Anthropogenic (and biomass burning) emissions at the global and regional scale during the past three decades

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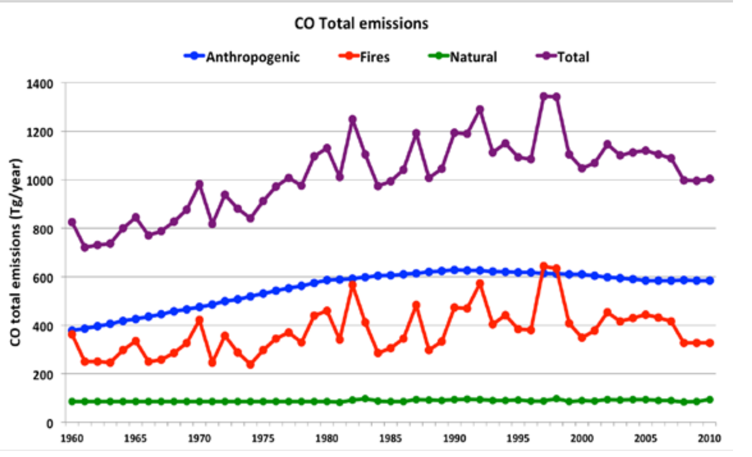
Outline:

- → **Goal of the work**
- → **Short description of the most recent global/regional inventories**
- → **Evaluation of anthropogenic emissions from 1960 to 2012**
- → **Evaluation of VOCs speciation: preliminary results**
- → **First results of the evaluation of emissions from fires since 1900**
- → **Conclusions and future work**

Goal of the work

Evaluate publicly available inventories for anthropogenic and fire emissions :
→ 1960-2012 for anthropogenic emissions
→ 1900-2015 for fire emissions



Evaluation to be used for the definition of a new historical emissions dataset to be used in different simulations of the evolution of the atmospheric composition during the past decades, for example:
→ The next IPCC report and the corresponding CMIP6 exercise
→ CCMI (Chemistry Climate Model Initiative), an international IGAC/SPARC project
→ MACC (Monitoring Atmospheric Composition and Climate), an European project developing forecasts and reanalysis of the global and regional atmospheric composition

and analysis of observations campaigns in different regions of the world

The inventory will be provided together with 2-3 alternate inventories, taking into account uncertainties

The most recent anthropogenic emissions inventories

- **Only public emissions inventories considered in this study**
- **Global and regional inventories considered**
- **Most recent datasets :**

Global:

- **Latest MACCity version (1960-2014)**
- **The EDGAR newest versions**
- **ECLIPSE European project (1990-2010)**

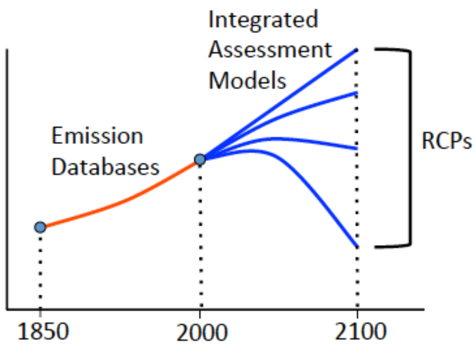
Regional:

- **TNO-MACC, TNO-MACCII and TNO-MACC-III (2003-2009) for Europe**
- **REAS-v2 for Asia (1980-2020)**
- **MEIC (China) for 2008 and 2010**
- ***Assamoi-Liousse for Africa***
- ***The latest releases of EPA, Environment-Canada, and EMEP emissions***

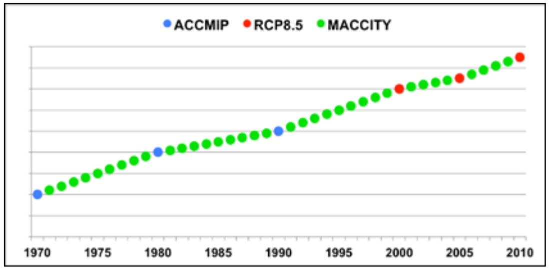
Others could be existing, thanks for telling us (only publicly available datasets)

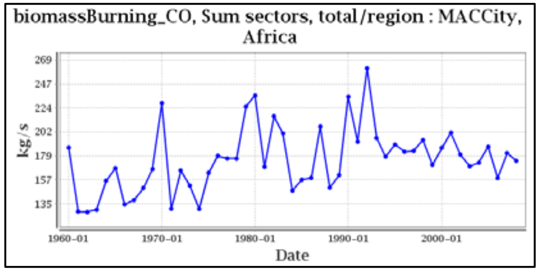
MACCity: inventory of anthropogenic and fires emissions developed as part of MACC and CityZen projects

- Period: 1960-2012; Monthly averages
- 0.5x0.5 degree resolution
- Species: CH_4, CO, NO_x, SO_2, BC, OC, NH_3 and a large set of VOCs (new VOCs generated, based on users requests)
- 9 emissions sectors



J.-F. Lamarque et al., *Atmos. Chem. Phys.*, 2010





Granier et al.., *Climatic Change,* 2011

Large community of users:

→ EU projects: PEGASOS, ACCESS, ACCENT-Plus, etc.

→ International modeling projects: CCMI (chemistry-climate, hindcast), CMIP5 (IPCC), AEROCOM (Aerosols), etc.

→ International programs: IGAC, iLEAPS, GEIA, etc.

→ Individual laboratories

EDGAR-family global anthropogenic emission gridmaps for air pollution models:

Trade-off between regional specificity and global consistency

LRTAP Long-range Transboundary Air Pollution — Task Force on Hemispheric Transport of Air Pollution

EDGAR EMISSION DATABASE FOR GLOBAL ATMOSPHERIC RESEARCH

PEGASOS Pan-European Gas-AeroSOls-climate interaction Study

- HTAPv2.2 provides detailed regional estimates of SO2, NOx, CO, NMVOC, NH3, PM10, PM2.5, BC and OC for 2008 and 2010 in monthly 0.1°x0.1° maps
  → **collection of official inventories**

- EDGARv4.2 provides emissions of greenhouse gases, ozone precursors, acidifying gases, primary particulates (BC, OC and PMs) and stratospheric ozone depleting substances from 1970 to 2010, at a 0.1°x0.1° resolution
  → **technology-based calculations**

- The EDGARv4.3 activity data provides emissions for 1970 and 2010 (PEGASOS)
  → **policy hindcast scenarios to evaluate the climate impact of European air quality legislation over the past 4 decades.**

EDGAR 4.3 scenarions for 2010:

1) Reference (REF): EDGAR v4.3 data represent our best estimate of the development of emissions (activity levels, emission factors, technology) for 1970 and 2010

2) Stagnation of fuel consumption (STAG_FUEL)
→ activity data kept constant at 1970 levels
→ emission factors vary over time and End-of-Pipe measures as in the REF scenario.
→ This scenario = the lowest emissions and illustrates how much of the emission reductions achieved in 2010 is off-set by higher fuel consumption.

3) Stagnation of technology (STAG_TECH):
→ Emission factors (EF) of 1970 are projected in 2010 for power and non-power industry and road transport

PEGASOS
Pan-European Gas-AeroSOls-climate interaction Study

ECLIPSE

Global air pollutant emission scenarios 1990-2050; ECLIPSE

Z. Klimont, C. Heyes, L. Höglund-Isaksson, J. Cofala, P. Rafaj, W. Schöpp, P. Purohit, J. Borken, M. Amann, K. Kupiainen, W. Winiwarter, I. Bertok, R. Sander, B. Zhao, S. Wang

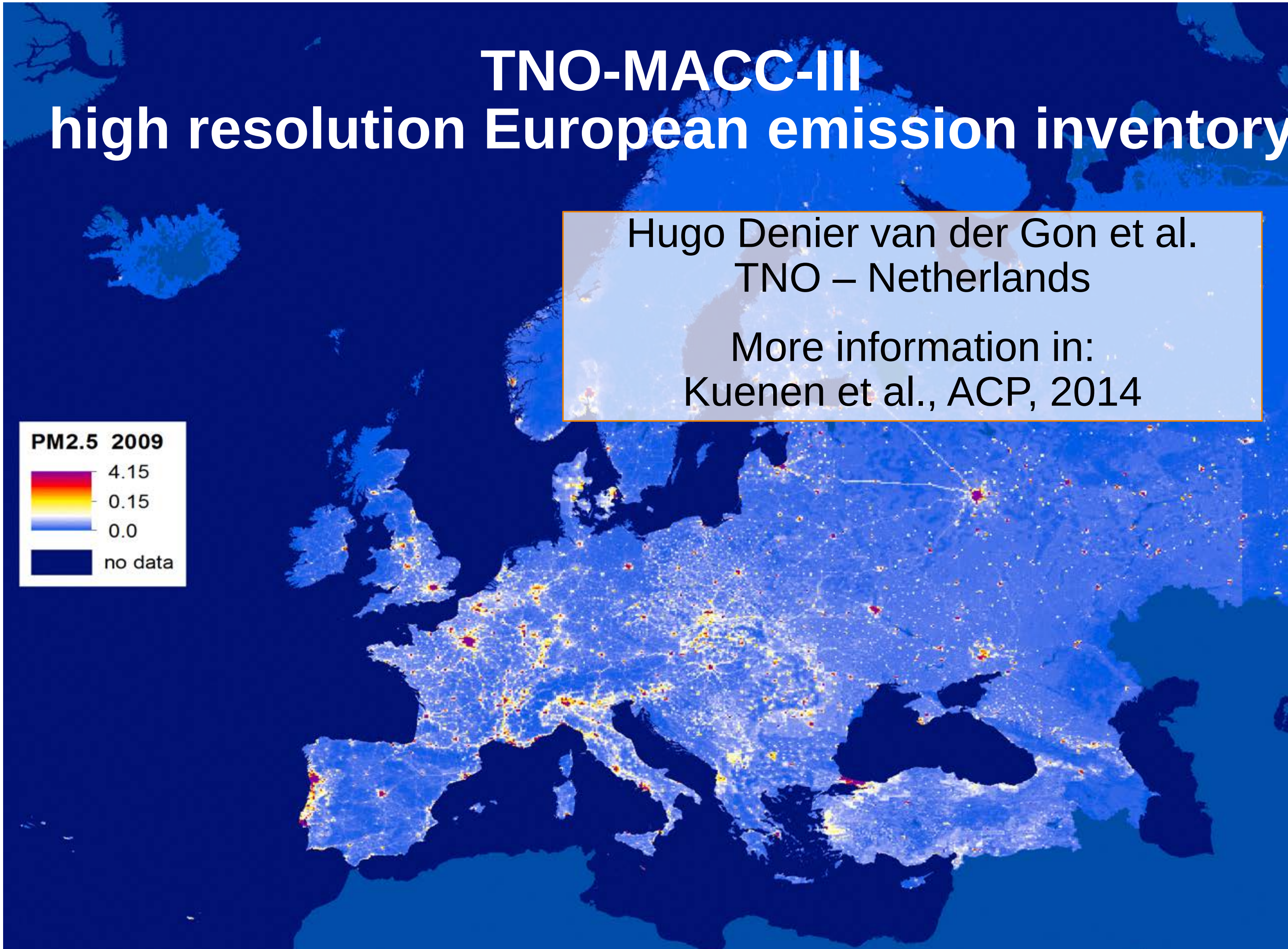
- Development driven by the need to improve aerosols emissions in long term IAM scenarios
- Multipollutant fine resolution inventory and projections including technology resolution (annual, monthly)
- Developed for a range of policies
- ‘New’ sources included, e.g., shale gas, gas flaring, wick lamps, diesel generators, superemitters
- Public access to gridded data
- Platform for further set of scenarios including also estimate of mitigation costs

science for global insight

TNO-MACC-III
high resolution European emission inventory

Hugo Denier van der Gon et al.
TNO – Netherlands

More information in:
Kuenen et al., ACP, 2014



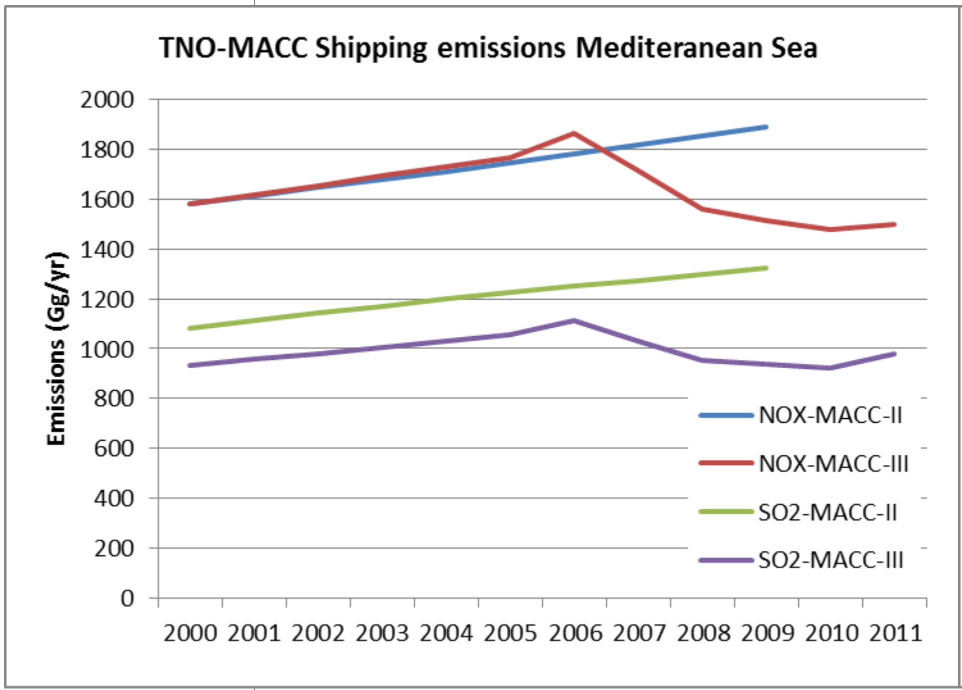
The TNO-MACC-III regional European emission inventory

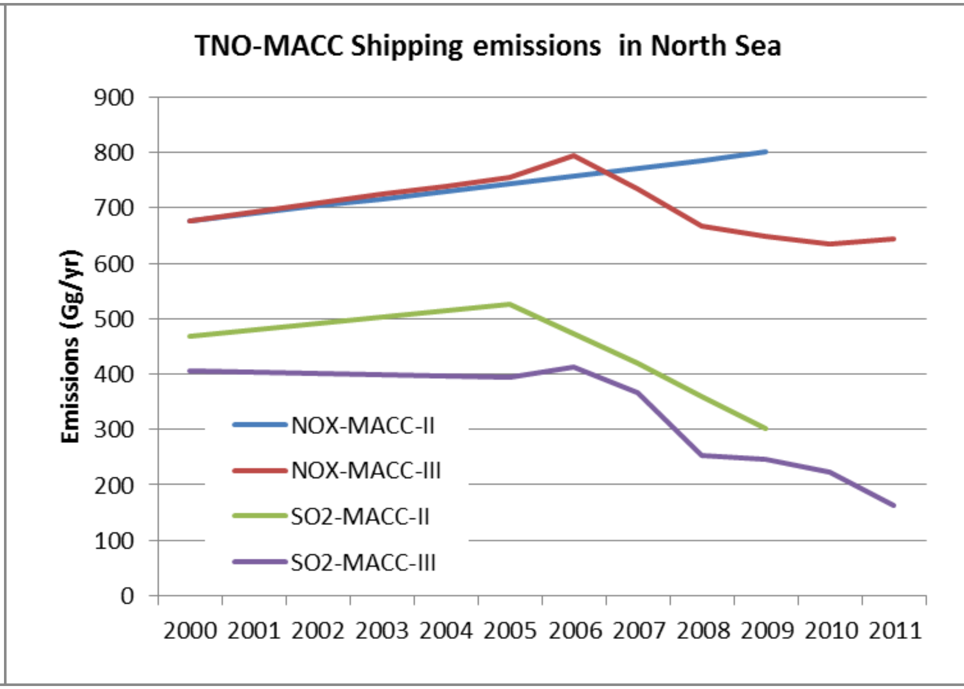
- New version of the **TNO-MACC** (2003-2007) and **TNO-MACC-II** (2003-2009) (Kuenen et al. 2011 and Pouliot et al. 2012)
- **Coverage UNECE-Europe; resolution ~7 x 7km**
- **Reanalysis of reported emissions data**: extended time series starting in year 2000 instead of 2003, all years revisited.
- **Addition of 2 new years, period covered in MACC-III <u>2000-2011</u>**
- **New European shipping emissions trend 2000-2011** based on review of available data and expert knowledge.
- **Spatial distribution proxies were updated and/or improved** (Industry, wood combustion, population, shipping), often based on user comments

- **Inclusion of CO_2 emissions (with a split in fossil – biofuel)** expected before Summer 2015

Documentation: Kuenen et al., ACP, 2014
http://www.atmos-chem-phys.net/14/10963/2014**/acp-14-10963-2014.pdf**

Shipping emission trend for NOx and SO2 in new MACC-III inventory

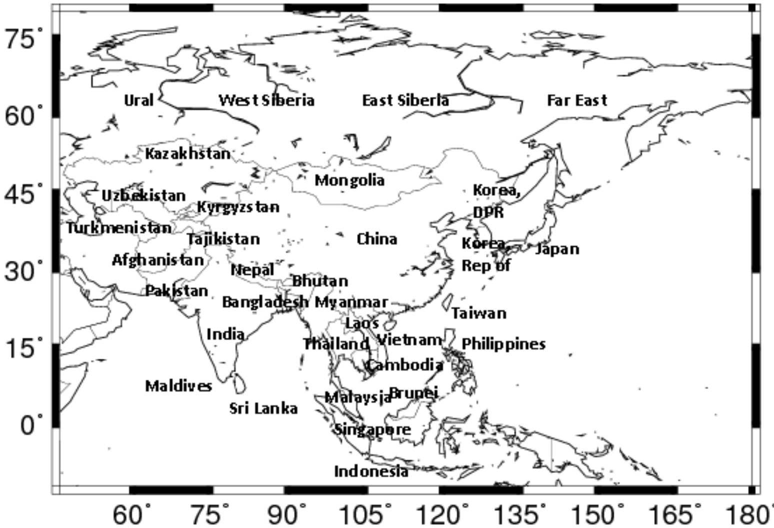




Impact of crisis: fuel saving by slow steaming, larger ships

Impact of crisis for NOx + SECA for SO2 (2 x; 2007;2010)

General information on REAS v1 & v2



REASv1: Ohara et al., ACP, 2007
http://www.jamstec.go.jp/frsgc/research/d4/emission.htm
REASv2: Kurokawa et al., ACP, 2013
http://www.nies.go.jp/REAS/

Item	Description
Target Areas	v1: E, SE, and S Asia v2: v1 + Central and Russian Asia
Target Years	v1: 1980-2003 v2: 2000-2008
Spatial Resolution	v1: 0.5 x 0.5 degree v2: 0.25 x 0.25 degree
Temporal Resolution	v1: Annual v2: Monthly
Species	v1: SO_2, NO_x, CO, BC, OC, NMVOC, NH_3, CH_4, N_2O, and CO_2 v2: v1 + PM_{10} and $PM_{2.5}$

Target	Sources for REAS
Japan for v2	JEI-DB (The Japan Auto-Oil Program Emission Inventory-Data Base) except for Ship OPRF (The Ocean Policy Research Foundation) for Ship
Korea for v2	National Air Pollution Emission developed by the National Institute of Environmental Research-Korea
Taiwan for v2	The Environmental Protection Administration of Taiwan
Aviation & Ship	EDGAR version 3.2 for v1 and 4.3 for v2

From Kurokawa et al., NIES

MEIC, an emissions database for China

- Years: 2008 and 2010
- Spatial domain: Mainland China
- Categories/Sectors: ~800 anthropogenic sources, aggregated to four sectors (Power, Industry, Residential, Transportation)
- Species: SO2, NOx, CO, NMVOC, NH3, BC, OC, PM2.5, PM10, and CO2
- VOC speciation: ~600 individual species, lumped to six mechanisms (SAPRC99, SAPRC07, CB05, CBIV, RADM2, and RACM2)
- Spatial resolution: user defined (0.25x0.25 degree or lower)
- Available at www.meicmodel.org

From Zhang et al., Tsinghua University

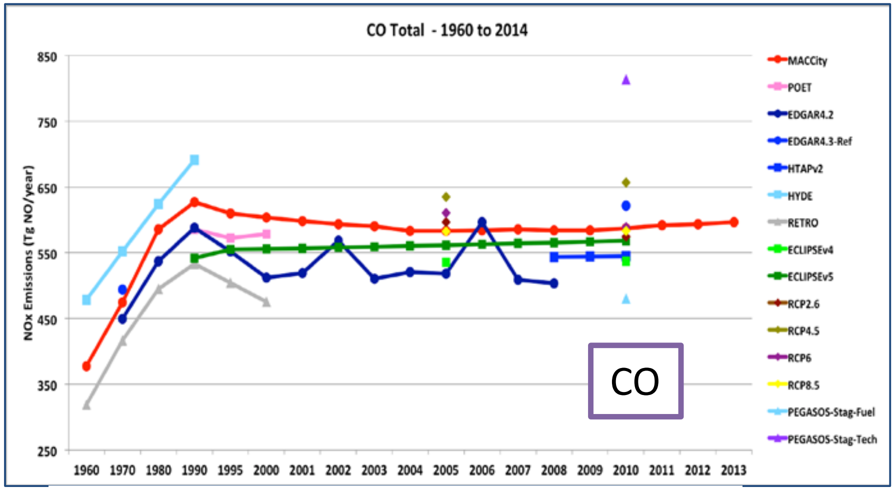
Comparisons of anthropogenic emissions:

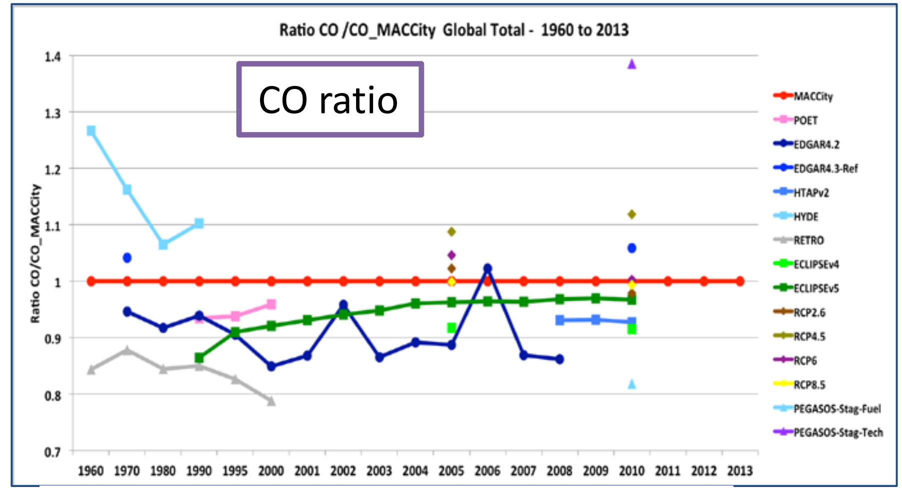
- **Use all datasets available providing emissions from 1960**
- **Up to now, comparisons for 22 world regions**
- **This talk: a few examples for global total, USA, Western Europe, Central Europe, China and India**
- **Compare the ratios between the totals in each region and the total from MACCity, the only inventory providing emissions from 1960 to 2012.**
- **The 4 RCPs (scenarios developed for the IPCC AR5 report) for 2005 and 2010 are included in the evaluation → information on which scenario is closest to current emissions**

CO and NOx global emissions

Global Total

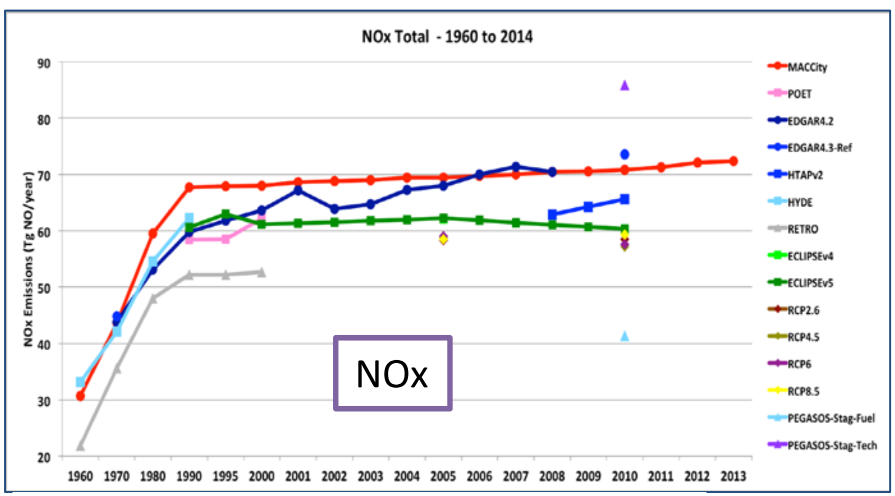
Ratio to MACCity (MACCity = 1)

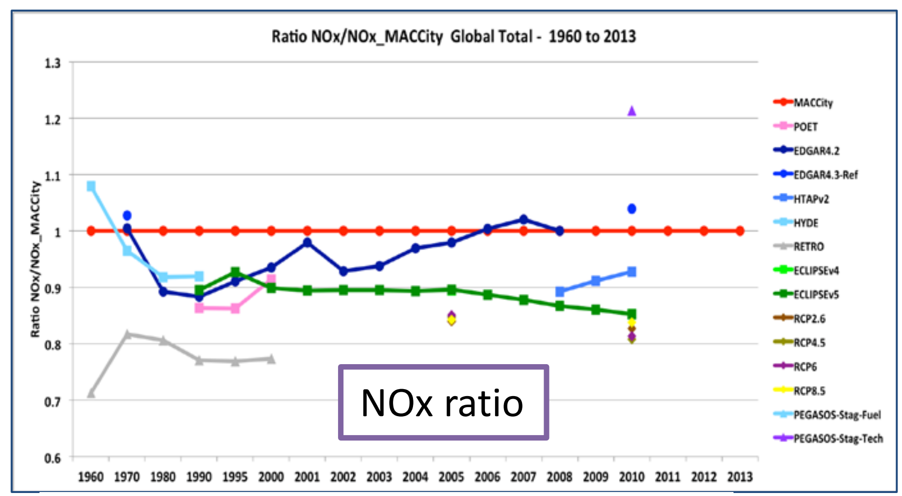




1960 2000 2005 2010

1960 2000 2005 2010





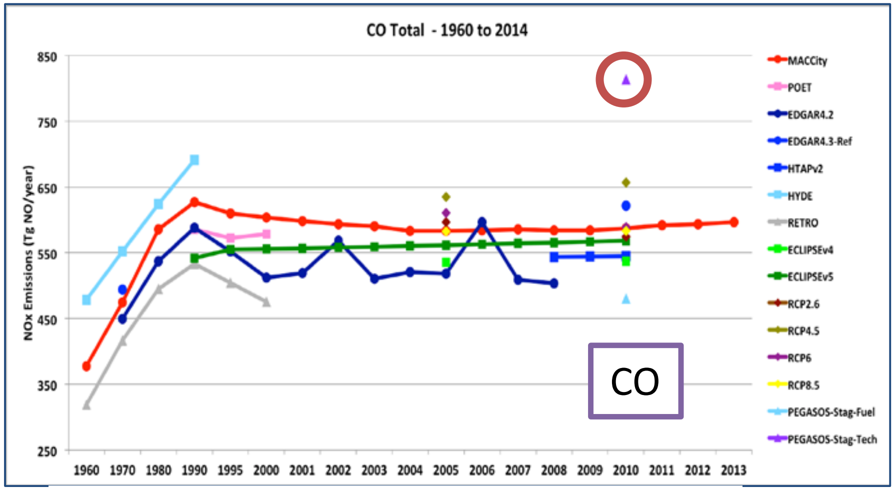
1960 2000 2005 2010

1960 2000 2005 2010

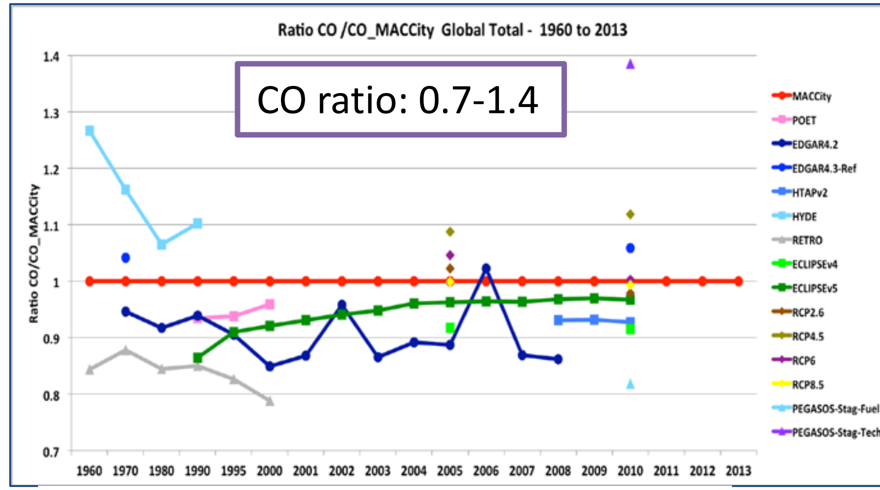
CO and NOx global emissions

Global Total

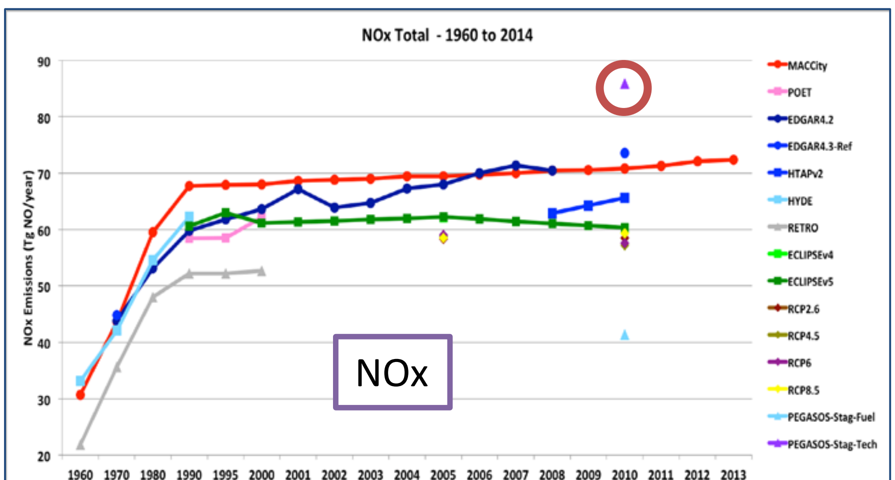
Ratio to MACCity (MACCity = 1)



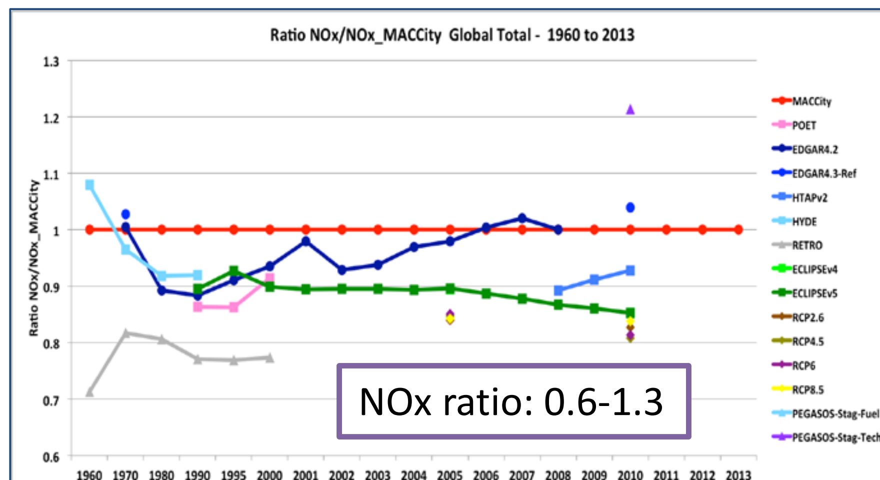
1960 2000 2005 2010



1960 2000 2005 2010



1960 2000 2005 2010

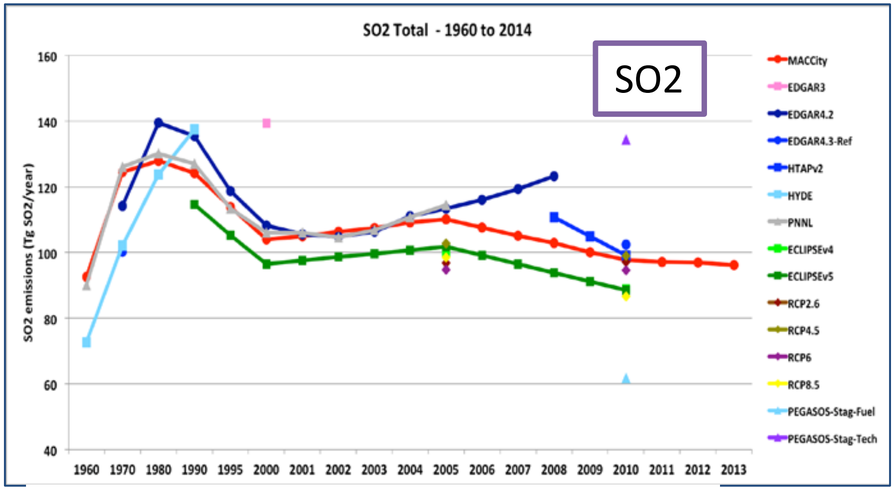


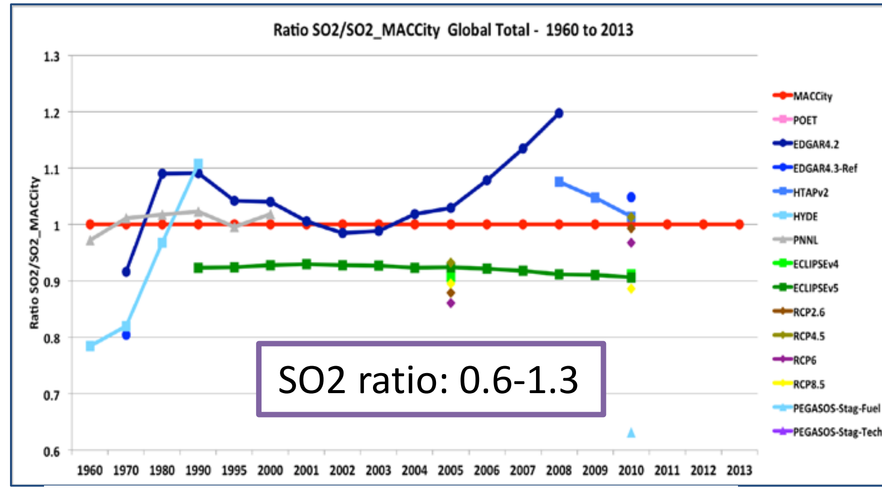
1960 2000 2005 2010

SO2 and NH3 global emissions

Global Total

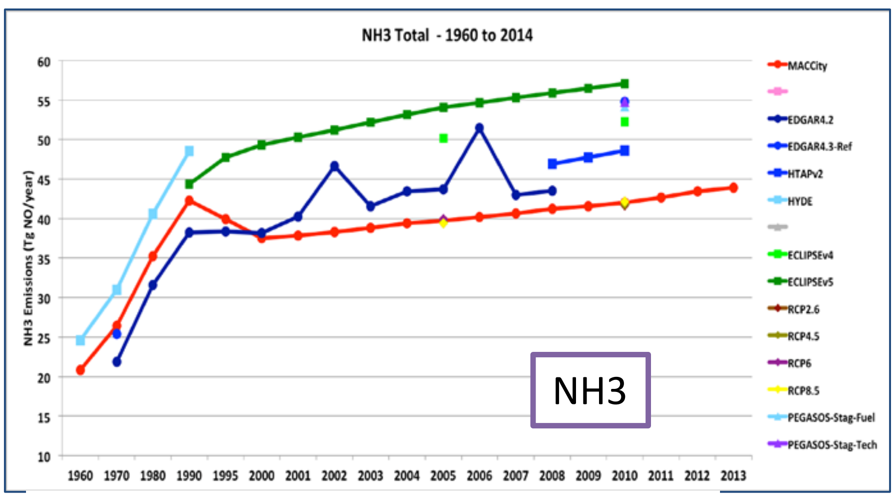
Ratio to MACCity

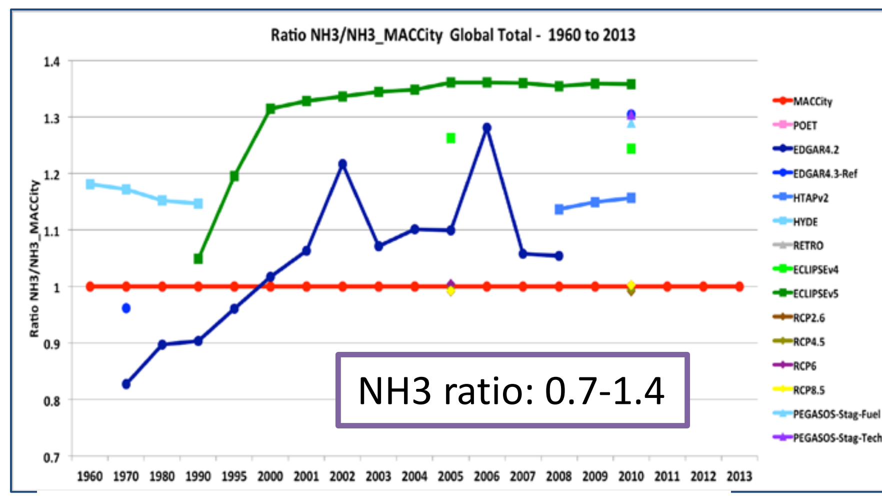




1960 2000 2005 2010

1960 2000 2005 2010



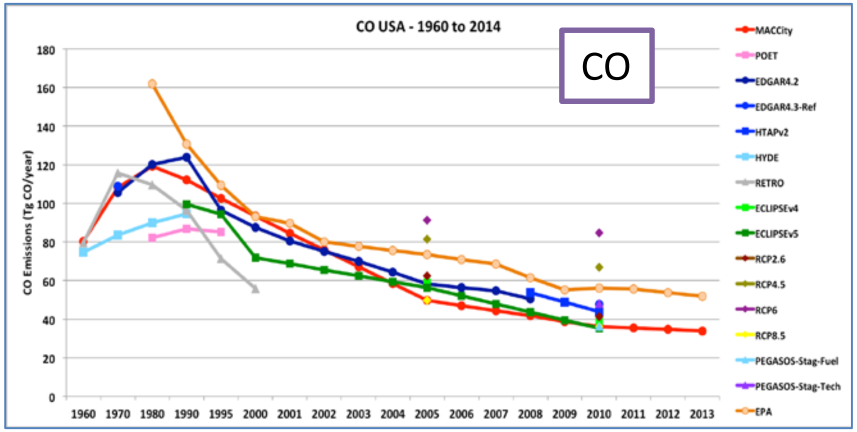


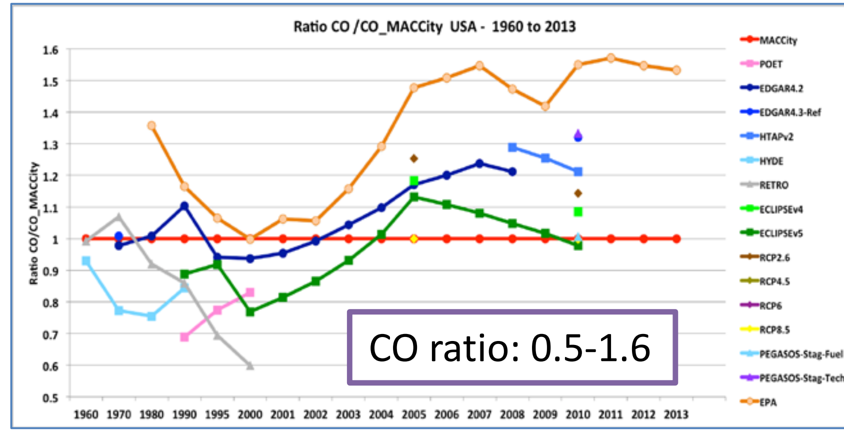
1960 2000 2005 2010

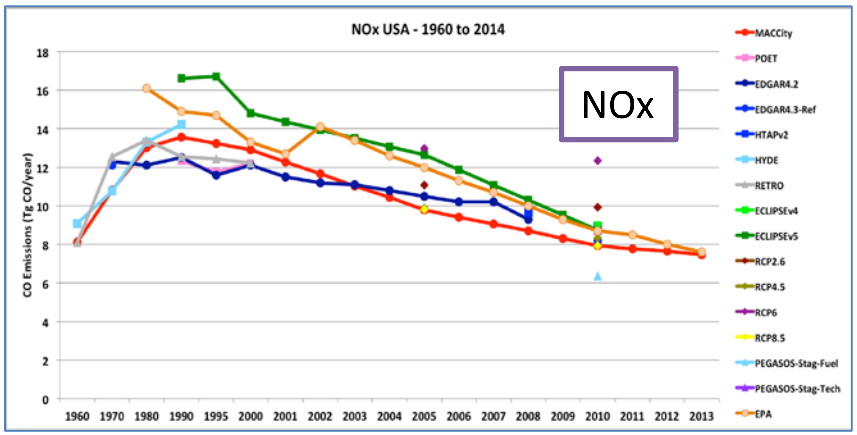
1960 2000 2005 2010

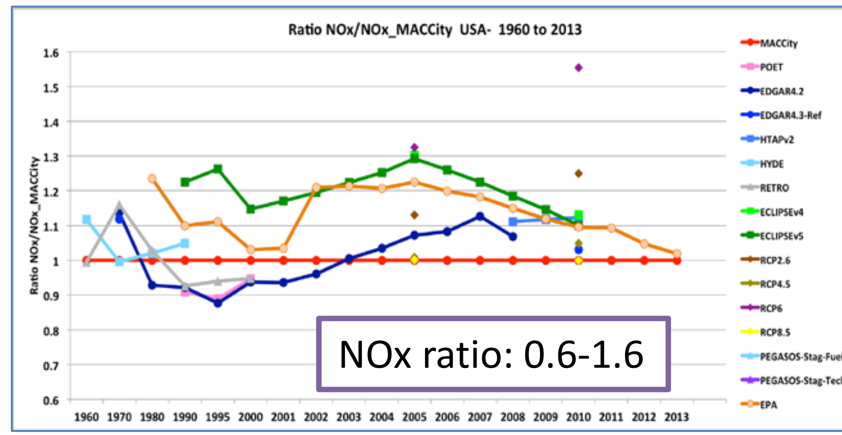
CO, NOx and NMVOC US emissions

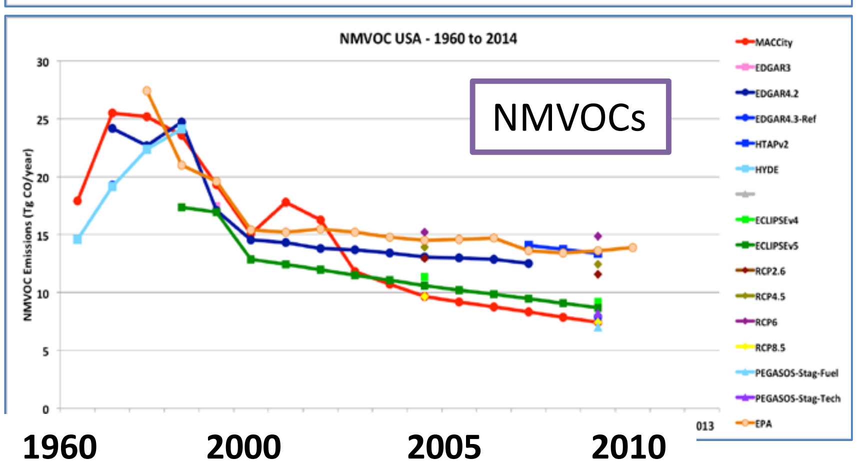
ratio to MACCity (MACCity = 1)

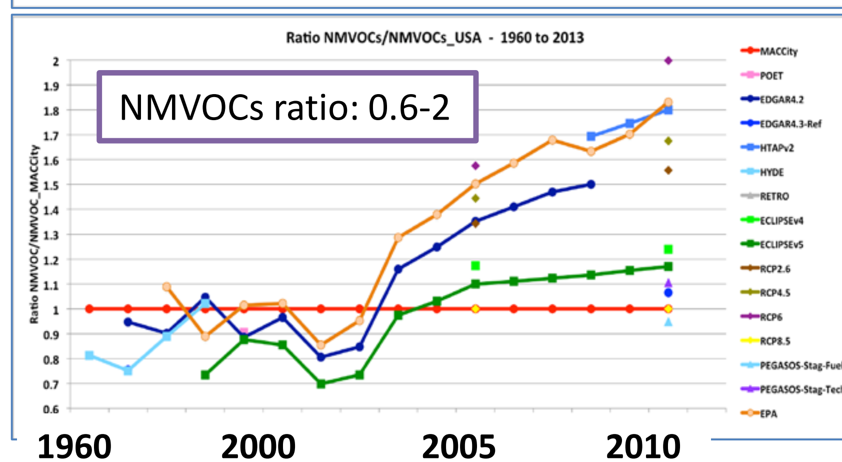






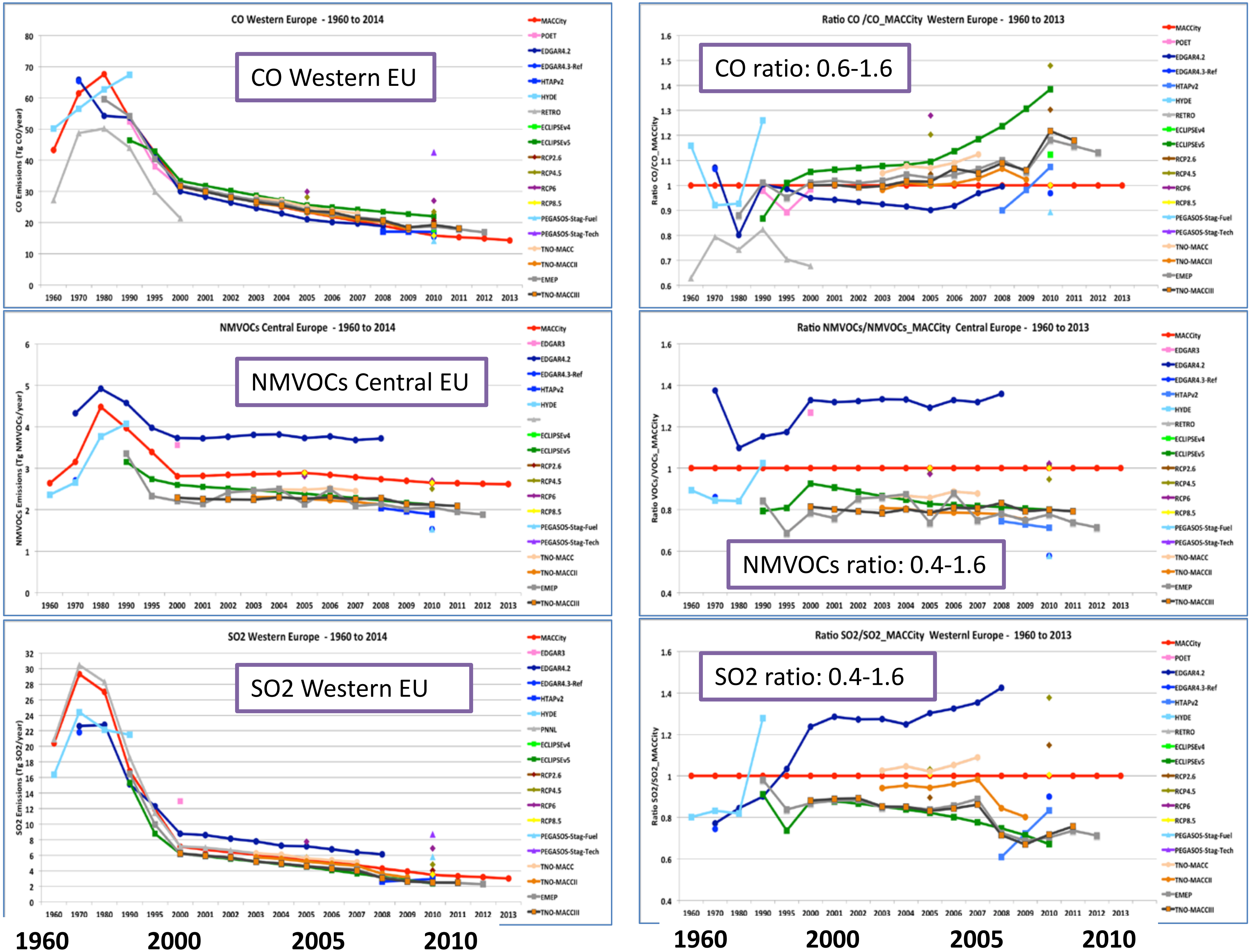






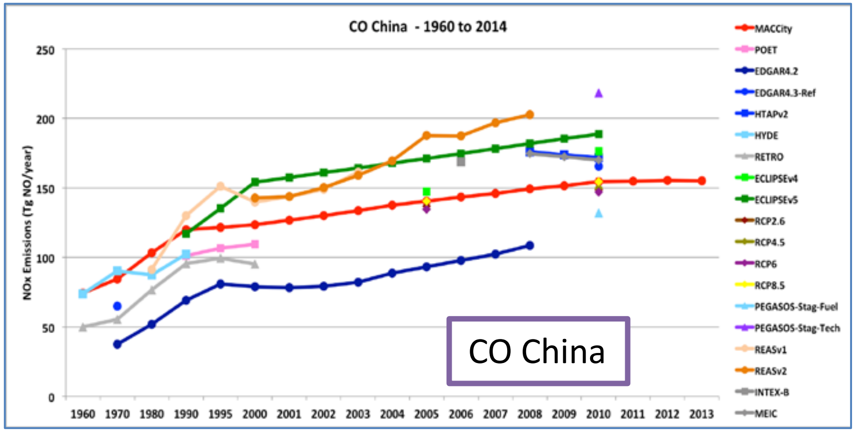
CO, NMVOC and SO2 European emissions

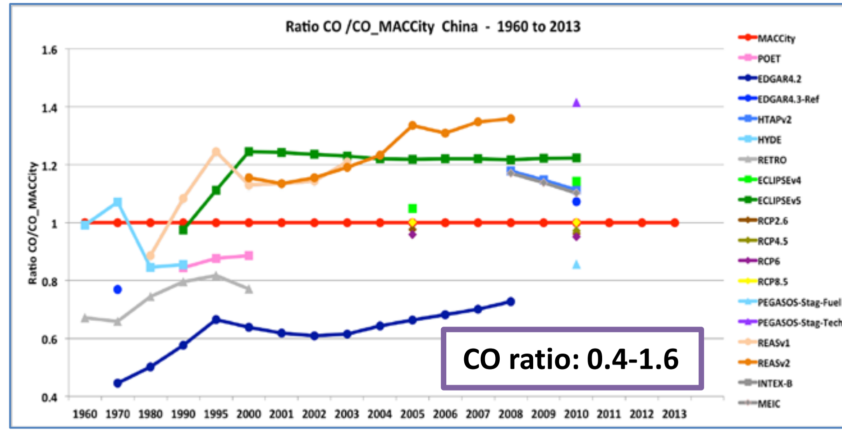
ratio to MACCity (MACCity = 1)

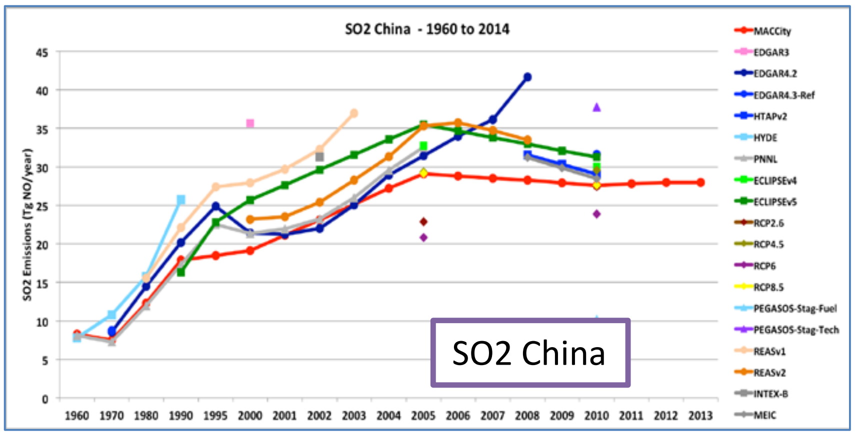


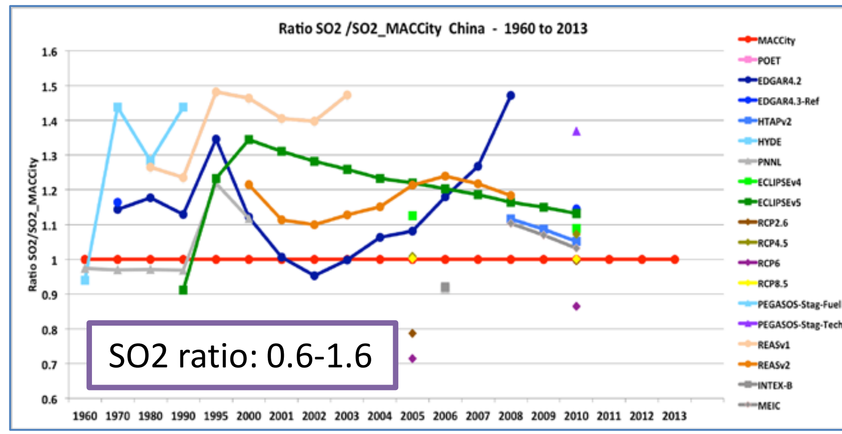
CO and SO2 – China / NH3 India

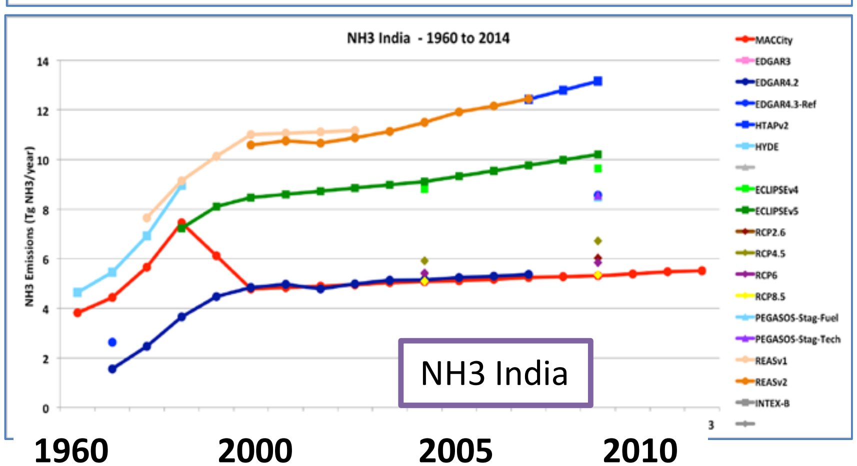
ratio to MACCity (MACCity = 1)

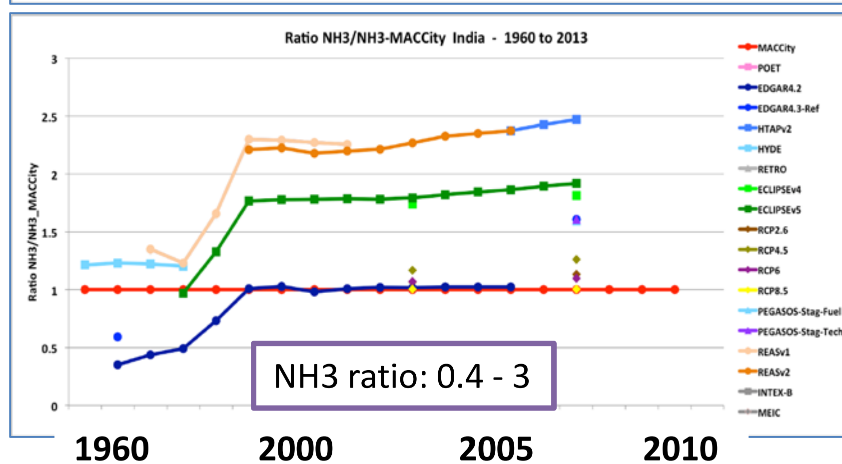












Evaluation of VOCs speciation through comparisons of VOC and CO measurements (Hassler et al., in preparation)

- Most inventories → provide only emissions for lumped total VOCs

Models and calculations of impacts of changing VOCs on gaseous and Particulate compounds requires a detailed knowledge of the speciation of VOCs

- Compare ratios of individual VOCs to CO in the MACCity inventory with observations in cities

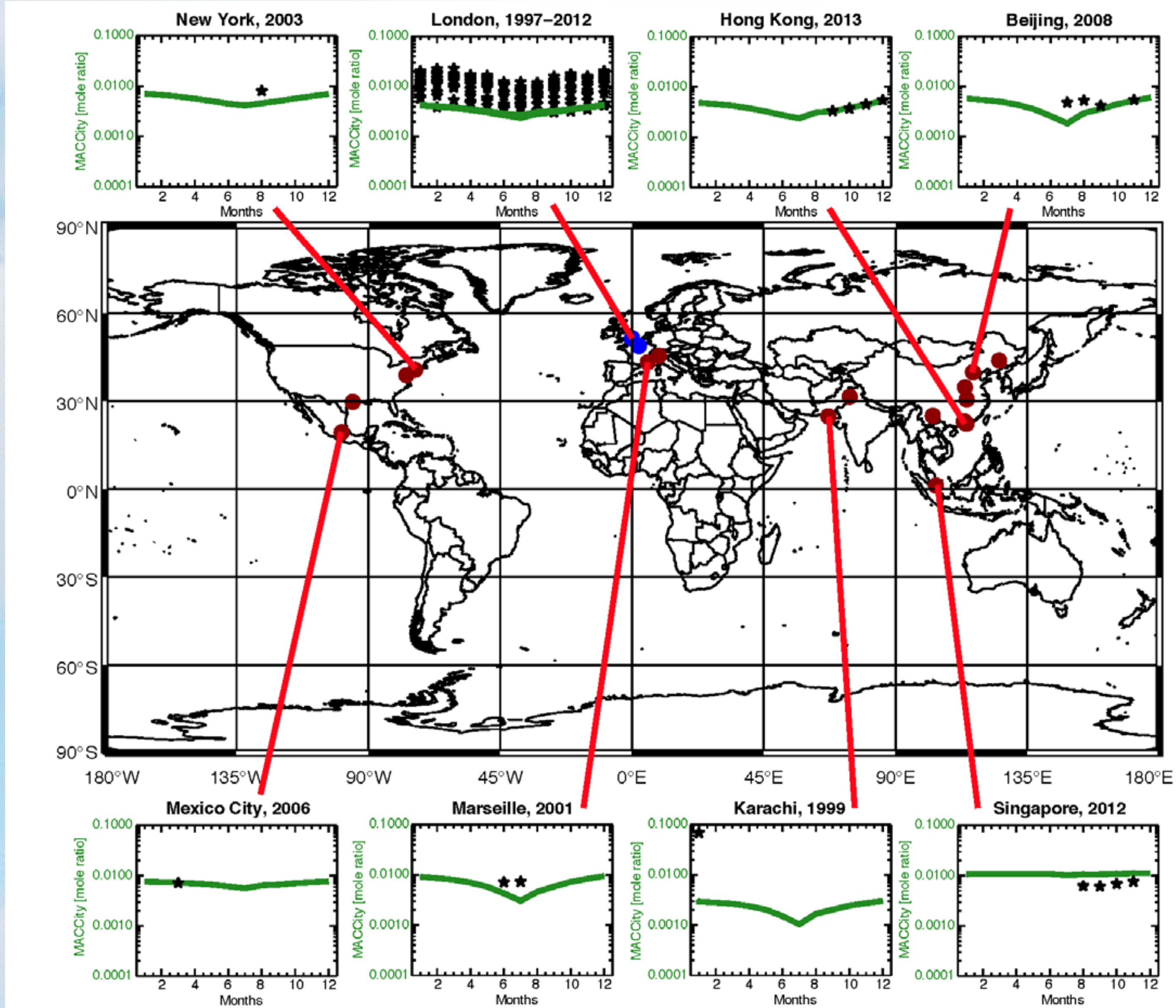
<u>MACCity emissions inventory</u>

- MACCity data from the grid point closest to the cities coordinates
- Annual cycle of same year as measurements
- Emission fluxes [kg/m^2/s] converted to mole emission fluxes [mole/m^2/s], then the VOC/CO ratios are determined

<u>Measurements</u>

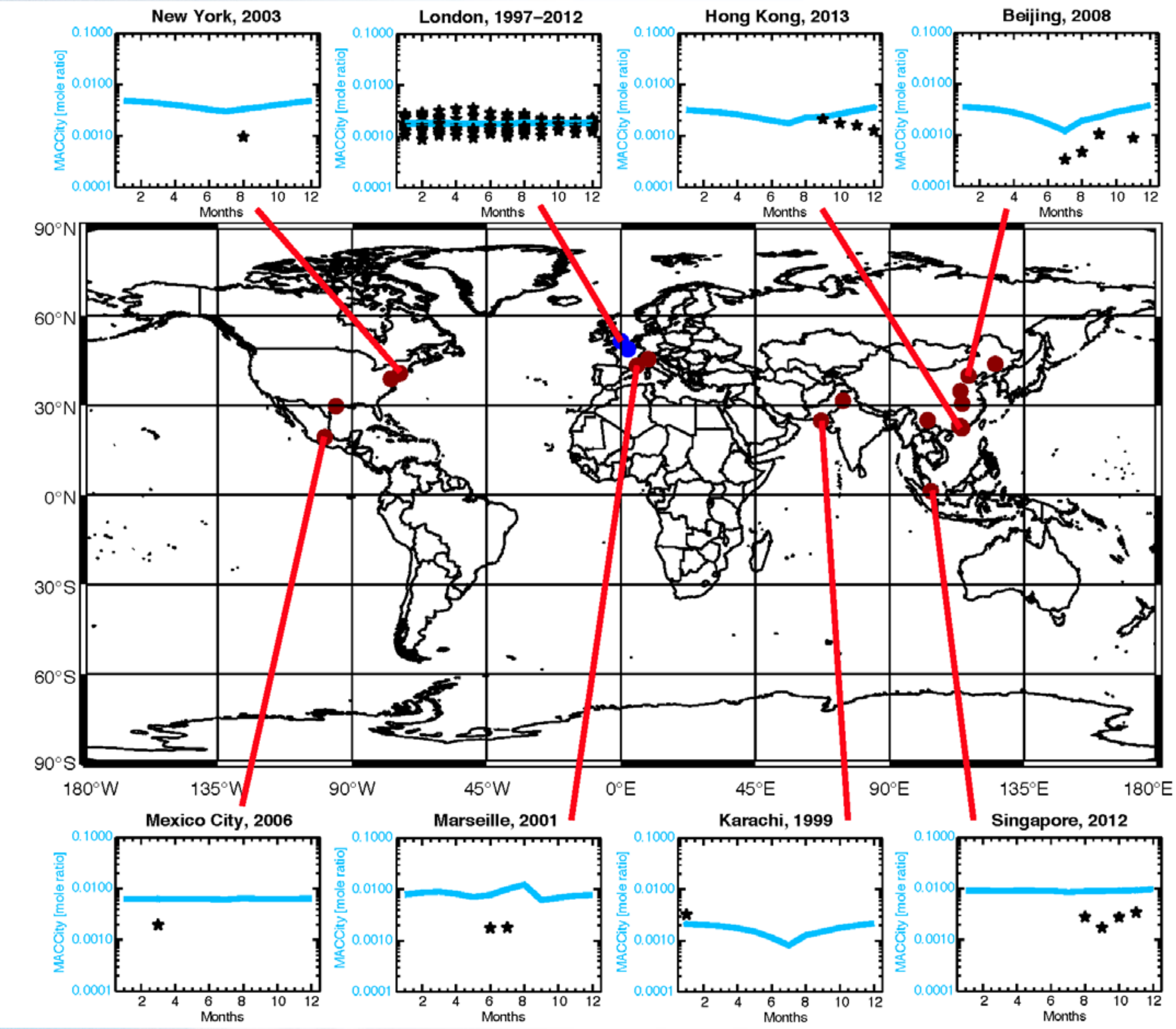
- Canister measurements provided by Don Blake's group (University of California, Irvine) for all cities except London
- London measurements (Marylebone Road site) provided by Erika von Schneidemesser (IASS, Potsdam, Germany)
- All individual measurements are converted from volume mixing ratio to mole mixing ratio, then the VOC/CO ratios are determined
- All available VOC/CO ratios are then combined to a monthly mean

Ethane/CO – comparison MACCity (green lines) and measurements (black stars)



Plots - log scale: 0.0001, 0.001, 0.01, 0.1

Propene/CO – comparison MACCity (blue lines) and measurements (black stars)



Plots - log scale: 0.0001, 0.001, 0.01, 0.1

Evaluation of emissions from fires for the past decades

Goal of the work: Evaluate the differences between existing biomass burning inventories and define a "best" inventory for the 1750-2015 period.

No inventory exist for the pre-1900 period
→ Need to use fire models coupled with earth-system models.

Datasets considered in this study:

<u>Fire models:</u>

- **MPI-ref and MPI-popd** : from the Max Planck Institute for Meteorology (S. Kloster and G. Lasslop), Hamburg, Germany
- **SIMFIRE:** from the SIMFIRE model (Knorr et al., 2014)

<u>Inventories:</u>

GICC (Mieville et al., 2010): Inventory based on an historical reconstruction for 1900 to 2000
Inventories based on satellite observations:
MACCity/ACCMIP (Granier et al., 2011) - **GFED2** (van der Werf et al., 2006)
GFED3 (van der Werf et al., 2010) - **FINNv1.5** (Wiedinmyer et al., 2011)
GFASv1.0 (Kaiser et al., 2012)

GFAS and GFED inventories based on satellite data

GFED3.1 (Global Fire Emission Database) *(van der Werf et al. 2010)*

"Conventional" Burned Area Approach (Seiler and Crutzen (1980))

$$E_i\,[g] = \boxed{A\,[m^2] * B\,[kg/m^2] * C\,[kg/kg]} * EF_i\,[g/kg]$$

E_i: Emission of trace species i
A: Area burned (MODIS burn scars)
B: Biomass density (Fuel load) (CASA biogeochemical model with satellite fAPAR data)
C: Combustion Completeness (CASA biogeochemical model with GPCP precipitation)
EF_i: Emission Factor for species i

Database: monthly, 0.5 deg, 1997-2009, http://www.falw.vu/~gwerf/GFED/GFED3/emissions/

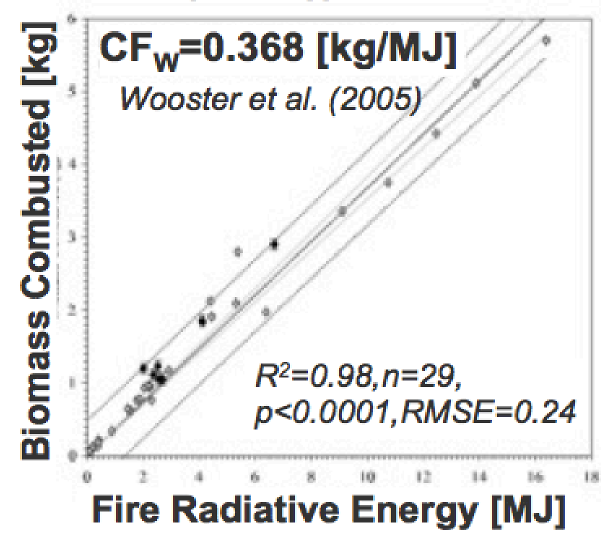
GFAS1.0 (Global Fire Assimilation System) *(Kaiser et al., in prep.)*

FRE-based Combustion Factor (CF) Approach (Wooster et al. (2005))

$$E_i\,[g] = \boxed{FRE\,[J] * CF\,[kg/J]} * EF_i\,[g/kg]$$

FRE: Fire Radiative Energy [J] (MODIS FRP)
(Time Integrated Fire Radiative Power (FRP) [W])
CF: Combustion Factor (fuel type dependent CF)

Database: daily, 0.5 deg, 2003-NRT,
http://www.gmes- atmosphere.eu/fire/



GFAS and GFED inventories based on satellite data

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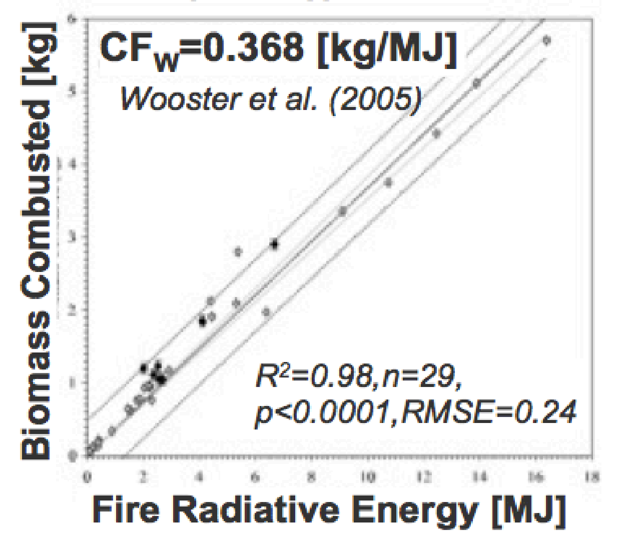
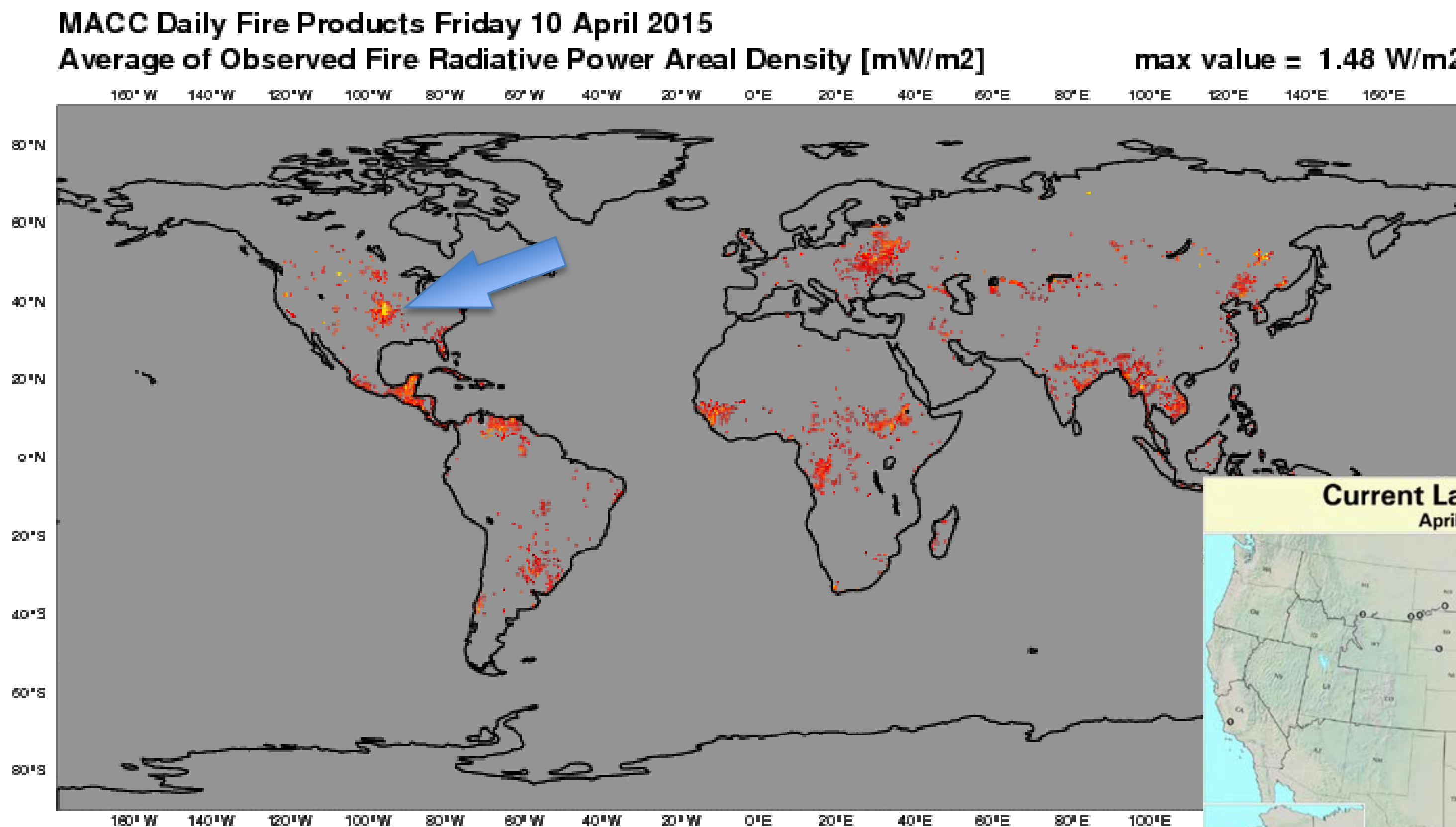
(Time Integrated Fire Radiative Power (FRP) [W])

CF: Combustion Factor (fuel type dependent CF)

Database: daily, 0.5 deg, 2003-NRT,
http://www.gmes- atmosphere.eu/fire/



NRT production of daily FRP and fire emissions



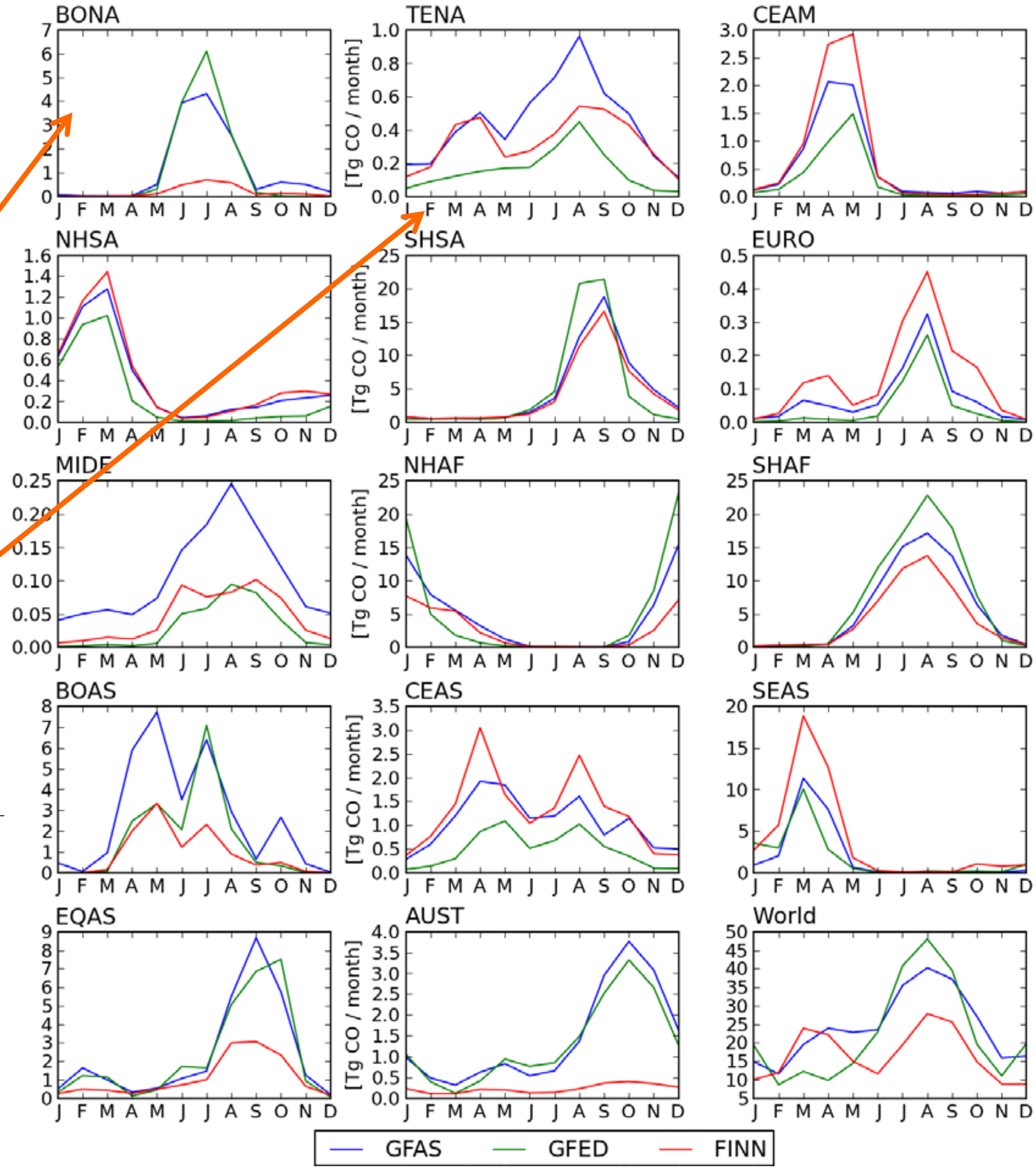
From USDA Forest Service

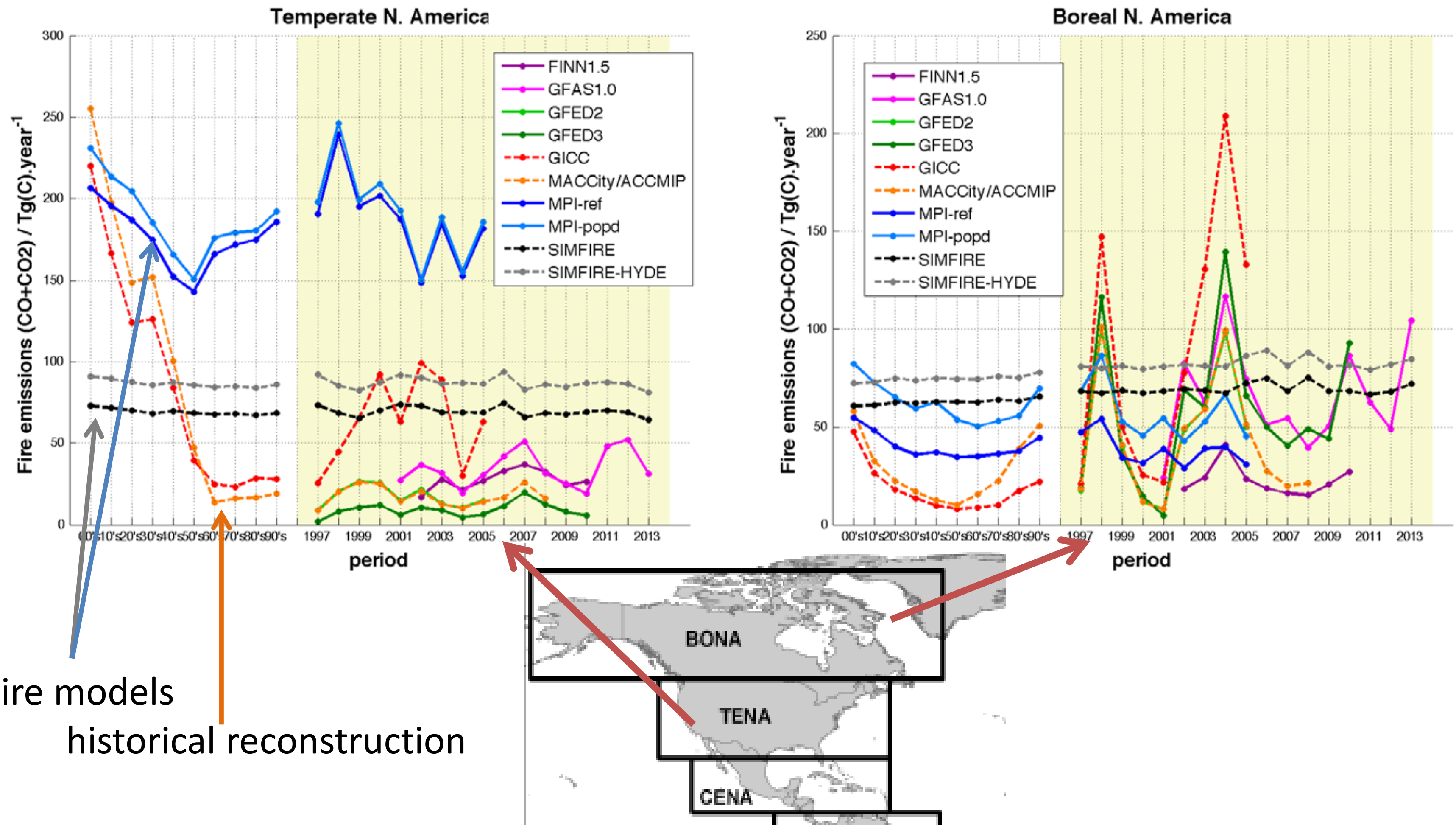
Publicly available at: http://www.gmes-atmosphere.eu/fire/
0.1deg (GFASv1.2): GRIB and NetCDF(ECMWF ftp server)
0.1deg (GFASv1.1): KMZ
0.5deg (GFASv1.0): GIF, KML, NetCDF (FZ Jülich), NetCDF & ASCII (available on ECCAD, 1 month behind real time)

Mean seasonal CO emissions for 14 selected regions and the world for 2003 until 2011.

Emissions are shown for three different fire emission inventories: GFAS, GFED and FINN.

(From Andela et al., Univ. Amsterdam)





Comparison of carbon emitted from fire emissions from different estimates for two regions in North America

➔ How to define the "best" inventory for the pre-satellite period, and how to assess the post-1997 to 2015 emissions?

(From Sindelarova, Granier, Heil, Kaiser, Kloster, Knorr, Kehrwald, Lasslop, Liousse, Marle, van der Werf and Wiedinmyer)

The next steps for developing more flexible and user-friendly emissions inventories:

On-line calculation of emissions

→ Anthropogenic emissions :
under development at Laboratoire d'Aerologie, Toulouse (C. Liousse)
next presentation par S. Smith

→ Biomass burning emissions
Tool already available in the ECCAD database (see G. Frost presentation this afternoon + poster)
Needs several updates: newer vegetation maps and updated algorithms

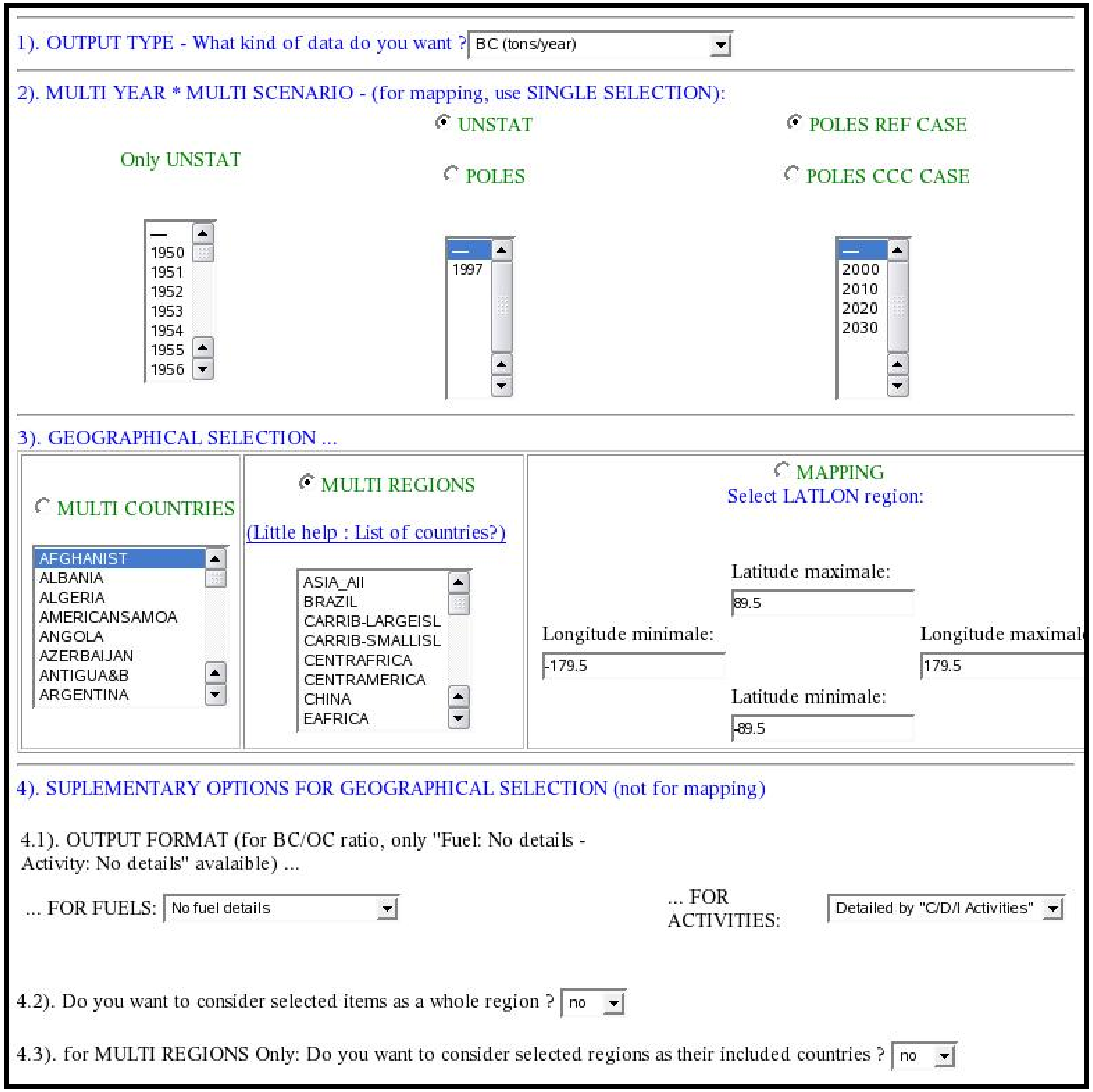
➔ User-friendly tool to calculate the impact of using different emission factors or activity data + estimation of uncertainties on emissions

On line emission calculation tool

On line emission calculation
Flexiblity
Uncertainty

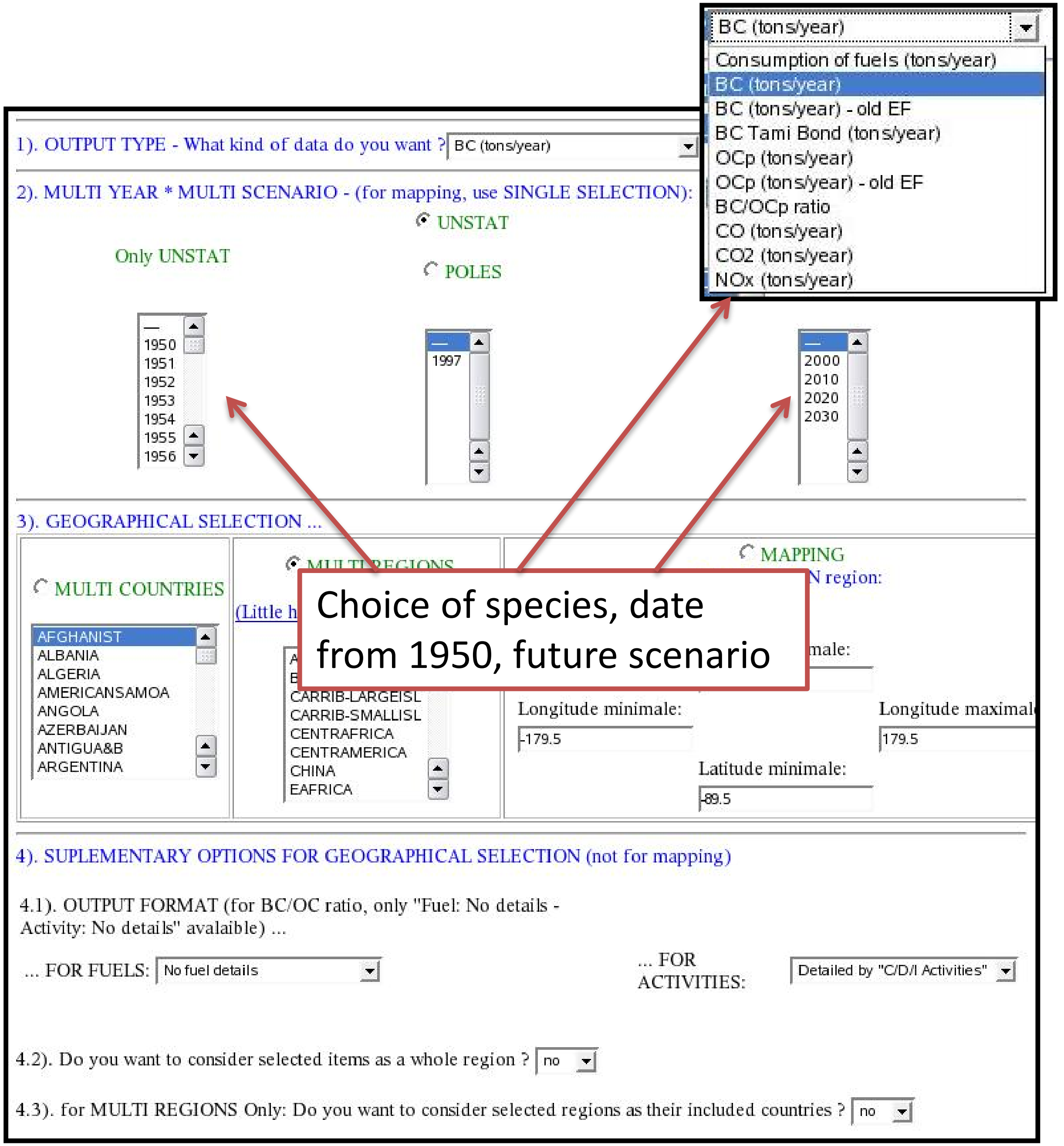
Under development
By C. Liousse and colleagues
at Laboratoire d'Aerologie, Toulouse

Tool
= OLE-CAPEDB



OLE-CAPEDB

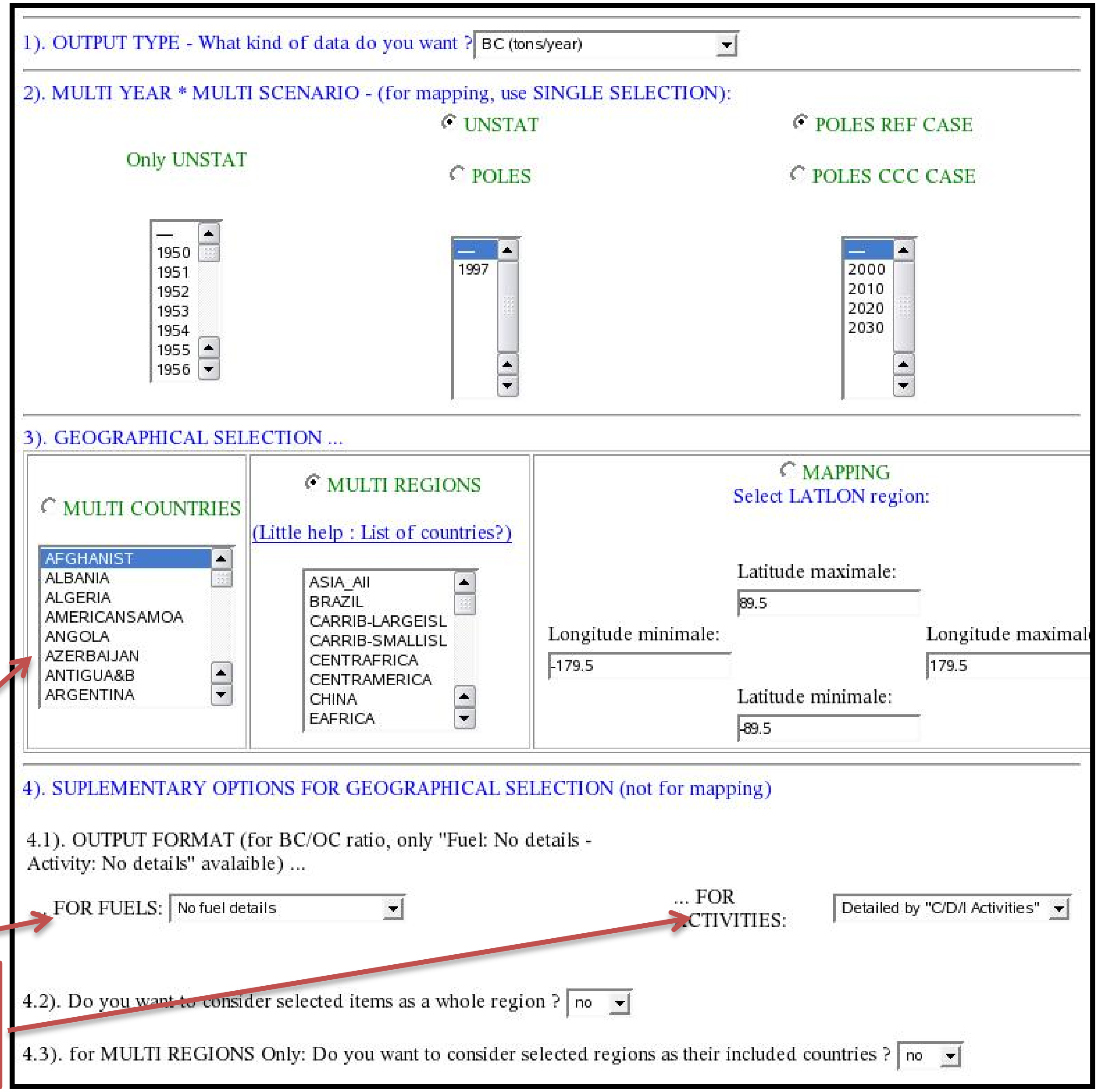
On line emission calculation tool



On line emission calculation

OLE-CAPEDB

On line emission calculation tool



Choice of region, type of fuel, output, etc.

Conclusions

- **Significant differences between emissions provided by different inventories in all regions of the world.**

- **Comparisons of available datasets will allow a quantification on the uncertainties on emissions.**

- **Large differences between the VOCs/CO ratios identified: use of surface observations from monitoring stations could help defining better speciations**

- **Very large differences among datasets providing emissions from fires in all regions**

- **Papers on the evaluation of anthropogenic emissions, VOCs speciation and evaluation of emissions from fires are in preparation**

→ Interested in participating? send an email to claire.granier@noaa.gov