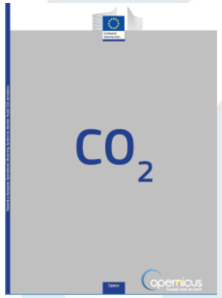
from the CO_2 report (1/2)

The abovementioned limitations can be overcome by collecting two types of atmospheric measurements:

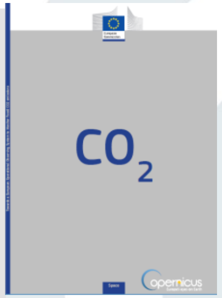
- Dense atmospheric CO_2 measurements, with detailed, high resolution, coverage of emissions hotspots. With their global and high revisit coverage, satellite observations of column integrated CO_2 (XCO_2) at high spatial resolution can meet this requirement, e.g., using space-borne sensors with imaging capabilities (**Chapter-3**).

- In-situ measurements of specific tracers in the atmosphere that allow the separation of fossil CO_2 from other sources. The best of these tracers is ^{14}C (radiocarbon) in atmospheric CO_2, which is nearly a direct tracer of emissions (Turnbull et al., 2014) but is so far expensive to measure because of its very low abundance. Fossil fuels do not contain any radiocarbon: when CO_2 from their combustion is released to the atmosphere, it dilutes with CO_2 from other sources that contain ^{14}C, which creates a measurable depletion of the ^{14}C isotope composition in air masses containing fossil CO_2. The accuracy at which the fossil fuel component of atmospheric CO_2 can be determined from ^{14}C measurements of CO_2 in air samples is about 1 ppm with Accelerator Mass Spectrometry. Carbon monoxide is also a tracer of combustion processes. In many environments, it is a reasonable tracer of fossil fuel emissions (Gammitzer et al., 2006) though subject to uncertainty in emission ratios of the two trace gases (CO_2 and CO) caused by differences in fuel type and combustion efficiency.



from the CO_2 report (2/2)

We recommend to build urban monitoring networks for selected European large cities. Results from city-scale inversions of CO_2 data from urban networks will be used to evaluate independently satellite-based city-scale emission estimates. ^{14}C measurements should be deployed a set of approximately 50 atmospheric CO_2 monitoring stations across the European continent, with higher density over regions with high emissions. Results from regional- and continental-scale inversions of in-situ ^{14}C and CO_2 measurements will be used to evaluate independently satellite-based emission estimates.



Co-ordinated by ECMWF

CO_2 Human Emissions

WP4: COORDINATING EFFORTS ON ATTRIBUTING CO_2 EMISSIONS FROM IN-SITU MEASUREMENTS

F. Chevallier, J. Marshall, P. Pickers, H. Denier van der Gon, Y. Wang, G. Broquet, and the WP4 team

Max Planck Institute for Biogeochemistry

LSCE

TNO

NILU

UEA University of East Anglia

cmcc

Empa Materials Science and Technology

Lund University

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776186.

WP4 goals

Survey current European in-situ observation capacity.

- “T0” Starting point definition (Lead MPG)

Define an operational strategy to separate anthropogenic CO_2 emissions from biogenic fluxes at regional and global scales through the use of additional tracers.

- T4.1 High-resolution scenarios of CO_2 and CO emissions (Lead: TNO, M1-M12)
- T4.2 Attribution Problem (Lead MPG:, M1-M33)

Shape the appropriate dimension and distribution of the corresponding in-situ network.

- T4.3 Practical Recommendations (Lead: CEA, M25-M36)

Lack of confidence in $CO:CO_2$ inventory estimates – Lower priority for CO surface measurements

Ex: $CO:CO_2$ emission ratios in the Paris area

- 90% of CO from the heating sector is emitted by wood burning, which is not part of the reference inventory

  => large and undocumented spatial variability of $CO:CO_2$

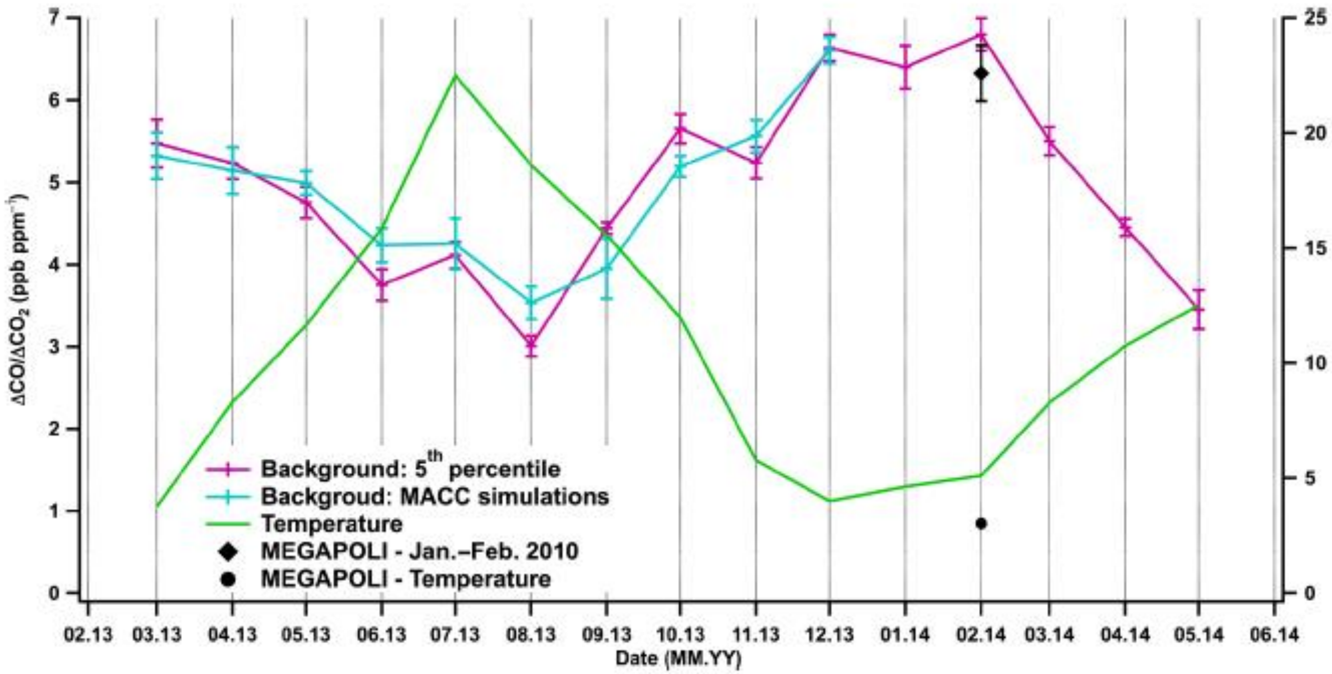
- Technological level of boilers may be overestimated by the reference inventory

  => Uncertain temporal variability of $CO:CO_2$

- Ammoura et al. (ACP, 2016).

Ex: $CO:CO_2$ emission ratios in the Oslo area

- ~ 0 for the transport sector (large fleet of electric cars)

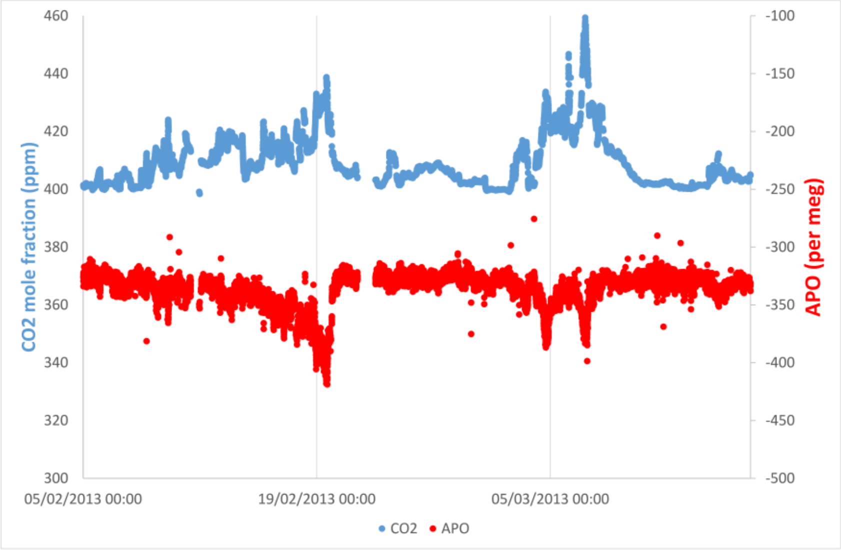


APO: a promising new tracer?

$APO = O_2/N_2 - \alpha_L \times CO_2$

α_L = oxidative ratio of terrestrial biospheric exchange

- Atmospheric Potential Oxygen (APO) is a tracer calculated from the sum of atmospheric O_2/N_2 and CO_2.
- It can be calculated from both flask (low frequency) and in-situ (high frequency) atmospheric measurements.
- APO is invariant to terrestrial biosphere O_2 and CO_2 exchange and is therefore only affected by ocean fluxes (mostly on seasonal timescales) and fossil fuel emissions (mostly on short-term timescales).

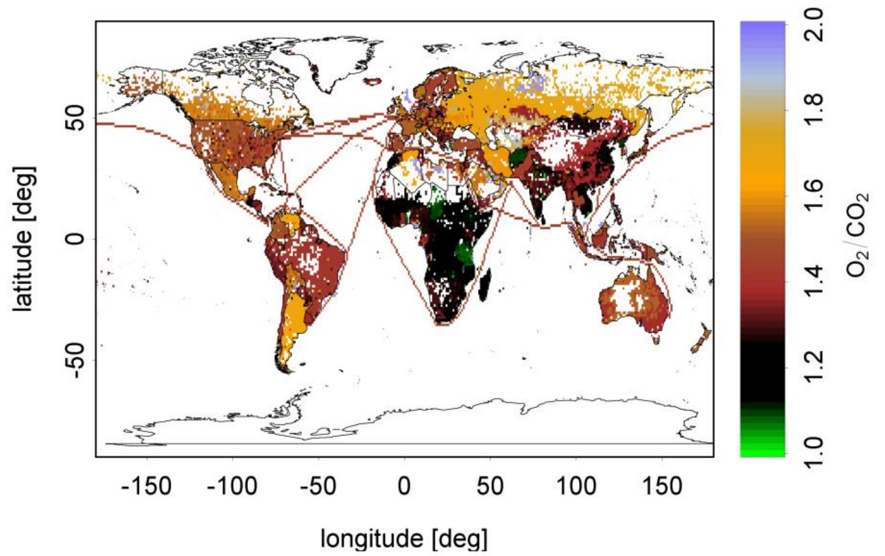


$ffCO_2$ related APO variability (red) from Weybourne Atmospheric Observatory, UK

Modelling APO (1/3)

$$APO\ (per\ meg) = \left(\frac{ocean_{O_2} - ((\alpha_F - \alpha_L) \times ff_{CO_2}) + (\alpha_L \times ocean_{CO_2})}{S_{O_2}} - \frac{ocean_{N_2}}{S_{N_2}}\right) \times 10^6$$

- α_F = O_2:CO_2 ratio of fossil fuel burning.
- Ranges from ~-1.20 to ~-1.95.
- Will be obtained from CO_2 inventory fossil fuel emissions combined with O_2:CO_2 ratio information for different fuel types.
- Uncertainty in α_F will be assigned where possible using the range of values in the literature, theoretical calculations and existing observation data.

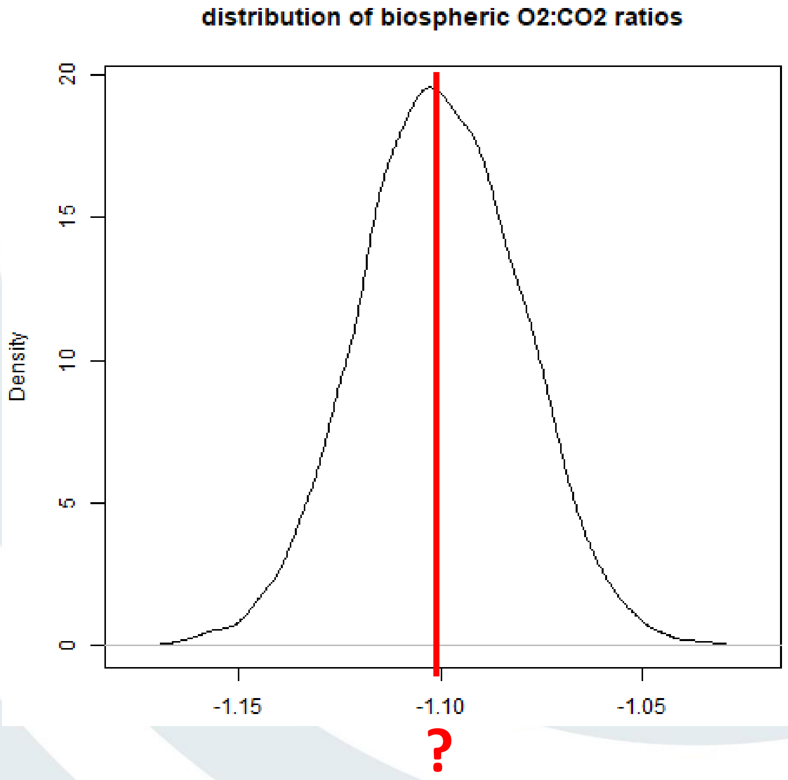


Estimated O_2:CO_2 ratios based on fuel type from Steinbach et al. (2011)

Modelling APO (2/3)

$$APO\ (per\ meg) = \left(\frac{ocean_{O_2} - ((\alpha_F - \alpha_L) \times ffco_{2}) + (\alpha_L \times ocean_{CO_2})}{S_{O_2}} - \frac{ocean_{N_2}}{S_{N_2}}\right) \times 10^6$$

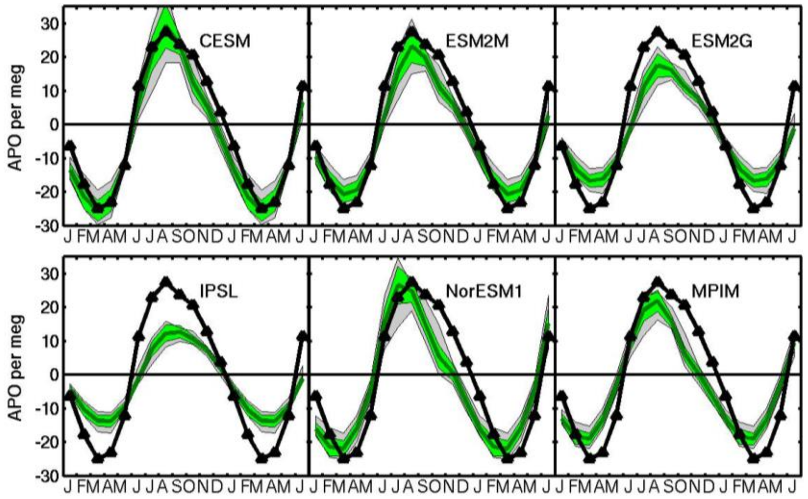
- α_L = O_2:CO_2 ratio of terrestrial biospheric exchange.
- Globally, this value on annual timeframes is -1.1.
- At the regional scale (i.e. Europe) on sub-annual timeframes, α_L may differ slightly from -1.1 (by up to ± 0.1).
- Uncertainties in modelled APO from α_L will be small, but should be investigated anyway.
- Uncertainty in α_L will be assessed using existing European atmospheric O_2 and CO_2 data.
- Diurnal and seasonal variability in α_L?
- Is -1.1 valid for Europe?
- Is there a gradient in α_L between north and south, or east and west?



Modelling APO (3/3)

$$APO\ (per\ meg) = \left(\frac{ocean_{O_2} - ((\alpha_F - \alpha_L) \times ff_{CO_2}) + (\alpha_L \times ocean_{CO_2})}{S_{O_2}} - \frac{ocean_{N_2}}{S_{N_2}}\right) \times 10^6$$

- $ocean_{O2}$ and $ocean_{CO2}$ gridded air-sea fluxes can be obtained from many of the Global Carbon Budget suite of ocean biogeochemistry models (OBGMs) and also possibly from the GFDL ESMs if required.
- $ocean_{N2}$ is estimated from OBGM heat fluxes and the Keeling et al. (1993) formula, since ocean N_2 fluxes are mostly thermally induced.
  - Nevison et al. (2015) already evaluated several of these OBGMs by comparing modelled and measured APO seasonality using 13 atmospheric transport models.
- $ffCO_2$ gridded fluxes will be obtained from CHE inventories (with uncertainties)
- S_{O2} and S_{N2} are the standard mole fractions of O_2 and N_2 in dry air (used to convert to per meg units) and are well constrained.



Modelled APO seasonal cycle at Barrow, Alaska (green) compared to observations (black); From Nevison et al. (2015)

University of East Anglia

Atmospheric measurements

Documentation of current European infrastructure for the measurement of:

- CO_2
- (CO)

→ Relatively common and widespread: "just need a (calibrated) Picarro"

- ^{14}C in CO_2
- Atmospheric Potential Oxygen (APO)

→ Comparatively sparse, difficult and expensive

Atmospheric measurements

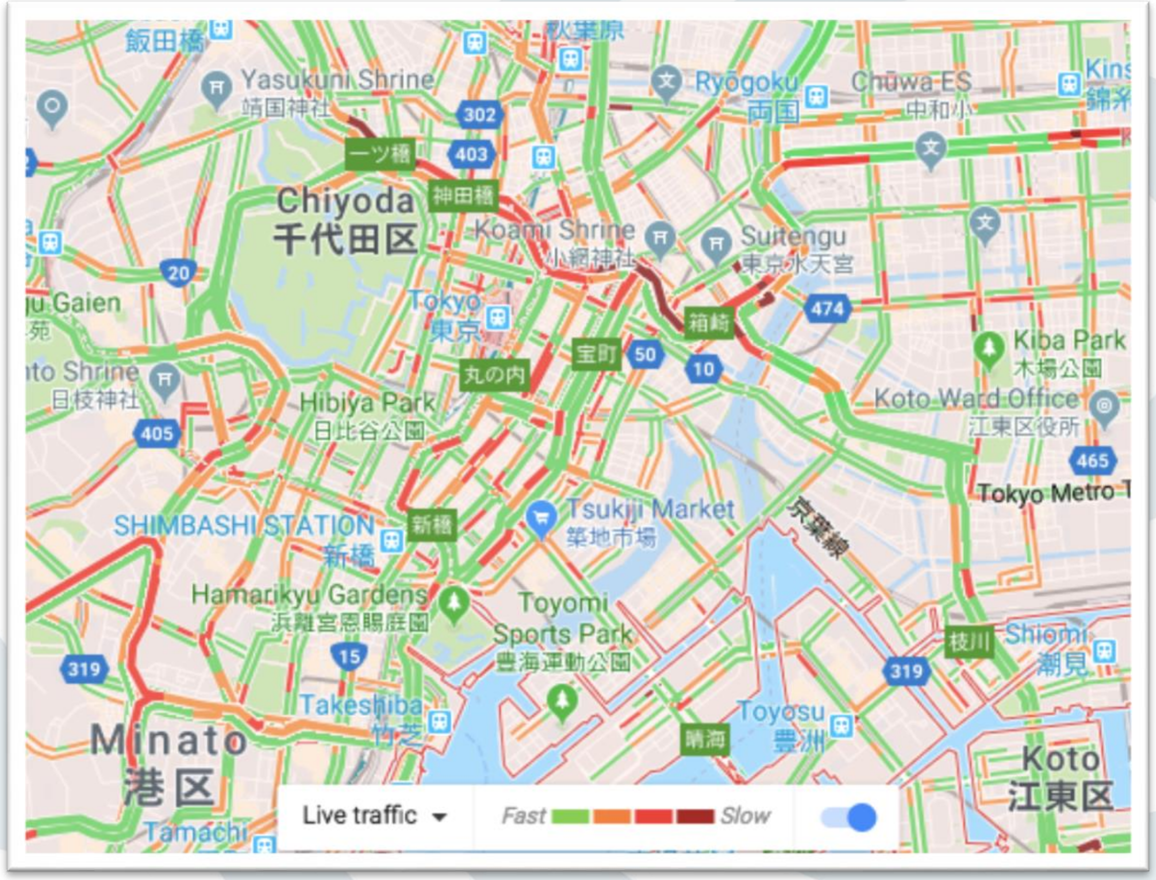
Largely falling under the auspices of ICOS | INTEGRATED CARBON OBSERVATION SYSTEM

- CO_2 → Measured at all ICOS Atmospheric Sites
- CO → Measured at Class 1 sites, recommended for 2
- ^{14}C in CO_2 → (To be) measured as two-week integrated signal at ICOS Class 1 sites
- O_2/N_2 ratio (for APO) → Recommended parameter for ICOS Class 1 sites

Activity data

Exploring the use of mobile phone activity data to constrain temporal signals of traffic emissions

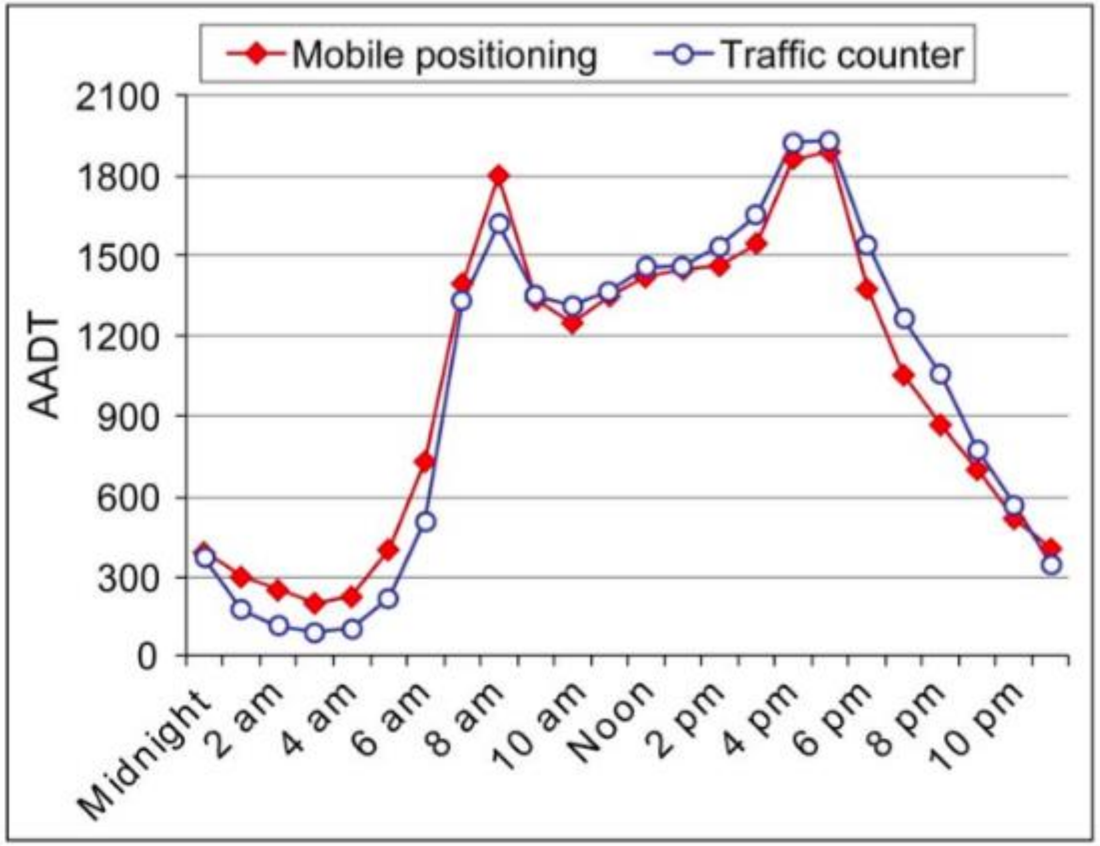
- Similar to how Google uses the location and speed of cars to produce traffic congestion maps:
- This information can also be used to estimate the total amount of traffic on roads, and its temporal signature



Activity data

Shown to work in other studies

- Different forms: recording call/text activity, active or passive positioning information
- Data are sometimes available for scientific use (e.g. http://www.manycities.org/), usually published studies have contacted national carriers directly
- In Estonia the data are collected by the government, and made available for study
- Matches the diurnal structure of data from traffic counters well for study in Tallinn (Järv et al., 2012), at right:



“LAY-OUT” OF THE EU EMISSIONS DATA SET
WP4 ATTRIBUTING CO2 EMISSIONS

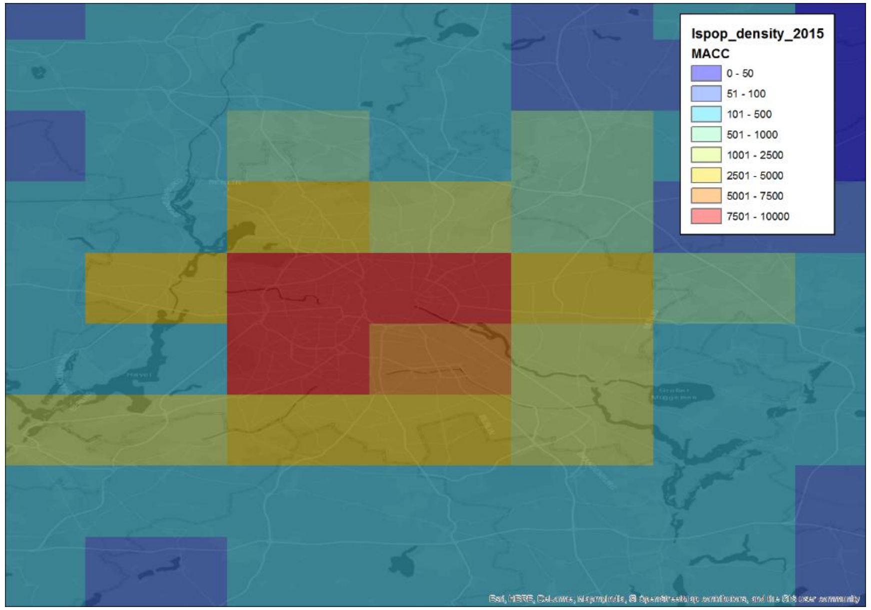
- Make a larger domain ~1 × ~1 km^2 (EU28) emission map
- Important: not about exact accuracy but realistic gradients (spatial & temporal)
- Include CO2_ff,CO2_bf and co-emitted species (CO, NOx, possibly APO)

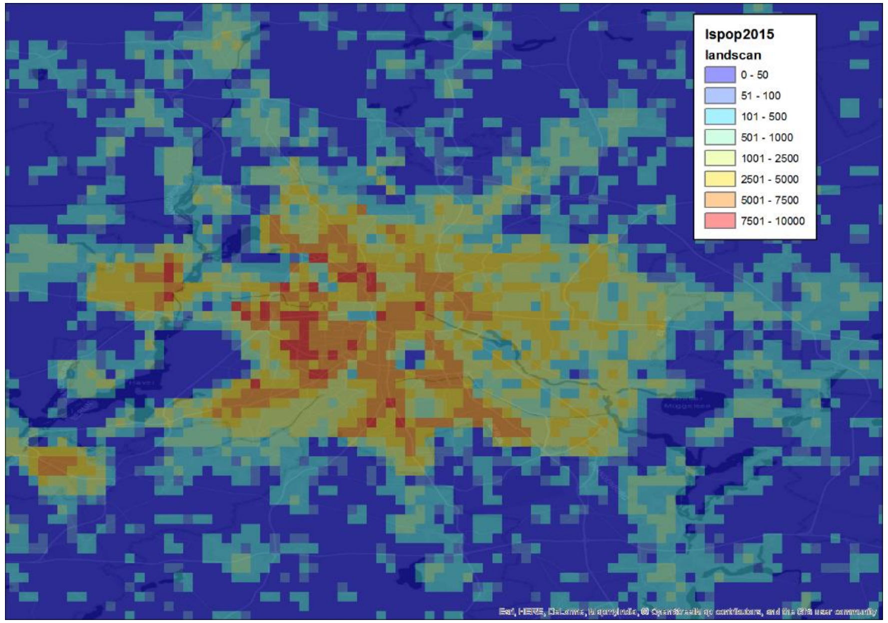
Steps –

- first make base year 2015 dataset under WP2 in parallel work on gridding proxies and time profiles for high resolution and uncertainties
- After base year gridded data are made – work on family of uncertainty grid maps (after summer 2018).

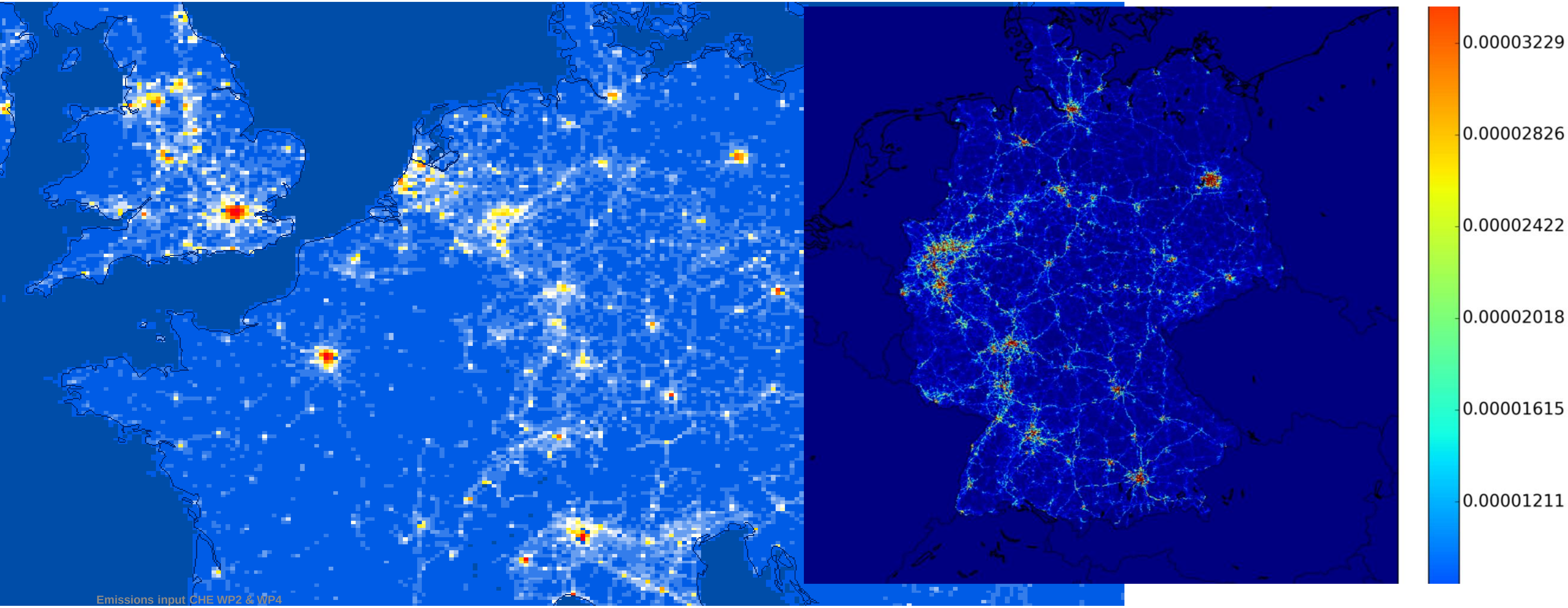
INCREASED GRADIENTS IN HIGH RESOLUTION: EXAMPLE POPULATION DENSITY AROUND BERLIN

- Left current TNO-MACC/CAMS resolution; right new high res population data
- Legend is the same: more people in bigger gridcells = redder area in left plot
- Increase in gradients and pattern number

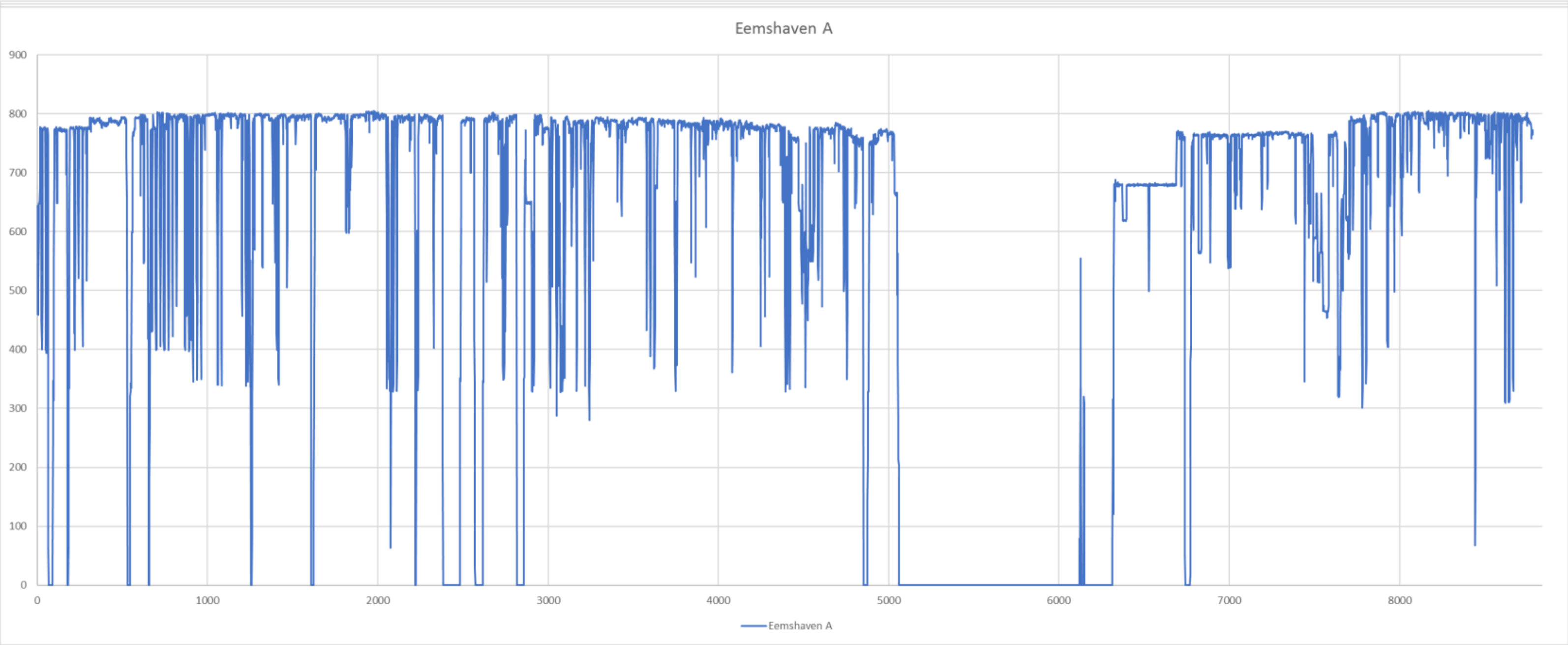




INCREASED RESOLUTION FOR ROAD TRANSPORT EMISSIONS (CO - TEST SET)



OPERATION HOURS OF INDIVIDUAL COAL FIRED POWER PLANTS

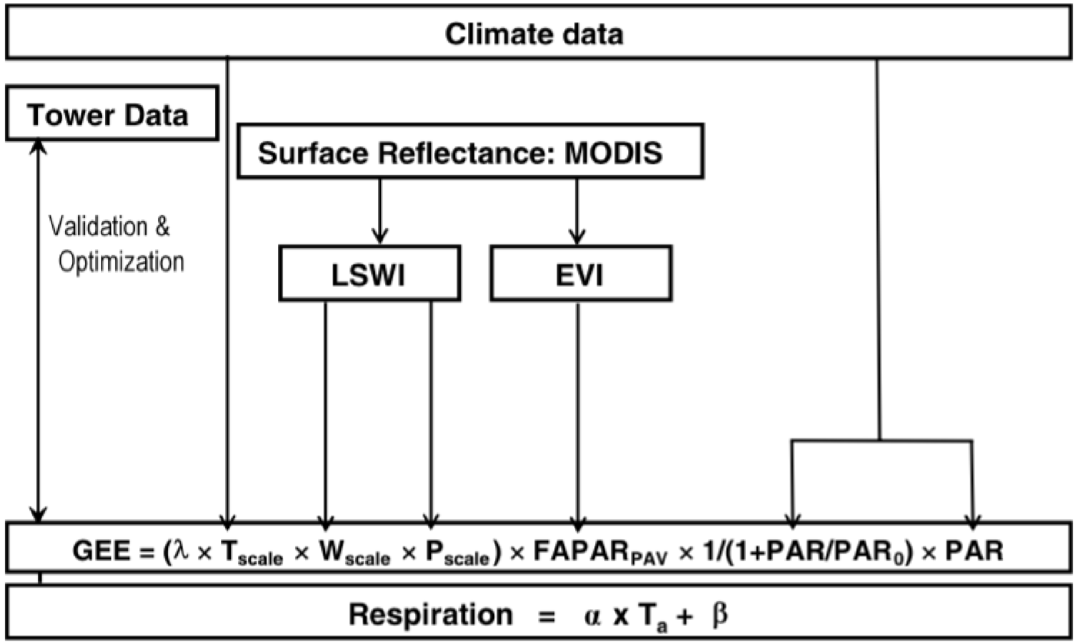


- Individual plants have specific on-off patterns not captured by default profiles
- Variability in production levels is higher than expected
- For Europe, data exist to incorporate this into the gridded emission maps

Biosphere fluxes

For use in WP2 and WP4

- Based on VPRM (Mahadevan et al., 2008), the Vegetation, Photosynthesis and Respiration Model
  - Uses MODIS 8-day reflectances at high resolution to produce indices EVI and LSWI
  - Requires meteorological input of temperature and shortwave radiation
  - Model parameters tuned to match flux tower measurements



Max Planck Institute for Biogeochemistry

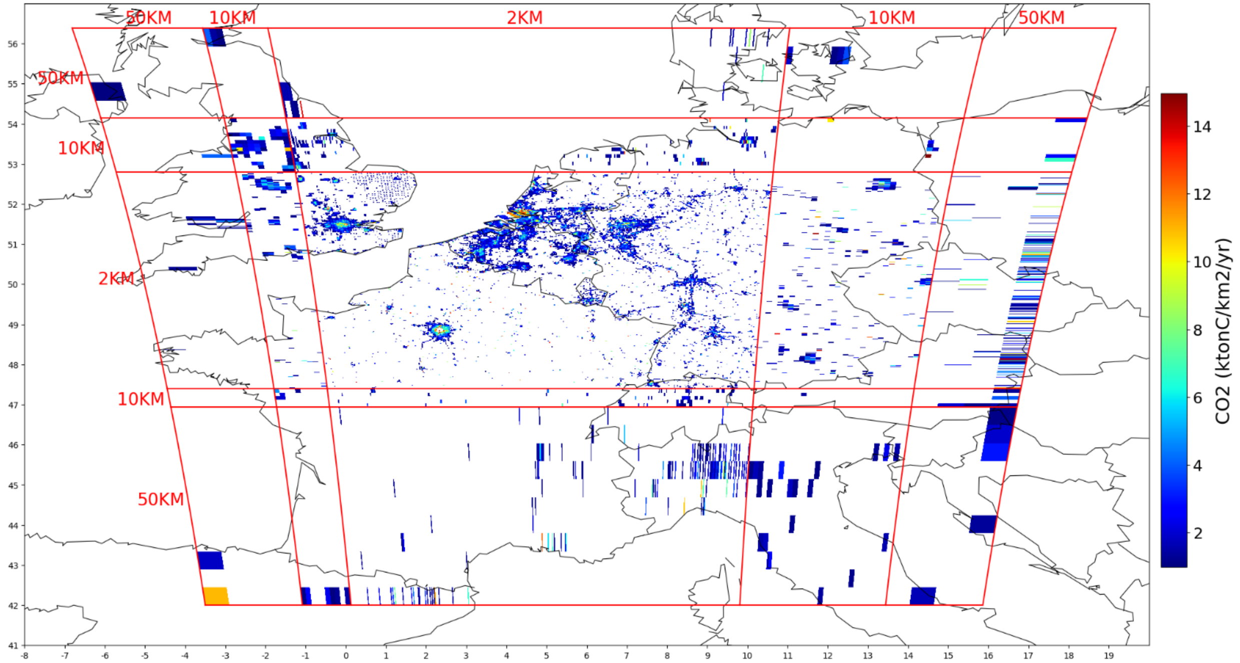
Fluxes for $^{14}CO_2$ atmospheric transport and inverse modeling at the European national scales

Proposition to work with $\delta^{14}C$ rather than $\Delta^{14}C$

1. Anthropogenic emissions:
   - Simple account of the fossil fuel fluxes using the CO_2 FF inventories
   - Biofuel emissions can be neglected
2. Biospheric fluxes:
   - Combination of VPRM and of the 0.5° / 1 d res complex product based on ORCHIDEE for 2000-2013 (= downscaling of ORCHIDEE using VPRM)
3. Oceanic fluxes:
   - Can be neglected at the considered scales for OSSEs
4. Nuclear power plant fluxes:
   - Annual product for all nuclear PP & 4 nuclear fuel reprocessing factories
   - Update of the Graven and Gruber (2011) database (by LSCE)
5. Cosmogenic fluxes (includes boundary conditions):
   - Annual average vertical profiles as a function of the pressure available at LSCE
   - Annual maps at 2.5° × 3.75° resolution

Four modelling frameworks

- Focus on year 2015
- Oslo area: Flexpart (1 km, NILU)
- Europe: COSMO-GHG (5 km, EMPA)
- Europe: WRF-STILT (5 km, MPI-BGC)
- Some of Europe: CHIMERE (2 km, LSCE)



Coming soon 

D4.1 Current European in-situ atmospheric measurement capacity (Lead: MPG; M6, R, PU).

- Summary of current European in-situ atmospheric measurement capacity and typical sampling for CO_2, CO, $^{14}CO_2$, and APO

D4.2 Database of high-resolution scenarios of CO_2 and CO emissions (Lead: TNO; M12, OTHER, PU)

- Database of high-resolution scenarios of CO_2 and CO emissions associated with anthropogenic activities in Europe over a full year including associated uncertainty statistics and documentation.

D4.3 Attribution Problem Configurations (Lead: MPG; M18, R, PU)

- Detailed description of the specific configurations implemented in the four modelling frameworks to study the attribution problem.

Open questions

Reliability of emission ratios from inventories

- $CO:CO_2$, $O_2:CO_2$

Interaction with other WPs

- Modelling hypotheses: WP2, WP3
    - Some of WP2 is implicit in WP4, but with a WP4 logic (no model simulation delivery).
- Inverse modelling hypotheses: WP3
    - Use of $CO:CO_2$, $NOx:CO_2$
    - Spatial and temporal correlations in prior inventory errors.
- From research to operations: WP5
    - What a full size system will look like

CO2 Human Emissions

THANK YOU

F. Chevallier, J. Marshall, P. Pickers, H. Denier van der Gon, Y. Wang, G. Broquet, and the WP4 team

Max Planck Institute for Biogeochemistry

LSCE

TNO

NILU

UEA University of East Anglia

cmcc

Empa Materials Science and Technology

Lund University