Towards Reconciling Bottom-up And Top-down Estimates of N_2O And CH_4 Emissions in Rotterdam

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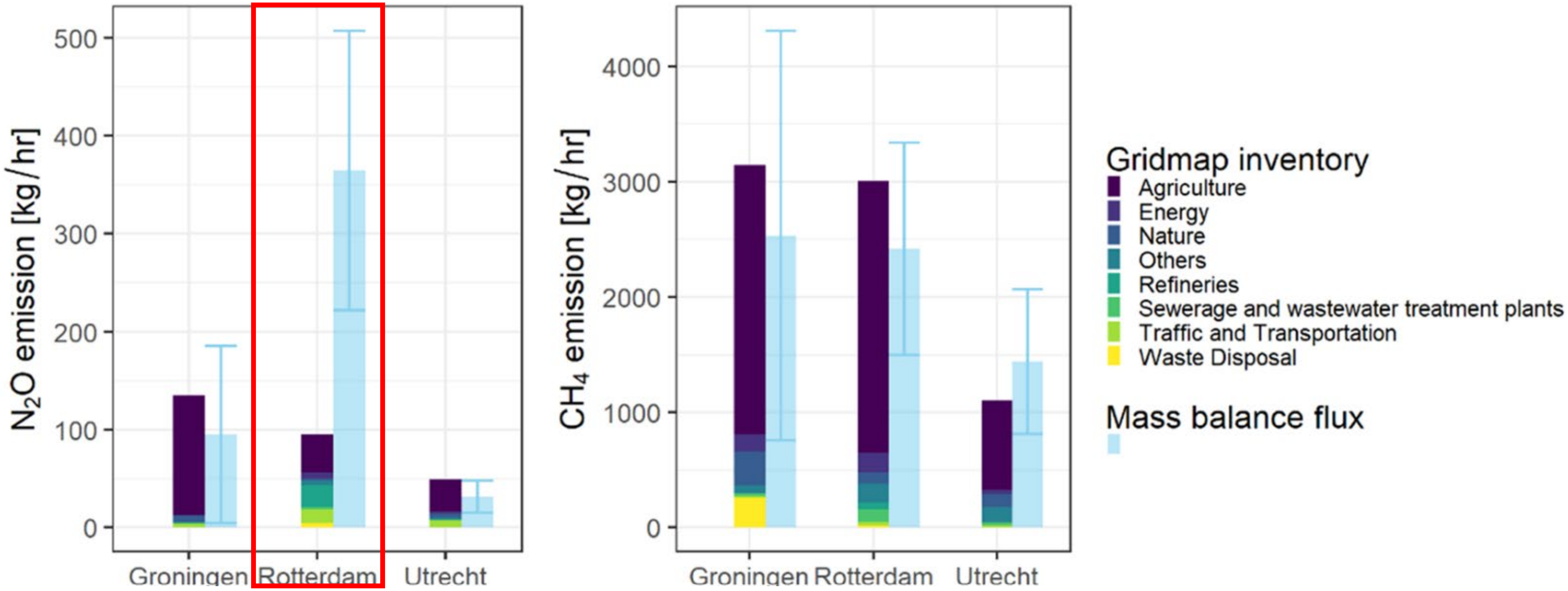
Introduction

- The GHGs emissions from urban areas account for 67-72% global GHGs emissions (IPCC, 2022)
- Identification, location, and quantification of individual CH_4 sources using ground-based mobile measurements
- The pattern of source composition of methane emissions varies from city to city
- N_2O emissions were scarcely studied for urban areas

The largest CH4 source	Cities
Natural gas leakage	Many American cities (Phillips et al., 2013) and several European cities such as Paris (Defratyka et al., 2021)、Hamburg and Utrecht (Maazallahi et al., 2020)
Landfills	The Greater Toronto Area (Ars et al., 2020)、Montréal (Williams et al., 2022)
Wastewater treatment	Bucharest (Fernandez et al., 2022)

Introduction

- Top-down estimates of N_2O emissions are about 3 times the inventory estimates

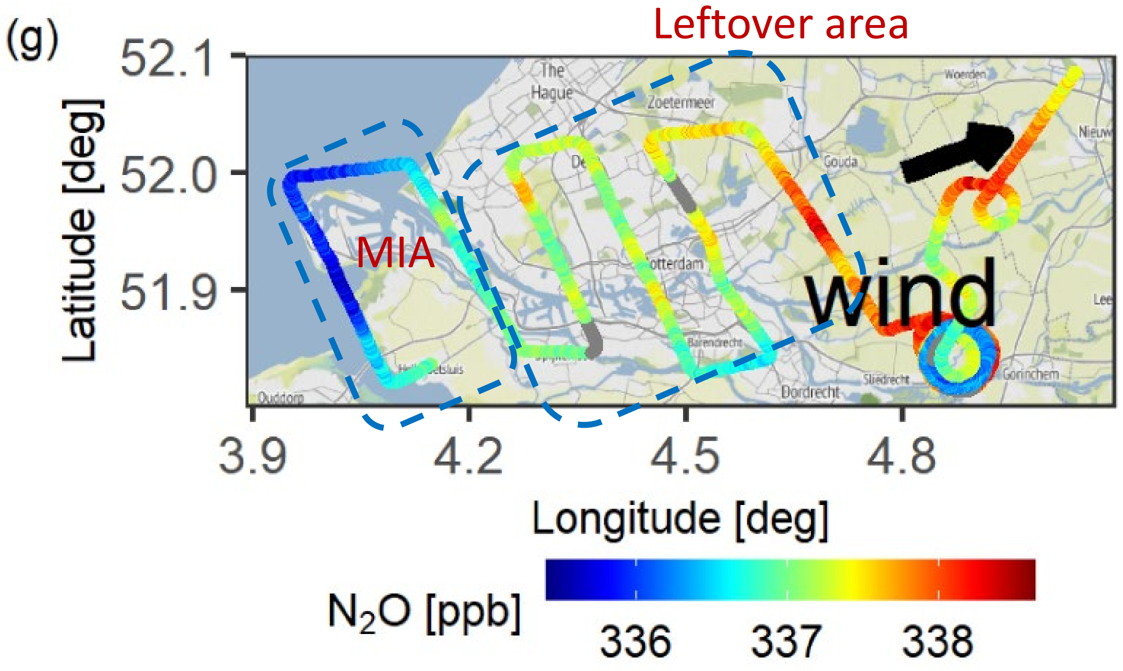


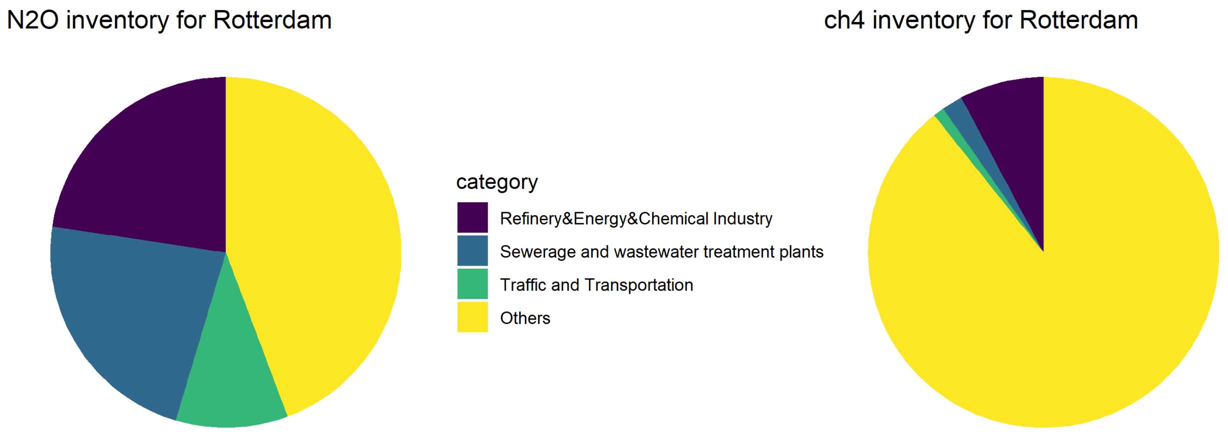
Source: Tong et al., 2023

Introduction

Top-down estimates (regional scale) VS The bottom-up inventory (specific categories)

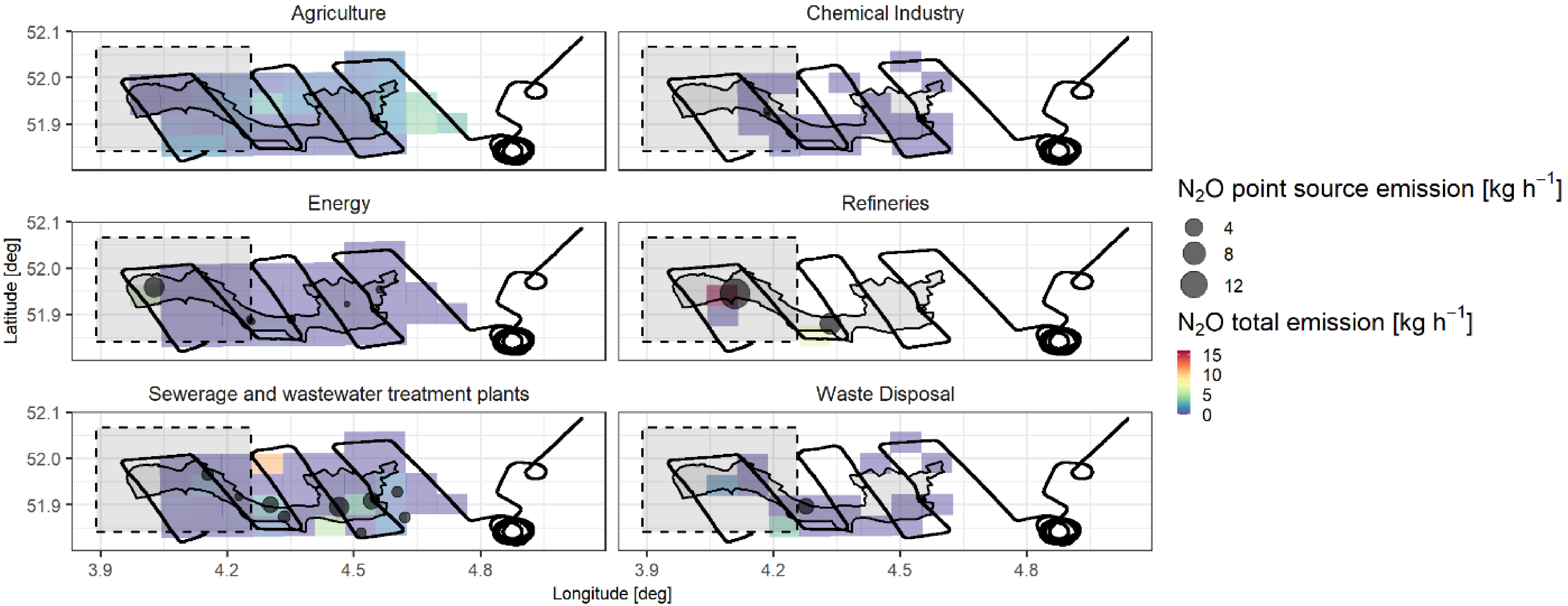
Aircraft-based mass balance approach



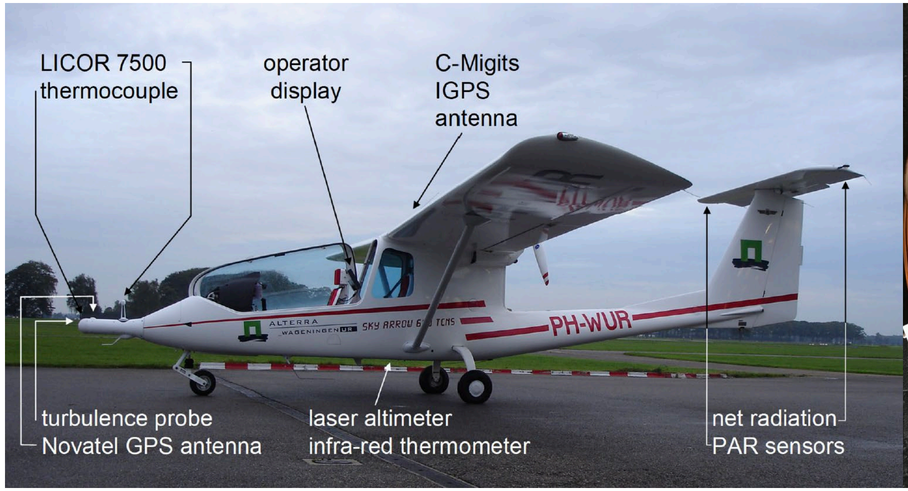


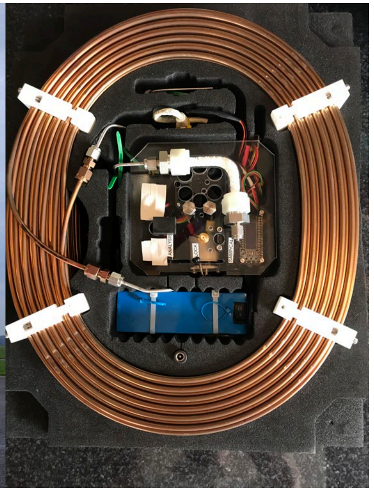
The 5*5 km2 Dutch governmental inventory

- National emissions (sum of point and diffuse sources' emissions) are allocated for 5*5 km_2/Provinces/municipalities



Aircraft-based AirCore measurements





1. AirCore N_2O, CH_4, CO_2, CO
2. LI-7810 CH_4 and CO_2
3. LI-7500, CO_2 and H_2O fluxes
4. Meteo.: U, V, RH, P, T, PAR
5. GPS altitude and coordinates

Flights	Urban area	Analysis	Year
4	Groningen	Two CRDS in series	2021 and 2020
5	Utrecht	Two CRDS in series or QCL	2021 and 2020
4	Rotterdam	QCL	2022

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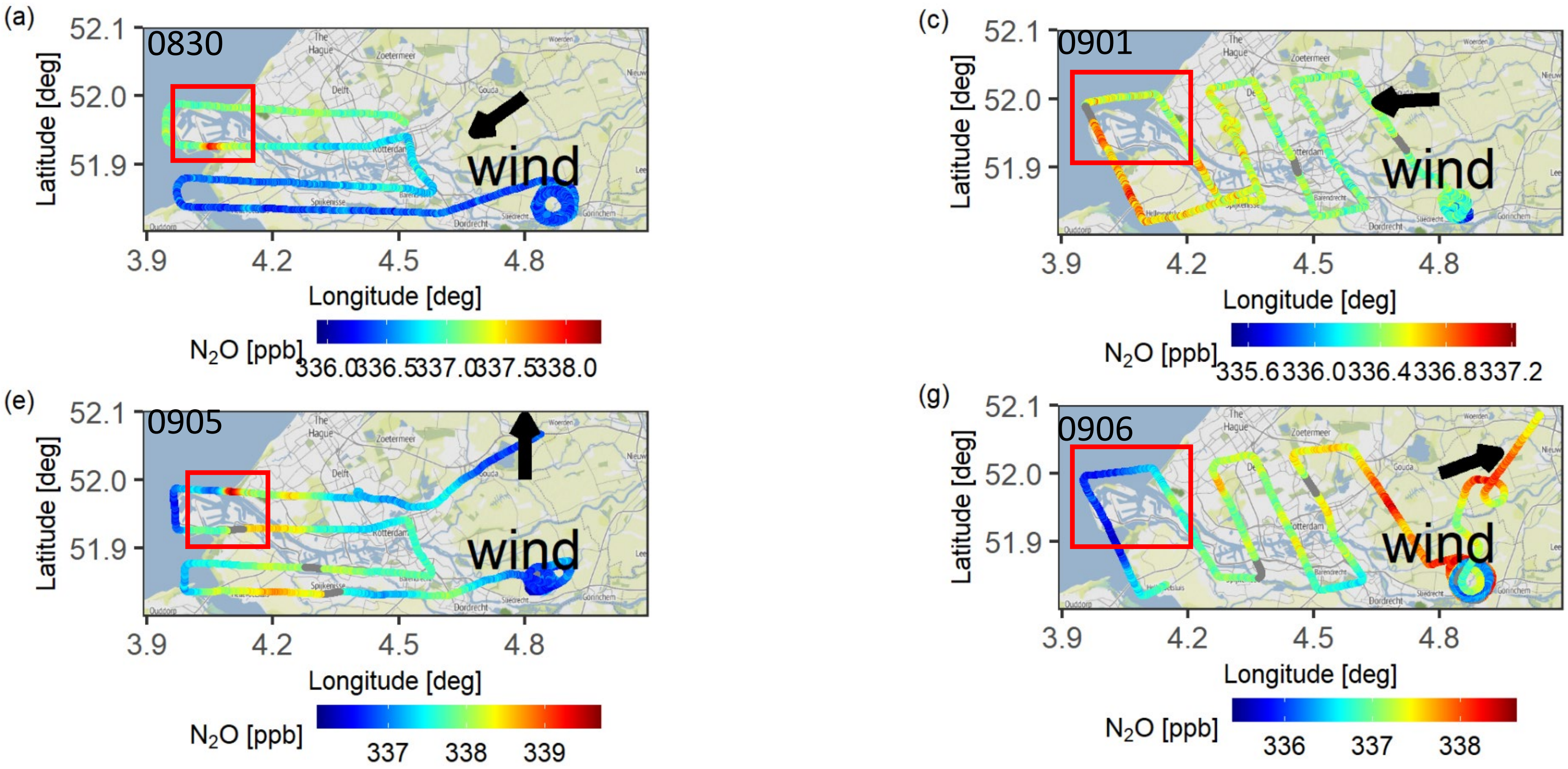
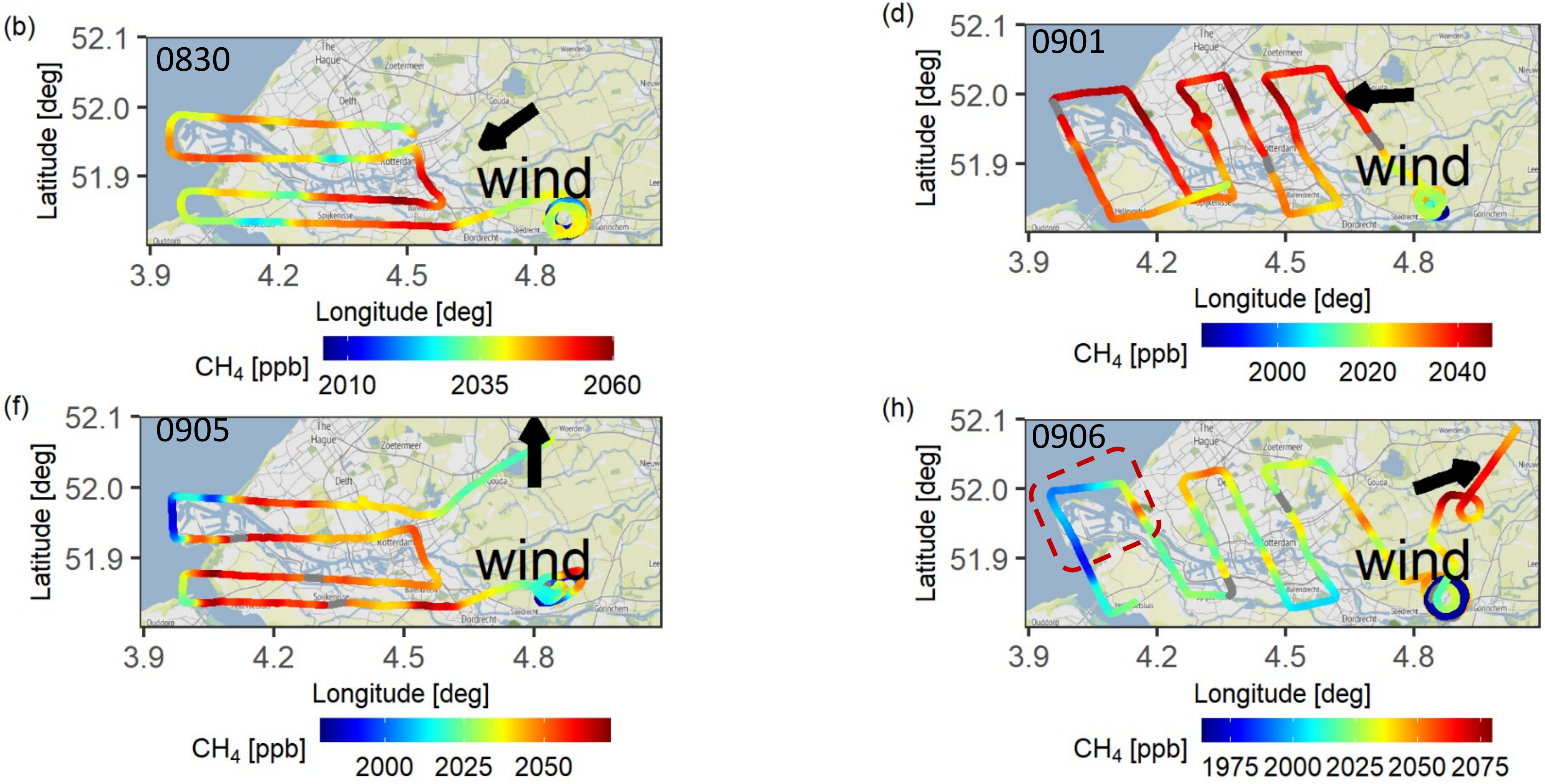
N_2O enhancements for four flights

Application of the Aircraft-based mass balance approach to single altitude measurements



CH_4 enhancements for one flight 0906

Inland wind brings high background



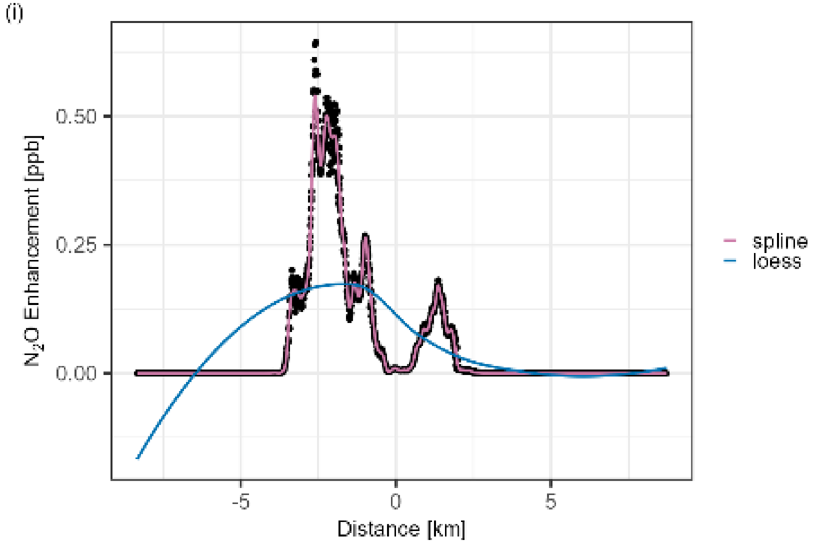
Concepts of emission estimation using the WRF-LES

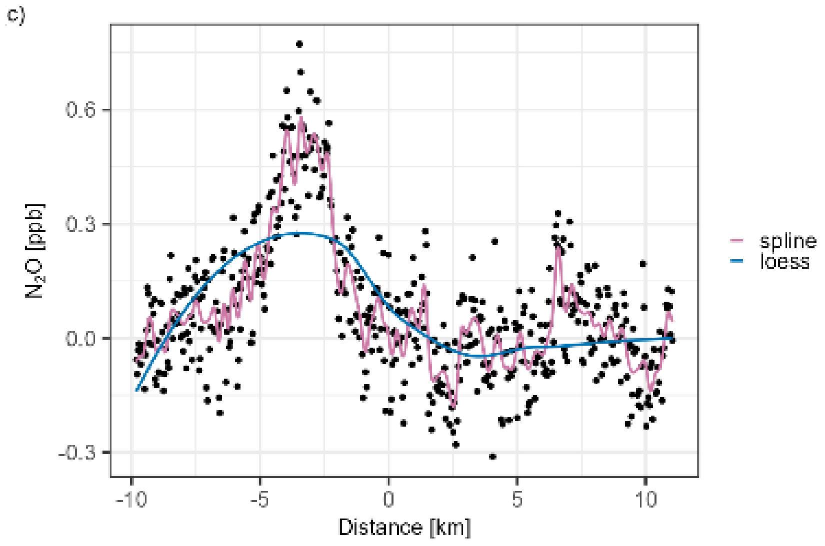
The large eddy simulation (LES) driven by the Weather Research and Forecasting (WRF) Model developed by NCAR&NOAA&…

$$Q = \frac{\sum c_{meas} \times u_{meas}}{\sum c_{LES} \times u_{LES}} \times Q_{LES}$$

u_{LES}: wind speed; Q_{LES}: emission rate in the model

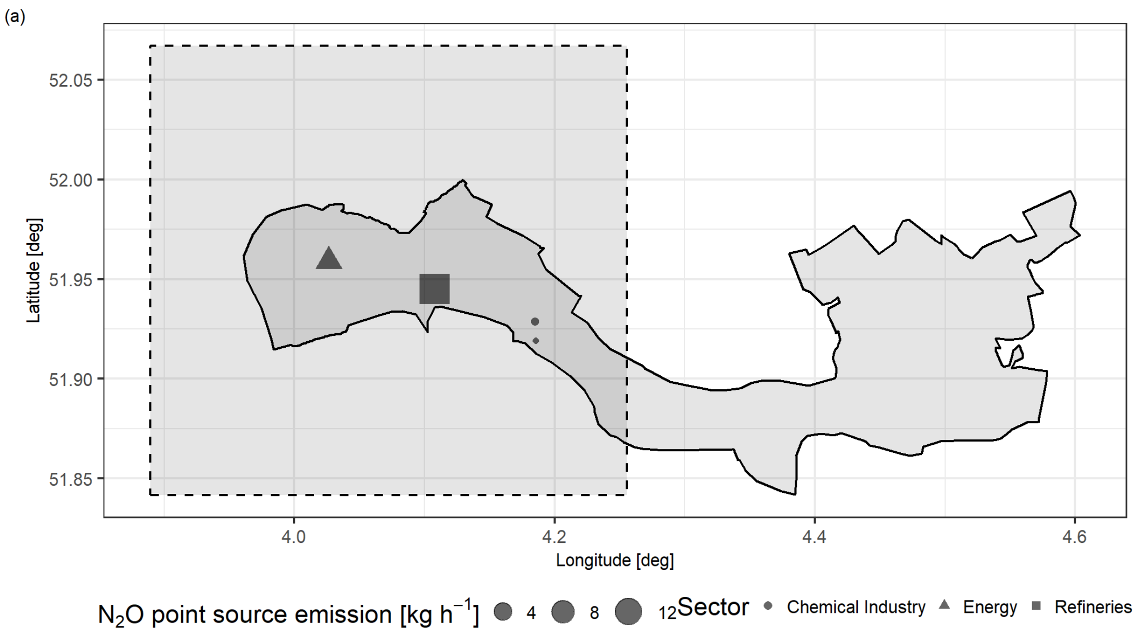
Modelld enhancements VS observed enhancements (aircraft-based AirCore)



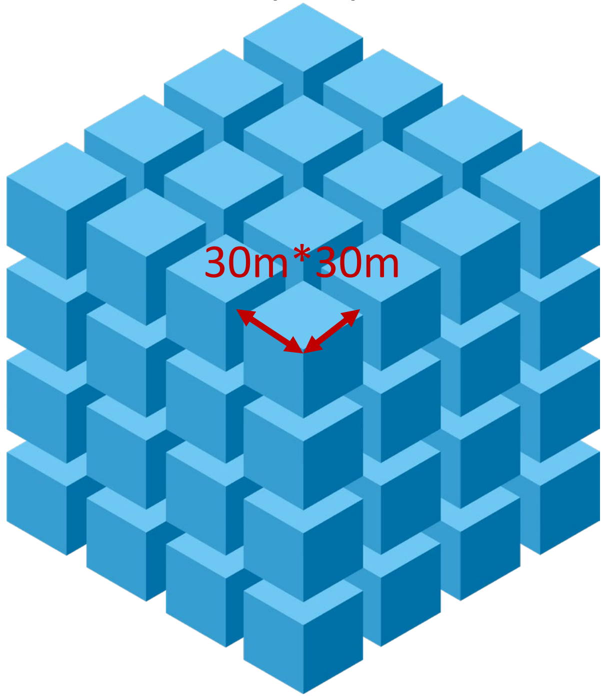


Configuration and output of the WRF-LES

- Deploy four point sources in the study domain
- Emission height: 50 m
- Resolution: 30 m * 30 m
- Multiple layers

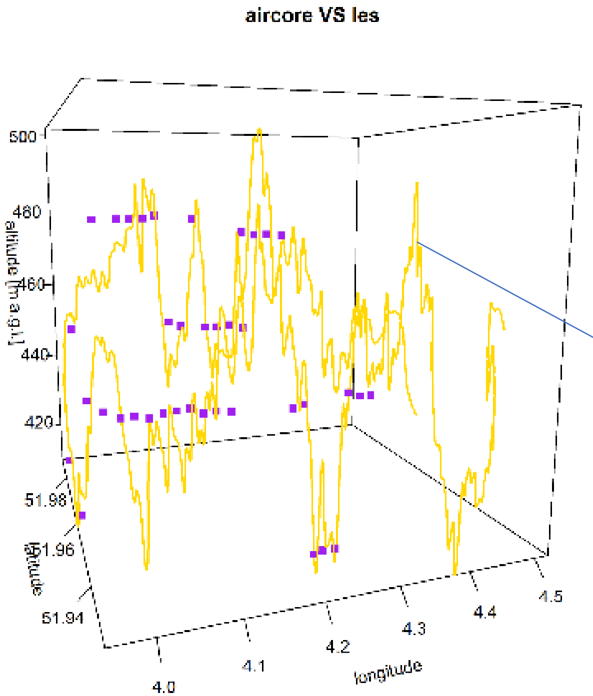


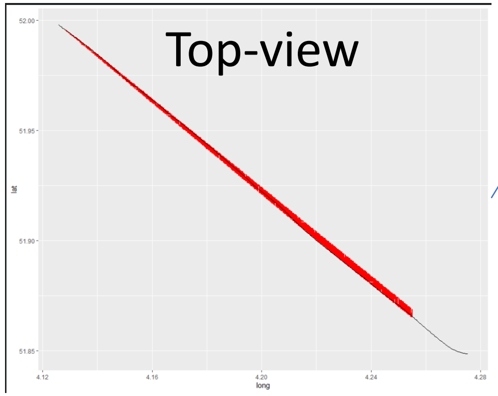
3 dimensional output per 30 seconds



Source: https://planbee.com/pages/cube-numbers

Emission Estimation using the WRF-LES model





- Combination of extraction methods and plumes

1. Extraction of grid cells

- Select the single grid cell that is closest to the spatial location of the aircraft at the same timestamp
- Select the grid cells in space where downwind transects were flown

2. Calculation of enhancement areas

- One plume

Two smoothing functions

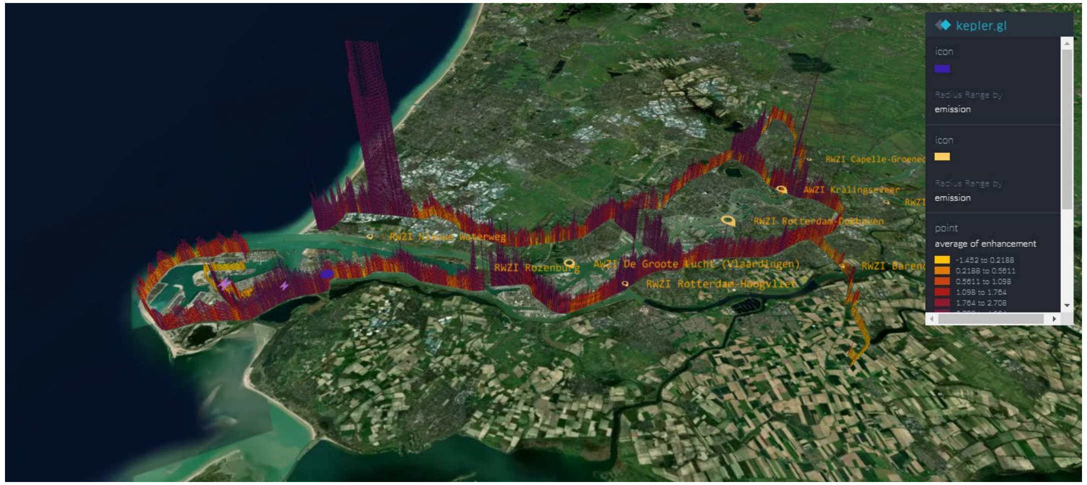
- Multiple instantaneous plumes

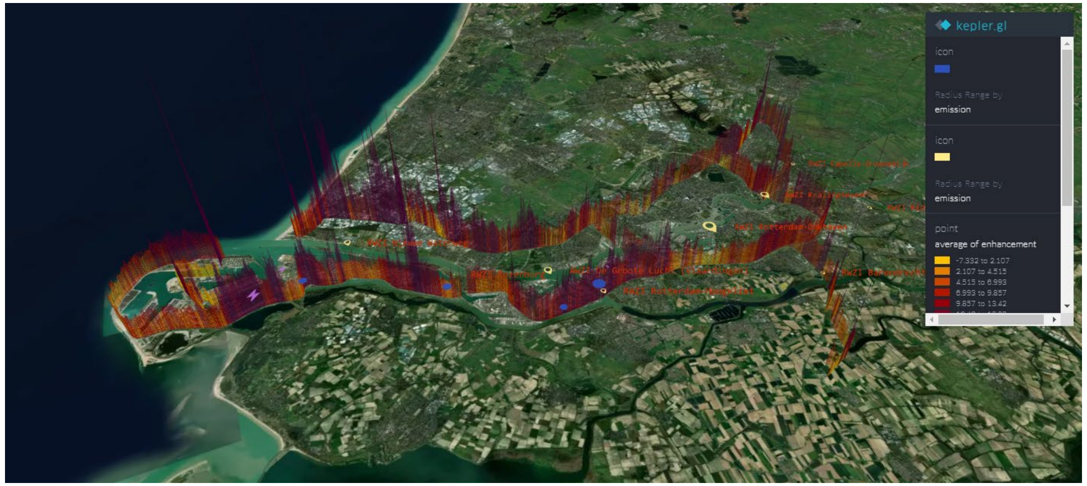
- instantaneous plumes
- Average plume for the whole simulation period
- Average plume for 2 minutes
- Average plume for 5 minutes
- Average plume for 10 minutes
- Average plume for 20 minutes

Mobile ground-based measurements

The TNO truck for mobile measurements (photo provided by Gerrit Jan)

sector	plumes
WWTP	10; 1; 1
Energy	1; 1; 1
refinery	1
Waste disposal	2
Transport and traffic	emission ratio





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Emission quantification

1. Wastewater treatment plants (WWTPs): inverse Gaussian plume model

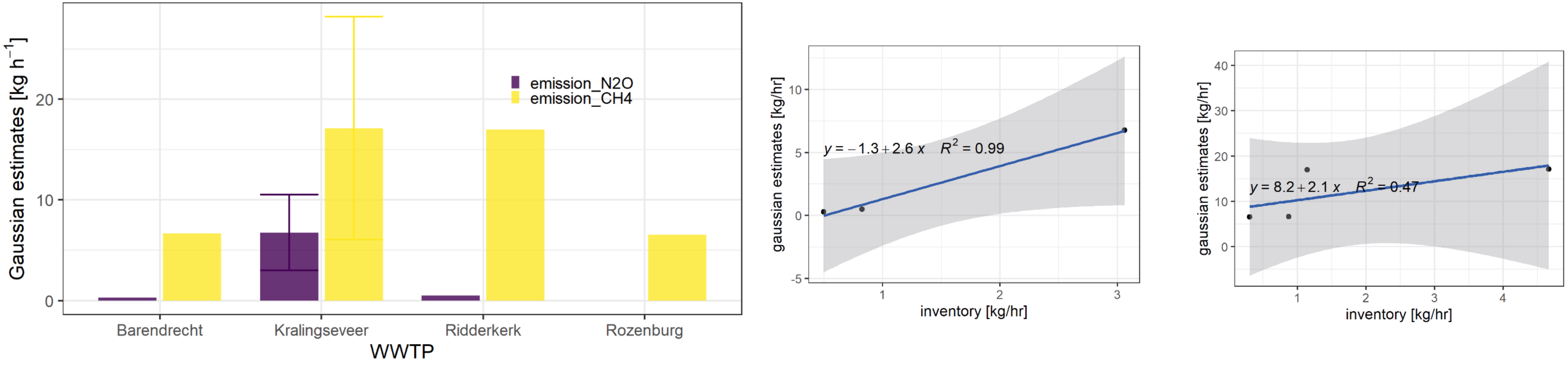
2. Vehicle emissions:

- $emi_{\mathrm{N2O}(CH4)} = \frac{\Delta c_{\mathrm{N2O}(CH4)}}{\Delta c_{CO2}} * emi_{co2}$

- Assuming CO_2 inventory emissions are reliable

- Represent the emissions from the category “traffic and transport”

The estimated emissions from WWTPs

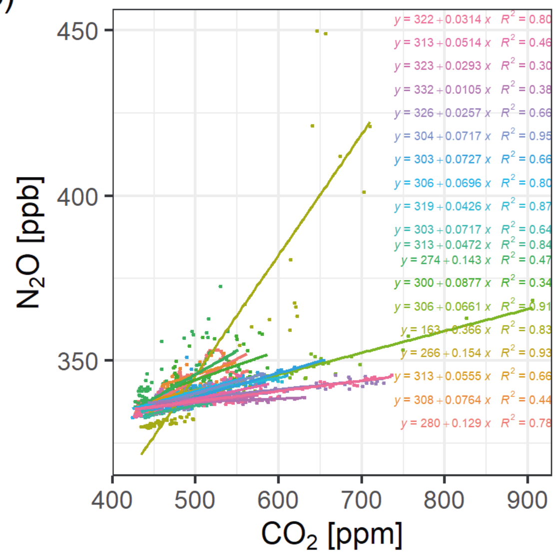


- 11 measurements for Kralingseveer and 1~3 measurements for others
- Determine the emissions from all WWTPs in Rotterdam based on the linear relationship

The estimated emissions from vehicles

- 19 plumes from tunnels
- High correlation & the number of available plumes

(c)



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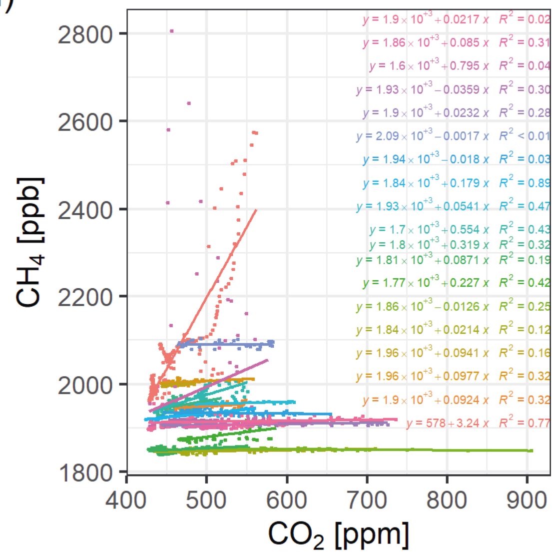
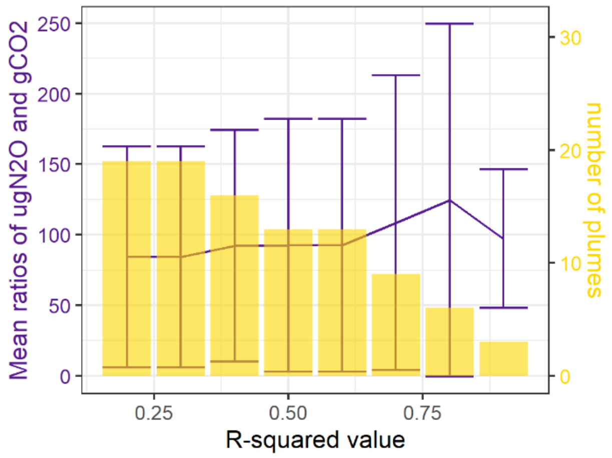
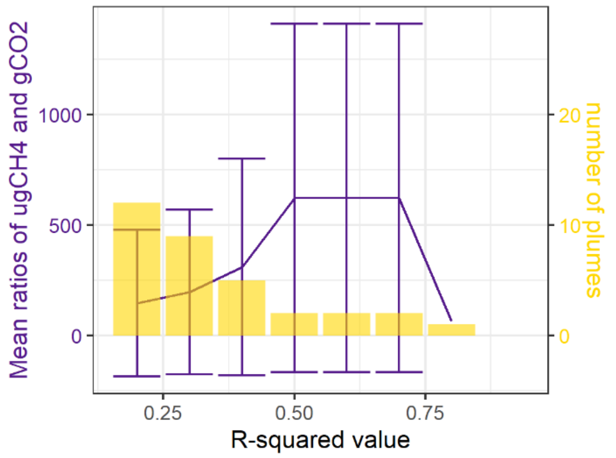
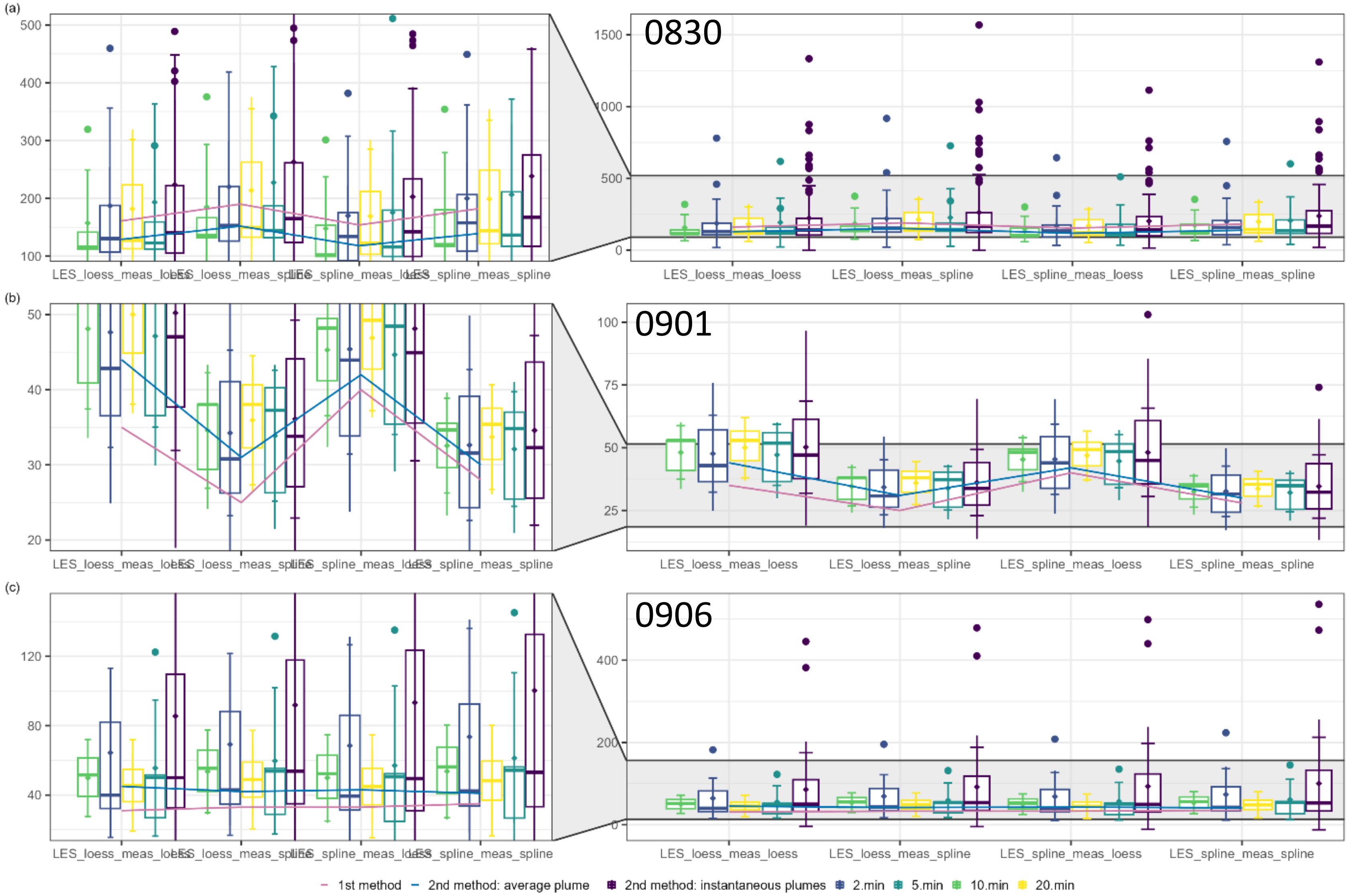




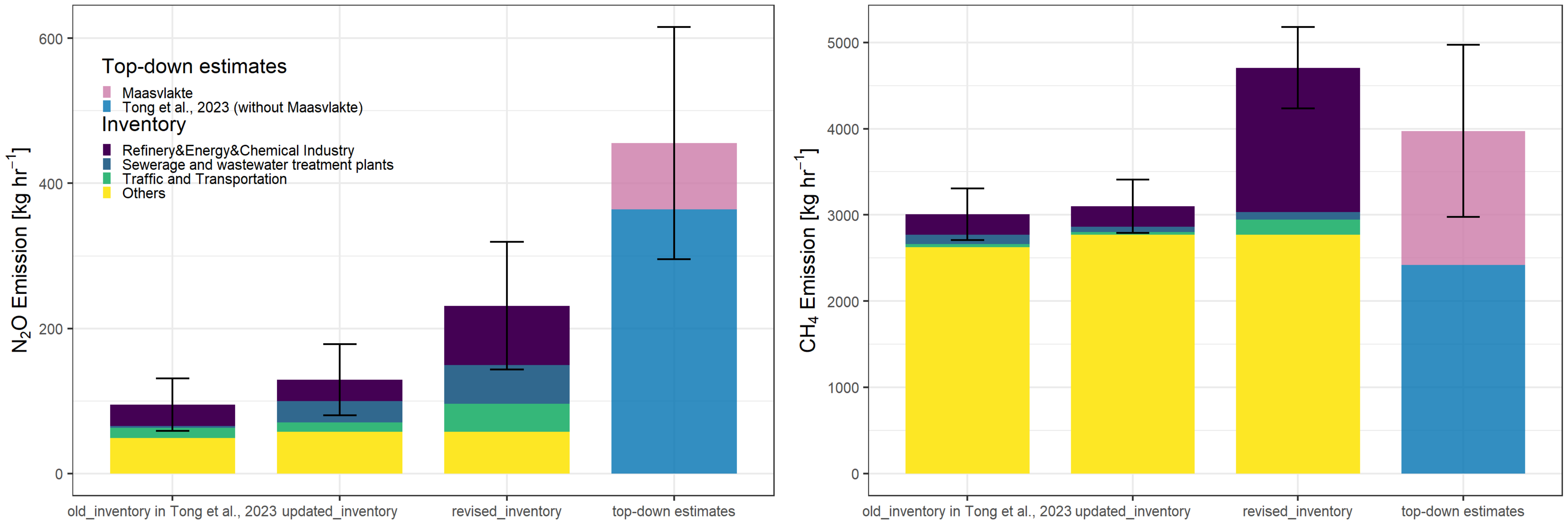


The WRF-LES modelled emissions



- “spline” function & the plume averaged from the whole simulation period
- represent the total emissions from the upwind point sources (refineries, energy plants, and chemical plants)

Bottom-up inventories VS top-down estimates



Note: different temporal representativeness of inventory (yearly) and top-down estimates (hours)

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Conclusions

- Mobile ground-based and airborne measurements are complementary means to validate emission inventories.

- Underestimation of specific categories' emissions accounts for the reduction of the gap in top-down estimates and bottom-up inventories from 4 to 2 times for N_2O.

- The top-down estimates of CH_4 emissions within the uncertainty do not show a significant difference with the pre- or post-revised inventory even if specific categories' emissions were underestimated.

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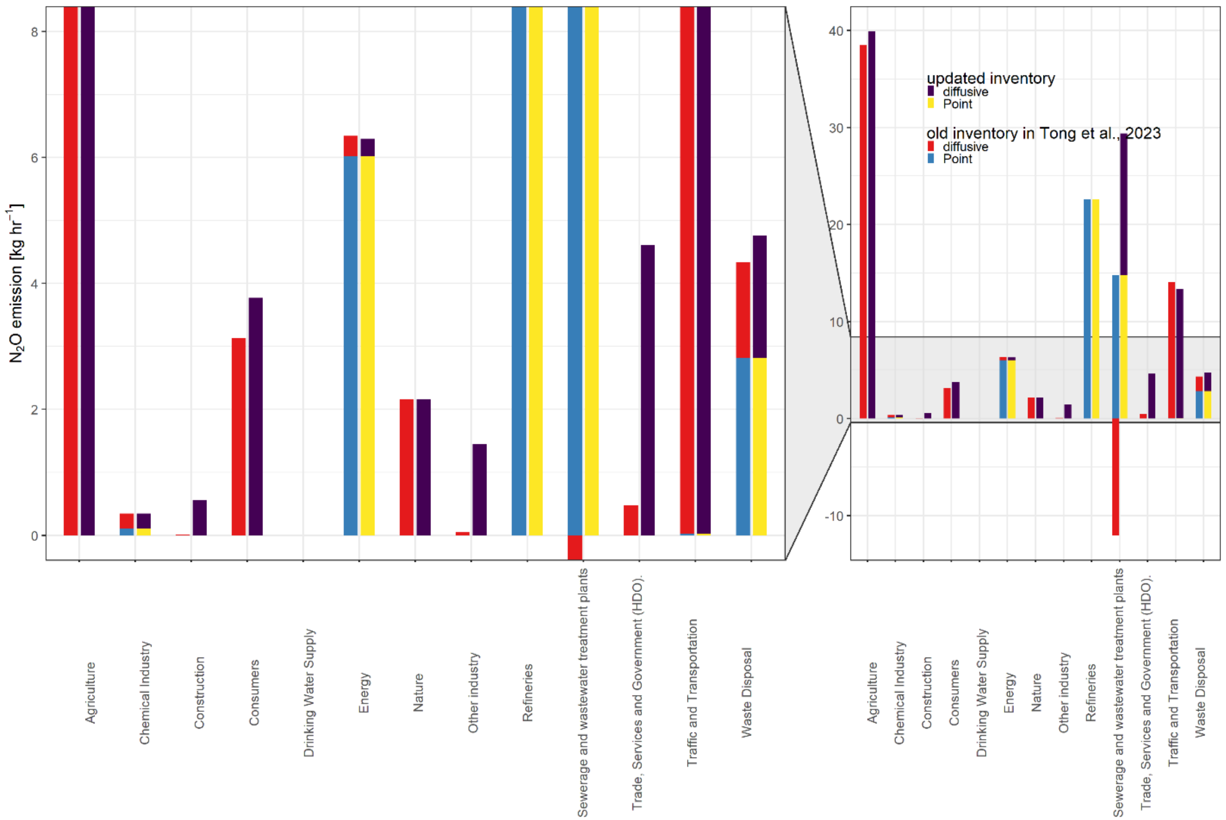
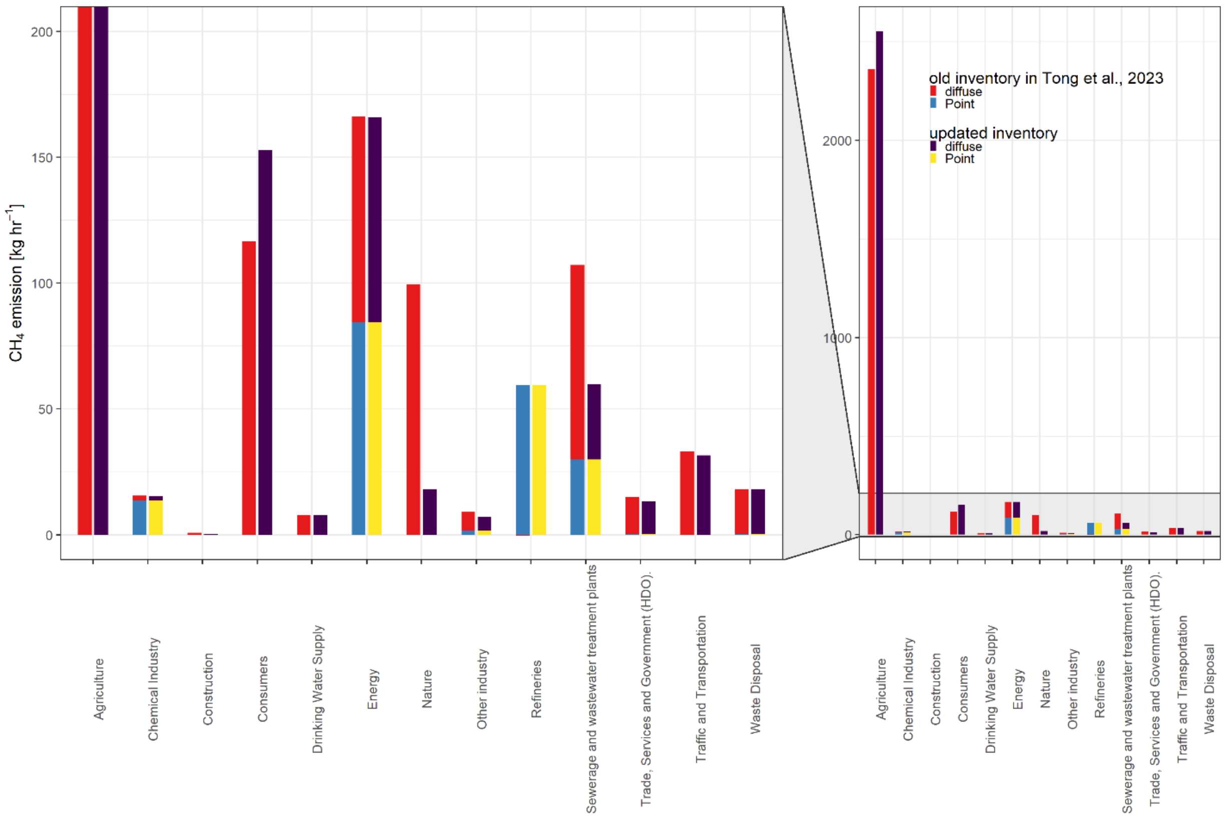

N$_2$O emission [kg hr^{-1}]
0
2
4
6
8
40
30
20
10
0
-10
updated inventory
diffusive
Point
old inventory in Tong et al., 2023
diffusive
Point
Agriculture
Chemical Industry
Construction
Consumers
Drinking Water Supply
Energy
Nature
Other industry
Refineries
Sewerage and wastewater treatment plants
Trade, Services and Government (HDO).
Traffic and Transportation
Waste Disposal


CH$_4$ emission [kg hr^{-1}]
0
50
100
150
200
1000
2000
old inventory in Tong et al., 2023
diffuse
Point
updated inventory
diffuse
Point
Agriculture
Chemical Industry
Construction
Consumers
Drinking Water Supply
Energy
Nature
Other industry
Refineries
Sewerage and wastewater treatment plants
Trade, Services and Government (HDO).
Traffic and Transportation
Waste Disposal

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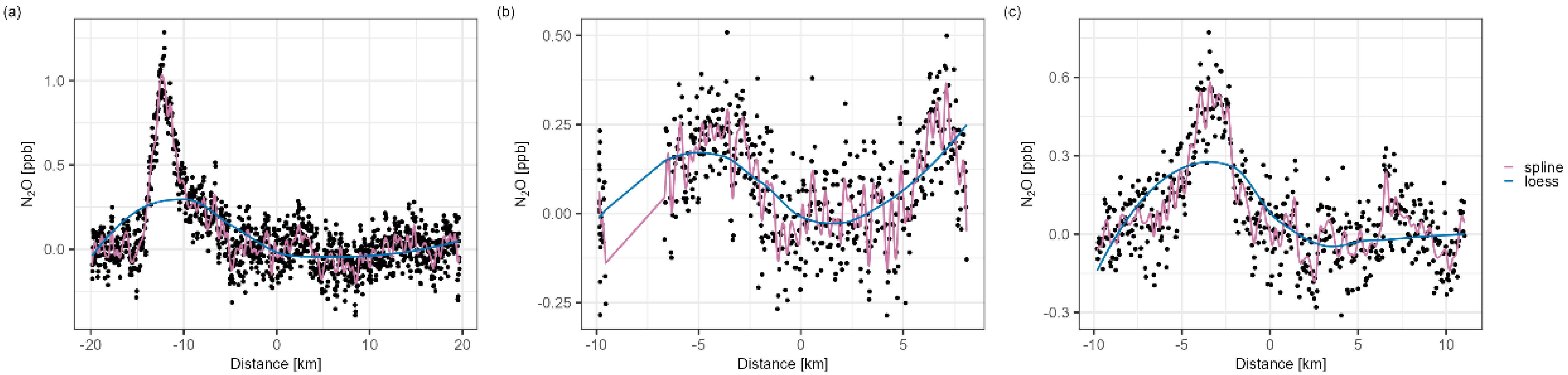
Results and discussions

Smoothed plumes of airborne measurements



Results and discussions

Smoothed modelled plumes

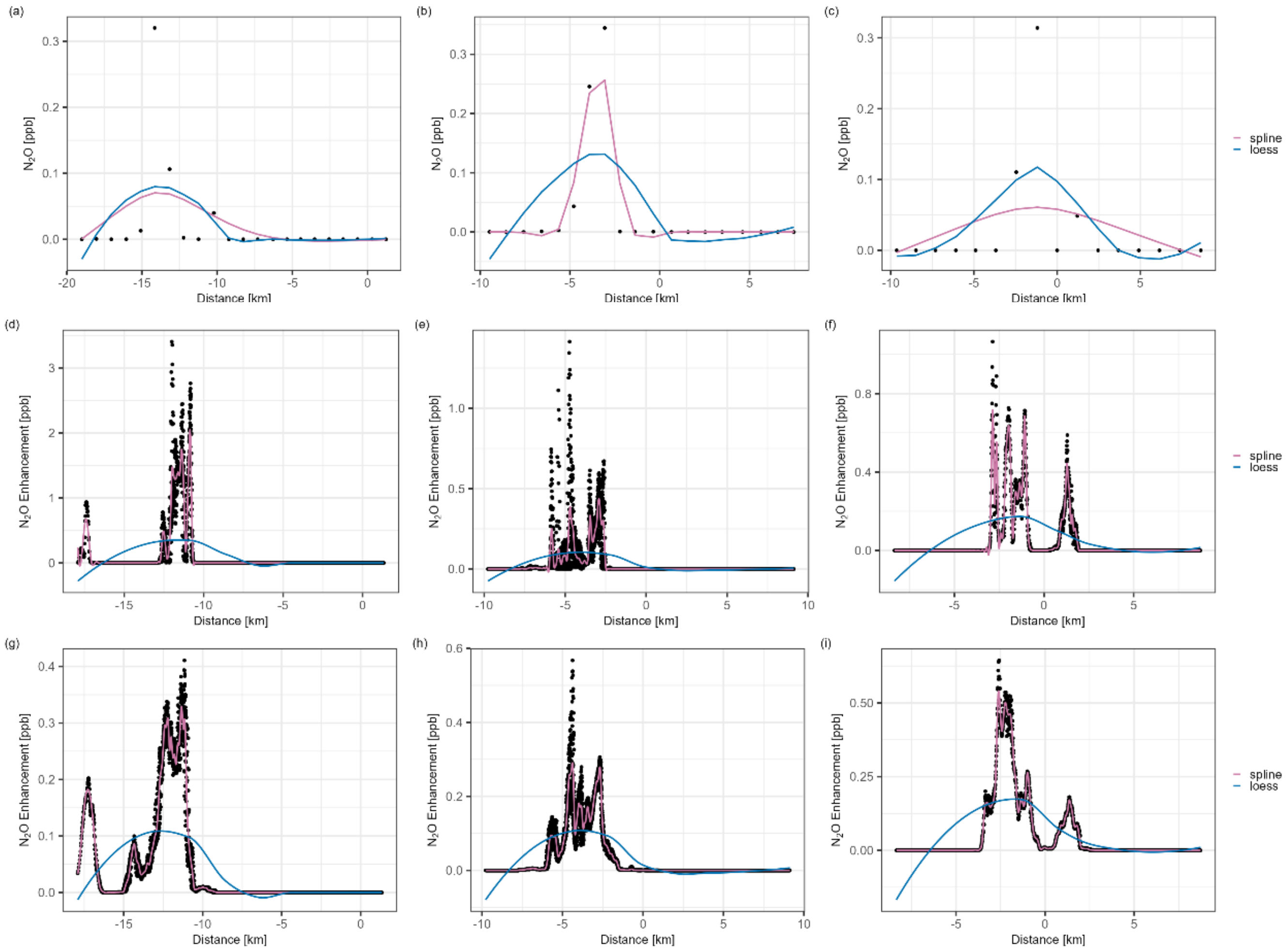


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Table 1.4 Approach 1 and the Approach 2 uncertainty assessment of 2019 emissions (without LULUCF).

Greenhouse gas	**Approach 1 annual uncertainty**	**Approach 2 annual uncertainty**
CO_2	2%	3%
CH_4	9%	9%
N_2O	38%	28%
F-gases	35%	26%
Total	**3%**	**3%**