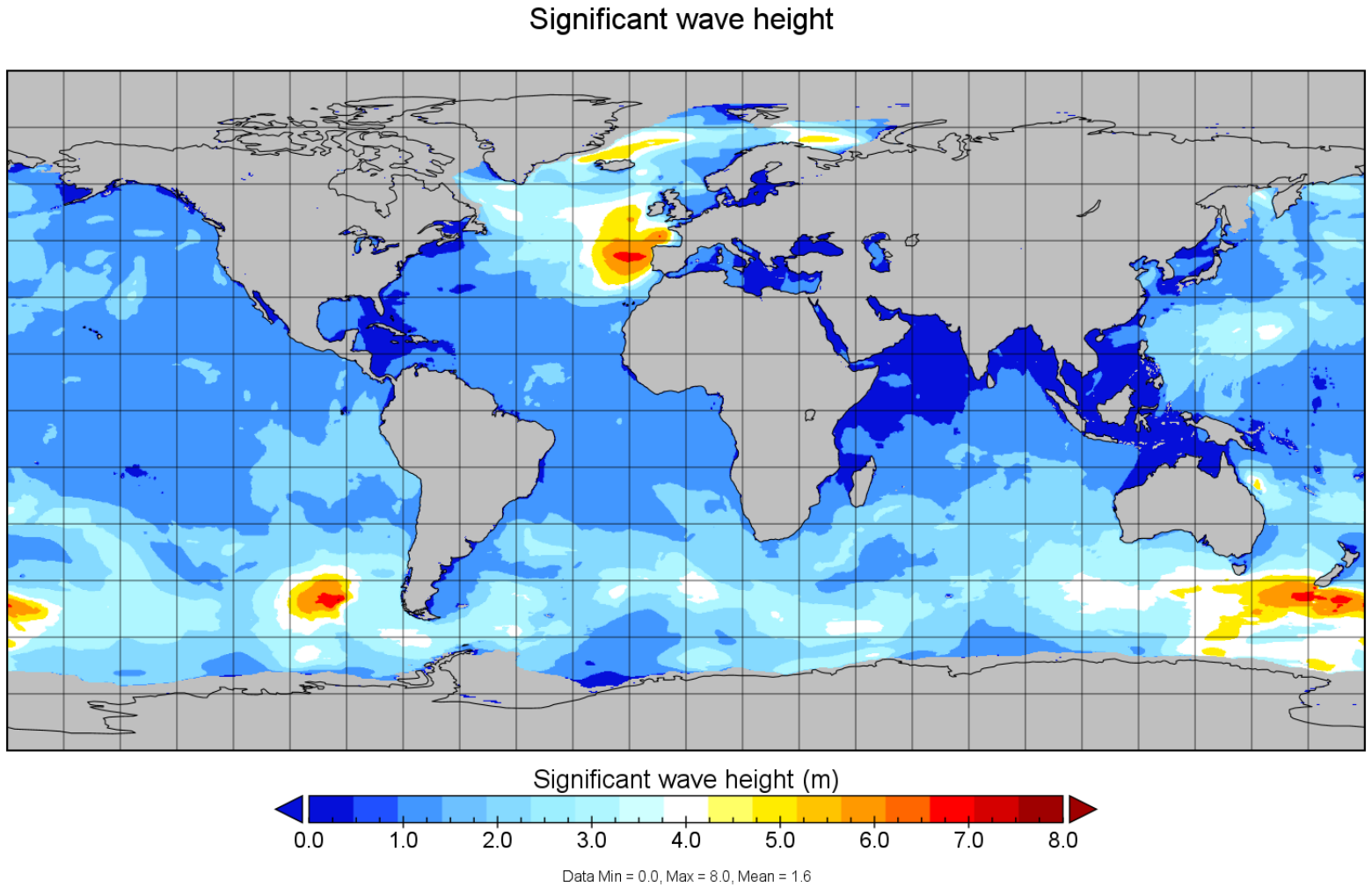
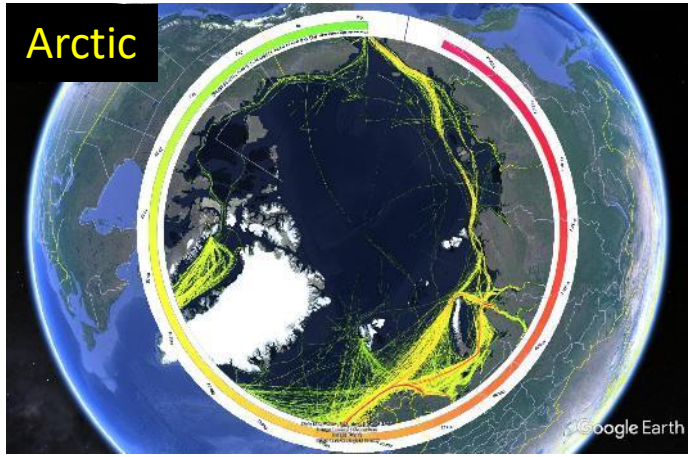
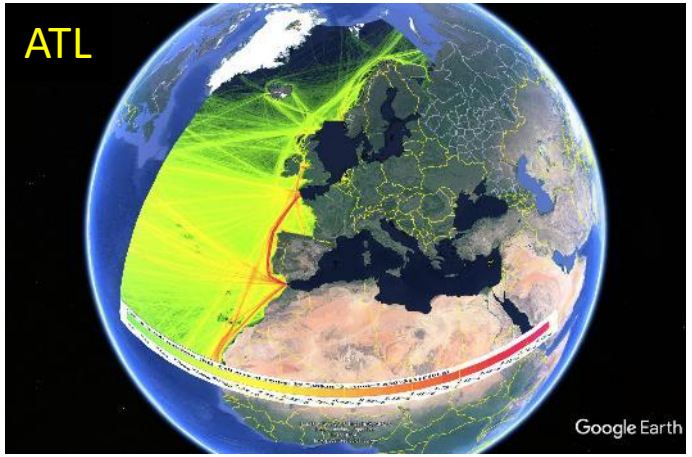
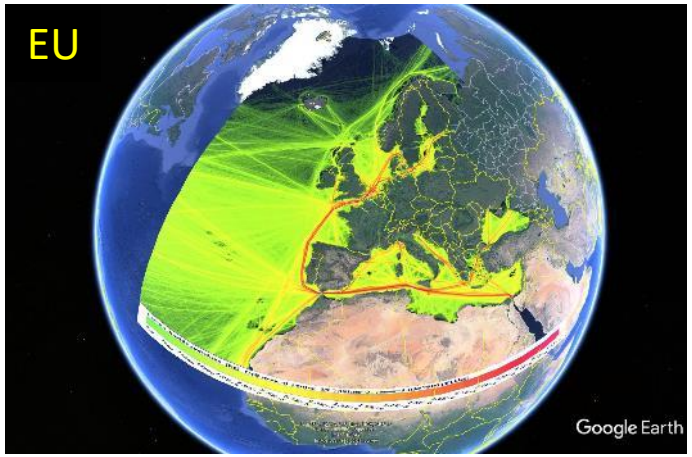
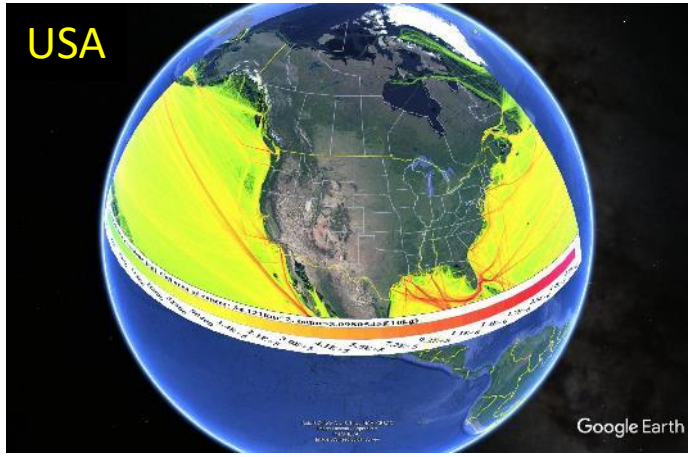


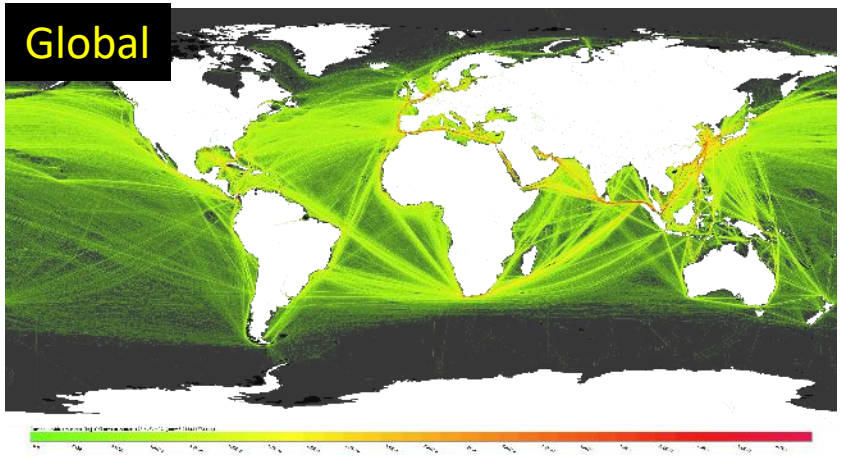
Figure 4 An example of significant wave height data used in calculation of the effect of waves to vessel power prediction. These data were obtained from Copernicus Marine Environment Monitoring Services of the ECMWF.

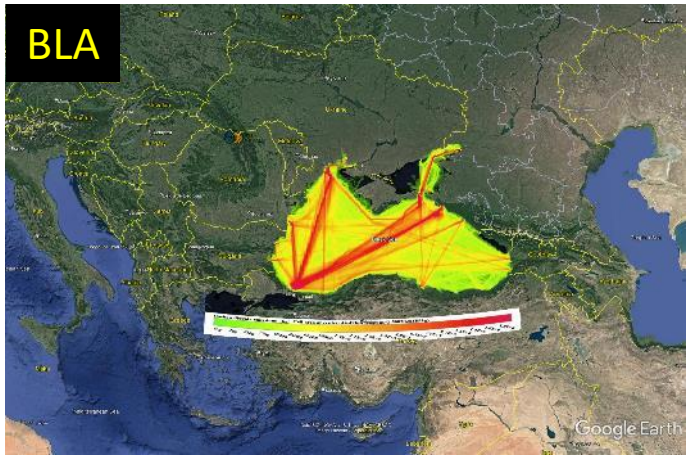

Arctic
Google Earth

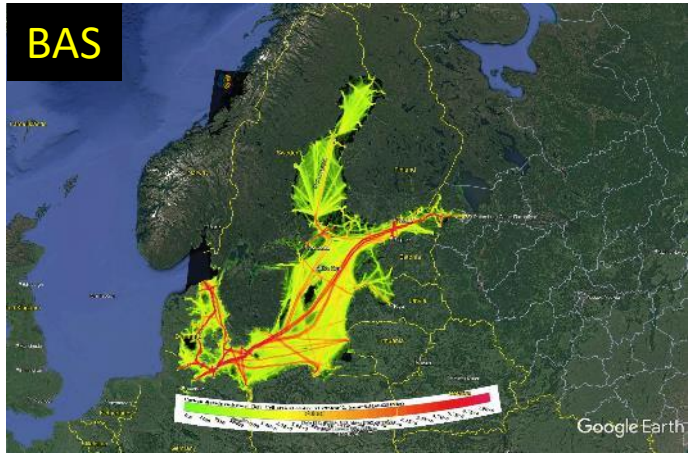

ATL
Google Earth

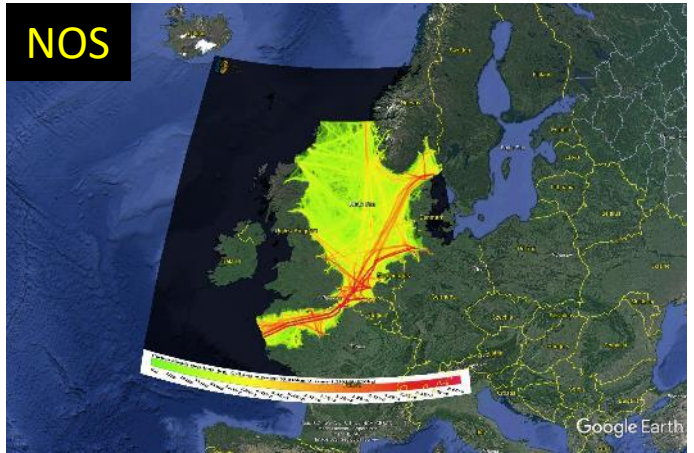

EU
Google Earth

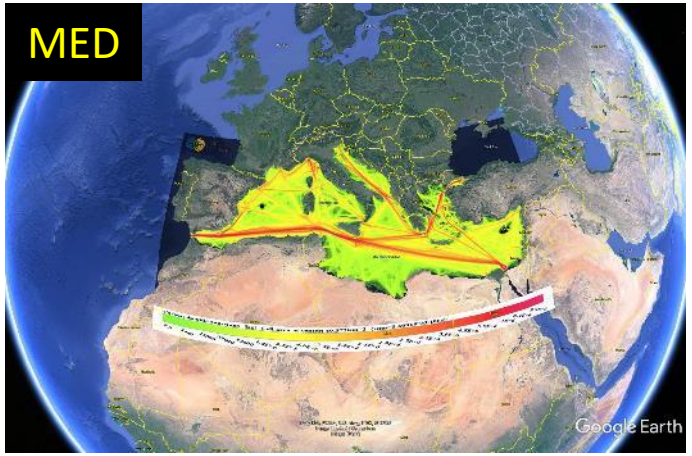

USA
Google Earth


Global


BLA
Google Earth


BAS
Google Earth

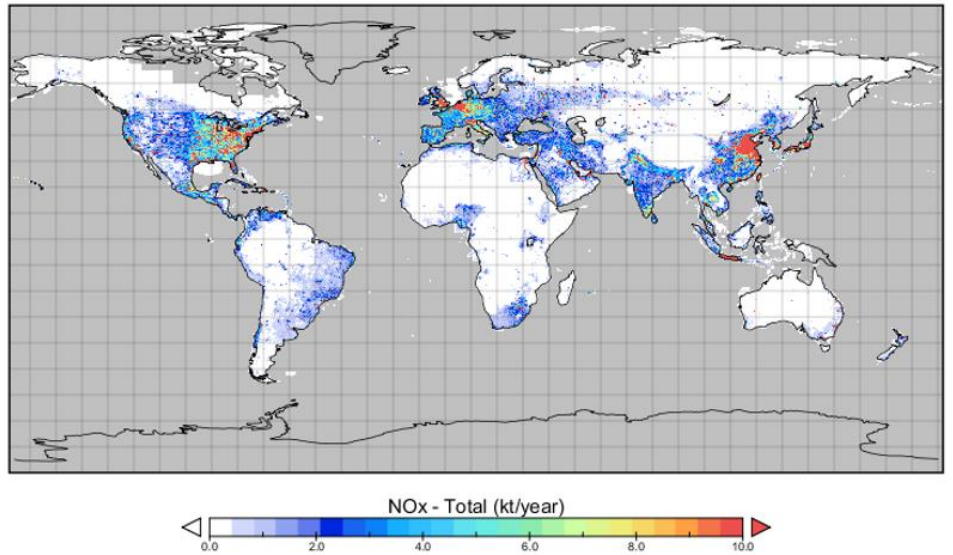

NOS
Google Earth


MED
Google Earth

ECLIPSE, developed at IIASA, Laxenburg, Austria
https://iiasa.ac.at/models-tools-data/global-emission-fields-of-air-pollutants-and-ghgs

A host of scientific chemistry and climate model experiments explore responses of the global atmosphere and climate systems to possible future changes in emissions of air pollutants and greenhouse gases.

The Pollution Management research group has used its GAINS model to develop a set of global emission fields of nine substances that provide consistent sets of future sectoral emissions for well-specified assumptions on economic development and the effectiveness of dedicated emission control policies.



ECLIPSE V6b Baseline scenario (CLE)

Gridded emissions (netcdf4 format) of SO_2, NOx, NH_3, nmVOC, BC, OC, OM, $PM_{2.5}$, PM_{10}, CO, CH_4

Anthropogenic emissions

Outline

1. General methodology to calculate emissions
2. Activity data
3. Emission factors
4. Spatial/temporal variations and VOCs speciation
5. Current public global inventories
6. **A few current public regional inventories**
7. **Evaluation of anthropogenic emissions**
8. Conclusions

Currently available regional inventories:

North America: EPA, USA and Environment Canada, Canada

Latin America: Castesana et al., 2021; Rojas et al., 2023; Huneeus et al. 2019

Africa: DACCIWA-2 (Keita et al, 2021)

Asia: MEIC and REASv3 (Kurokawa et al., 2019)

Europe: CAMS-REG (Kuenen et al., 2022)

+ more, not always published, not always publicly available or unknow to me

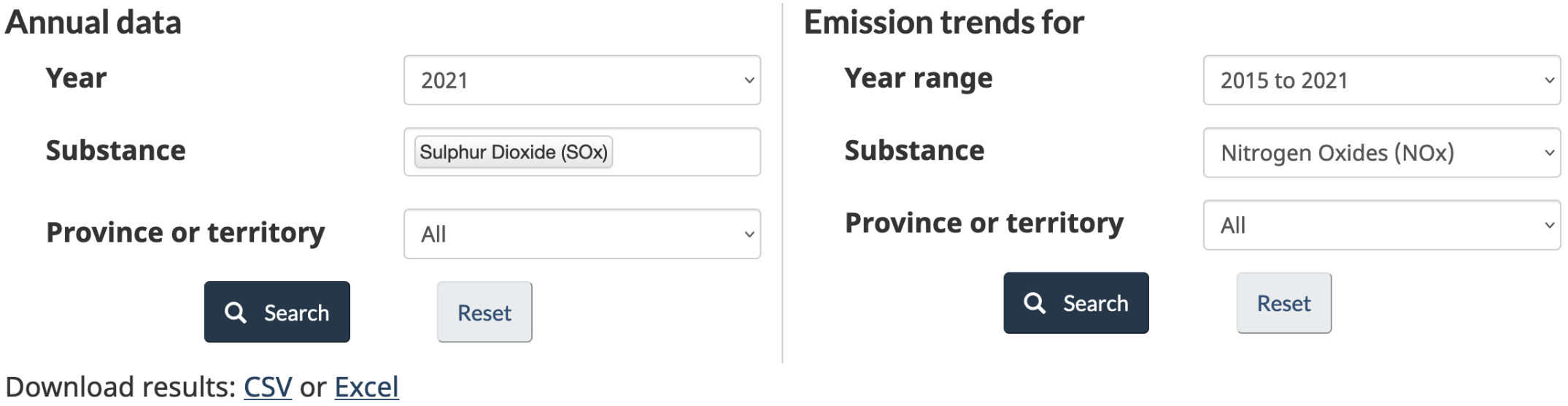
A few details on each inventory + comparisons with global datasets

USA and Canada

→ **EPA, USA and Environment Canada, Canada: well documented, gridding linked to regional models**

Canada

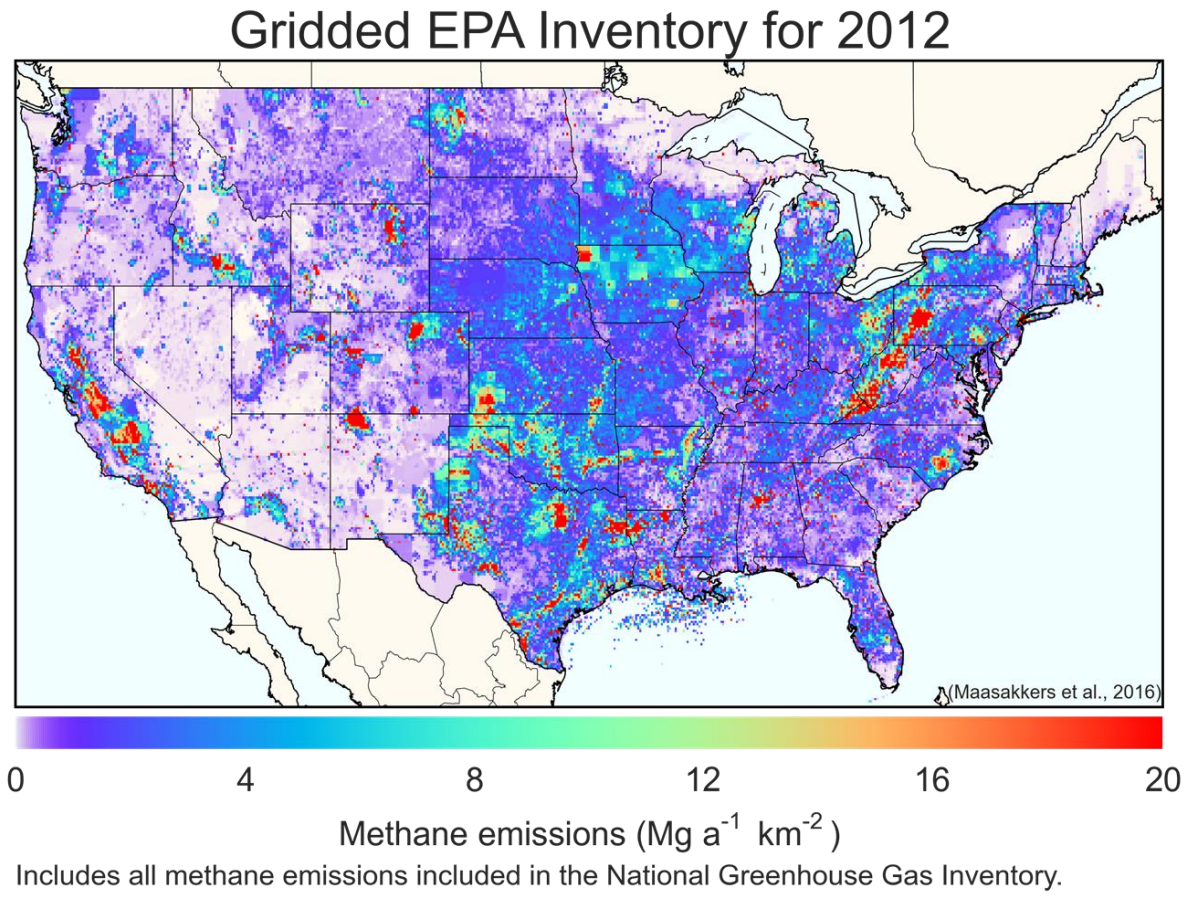
https://pollution-waste.canada.ca/air-emission-inventory/



Trends and national totals/ totals per province available

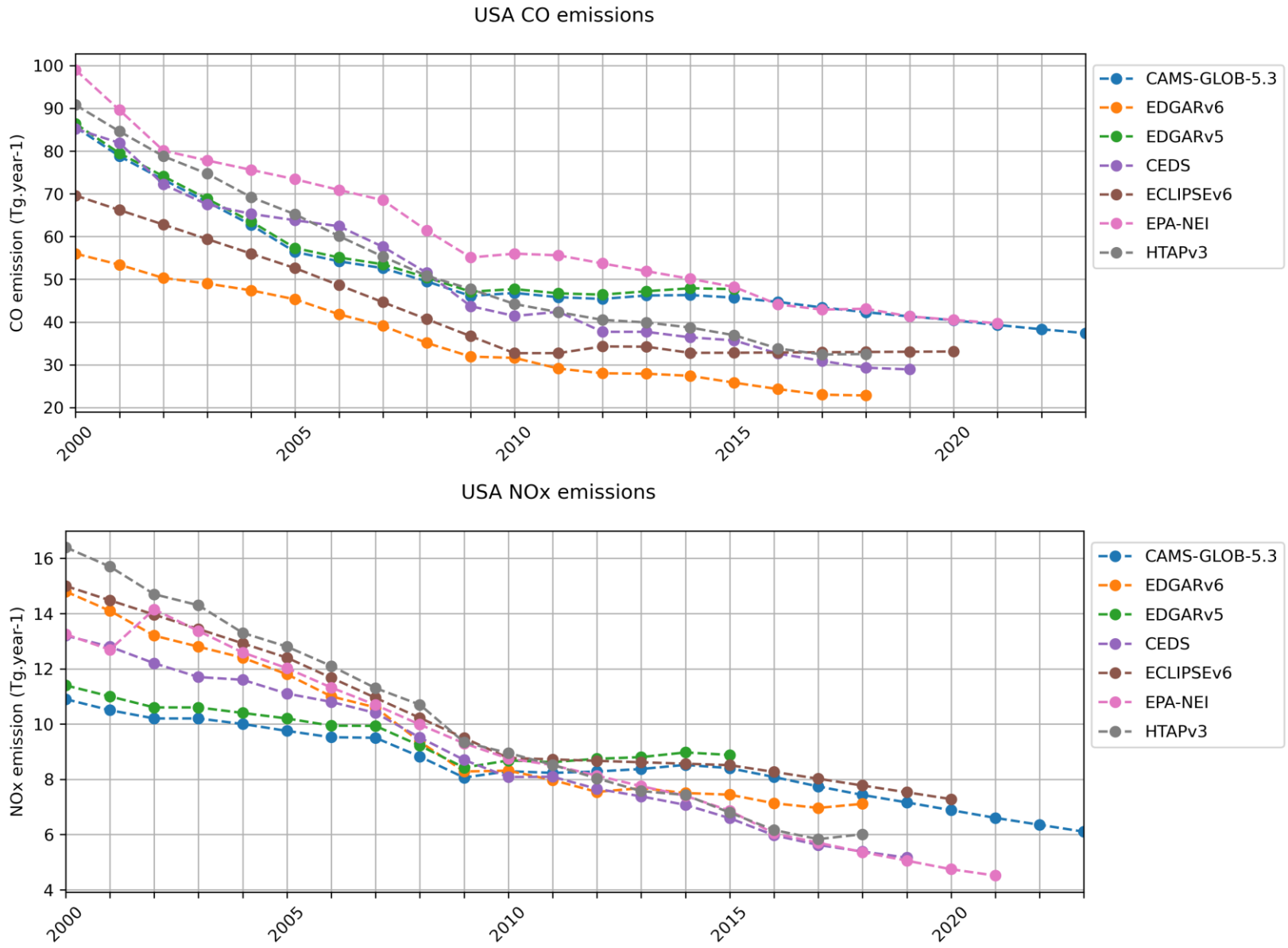
USA: Environment Protection Agency
https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei

For use in models
https://www.epa.gov/air-emissions-modeling/emissions-modeling-platforms



More information: ask Brian McDonald and other US colleagues

Comparison of the EPA inventory with global datasets (from Soulie et al., 2023)



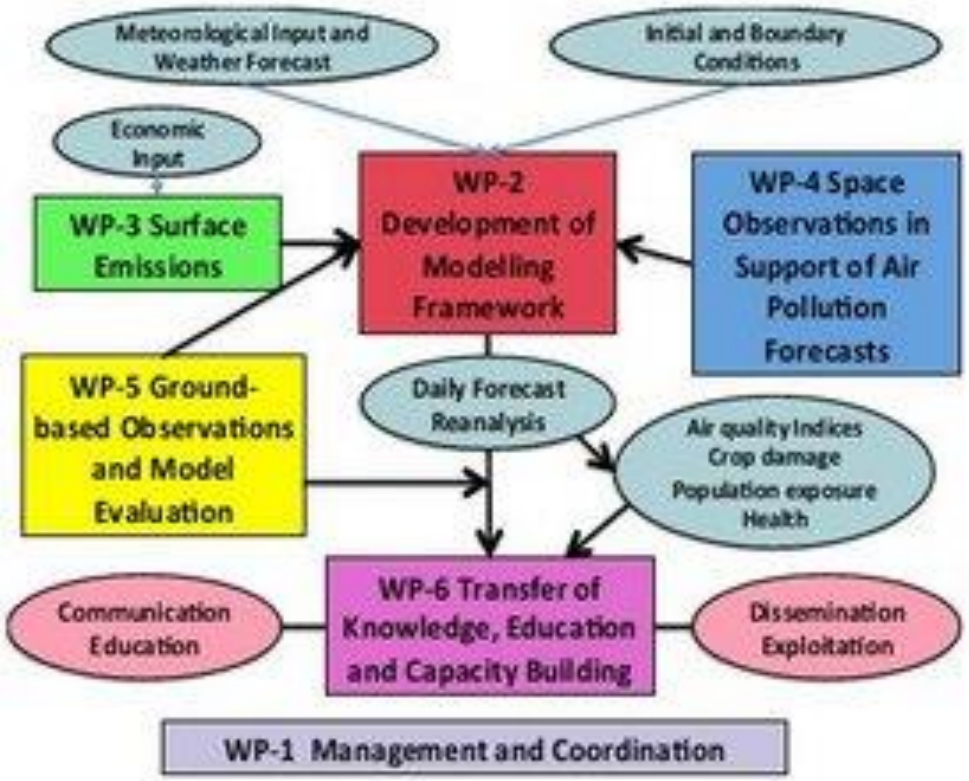
Such comparisons

→ **Some evaluation of the uncertainties between inventories**

→ **No statistical evaluation of uncertainties as all global inventories are dependent on each other**

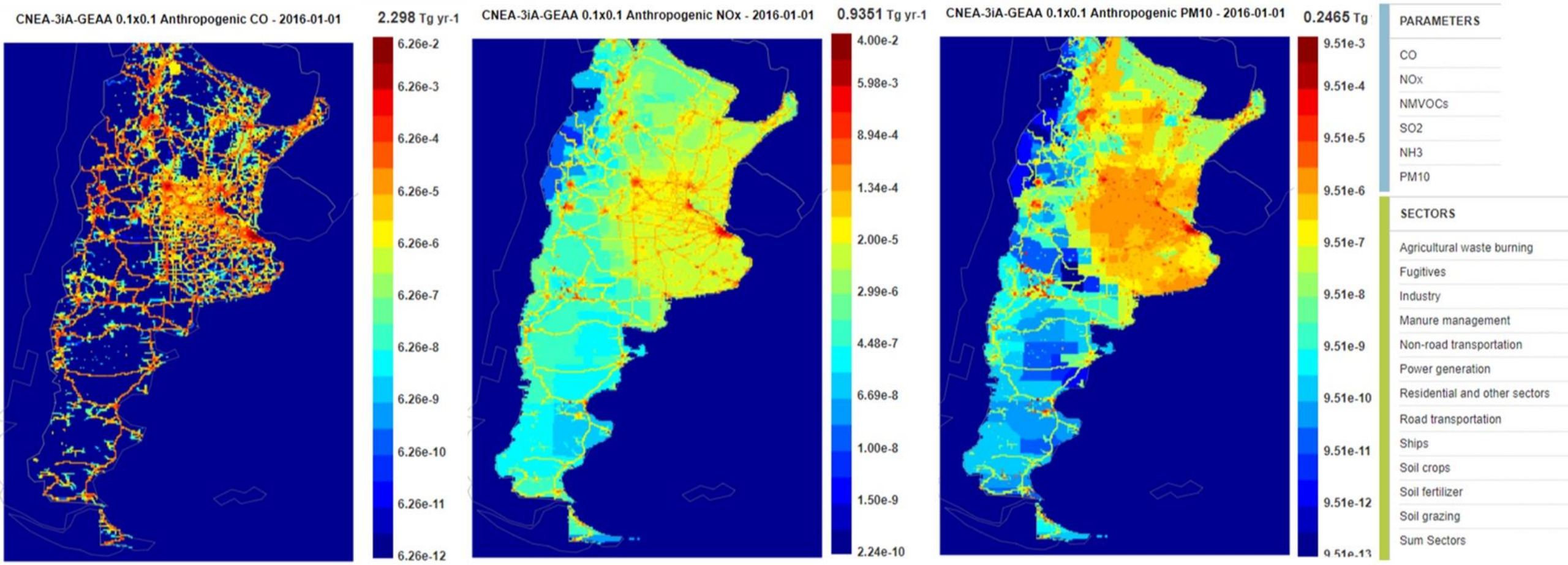
Latin America / Carribean: work done in LAC country + work done as part of PAPILA

PAPILA: Prediction of Air Pollution in Latin America and the Caribbean (2018-2023) https://papila-h2020.eu



Anthropogenic emission inventories of Argentina

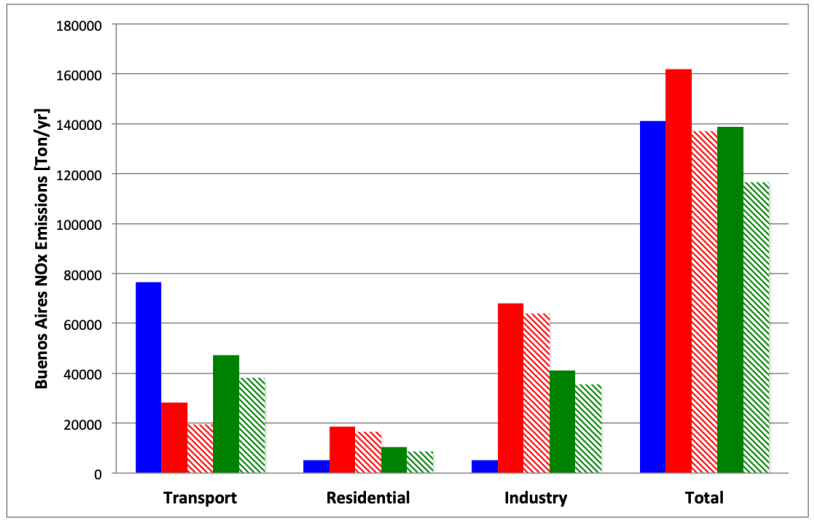
Argentina – local inventory:
Spatial resolution: 0.1° x 0.1° (coverage: Argentina)
Temporal coverage: Yearly (2016)

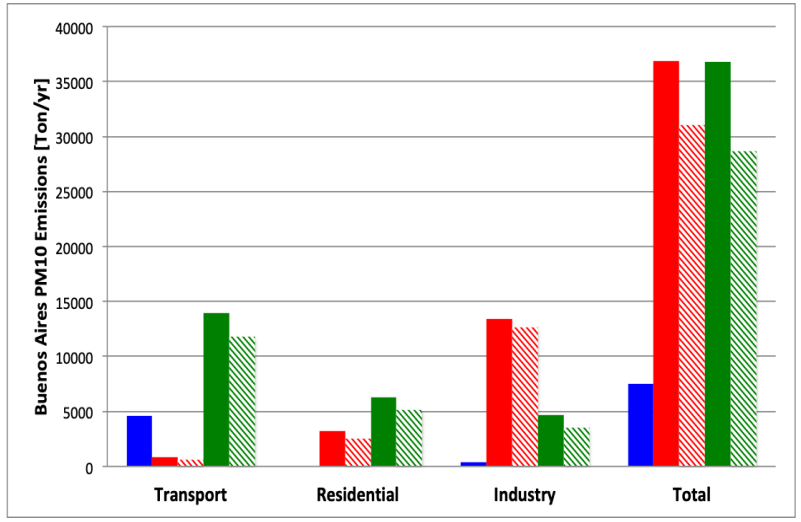


From Paula Castesana, CNEA

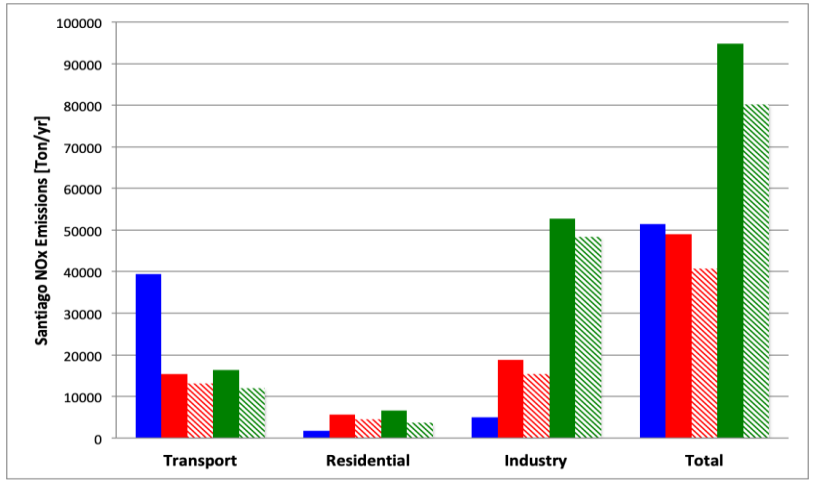
Castesana, P.; Dawidowski, L.; Finster, L.; Gómez, D.; Taboada, M. (2018). Ammonia emissions from the agriculture sector in Argentina; 2000–2012. Atmospheric Environment, 178, 293–304.

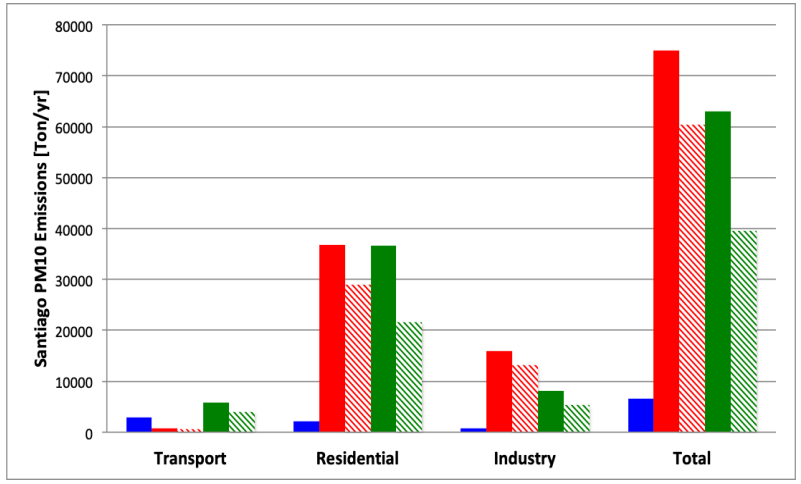
Puliafito, S.; Allende, D.; Castesana, P.; Ruggeri, F.; (2017). High-resolution atmospheric emission inventory of the argentine energy sector. Comparison with EDGAR global emission database. Heliyon, 3 (12), e00489.





Buenos Aires: NOx (left) and PM10 (right)





Santiago: NOx (left) and PM10 (right)

Blue: local inventory

Red: EDGAR

Green: ECLIPSE

From Huneeus et al., Atmos Env. 2019

Discussion of LAC emissions during the GEIA conference on Thursday afternoon + several talks/posters

Paper that just came out in "Transportation Research"

Road transport exhaust emissions in Colombia. 1990–2020 trends and spatial disaggregation

Néstor Y. Rojas [a], Sonia C. Mangones [b], Mauricio Osses [c,*], Claire Granier [d,e], Ignacio Laengle [f], Julieth V. Alfonso A. [g], Johann A. Mendez [h]

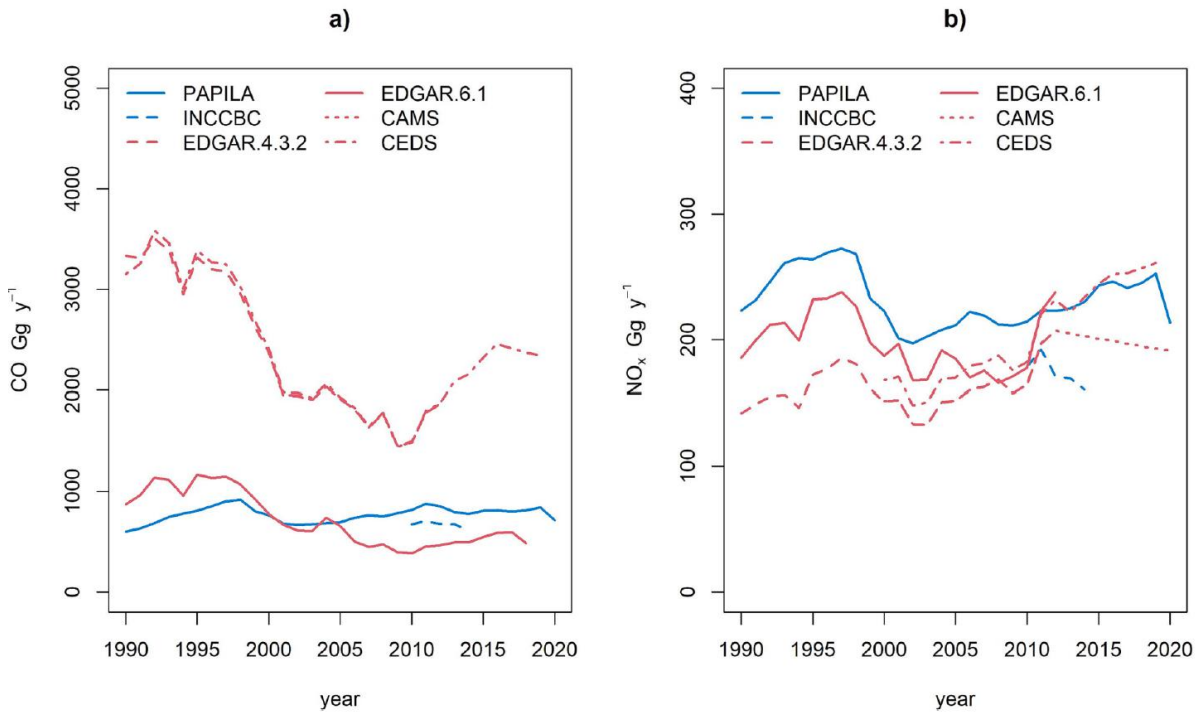
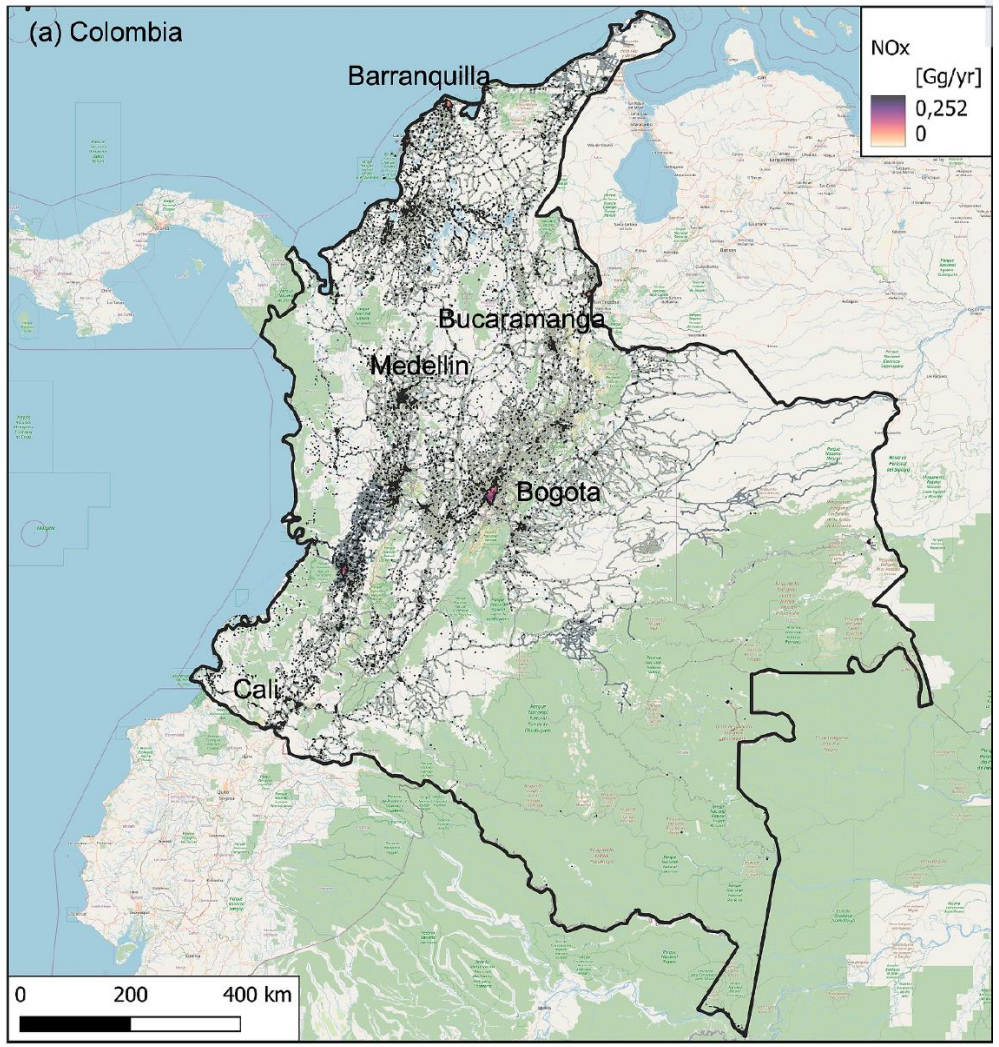


Fig. 9. Comparison between this work (PAPILA) and other emissions inventories for a) CO and b) NO_x.

Emissions at ~ a 1x1 km resolution

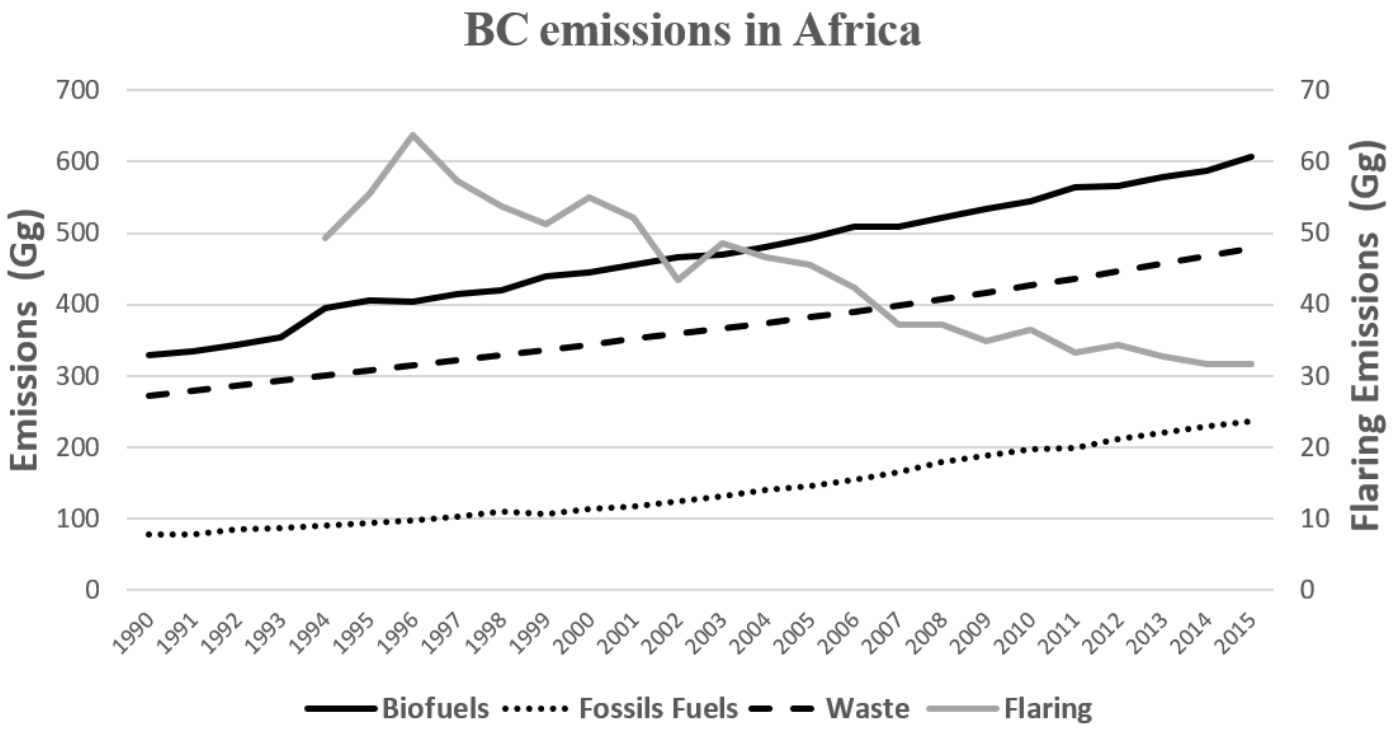


Emissions in Africa

First version of a regional inventory: published by Keita et al., ESSD, 2021
1990-2015, 0.1x0.1 degree resolution

Only combustion sources

Discussion of emissions in Africa during the GEIA conference on Thursday afternoon + several talks/posters

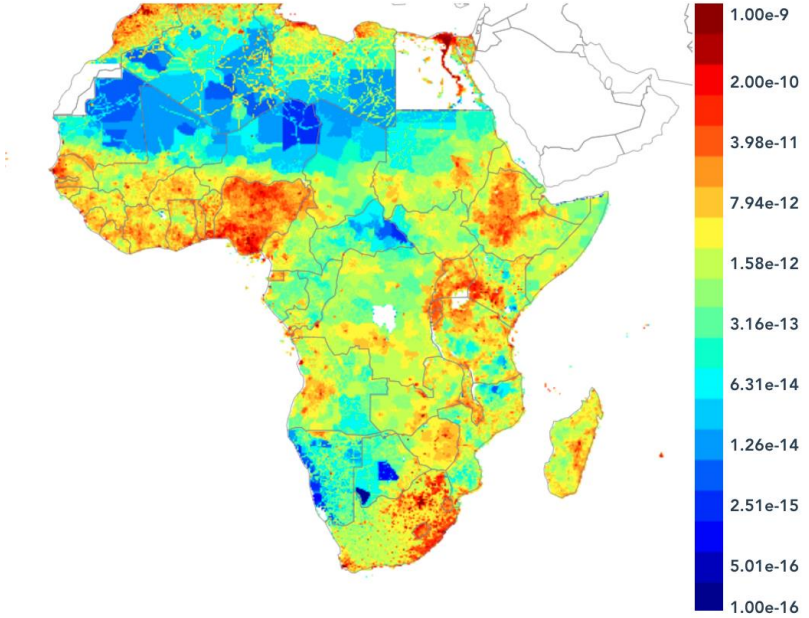


A new version of DACCIWA emissions for Africa = DACCIWA-2
Developed under the CoCO2 project in LAERO, Toulouse

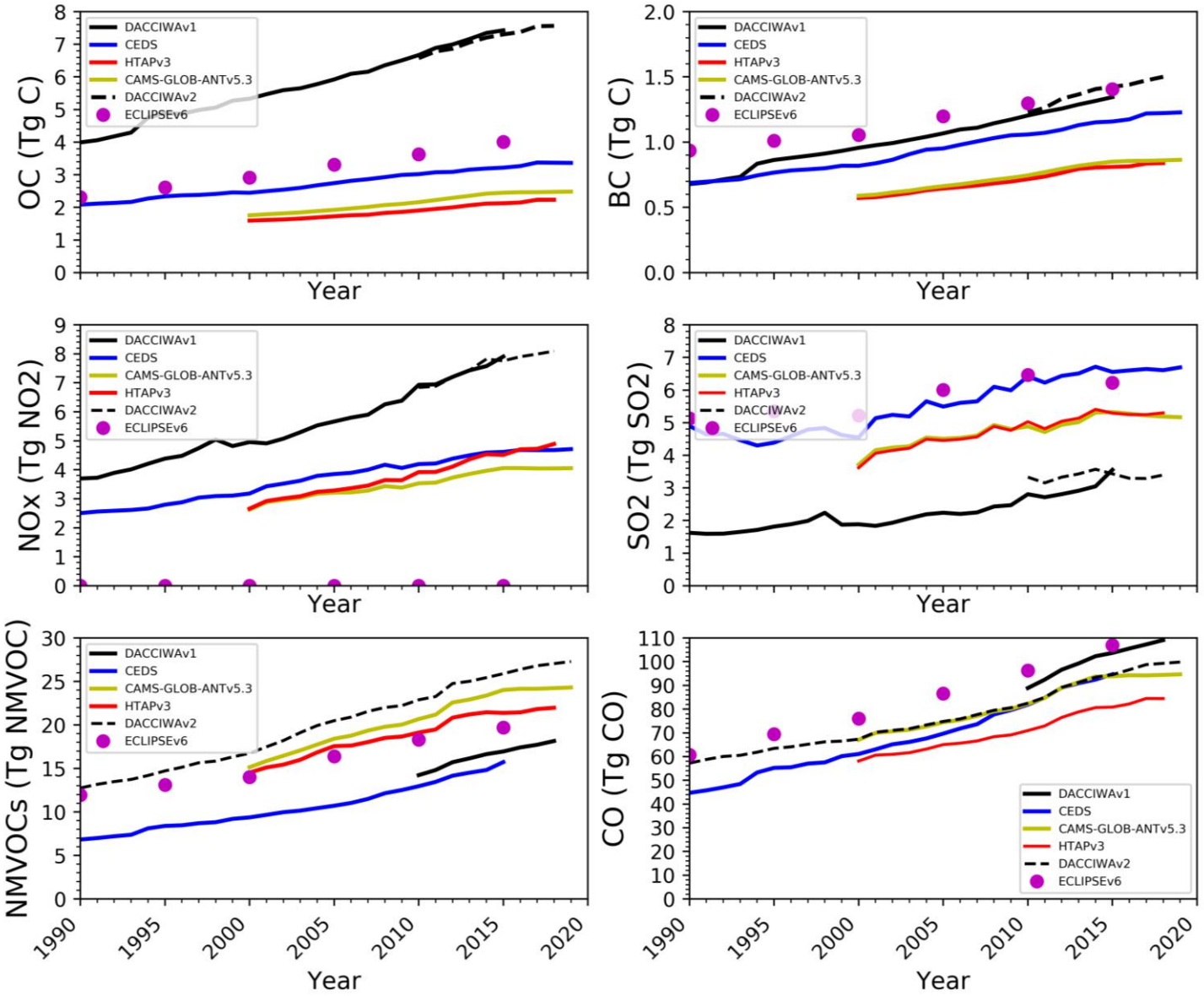
New dataset DACCIWAv2 includes:

- Emissions for combustion and fugitive sources, emissions from agriculture/livestock, waste and solvents

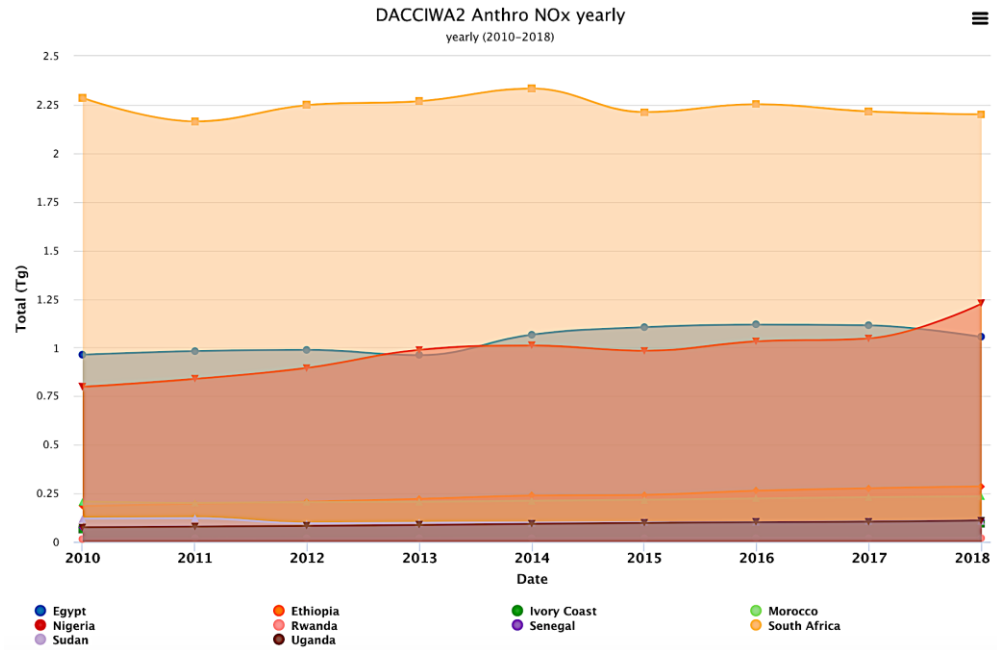
- Use of activity data and emission factors from local measurements (and also literature if not available)
- Species included: **CO_2, CH_4, BC, OC, CO, NOx, SO_2** and **NMVOC**.
- Sectors compatible with CAMS-GLOB-ANTv5.3 global emissions
- Use of CAMS-GLOB-TEMPO monthly temporal profiles
- 2000 -2018; 0.1x0.1 degree resolution



NOx emissions in June 2018



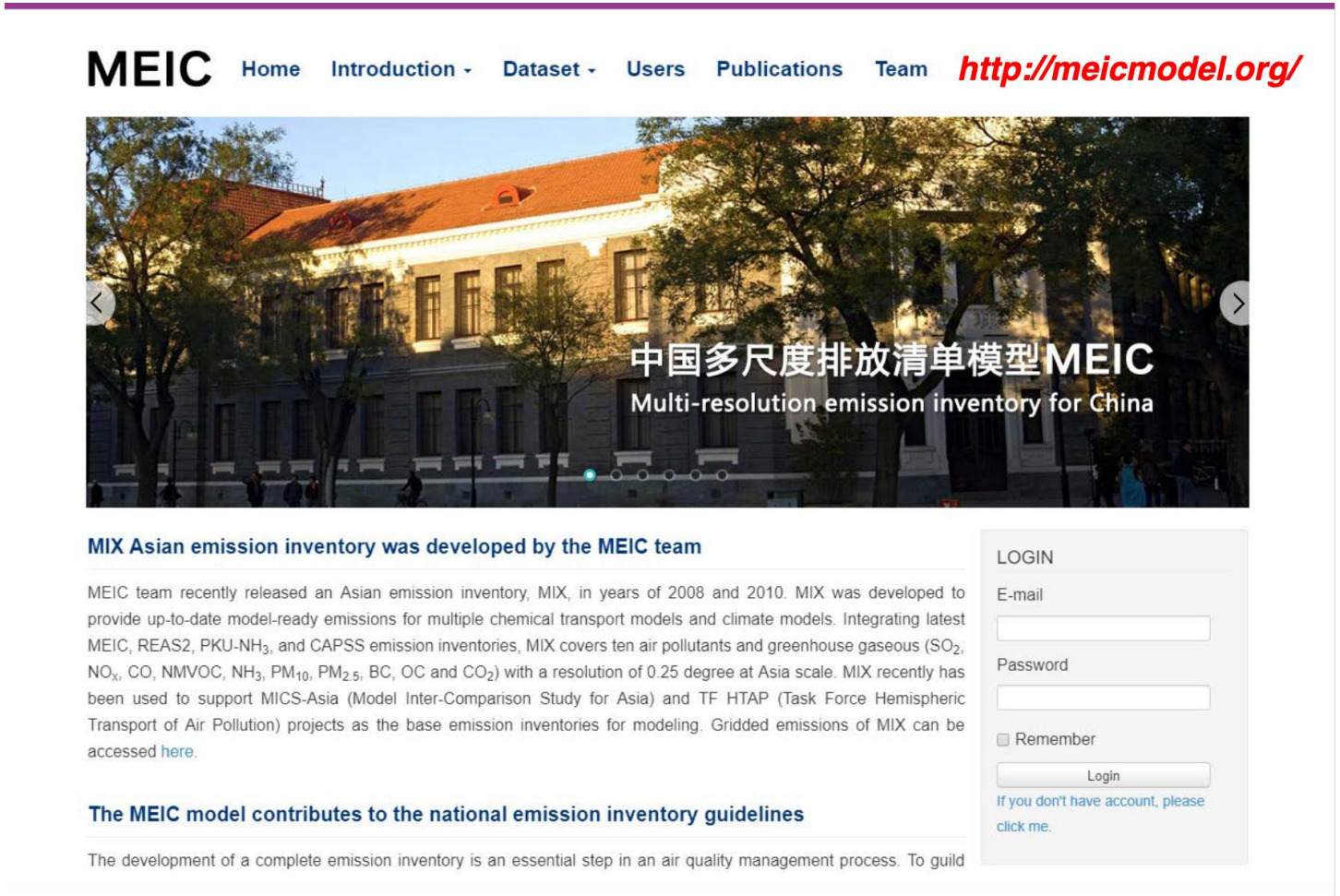
Comparisons with other datasets



Largest emitting countries for NOx

Emission inventories in Asia

Two datasets used widely: MEIC and REAS



MEIC = meicmodel.org

Older view of the website

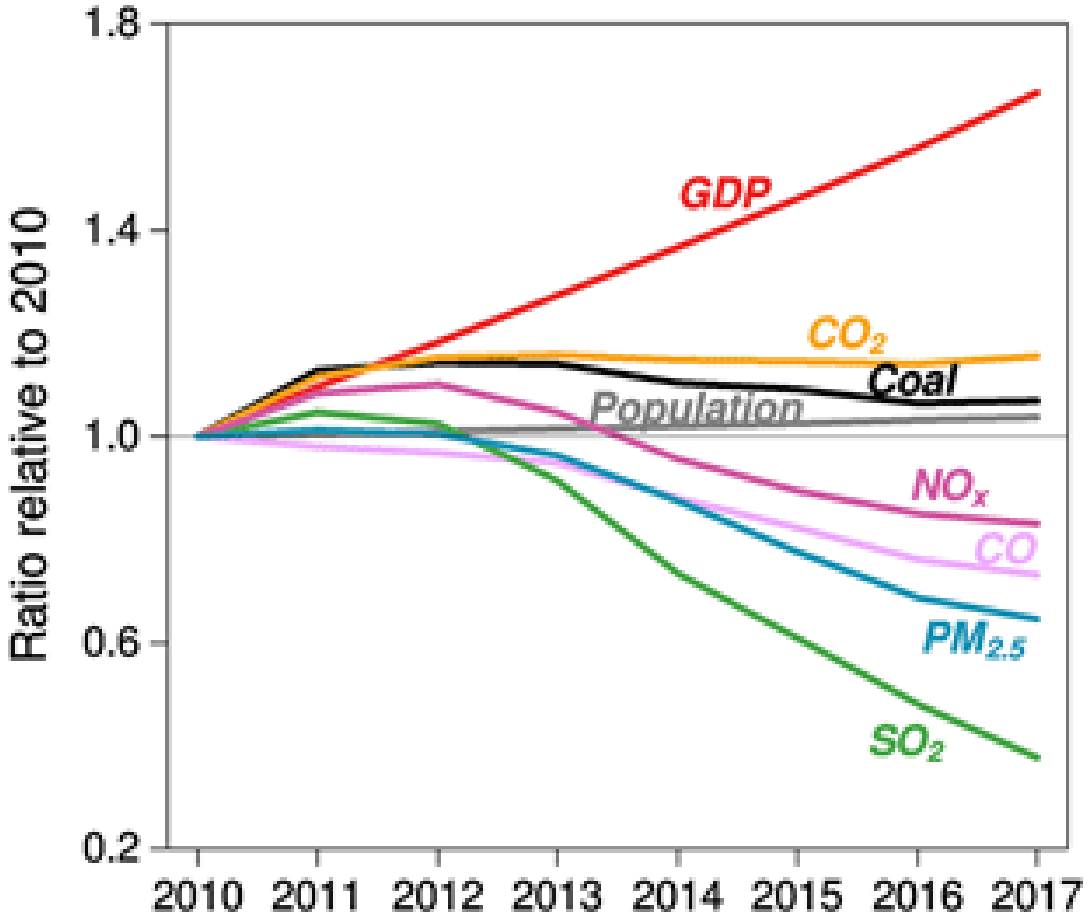
Site is currently down
(see with Qiang Zhang during GEIA)

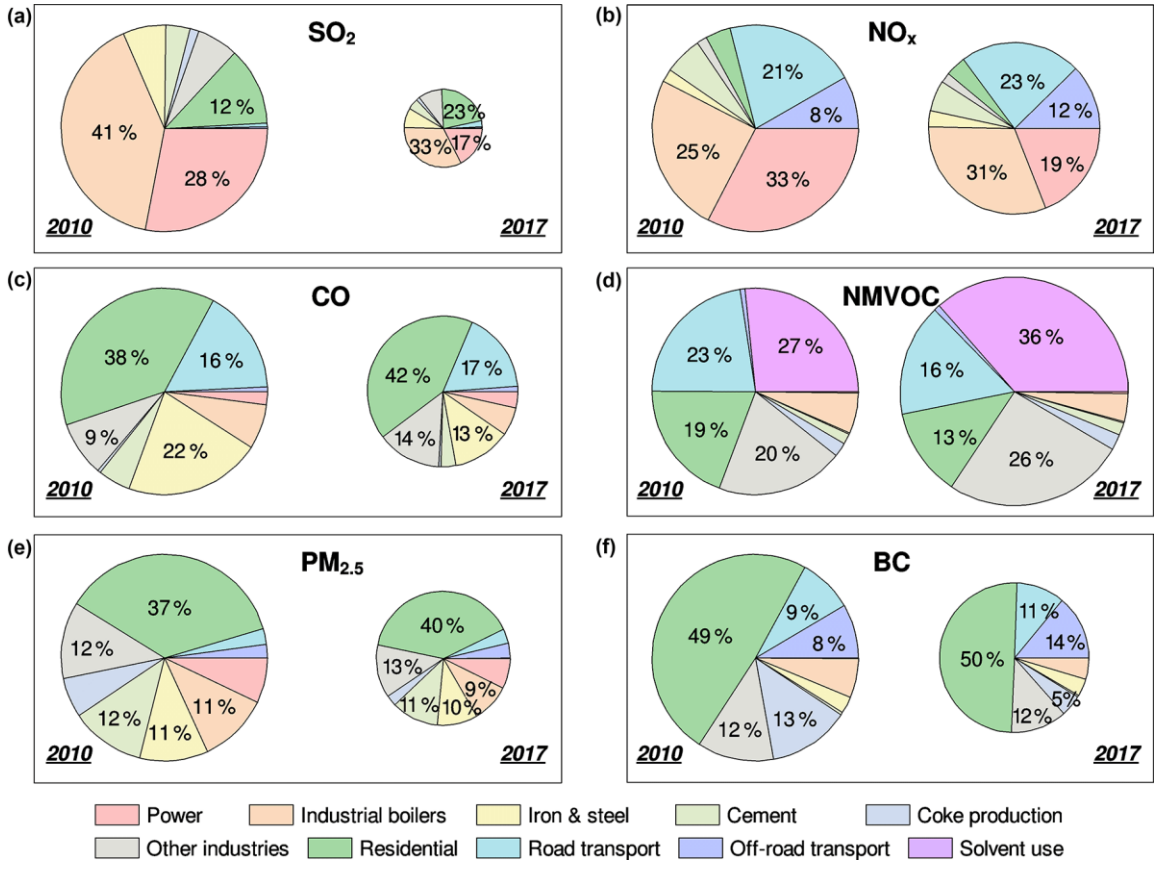
More details in Bo Zheng et al., ACP, 2018

Discussion of emissions in Asia during the GEIA conference on Thursday afternoon + several talks/posters

Emission inventories in Asia

Trends in MEIC from Bo Zheng's ACP 2018 paper





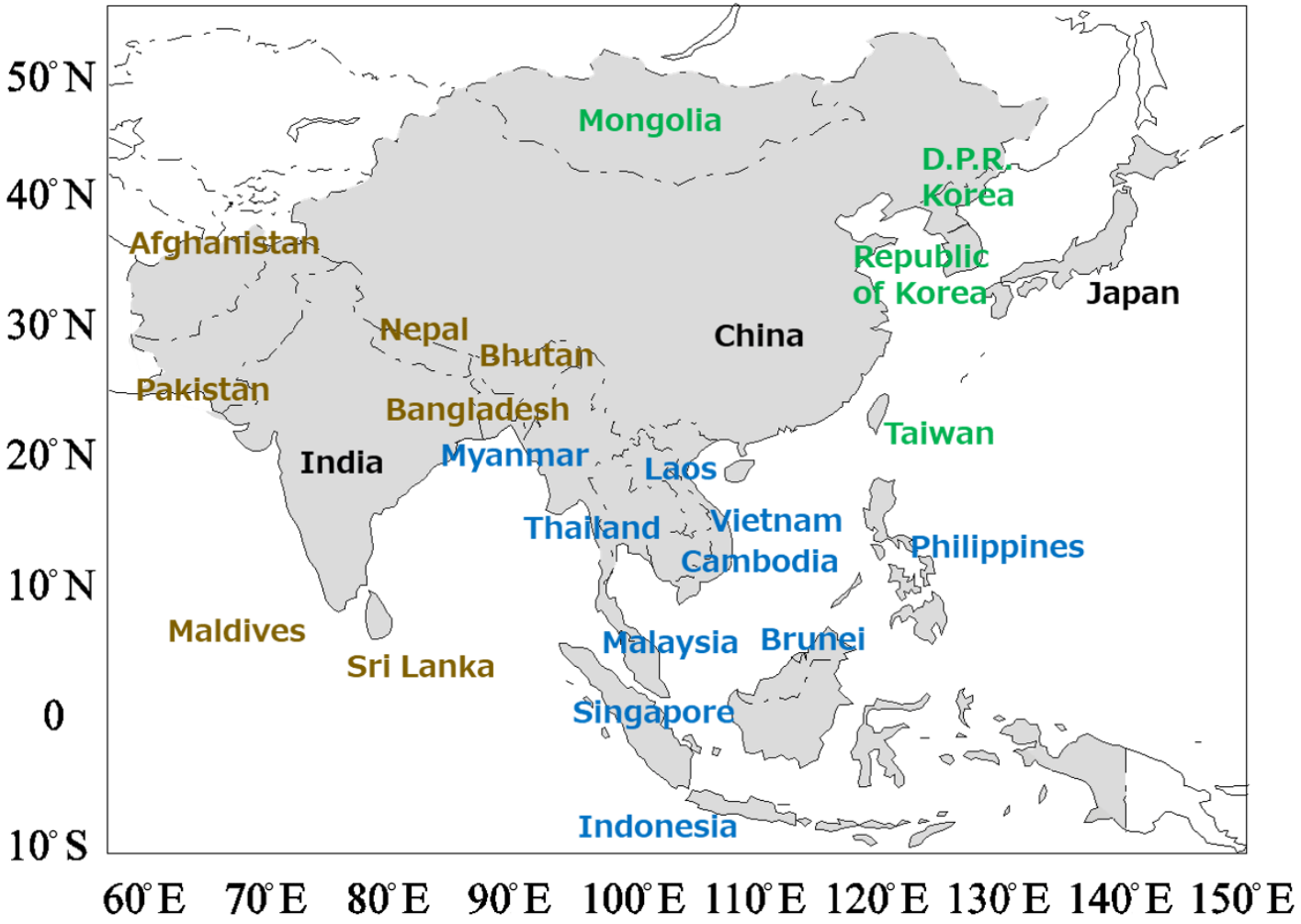
REASv3 emissions in Asia

Long-term historical trends in air pollutant emissions in Asia: Regional Emission inventory in ASia (REAS) version 3

Junichi Kurokawa[1] **and Toshimasa Ohara**[2]

[1]Asia Center for Air Pollution Research, 1182 Sowa, Nishi-ku, Niigata, Niigata, 950-2144, Japan
[2]National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki, 305-8506, Japan

ACP, 2019



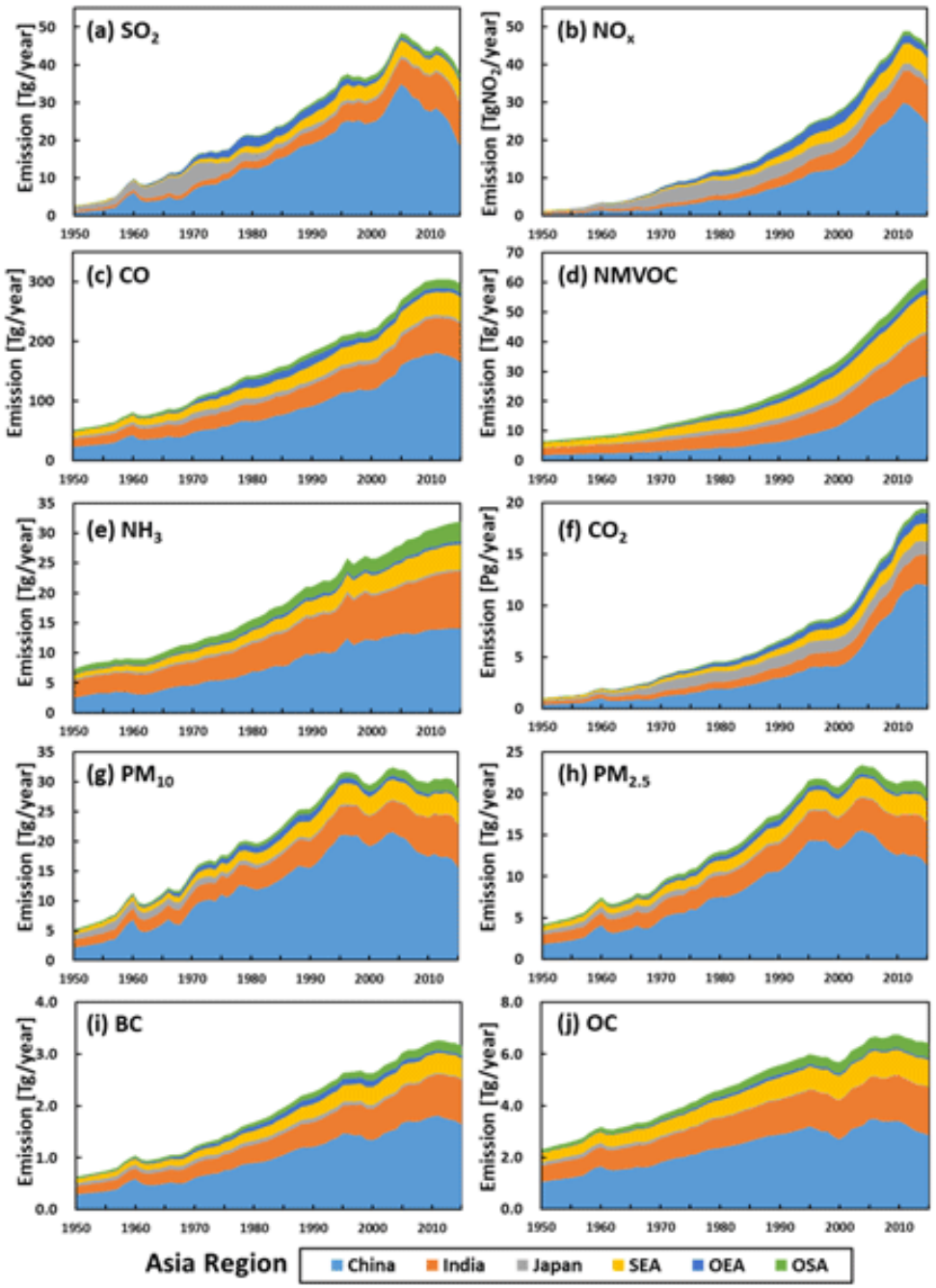
Website:
https://www.nies.go.jp/REAS/

1950-2015

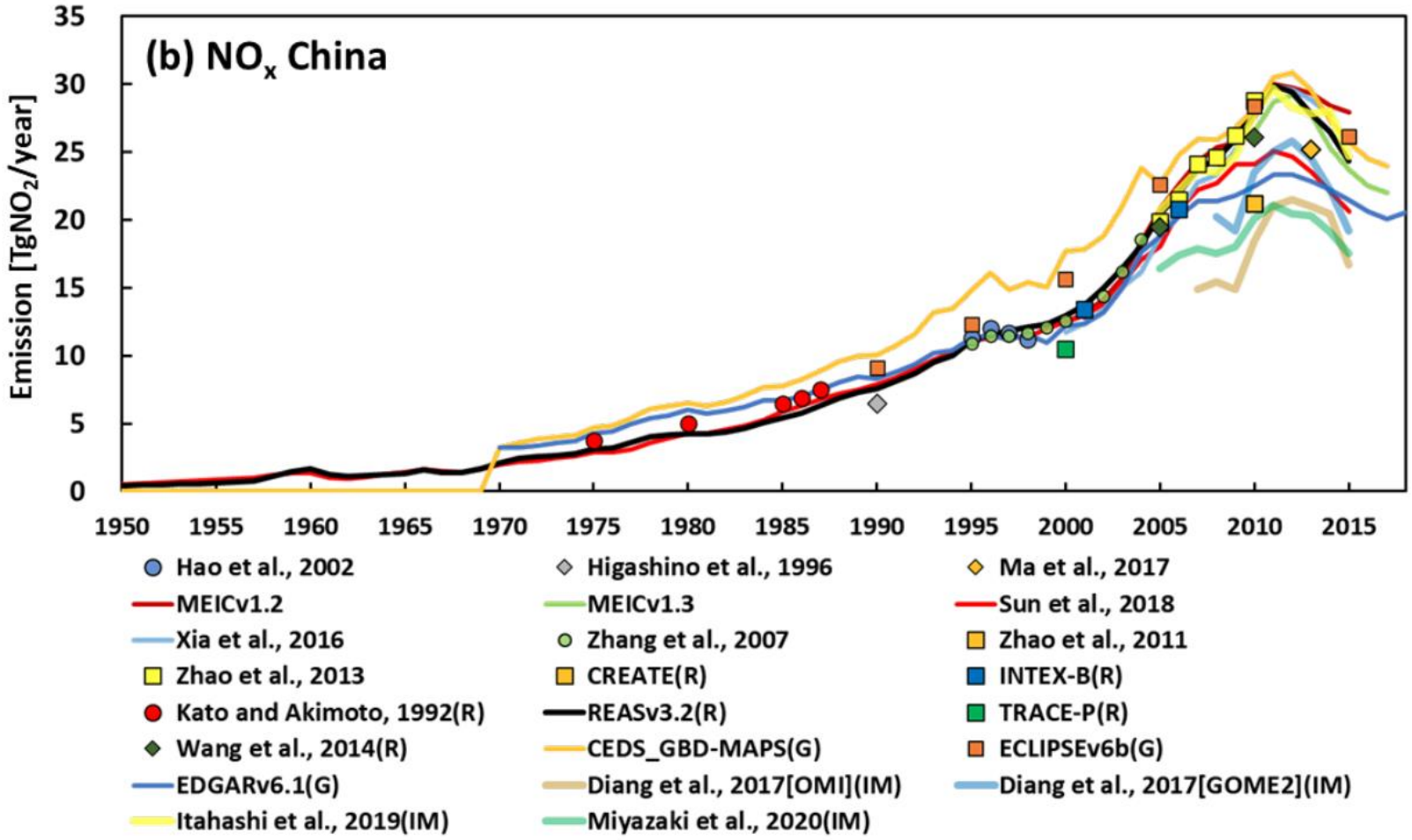
0.25 x 0.25 degree

Species: Species: SO2, NOx, CO, NMVOC, PM10, PM2.5, BC, OC, NH3, and CO2

Junichi will present poster 1.18



Changes in emissions in the REASv3 emissions from 1750 to 2015



Comparisons of a large number of datasets providing NOx emissions in China :
in Granier at al. : Anthropogenic emissions inventories of air pollutants, in Handbook of atmospheric Chemistry and Climate Change (community paper, 23 co-authors)

Emissions in Europe:

EMEP = emissions reported by each country
available at: https://www.ceip.at/webdab-emission-database

EMEP emissions checked, completed, gridded, etc. by TNO (The Netherlands)
As part of the CAMS project ➔ CAMS-REG

Detailed in Kuenen, ESSD, 2022

CAMS-REG - developed at TNO

Official reported GHG emissions (UNFCCC NIR – CRF)

Official reported Air Pollutant emissions (EMEP CEIP)

Other emission datasets IIASA GAINS & JRC EDGAR

TNO internal estimates Bottom-up checks

- Small combustion (wood)
- Non-international shipping
- Agricultural waste burning
- Etc.

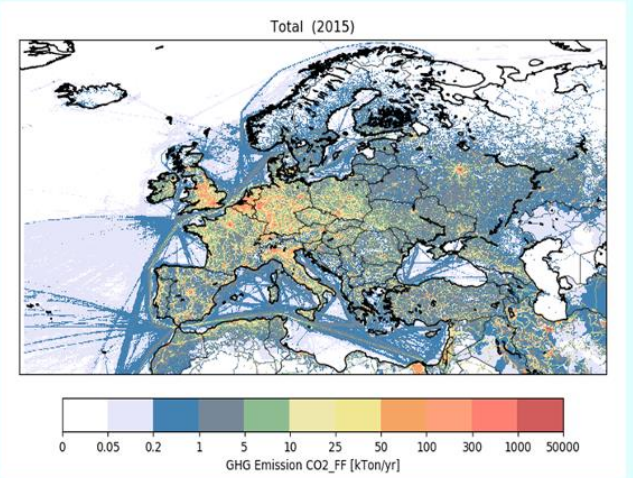
80+ subsectors: aggregated NFR with fuel splits

CAMS / TNO emissions by subsector

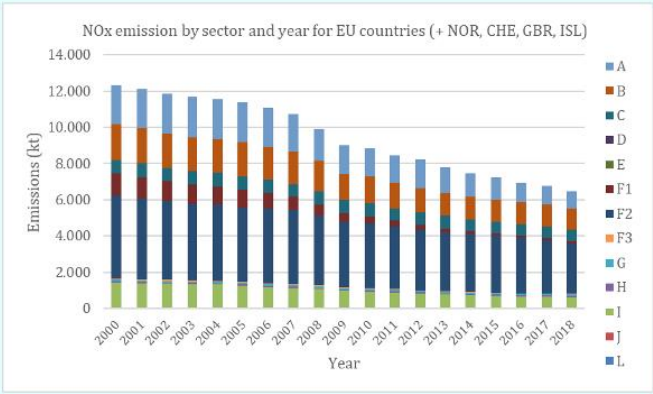
Shipping grids *(CAMS - FMI)*

Spatial proxies

- Population
- Road transport
- Animal densities
- E-PRTR, etc. etc.



Gridded European regional emission product (time series)

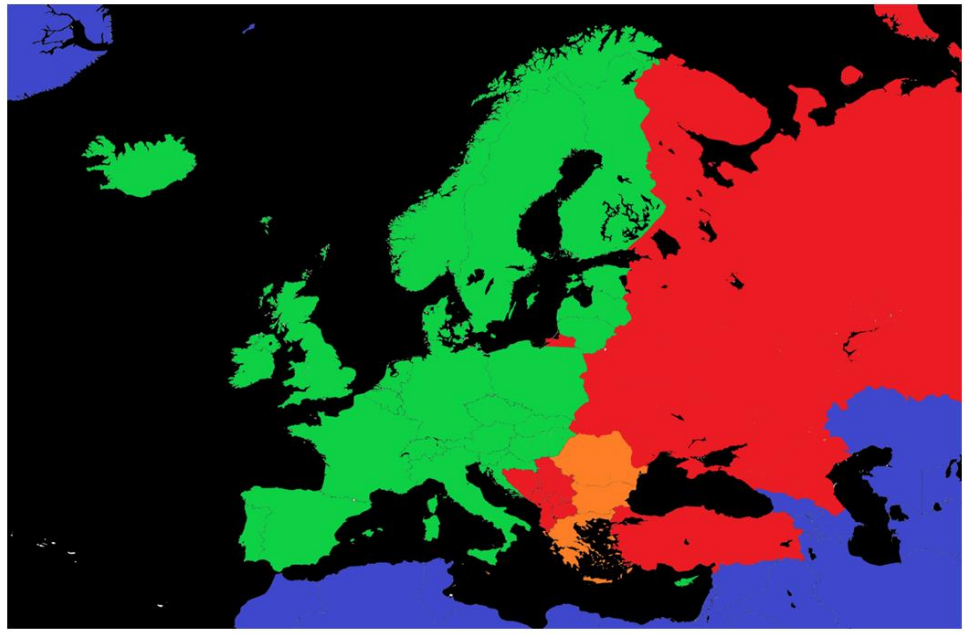


2000-2018; 0.05x0.1 degree spatial resolution

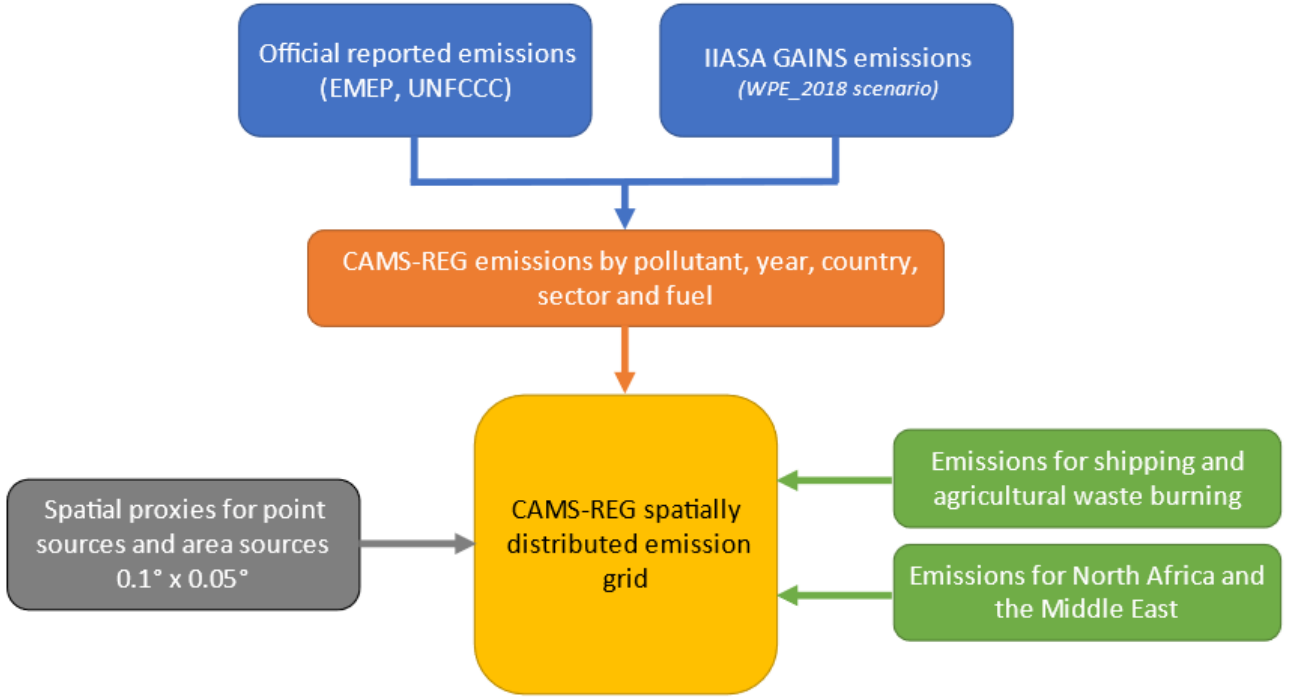
More details in **Kuenen et al., Earth Syst. Sci. Data, 2022**

Atmosphere Monitoring

- Inventory building on already existing inventories from each country in Europe - the “official” reported emission data which are submitted annually
  - Emissions by species, year, sector and pollutant
  - “Accepted” and used for many policy applications
  - Advantage of incorporating specific national circumstances
- Gapfill with alternative data sources where necessary (mostly IIASA GAINS model)
- Apply a consistent European spatial distribution methodology



Data source for CAMS-REG-v4: official reported, official reported gapfilled, GAINS, EDGAR



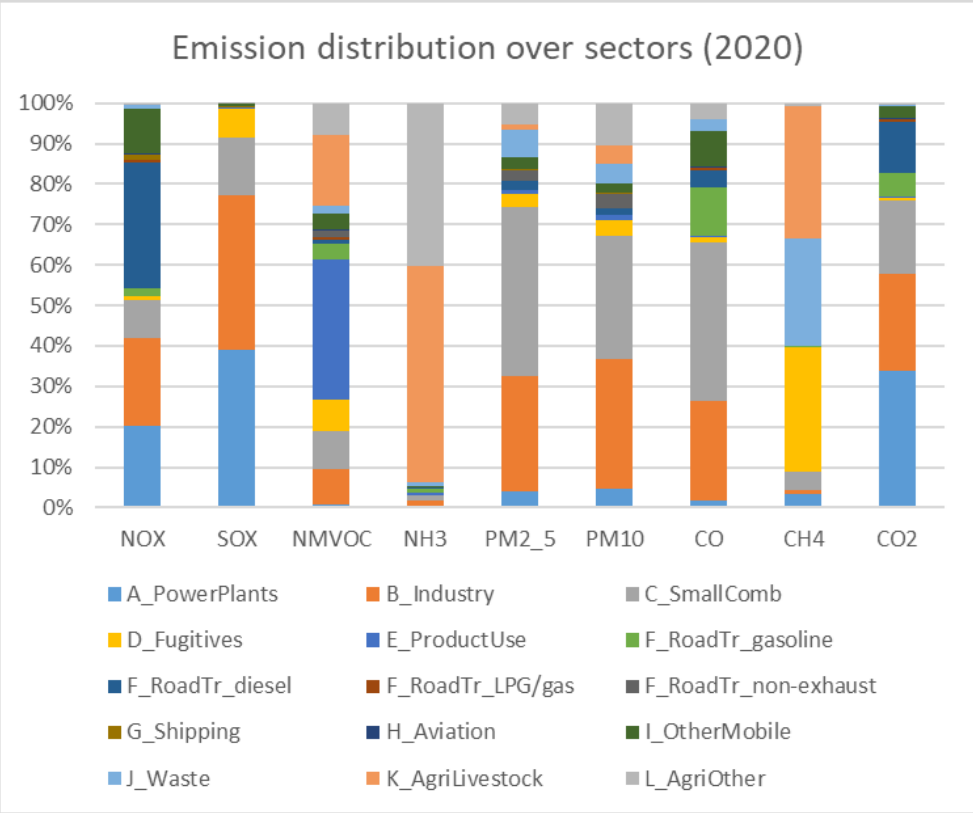
For details, see Kuenen et al. (2022)

Atmosphere Monitoring

Resulting dataset

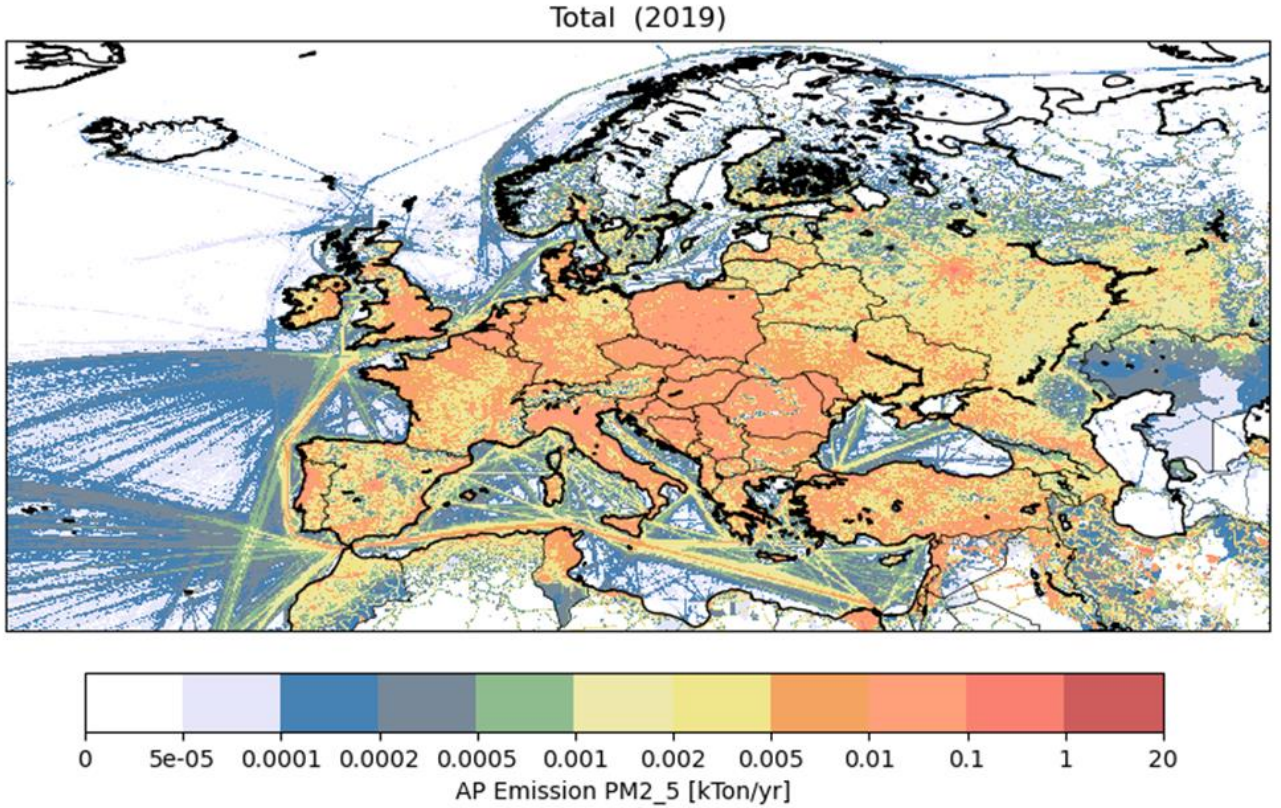
CAMS-REG version 6.1

Years: 2019 & 2020



Change 2020 compared to 2019 per region (%)

	NOX	SOX	NMVOC	NH3	PM2.5
EU+_North	-9%	-16%	1%	1%	-5%
EU+_WestCentral	-14%	-10%	-2%	-4%	-8%
EU+_East	-8%	-7%	-2%	0%	-1%
EU+_South	-16%	-17%	-2%	3%	-4%
NON_EU	-3%	-12%	-2%	1%	0%
Average	**-9%**	**-12%**	**-2%**	**0%**	**-2%**



Anthropogenic emissions

Outline

1. General methodology to calculate emissions
2. Activity data
3. Emission factors
4. Spatial/temporal variations and VOCs speciation
5. Current public global inventories
6. A few current public regional inventories
7. A few remarks on the uncertainties on anthropogenic emissions
8. **Conclusions → Access**

Atmosphere Monitoring

Where can you get access to emissions data?

ECCAD database = Emissions of Atmospheric Compounds and Compilation of Ancillary Data eccad.aeris-data.fr or eccad.sedoo.fr

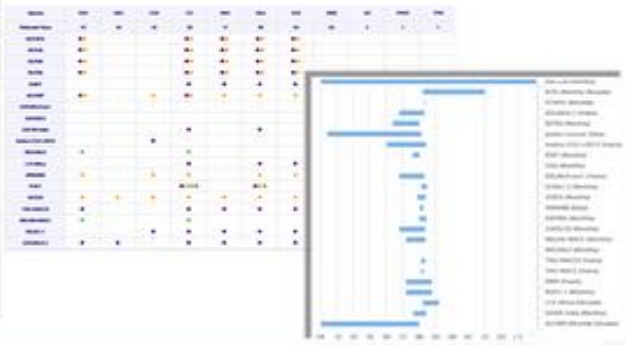
ECCAD is the official emissions database for:

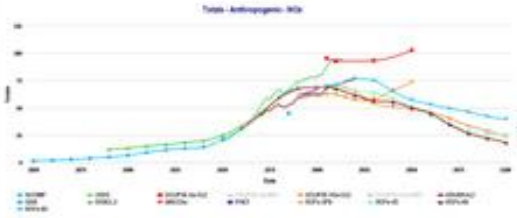
- **The GEIA (igacproject.org): Global Emissions InitiAtive**
- **The CAMS project**

ECCAD provides:

- **A large diversity of datasets and chemical compounds**
- **Global and regional emissions at various grid resolution**
- **Detailed metadata with complete reference**
- **User-friendly tools to visualize and analyse emissions**
- **A download system for of all the data**
- **The possibility of hosting data with restricted access while the data are being checked and analyzed**

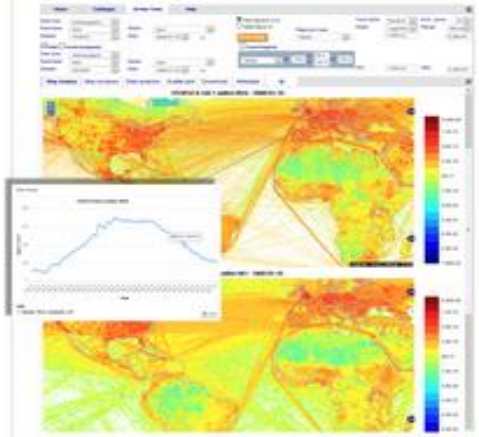
Example of ECCAD tools



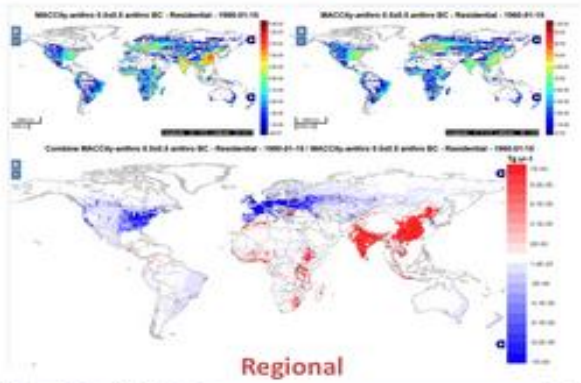


Catalogue & Metadata | Species | Temporal | Emissions Time Series | Inventory Time Series

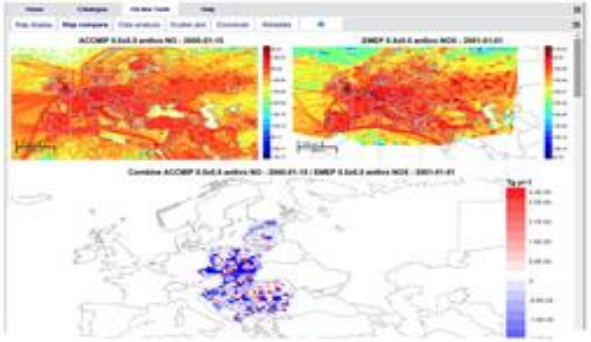
Display | Map Compare | Data Analysis | Scatter Plot

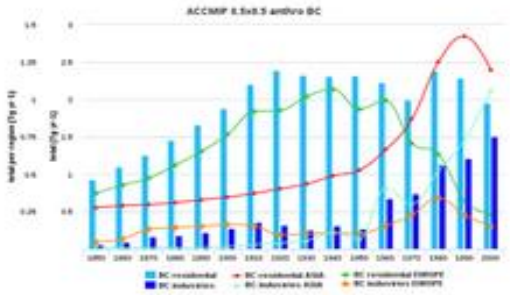


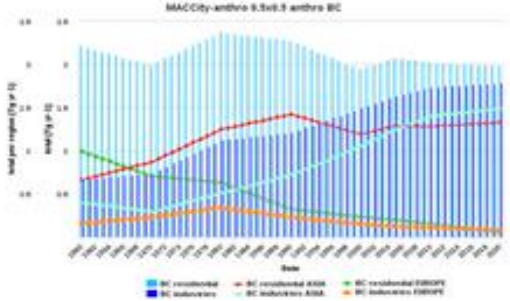
Regional totals

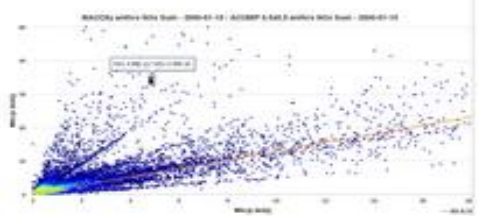


Regional

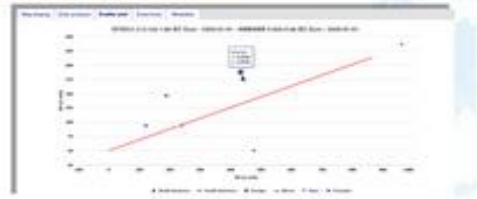








Regional



Summary

- High quality emissions information is critical to understand the atmosphere and make good decisions about how to manage it
- Bottom-up inventories are integral to these efforts, but there are challenges associated with these complex datasets
- There are significant disagreements between different global and regional bottom-up inventories ; identifying the causes of these differences and the uncertainties in these datasets is difficult because of lack of information
- Many publicly available inventories are accessible through the ECCAD database
- More information later on how to improve these datasets using inverse methods