Emissions inventories and data for AQF models (GEIA African experiences)

Part 1. Global, Regional and local anthropogenic and fire emissions inventories

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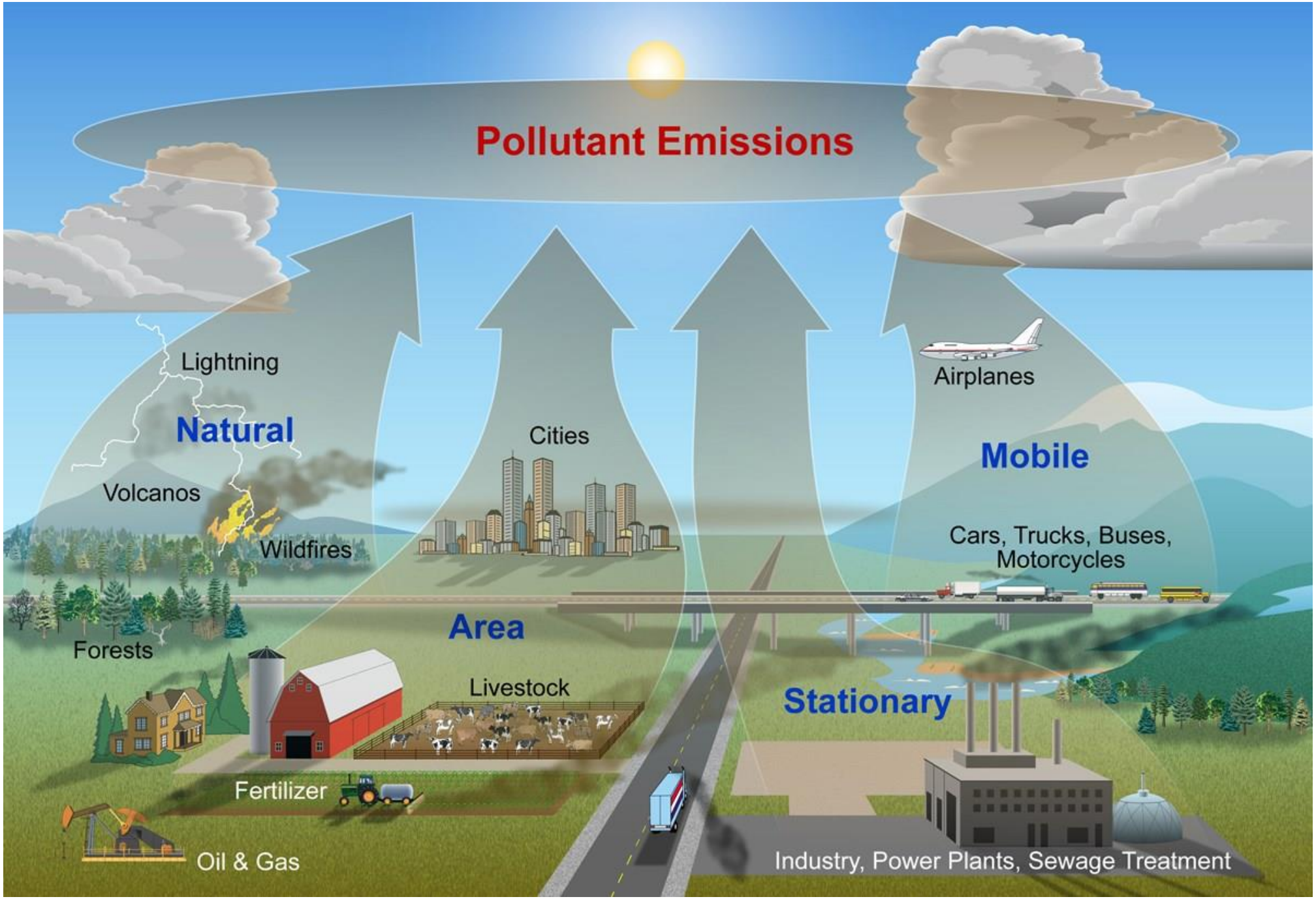
Part 2. Air Pollution in Africa: Overview of emission sources, impacts, and mitigation strategies

→ **Evelyne TOURE**


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

Motivation for Understanding Emissions

Actions and decisions about the atmosphere focus on emissions

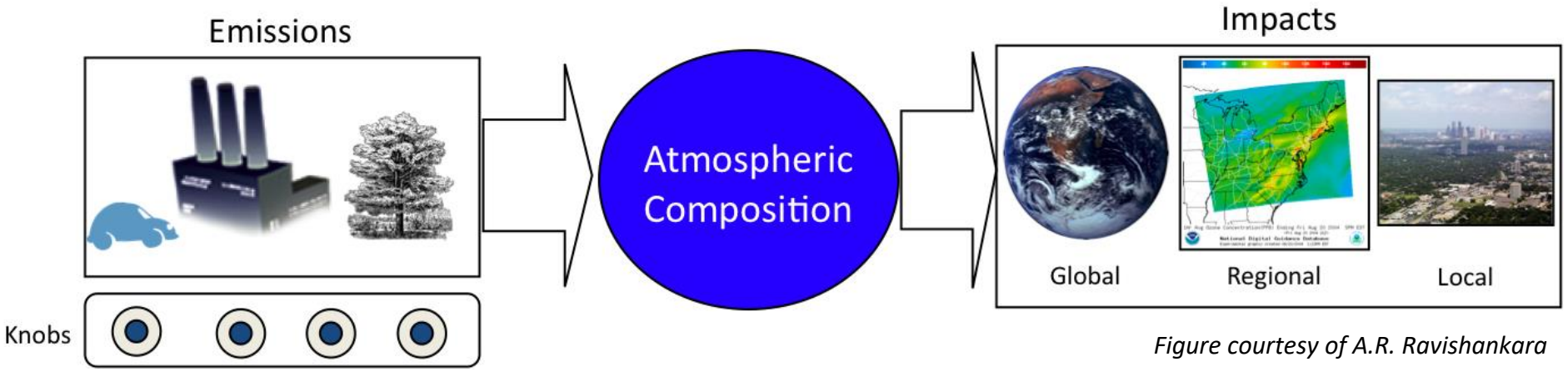
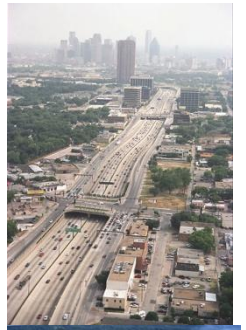


Figure courtesy of A.R. Ravishankara

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**

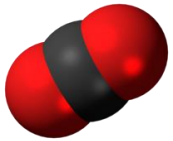
- limited number of chemical species
- moderate spatial and temporal resolution
- long-term variation (a few decades)
- need some coupling emissions/meteorological conditions

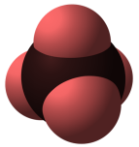
→ **Climate studies: impact of climate on emissions and of emissions on climate**

- 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)

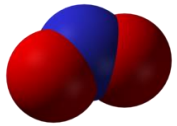
Which species are we talking about?

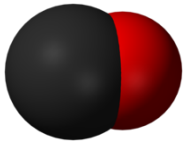
- **Greenhouse gases**

CO2 (carbon dioxide) 

CH4 (methane) 

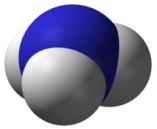
- **Pollutants (a few)**

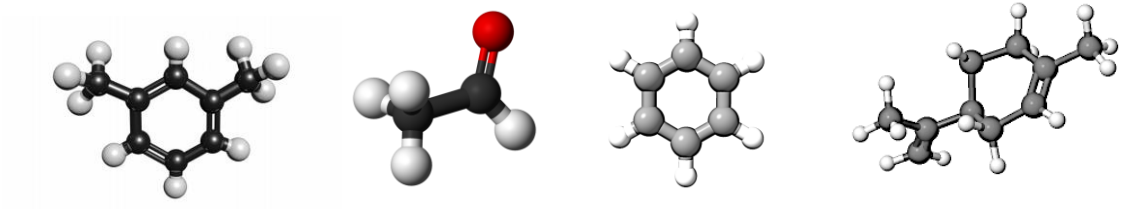


CO (carbon monoxide) 

NOx = NO (Nitric oxide) + (NO2) nitrogen dioxide

SO2 (Sulfur dioxide) 

NH3 (ammonia) 

and a lot of organic compounds: 

BC (black carbon), OC (organic carbon), PMs (PM2.5, PM10)

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

Surface emissions

1. General methodology to calculate emission inventories
2. Activity data and emission factors
3. Spatial/temporal variations and VOCs speciation
4. Current global inventories, African regional and local inventories
5. Biomass burning emissions
6. Access to emissions datasets

1. General methodology to calculate emissions inventories

Emissions Calculation General Methodology: Bottom-Up

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:

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

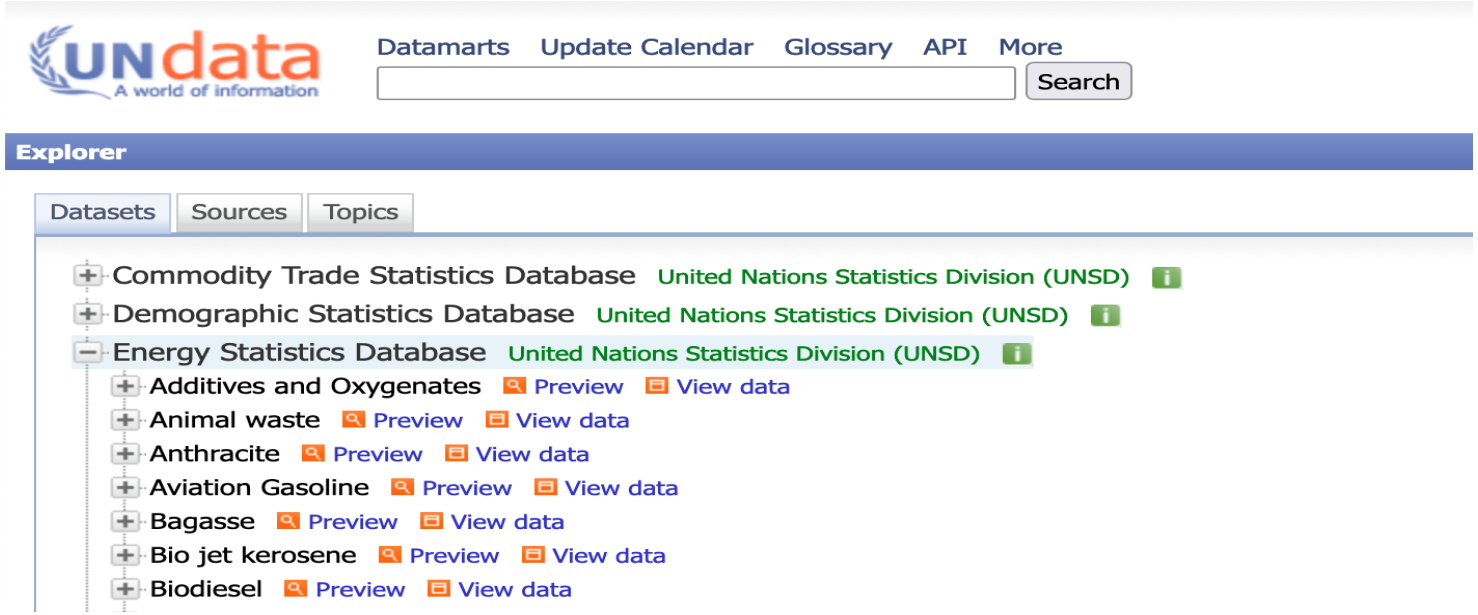
EE = Escape efficiency; EA = Emission activity (depends on light, temperature, leaf age, leaf area index, soil moisture, etc.

2. Activity data and emission factors

Acces to activity data :

- **International Energy Agency (IEA**: https://www.iea.org**) → Data are not free → cannot be put directly on a website and cannot be shared (The dataset used by many groups)**

- **Undata Energy statistics database (http://data.un.org/Explorer.aspx) → A free dataset → Open to all → can be shared**



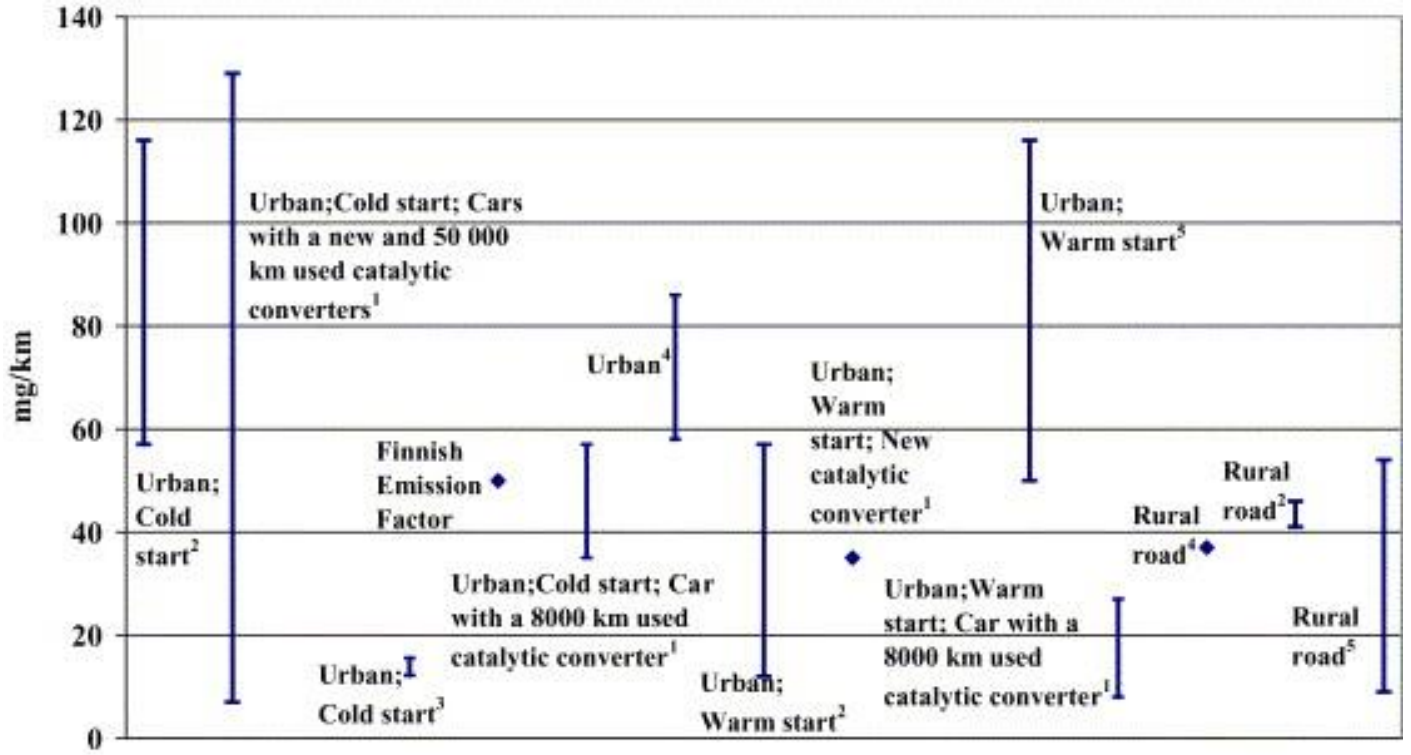
- **National statistical data as disaggregated as possible**

Emission Factors : One of the main uncertainties

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**

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



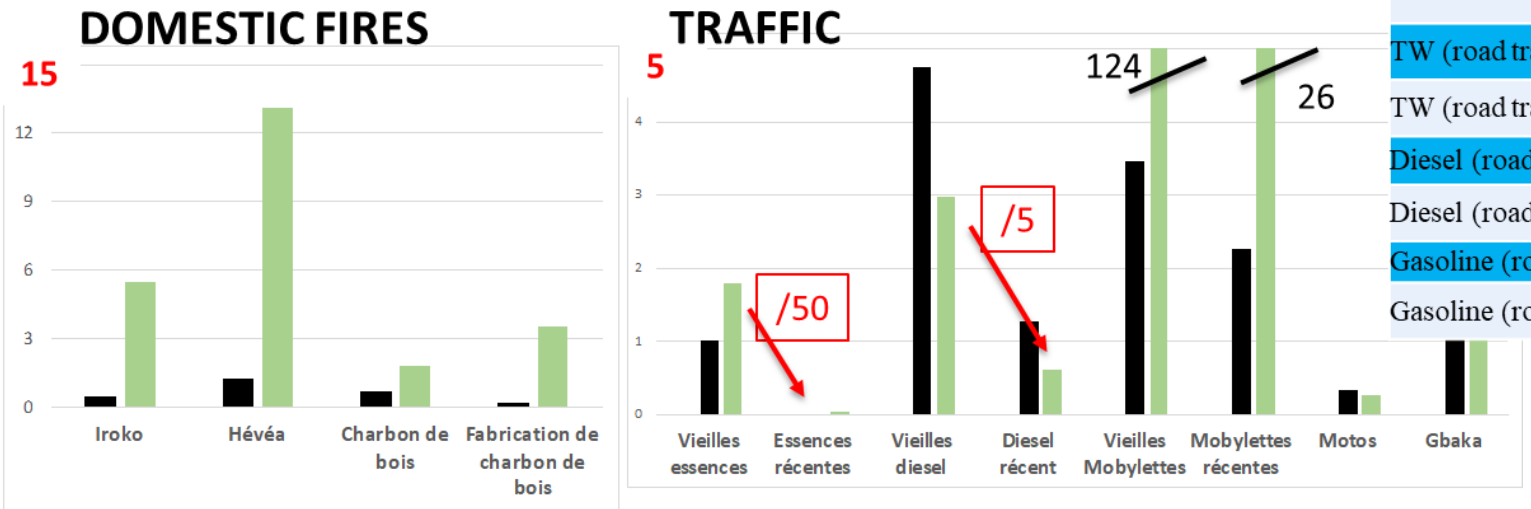
From Monni et al., 2004 (Measurement results of N_2O emission factors (mg/km) of cars with catalytic converters in different studies)

Measurement of emission factors in different parts of the world

Emission Factors : measurements in Africa (BC, OC, total PM, VOCs)

EMISSION FACTORS (g/kg)

Black: BC
Green : OC



- ✓ Domestic fire emissions : importance of fuel choice (season also)
- ✓ Traffic emissions : importance of vehicule park
- ⇒ Old/new cars; 2-stroke/4-stroke; Gbaka
- ✓ Waste burning emissions => EF(BC)= 3, EF(OC)=6.4

Old (Liousse et al.) versus new (Keita et al.) EF

Fuels	EF BC (g/kg)	EF OC (g/kg)	References
Wood	0.9	2.7	Liousse et al., 2014
Wood	0.8 ± 0.4	9.3 ± 3.8	Keita et al., 2018
Charcoal	0.75	2.25	Liousse et al., 2014
Charcoal	0.65 ± 0.3	1.8 ± 2.8	Keita et al., 2018
Waste Burning	0.7	5.3	Christian et al., 201
Waste Burning	2.8 ± 3.3	6.4 ± 4.6	Keita et al., 2018
TW (road traffic)	2.31	30.56	Liousse et al., 2014
TW (road traffic)	2.13 ± 0.42	28.46 ± 0.4	Keita et al., 2018
Diesel (road trafic)	5	2.5	Liousse et al., 2014
Diesel (road traffic)	3.1 ± 1.9	2.14 ± 1.2	Keita et al., 2018
Gasoline (road trafic)	0.15	0.73	Liousse et al., 2014
Gasoline (road traffic)	0.62 ± 0.49	1.10 ± 0.77	Keita et al., 2018

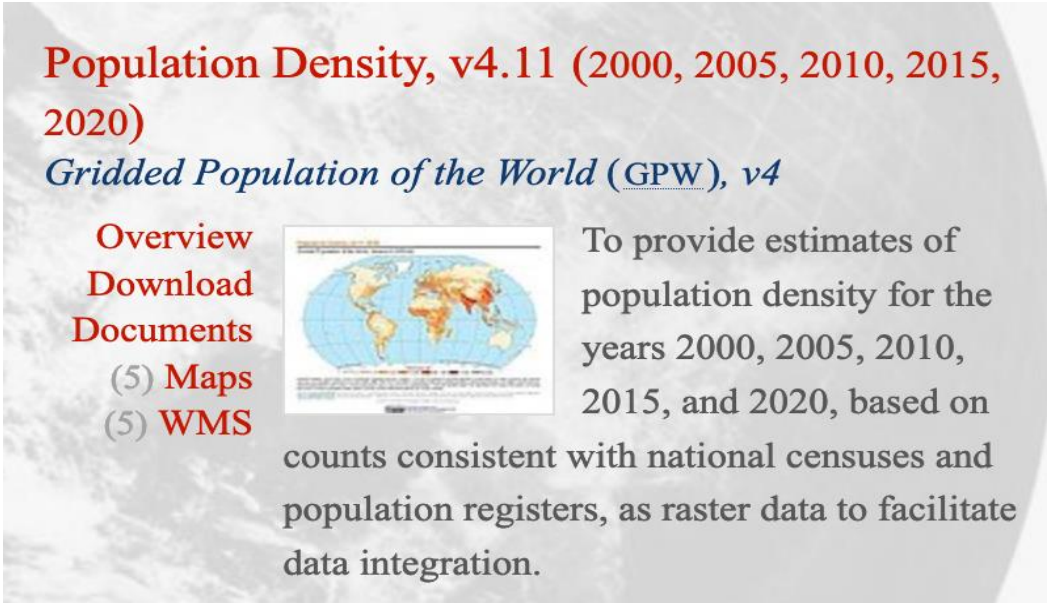
Keita et al. (2018). Particle and VOC emission factor measurements for anthropogenic sources in West Africa. Atmospheric Chem. Phys. 18, 7691–7708. https://doi.org/10.5194/acp-18-7691-2018

3. Spatial/temporal variations and VOCs speciation

Population data

- Data used by many groups: CIESIN

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



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

Spatial proxy for DACCIWA inventory

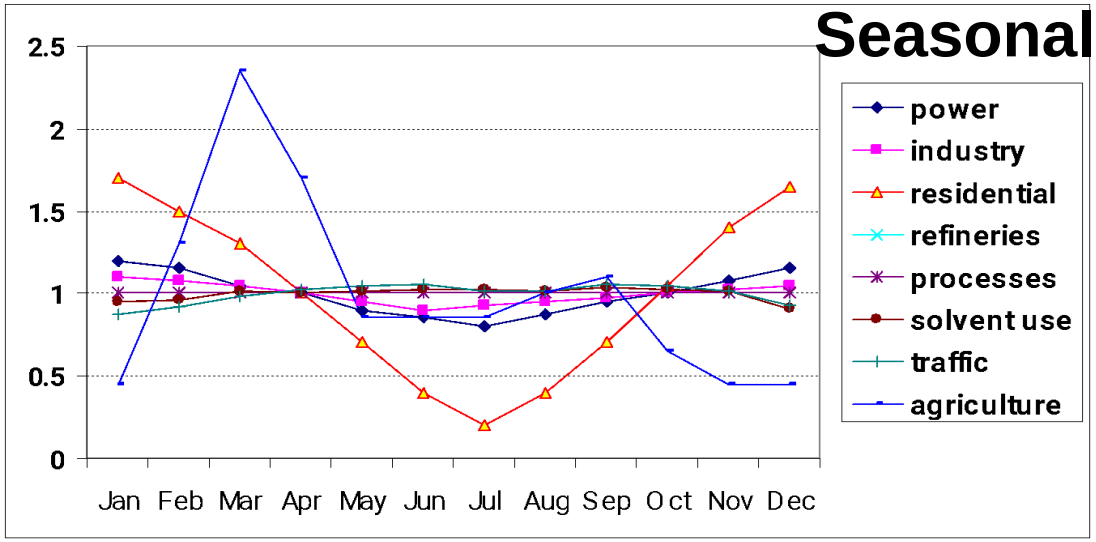
Emissions by countries => African emissions inventories at 0.1°× 0.1° spatial resolution

- **DOMESTIC FIRES** : Population density given by CIESIN (Gridded Population of the World Future Estimate: GPWFE)
- **ROAD TRAFIC** : African country road networks given by Africa infrastructure (2009)
- **INDUSTRIES and POWER PLANTS** : African power plant networks given by Africa infrastructure, (2009)
- **FLARING** : DMSP/VIRRS

Keita et al., 2021

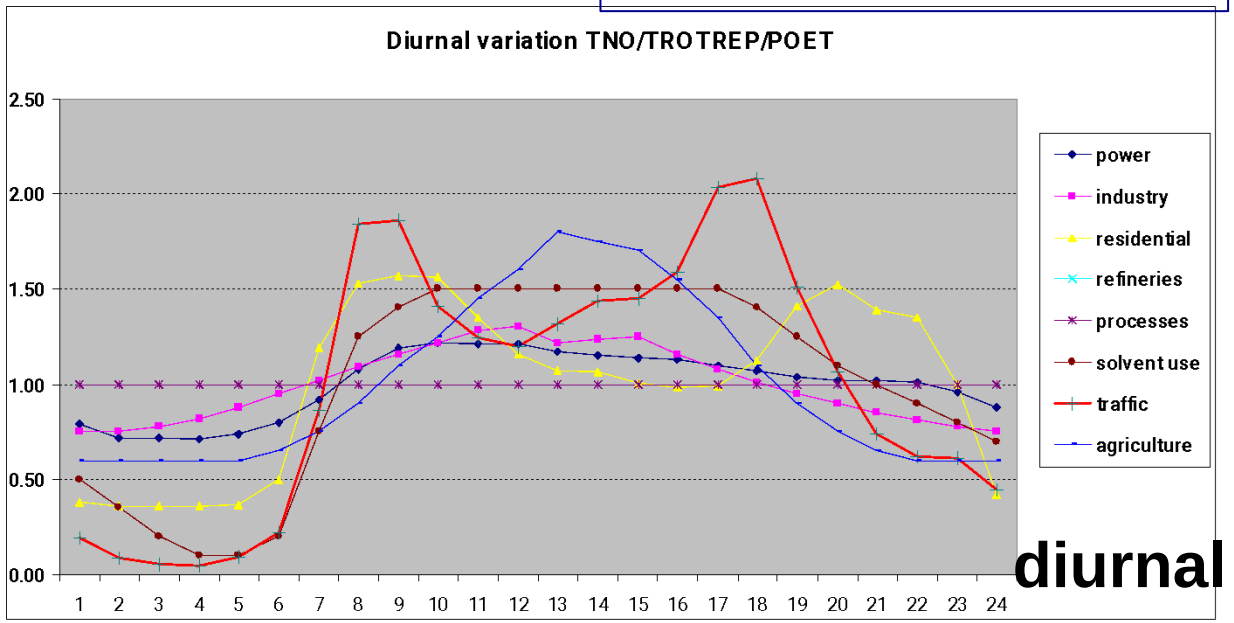
Temporal variations of the emissions: data used for a long time

- **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

- **Some recent works use Guevara et al.(2021) data**

Gridded monthly, weekly, daily and hourly temporal profiles → Sectoral coverage: energy & manufacturing industry, residential/commercial combustion, road transport, agriculture aviation, shipping

- **Need of temporal variation specific for African countries**

What VOCs - NMVOCs speciation mean:

- VOCs = volatile organic compounds = A group of chemicals (methane is excluded) that contain the element carbon in their molecular structure

- Most inventories = emissions of total NMVOCs . Most datasets provide surface emissions of total NMVOCs, without any indication of the emission of individual VOCs (speciation)

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

- 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

4. Current global inventories, regional and local inventories

➢ **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/

➢ **Current regional inventories publicly available (Many accessible through ECCAD) :**

- **North America: EPA, USA and Environment Canada**
- **Latin America: PAPILA**
- **Asia: MEIC, MIXv2 and REASv3**
- **Europe: CAMS-REG**
- **Africa: DACCIWA (v1 & v2)**

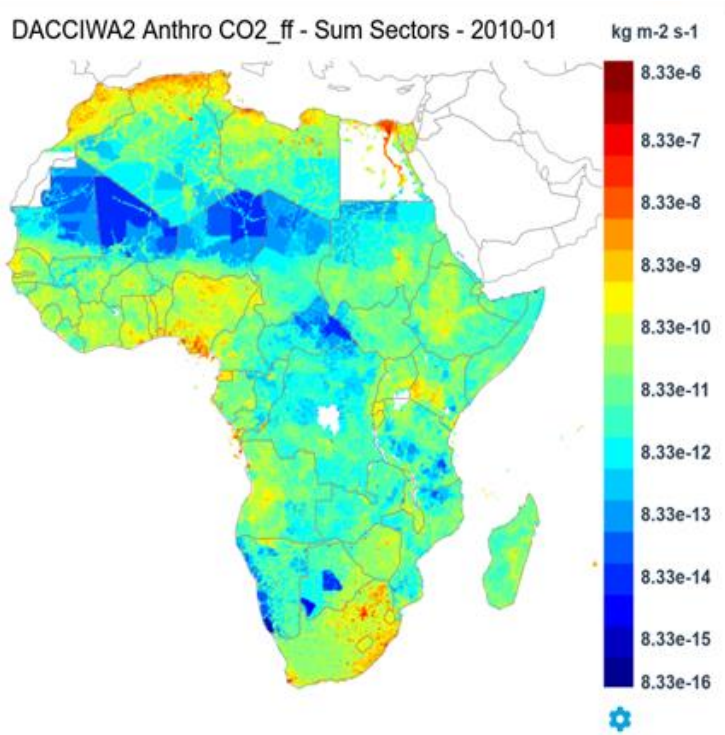
DACCIWA emissions inventories

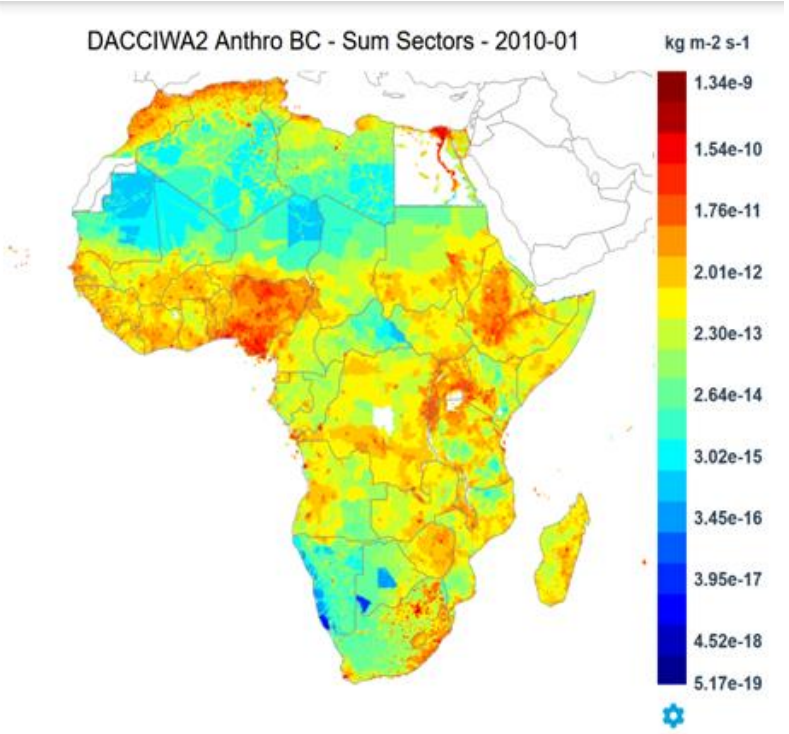
- **DACCIWA version 1. African anthropogenic emissions inventory for gases (OC, SO2, NOx, CO, VOC) and particles (BC, OC) from 1990 to 2015. (Keita et al., 2021)**

- **DACCIWA version 2. African Anthropogenic Emissions Inventories for GHG and air pollutants (provide detailed regional estimates of CO2ff, CO2bf, CH4, BC, OC, SO2, NOx, CO, VOC for the period 2010-2018 yearly/monthly 0.1° x 0.1° maps including both combustion and non combustion sources**

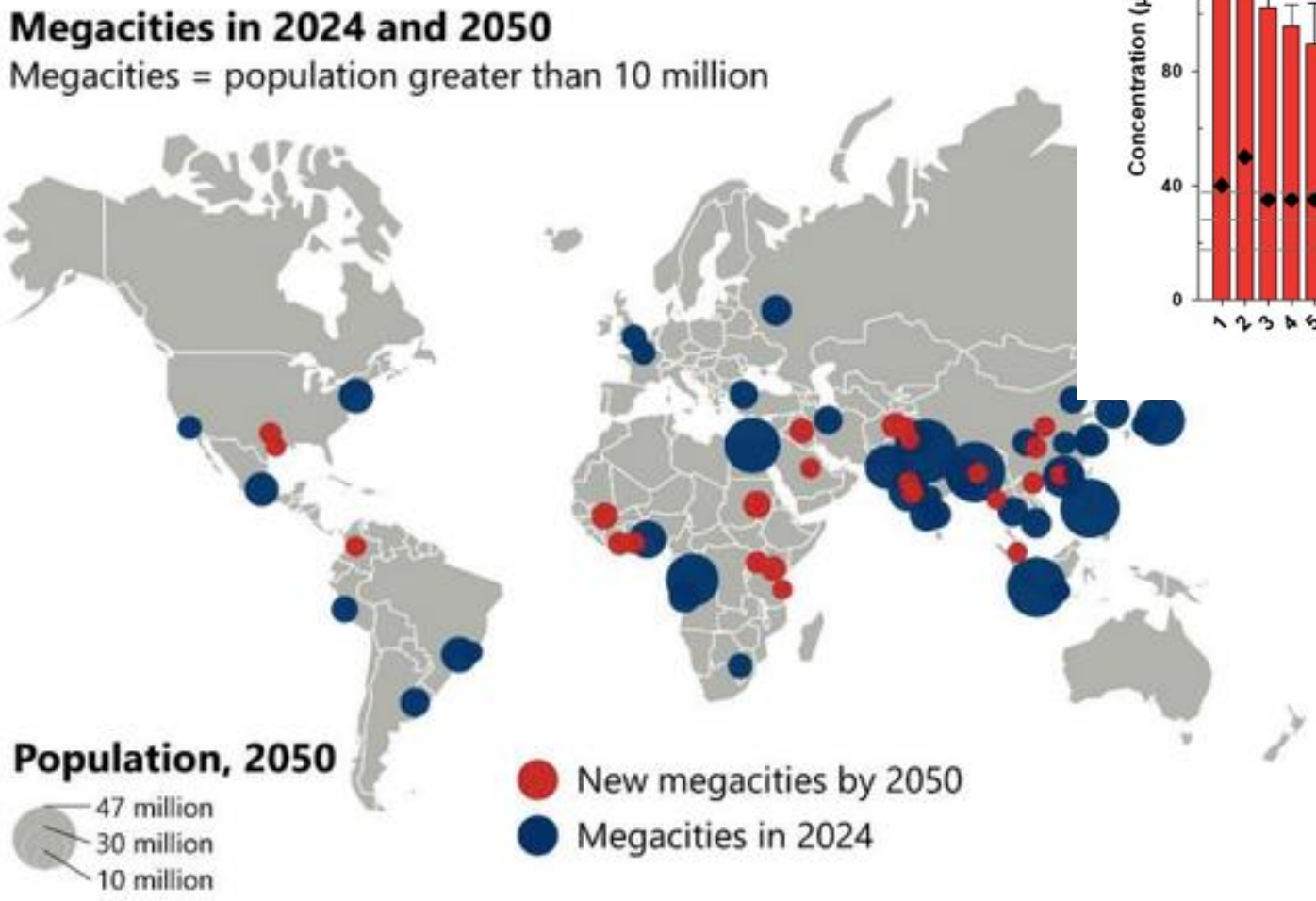
- West Africa's contribution is greater than that of the other 4 regions of Africa in terms of BC, OC, CO and VOC

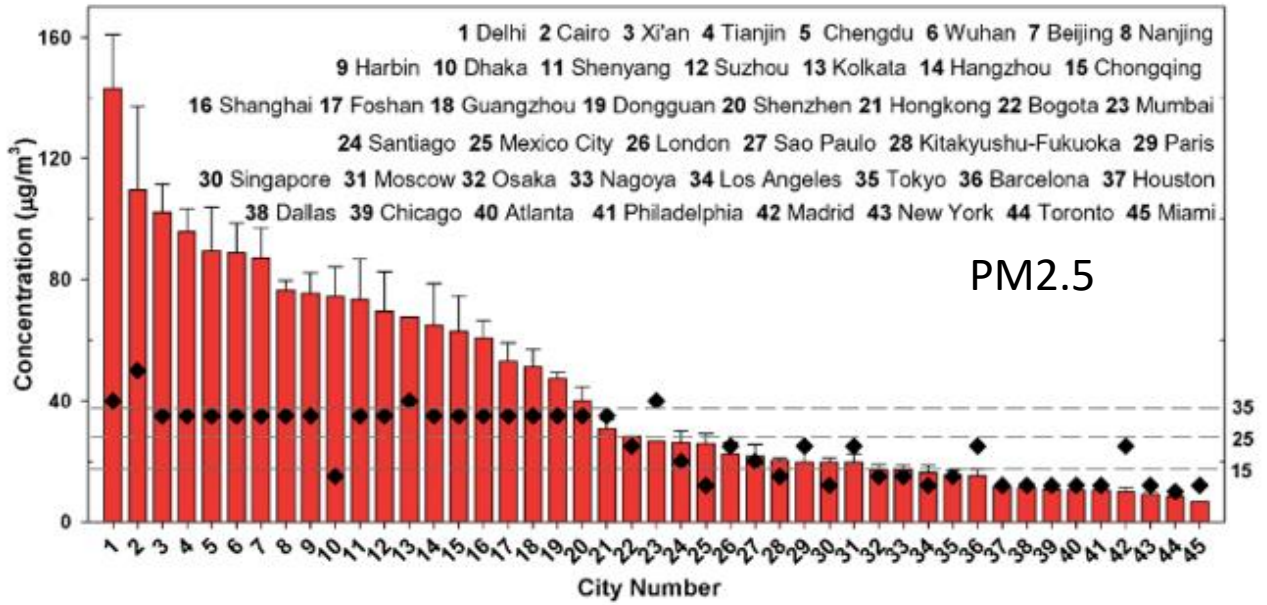
- These pollutants are mainly emitted in the residential and traffic sectors which are the main emitting sectors in WAF





Urban emission inventories: Urbanization



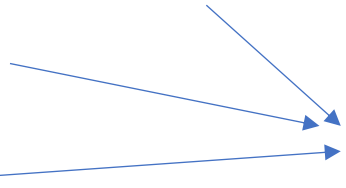


MEGACITIES

Source: Oxford Economics Global Cities, November 2023

Local emission inventories (LEI) : big challenges…

- LEI are needed to set up mitigation actions to reduce AQ and CC
- Socio-economical, political specificities depending on where we are
- Same for the list of polluting sources.
- Access to the database (or even existence of the data required)
- In developed countries, LEI can be done by Air quality agency, cities etc. whereas by researchers in other parts of the world.
- Different methods are used to develop LEI : need comparisons
- Comparison Local/Regional emission inventory
- To deal with both GES and air pollutants



GEIA Urban working group

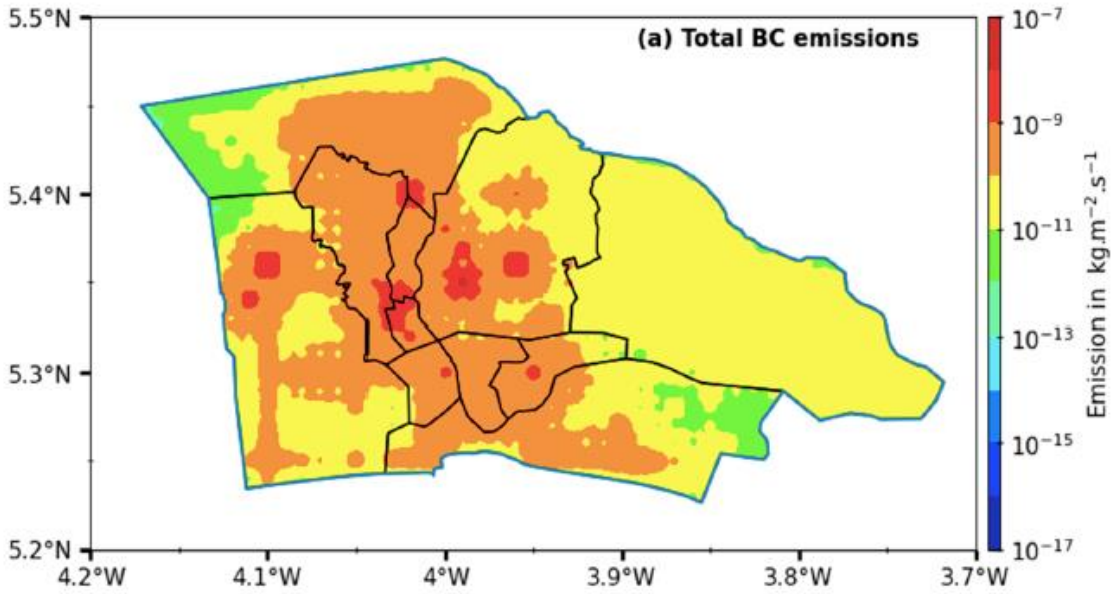
Emissions inventory for Abidjan (Côte d'Ivoire)

The first urban emission inventory in West Africa (1km*1km)

BC, OC and SO2 included

Traffic, Residential and commercial cooking, industries and power plants and Waste burning.

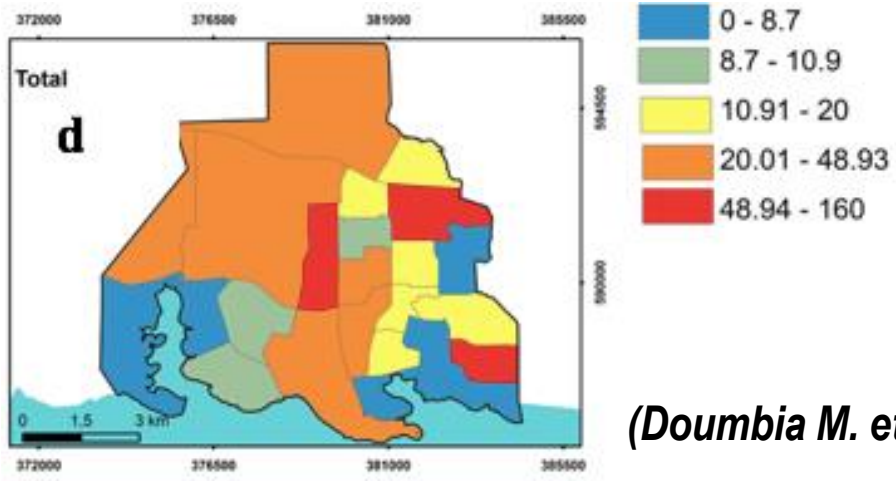
Emission factors based on local measurements



Gnamien et al., 2024

At downtown level (Yopougon)

BC domestic emissions in Yopougon (a district of Abidjan, Cote d'Ivoire)



(Doumbia M. et al., 2019)

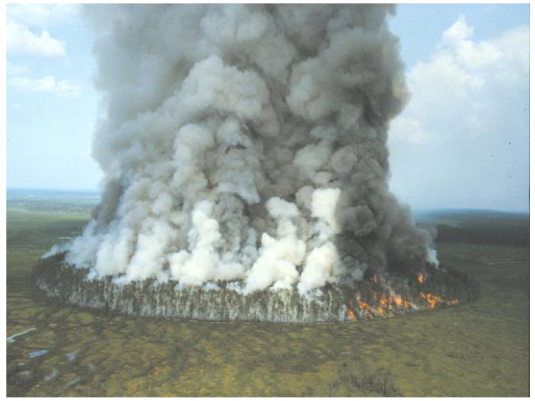
5. Biomass burning emissions

Bottom-up Method for deriving Biomass burning emissions

In global and regional existing inventories, *(Cooke and Wilson, 1996, Liousse et al., 1996, Reddy et al. 2001, Galbally et al. 2001,…)* gaz and aerosol source emissions (Q(X)) is calculated as following :

Q = M x EF(X) where
EF(X) is the emission factor (gX/kgdm)
M is the burnt biomass ; it may be obtained from :

$M = A \times B \times \alpha \times \beta$ *where*
A is the burned area
B the biomass density
α*, the fraction of aboveground biomass and* β *the burning efficiency.*



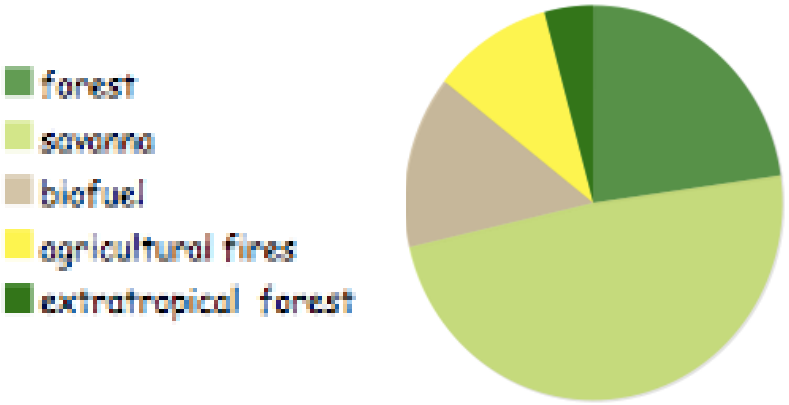
Thanks to many experiments (under the IGAC flag : DECAFE, EXPRESSO, SAFARI, SCAR-B, LBA, FIRESCAN…)

- **Uncertainty on EF has been improved** ***(Andreae and Merlet, 2001, Scholes and Andreae, 2001, Akagi et al., 2011)***

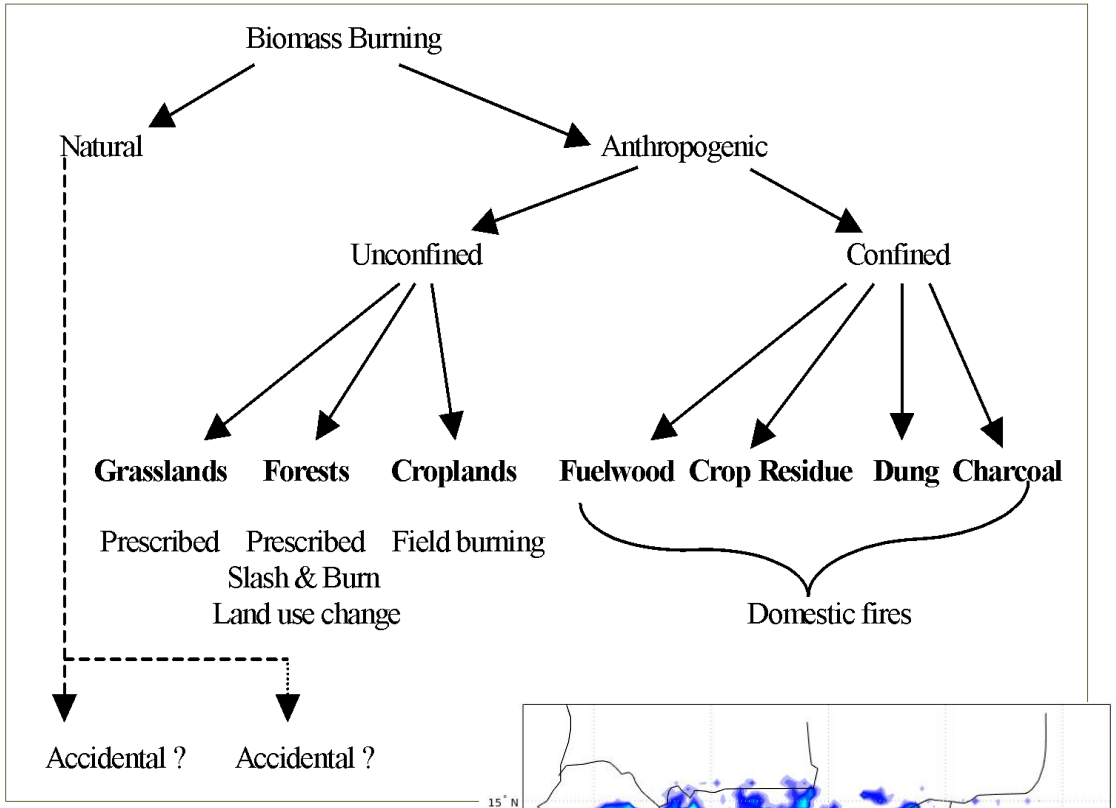
Investigations are still needed for agricultural fires, humid forest fires, boreal and mediterranean ecosystems, for some compounds (WSOC emissions)..

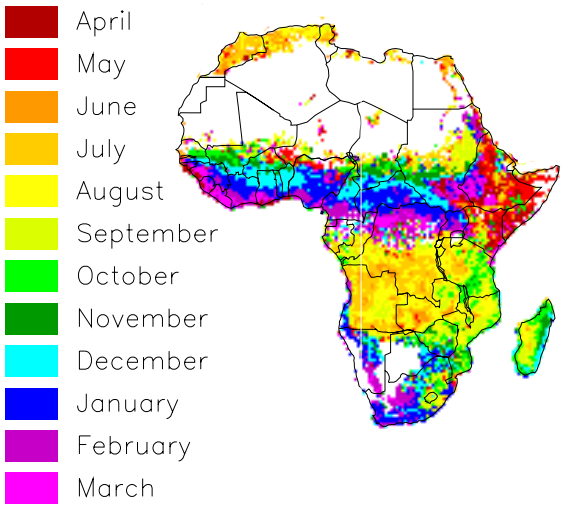
Biomass burning emissions

Relative contribution of each ecosystems in the global burnt biomass (5293 Tgdm/yr) in 2010

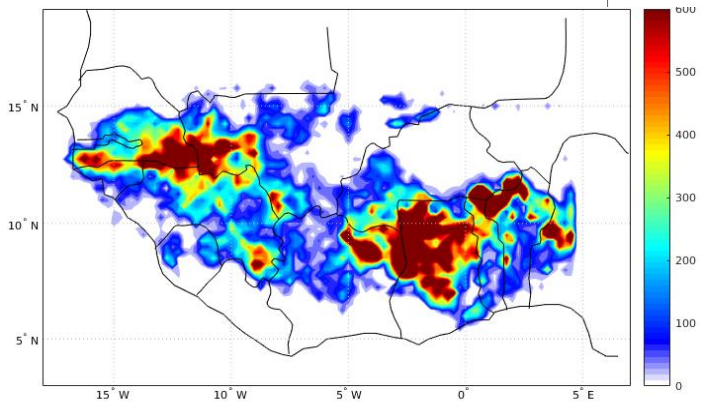


Anthropogenic/Natural origin





Spatial and temporal variability



Spatial distribution of Biomass burning mean BC over West Africa between 2001- 2012 (N'datchoh et al. In preparation)

How to limit uncertainties on Emissions inventories ?

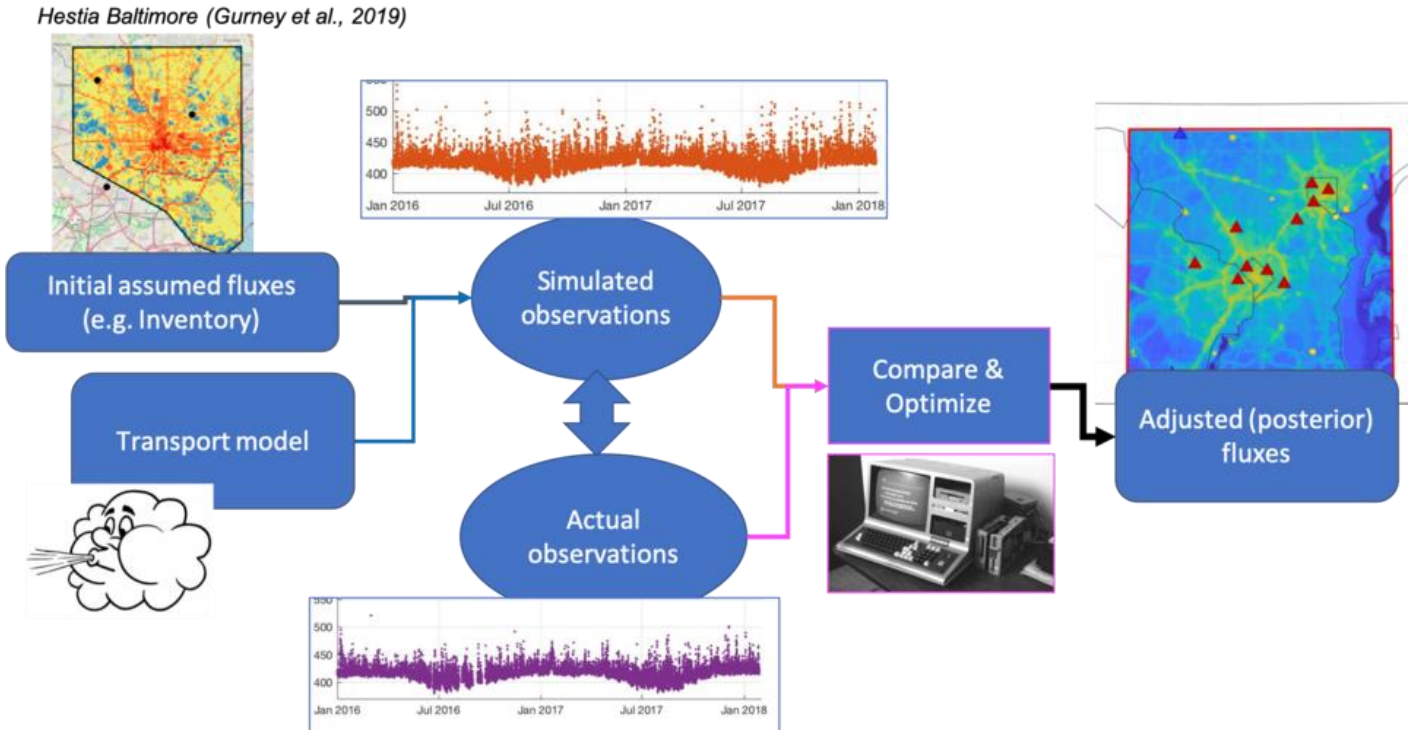
- Emission inventories for gases and particles (same ancillary data)
- Local/Regional/Global inventories Emission inventory intercomparisons
- Emission experiments (Lack of EF for some species and some sources/ properties..)
- Organic budget : VOC/SVOC/POC
- Temporal variations (diurnal/seasonal/interannual/projections)
- Spatialization keys
- by including these inventories in multi scale models and comparing modeled and measured pollutant concentrations and/or optical properties

A word on inverse modeling

- Inventories not available for the most recent years : collecting and checking activity data takes time

- How are we sure that inventories provide correct data?

- Methodology to check emissions and quantify emissions for the most recent years → inverse modeling



- use inventories
- evaluate uncertainty on emissions
- have a chemistry/transport model
- evaluate the uncertainties on the model results
- use observations (surface/satellite, etc.) and their uncertainties

→ Optimize the emissions to have a good match between model and observations

→ Tutorial on methodology in many papers, including the Brasseur and Jacob 2017 book (Modeling of Atmospheric Chemistry)

GEIA
Global Emissions InitiAtive

Cathy Liousse
GEIA Co-Chair

Brian McDonald
GEIA Co-Chair

Claire Granier
GEIA Database Manager

Paulette Middleton
GEIA Network Manager

- *Founded in **1990**, a community initiative*
- *Bridging science, society and policy*
- *Bringing together people, data, and tools*
- *Creating and communicating emissions information*
- *Key forum for emissions knowledge, serving stakeholders in rapidly evolving global society*

https://www.geiacenter.org

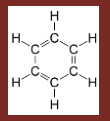
Analysis of emissions : GEIA working groups (WG)

China Emissions WG (K. He, Q. Zhang)

- *Development of the Multi-Resolution Emission Inventory for China (MEIC)*
- *Development of Mosaic emission inventory for China*
- *Organizing training workshop and conferences & Special issue on top journals*

VOC Emissions WG (Eva Pfannerstill , P. Dominutti, A. Borbon)

- *Improving global understanding of VOC emissions, including methane*
- *Creating a global directory of VOC observations to enhance discoverability of data*
- *Long-term trends in VOCs*
- *Effects of VOC speciation on secondary pollutant production*



Latin America/Caribbean Emissions WG (N. Huneeus, L. Dawidowski, N. Rojas)

- *Developing and evaluating LAC-specific emissions information*
- *Creating LAC regional emissions database and inventory*
- *Building LAC emissions expert community linked to global efforts*

Urban Emissions WG (L. Tarrasón)

- *Leveraging techniques for urban emissions characterization*
- *Building capacity in megacities around the world*

Africa Emissions WG (C. Leal-Liousse, S. Keita, M. Naidoo)

- *Creating a network of experts on African emissions*
- *Evaluating African-specific emission inventories*
- *Creating a regional database (fuel consumption, emission factors and inventories) and a continental-wide African emission inventory*

Near-real-time (NRT) Emissions WG (M. Guevara, B. H. Baek)

- *Creating a network of experts on NRT emissions and corresponding applications*
- *Review of current practices and applications of NRT emission estimates*
- *Perform benchmarking exercises (i.e. NRT vs official estimates)*
- *Provide recommendations/guidance in the form of a publication*

GEIA Africa Emissions Working group

NEW WORKING GROUP

Cathy Liousse, Mogesh Naidoo, Sekou Keita

Next GEIA Conference : July 9 to 11
Training sessions on emissions : July 7 to 8
UFHB, Abidjan (Côte d'Ivoire)

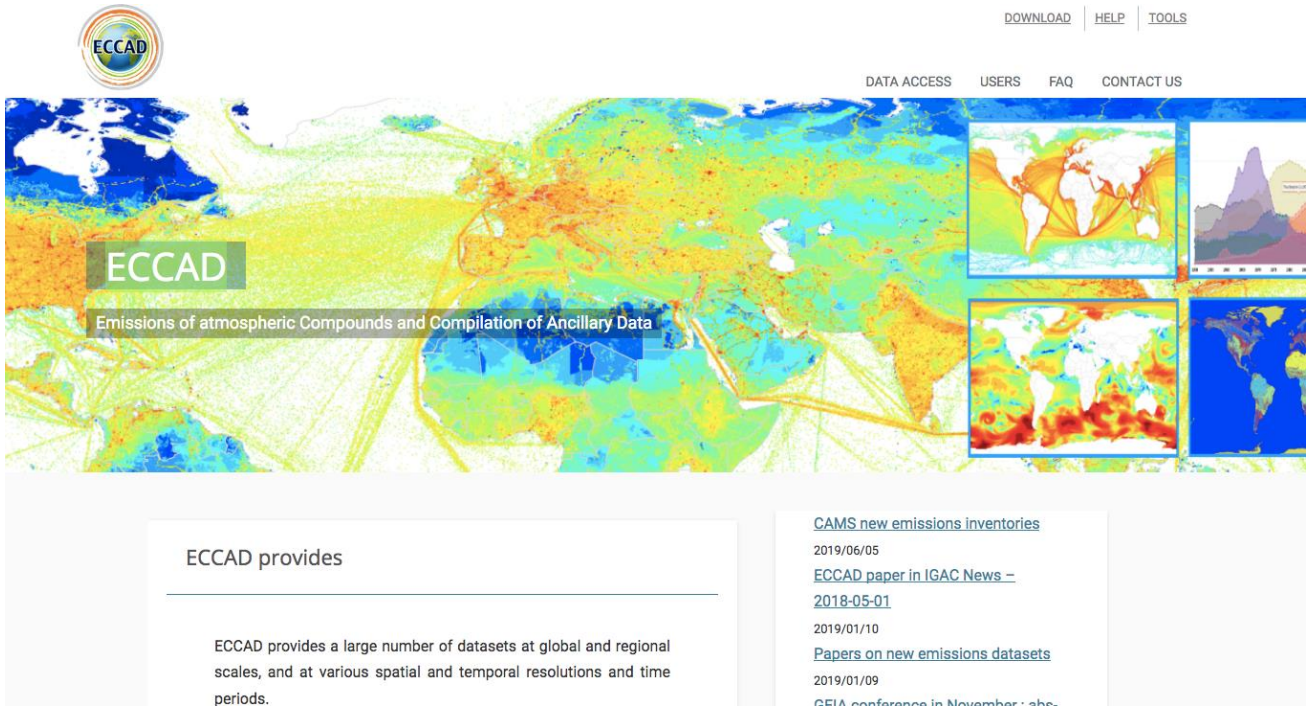
GEIA's AFE WG is promoting community efforts in emission development for Africa. The working group consists of a list of members, which is in construction, to create a network on emissions with strong connections between experts (African and non-African) on African emissions, representatives of international groups and projects such as IGAC, IGAC-Africa ANGA, WMO, ILEAPS, AMIGO, MAP-AQ, IBBI, DEBITS, PASMU, LIA-ARSAIO etc .. and regional decision makers. The WG is currently planning :

- To evaluate African-specific emission inventories.
- To consider specific emissions in Africa, for each sector from regional to city spatial resolution.
- To create a regional database including local informations on fuel activity and consumption, emission factors and emission inventories. This database will deal with sources for present, historical and future emissions including mitigation scenario.
- To develop a continental wide African emission inventory, with the most recent DACCIWA inventory as a baseline and local informations (e.g. Doumbia for Cote d'Ivoire, South Africa new inventory …)
- To organize training sessions on emissions in Africa.

6. Access to emissions datasets

ECCAD ***Emissions of Atmospheric Compounds and CompilaFon of Ancillary Data***

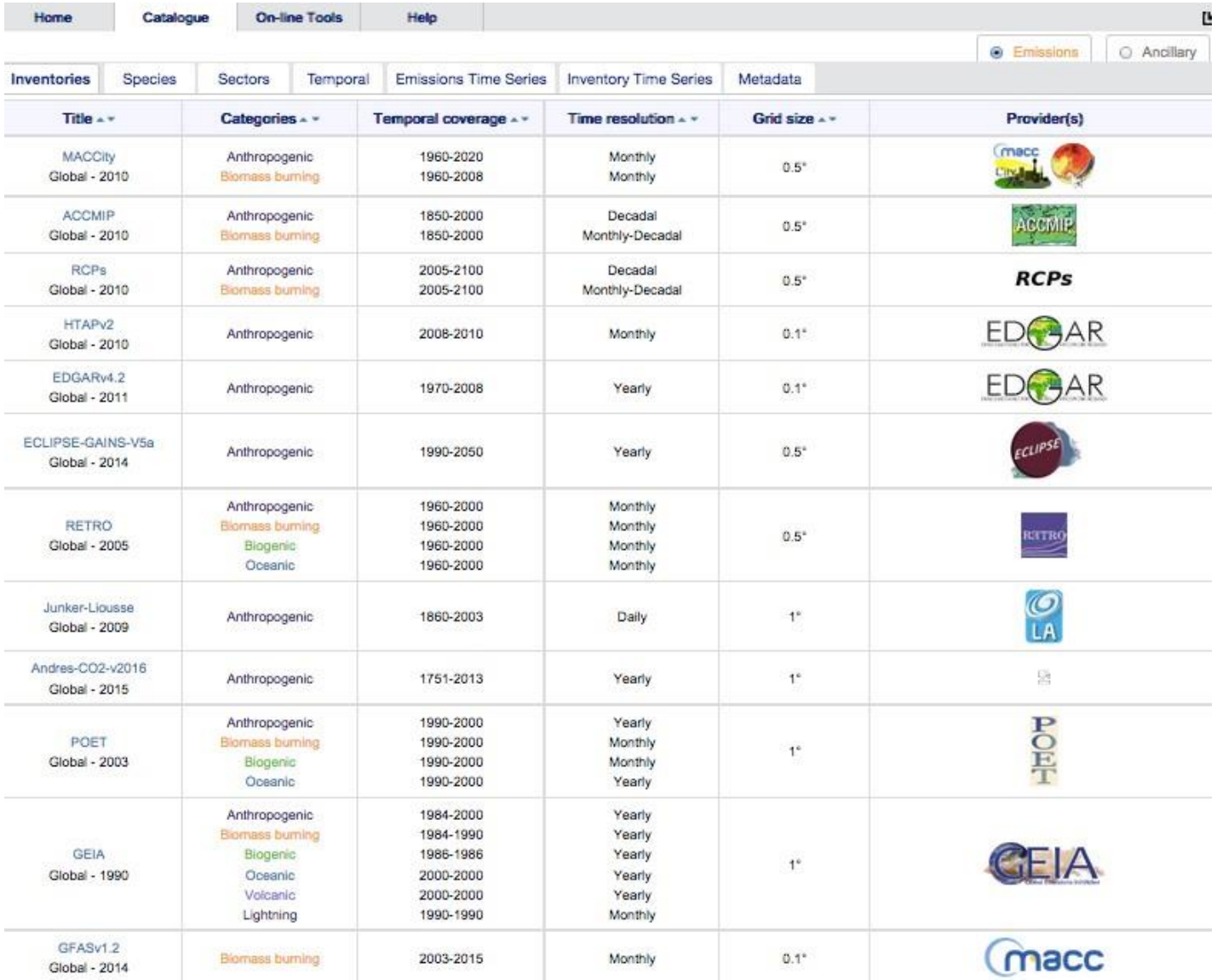
GEIA's emissions database and visualization/ analysis platform with calculation tools



http://eccad.aeris.fr/

Make sure you have your ECCAD account set up before accessing the data.

Many existing inventories … (from ECCAD database)



Home | Catalogue | On-line Tools | Help

Emissions | Ancillary

Inventories | Species | Sectors | Temporal | Emissions Time Series | Inventory Time Series | Metadata

Title	Categories	Temporal coverage	Time resolution	Grid size	Provider(s)
MACCity Global - 2010	Anthropogenic Biomass burning	1960-2020 1960-2008	Monthly Monthly	0.5°	
ACCMIP Global - 2010	Anthropogenic Biomass burning	1850-2000 1850-2000	Decadal Monthly-Decadal	0.5°	
RCPs Global - 2010	Anthropogenic Biomass burning	2005-2100 2005-2100	Decadal Monthly-Decadal	0.5°	
HTAPv2 Global - 2010	Anthropogenic	2008-2010	Monthly	0.1°	
EDGARv4.2 Global - 2011	Anthropogenic	1970-2008	Yearly	0.1°	
ECLIPSE-GAINS-V5a Global - 2014	Anthropogenic	1990-2050	Yearly	0.5°	
RETRO Global - 2005	Anthropogenic Biomass burning Biogenic Oceanic	1960-2000 1960-2000 1960-2000 1960-2000	Monthly Monthly Monthly Monthly	0.5°	
Junker-Liousse Global - 2009	Anthropogenic	1860-2003	Daily	1°	
Andres-CO2-v2016 Global - 2015	Anthropogenic	1751-2013	Yearly	1°	
POET Global - 2003	Anthropogenic Biomass burning Biogenic Oceanic	1990-2000 1990-2000 1990-2000 1990-2000	Yearly Monthly Monthly Yearly	1°	
GEIA Global - 1990	Anthropogenic Biomass burning Biogenic Oceanic Volcanic Lightning	1984-2000 1984-1990 1986-1986 2000-2000 2000-2000 1990-1990	Yearly Yearly Yearly Yearly Yearly Monthly	1°	
GFASv1.2 Global - 2014	Biomass burning	2003-2015	Monthly	0.1°	

+ CAMS ..

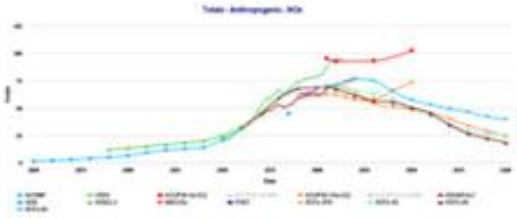
Many existing inventories … (from ECCAD database)

MPI-CNRS South Asia	Anthropogenic	2008-2016	Yearly	0.25°	
CR2-MMA Chile	Anthropogenic	2014-2014	Yearly	0.1° 0.01°	
CNEA-3iA-GEAA Argentina	Anthropogenic	2016-2016	Yearly	0.1°	
REAS2.1 East Asia	Anthropogenic	2000-2008	Monthly	0.25°	
IASB-TD-OMI-NCP North China Plain	Anthropogenic	2007-2012	Monthly	0.25°	
IASB-TD-OMI Global	Biomass burning Biogenic	2005-2014 2005-2014	Monthly Monthly	0.5°	
MarcoPoloKNMI China	Anthropogenic	2007-2013	Yearly	0.25°	
SAFAR-India India	Anthropogenic	1991-2011	Monthly	1°	
DACCIWA Africa	Anthropogenic	1990-2015	Yearly	0.1°	
DACCIWA-flaring Africa	Anthropogenic	1994-2015	Yearly	0.125°	
L14-Africa Africa	Anthropogenic	2005-2030	Decadal	0.25°	

Etc…

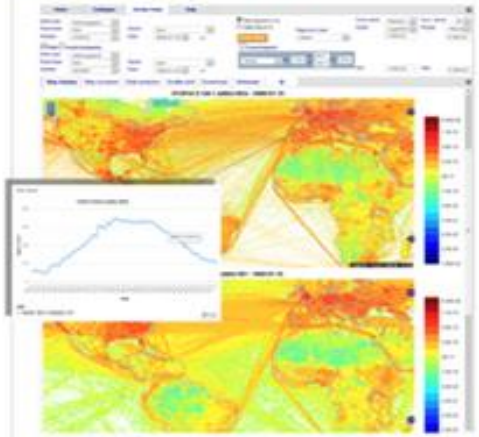
What to choose for AQF studies over Africa ….

Example of ECCAD tools

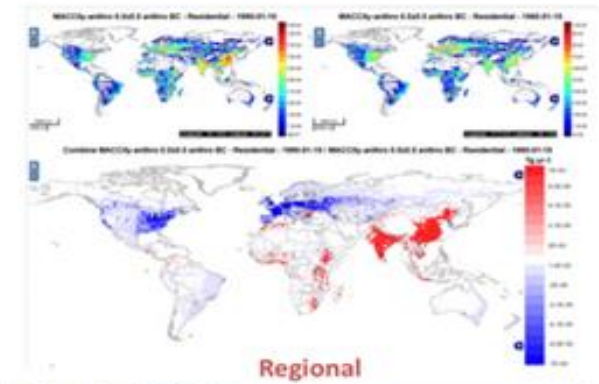


Catalogue & Metadata | Species | Temporal | Emissions Time Series | Inventory Time Series

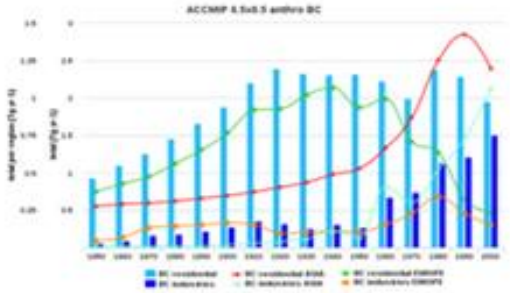
Display | Map Compare | Data Analysis | Scatter Plot

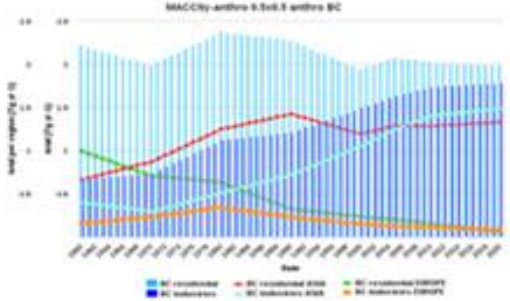


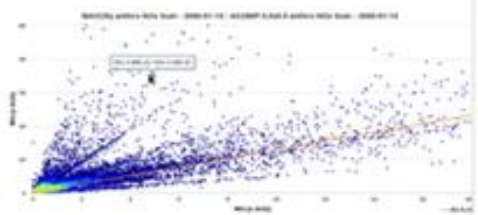
Regional totals



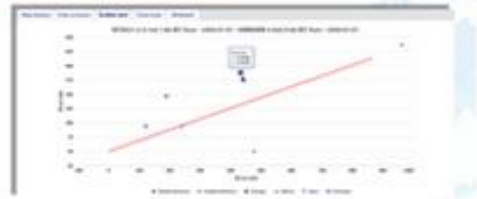
Regional







Regional



Thank you → 2nd part