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HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

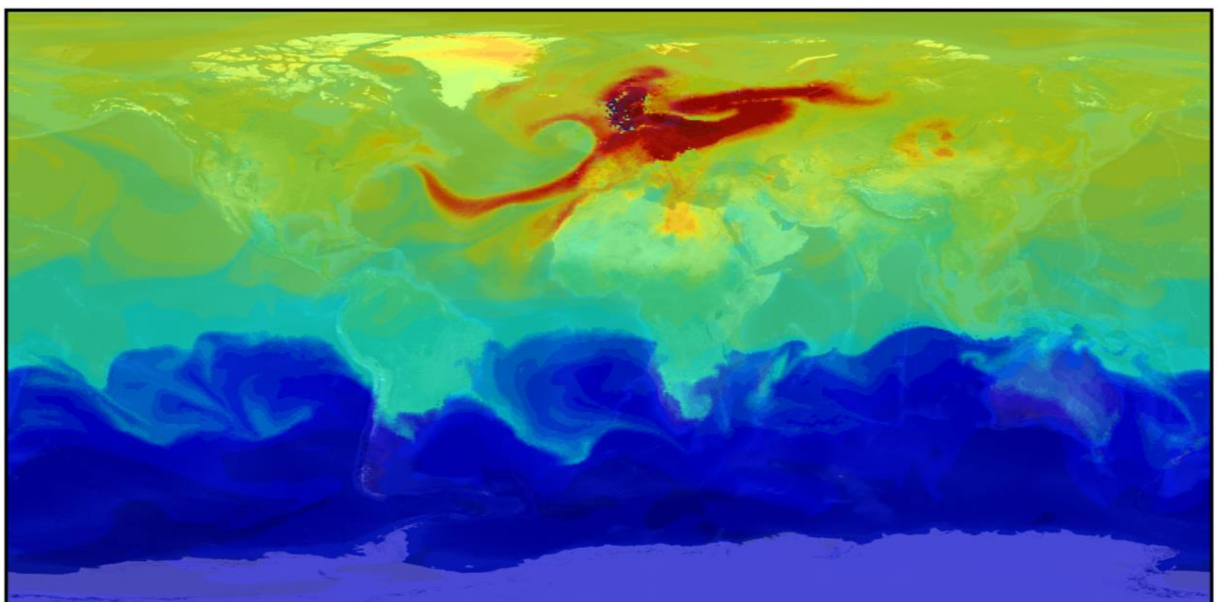
DIGITAL EARTH

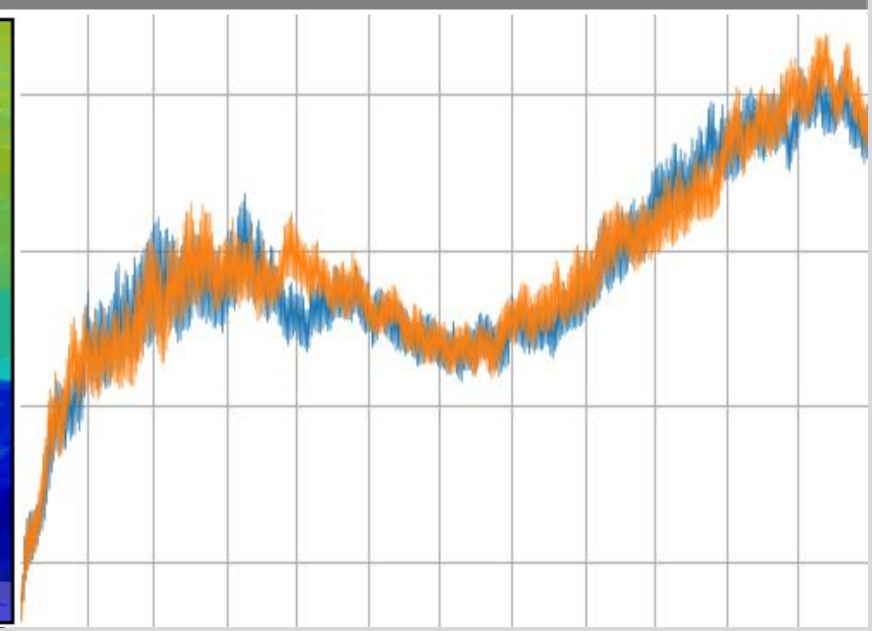
Modeling methane from the North Sea Region with ICON-ART

Christian Scharun[1], Roland Ruhnke[1], Jennifer Schröter[2], Michael Weimer[1], Peter Braesicke[1]

[1] Karlsruhe Institute of Technology - Institute of Meteorology and Climate Research
[2] Karlsruhe Institute of Technology - Steinbuch Centre for Computing

Institute of Meteorology and Climate Research





Agenda

Agenda

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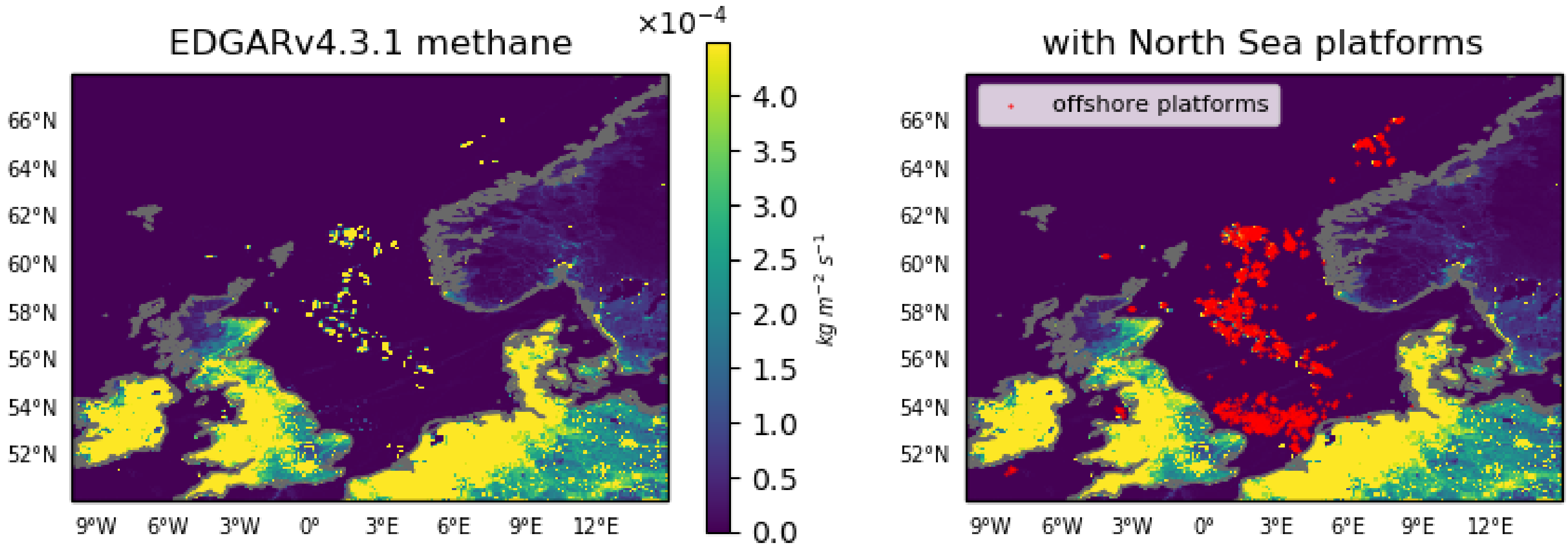
1) **Motivation and Scientific Goals**
2) Correlation of fluxes and platforms
3) ICON-ART sensitivity studies
4) The pointsource module of ART
5) Sentinel-5P satellite measurements
6) Summary

Motivation: Methane fluxes and offshore platforms

EDGAR The Emissions Database for Global Atmospheric Research

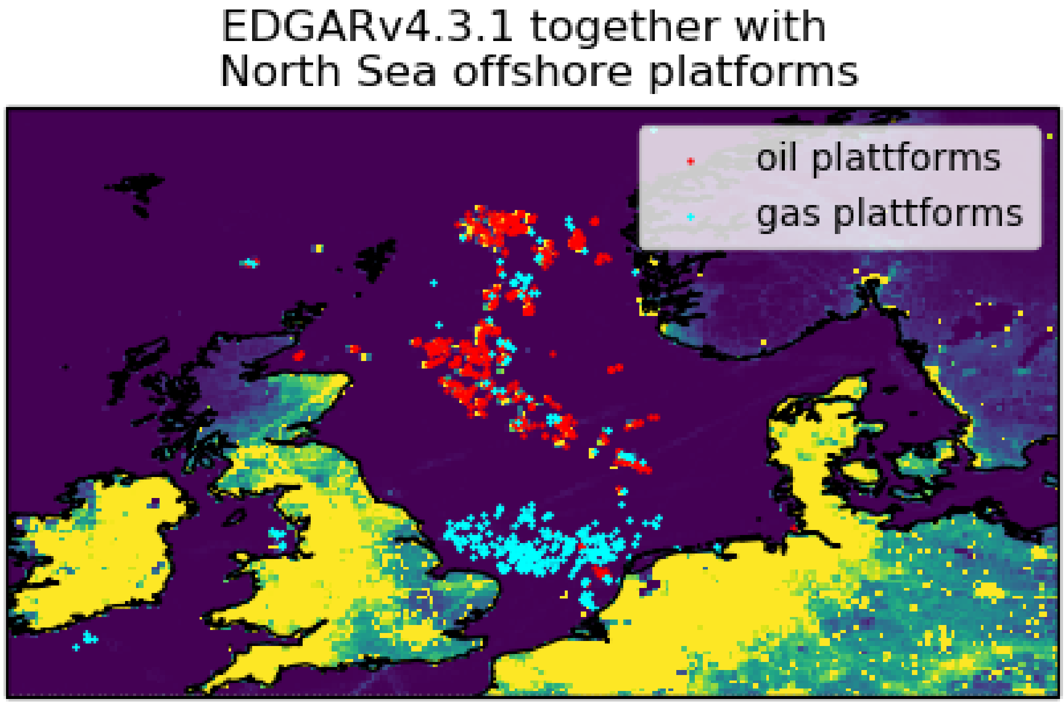


1) High methane fluxes are fitting with platform locations in the North Sea Region

2) In the southern part: Many platforms but very low methane fluxes

Janssens-Maenhout et al., NAS, 2010
OSPAR, 2011

Motivation: Methane fluxes and offshore platforms



3.3.2.1.1.1 Beschreibung der Kategorie „Öl, Exploration" (1.B.2.a.i)

Die Emissionen der Kategorie setzen sich aus den Tätigkeiten der Bohrfirmen und der Beteiligten in der Branche der Exploration zusammen. In Deutschland wird nach Erdöl und Erdgas gesucht. Es wird in der Statistik nicht nach reinen Erdöl- und Erdgasbohrungen unterschieden.

Janssens-Maenhout et al., NAS, 2010
OSPAR, 2011
Umweltbundesamt, 2018

Motivation: Methane fluxes and offshore platforms

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3.3.2.1.1.2 Methodische Aspekte der Kategorie „Öl, Exploration“ (1.B.2.a.i)

Nach Aussagen des BVEG (ehemalig WEG) treten so gut wie keine diffusen Emissionen bei Bohrvorgängen auf, da an Bohrlöchern regelmäßig Messungen durchgeführt (Methansensoren in der Schutzhütte um das Bohrloch, Ultraschallmessungen, Ringraummanometer) und alte nicht mehr genutzte Bohrungen verfüllt und in der Regel mit einem Betondeckel versehen werden.

Umweltbundesamt, 2018
Digital Earth, 2020

Motivation: Methane fluxes and offshore platforms

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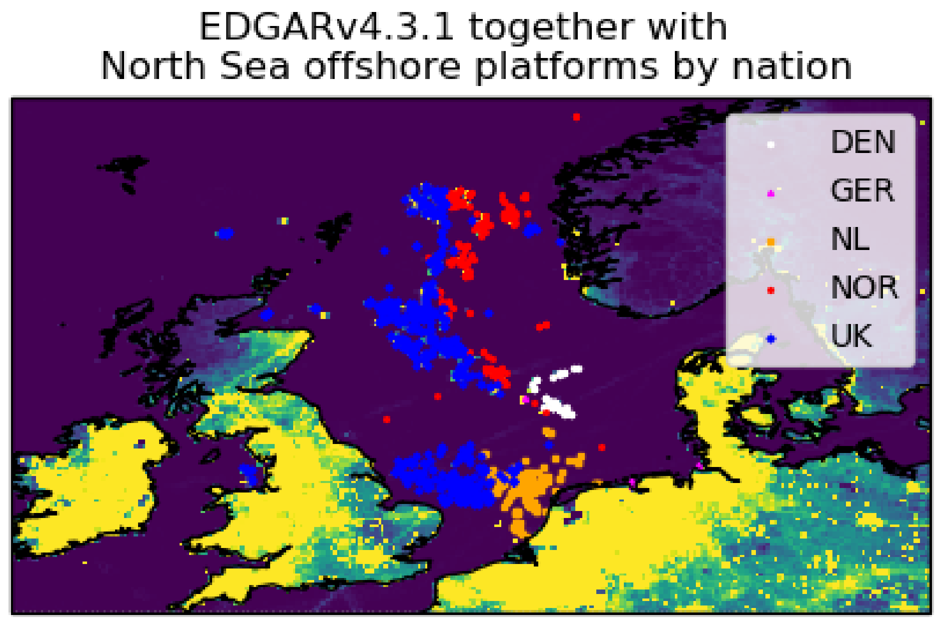
3.3.2.1.1.4 Kategoriespezifische Qualitätssicherung/-kontrolle und Verifizierung der Kategorie „Öl, Exploration“ (1.B.2.a.i)

(...)

Aufgrund fehlender landesspezifischer Daten wurde ein externes Gutachten (Bender, 2009b) in Auftrag gegeben. Es kam in seiner Quellgruppenanalyse zu dem Ergebnis, dass die Default-Faktoren für Deutschland anwendbar sind. Ein Vergleich mit anderen Ländern konnte aufgrund der geringen Vergleichsmöglichkeiten und aufgrund nicht ineinander umrechenbarer Einheiten nicht durchgeführt werden.



Janssens-Maenhout et al., NAS, 2010
OSPAR, 2011
Umweltbundesamt, 2018

Scientific Goals

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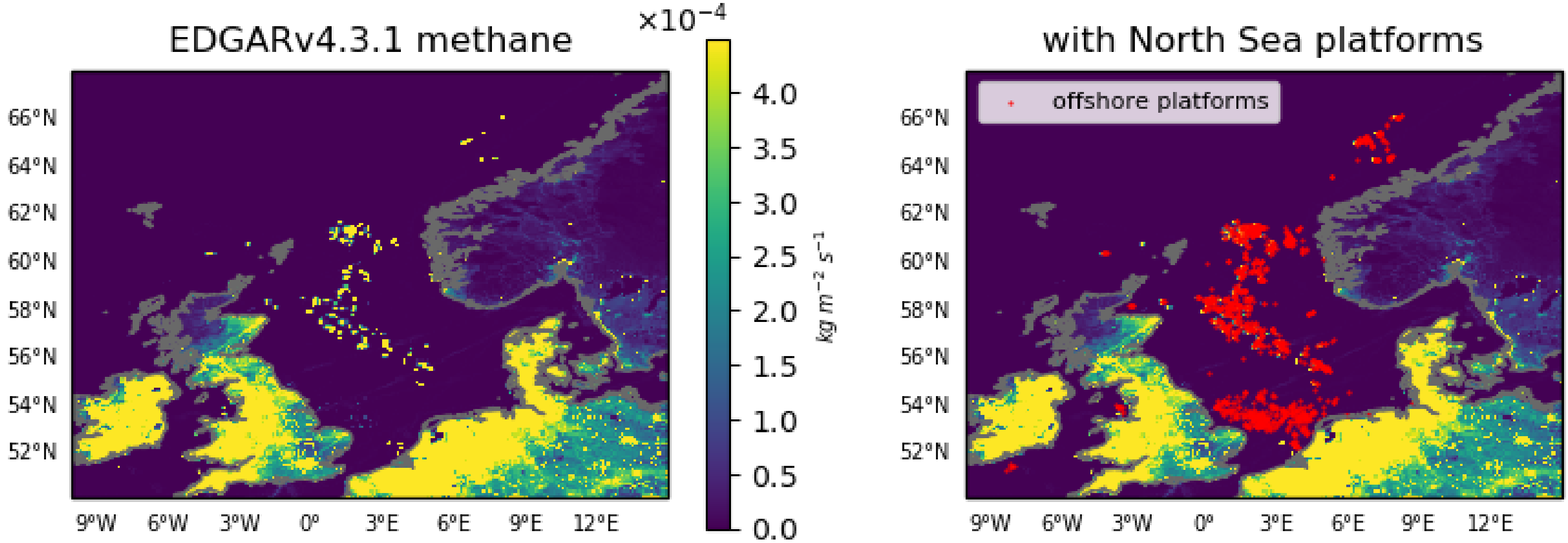
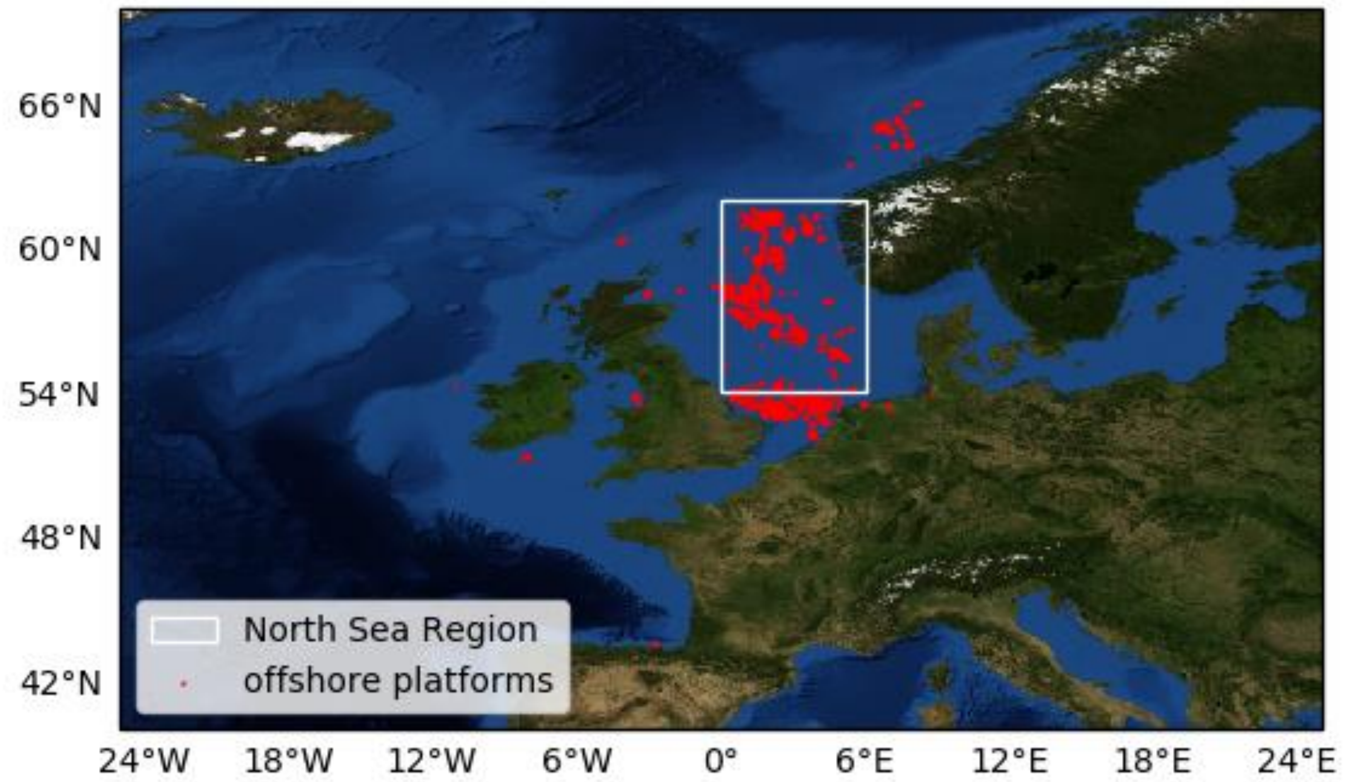


- Adjustment of CH_4 emissions fluxes from the North Sea
- Evaluation of the differences compared to established emission data bases like EDGAR
- Investigation of the impact of adjusted emission fluxes for CH_4 budget (Europe and global)

Janssens-Maenhout et al., NAS, 2010 and OSPAR, 2011

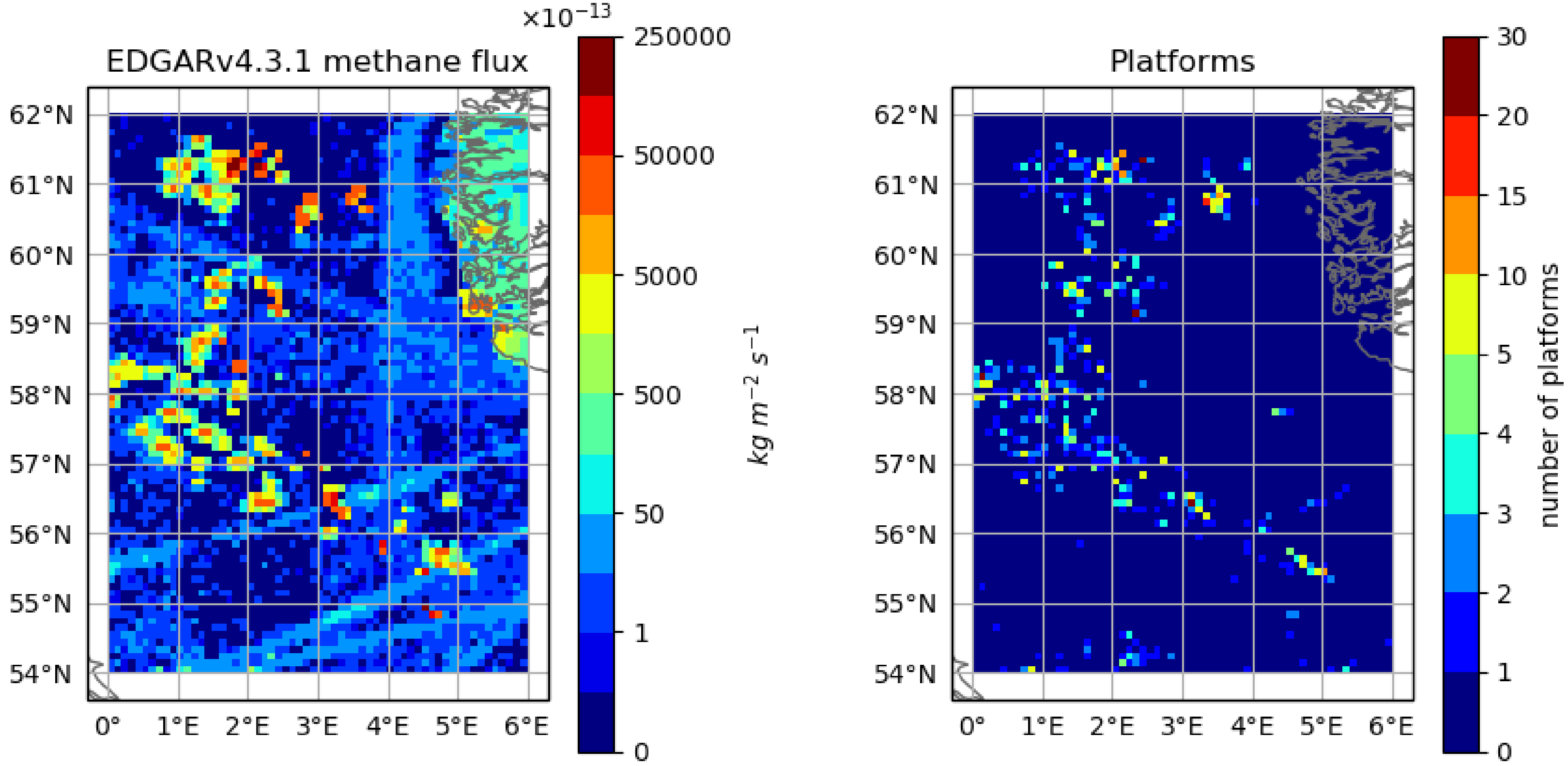
Agenda

Definition of the North Sea Region



OSPAR, 2011
NASA visible earth, 2019

Correlation of fluxes and platforms

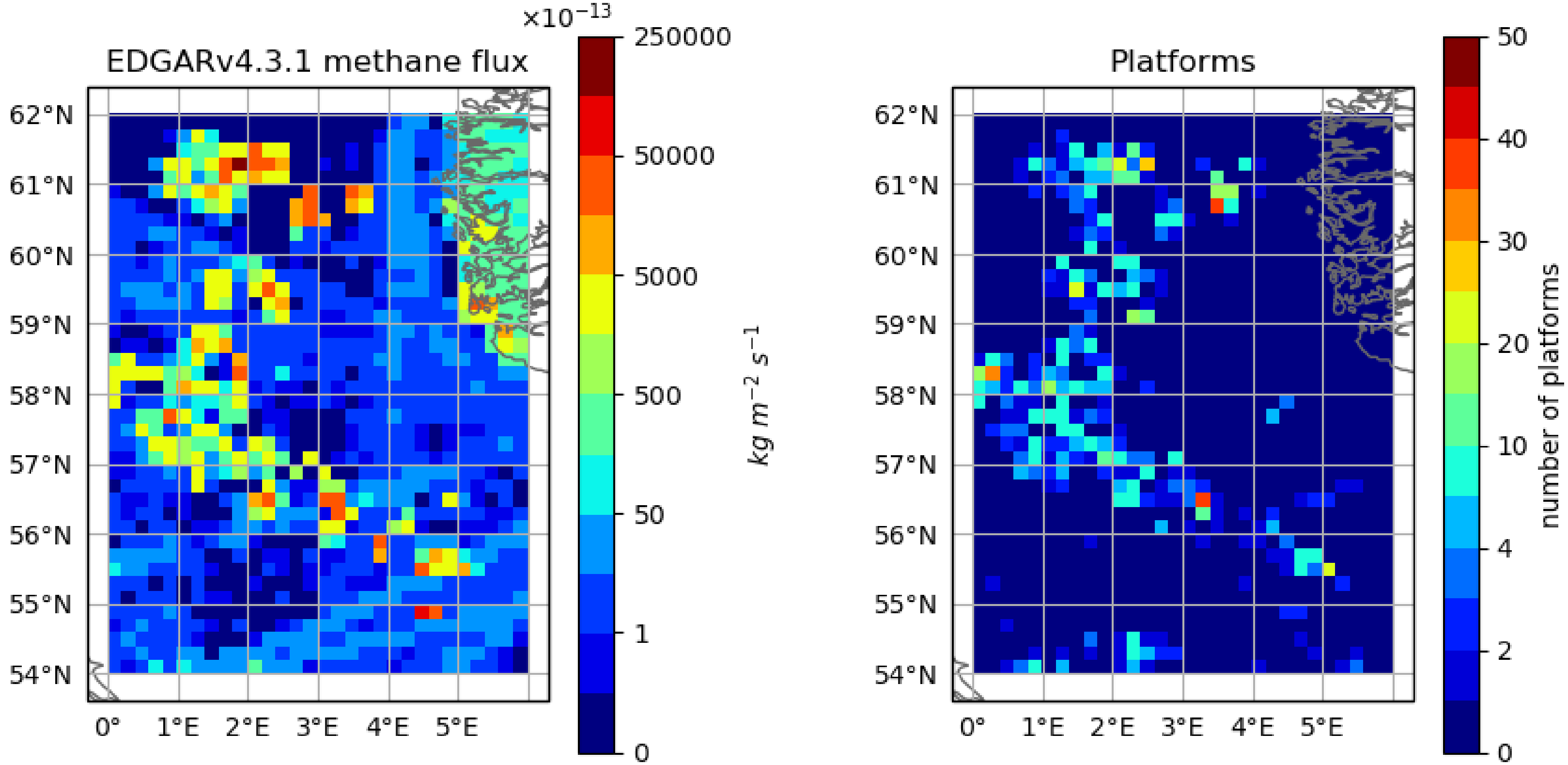


Grid resolution: 0.1° x 0.1°

r = 0.205

Janssens-Maenhout et al., NAS, 2010 and OSPAR, 2011

Correlation of fluxes and platforms

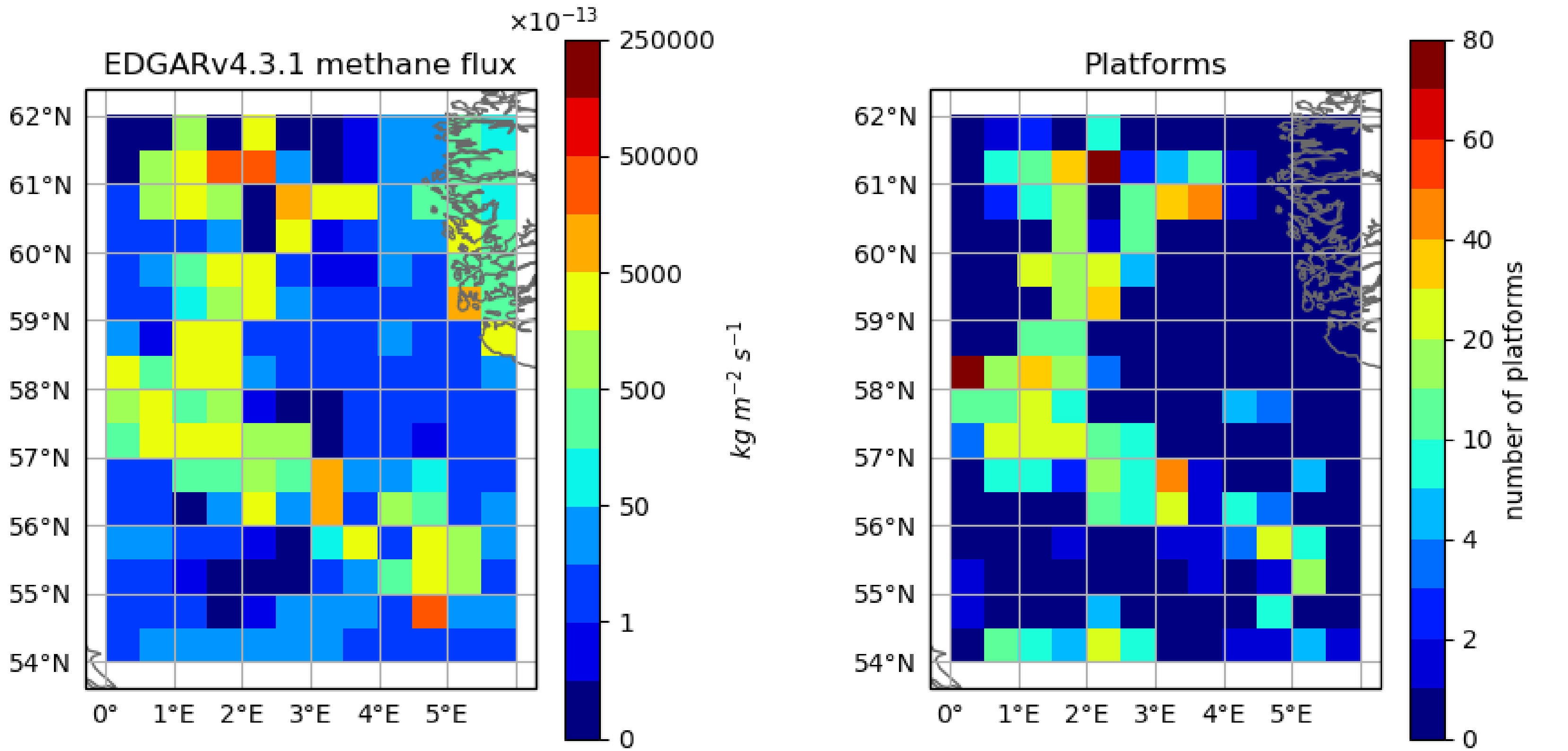


Grid resolution: 0.2° x 0.2°

r = 0.381

Janssens-Maenhout et al., NAS, 2010 and OSPAR, 2011

Correlation of fluxes and platforms

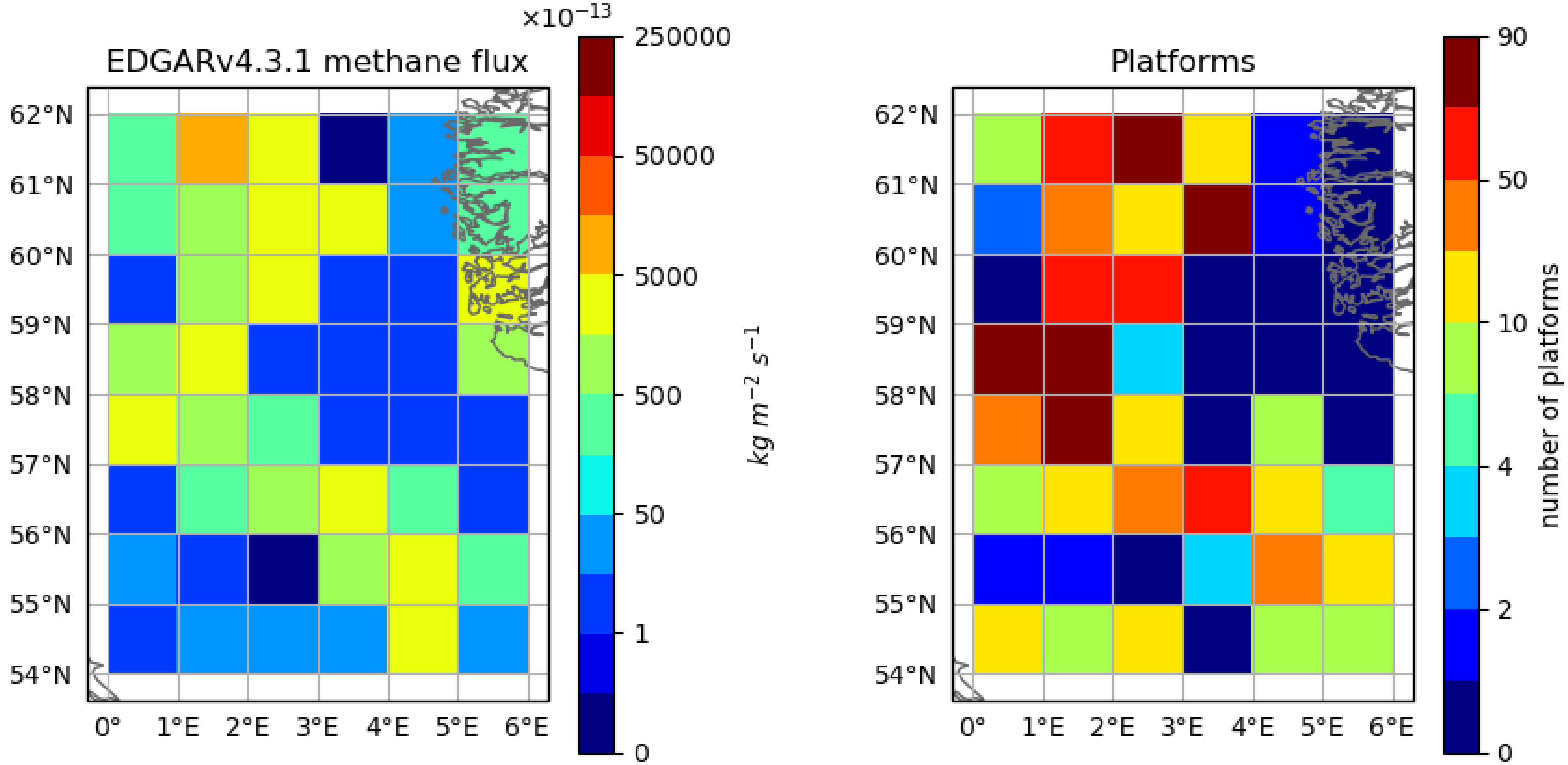


Grid resolution: 0.5° x 0.5°

r = 0.548

Janssens-Maenhout et al., NAS, 2010 and OSPAR, 2011

Correlation of fluxes and platforms

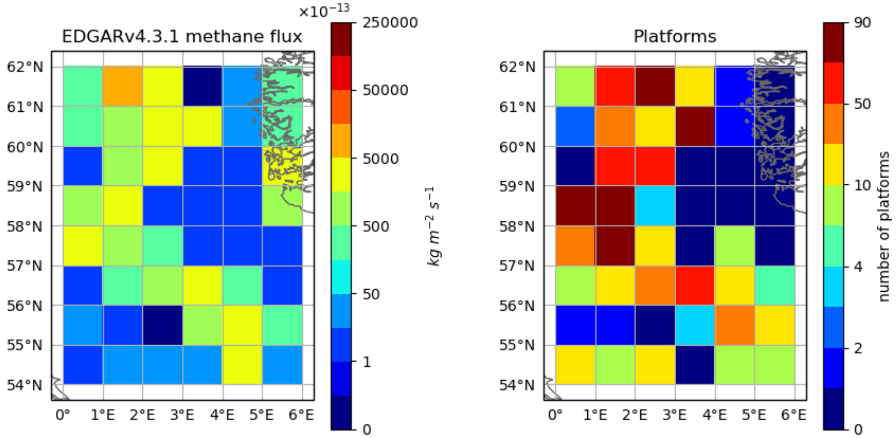


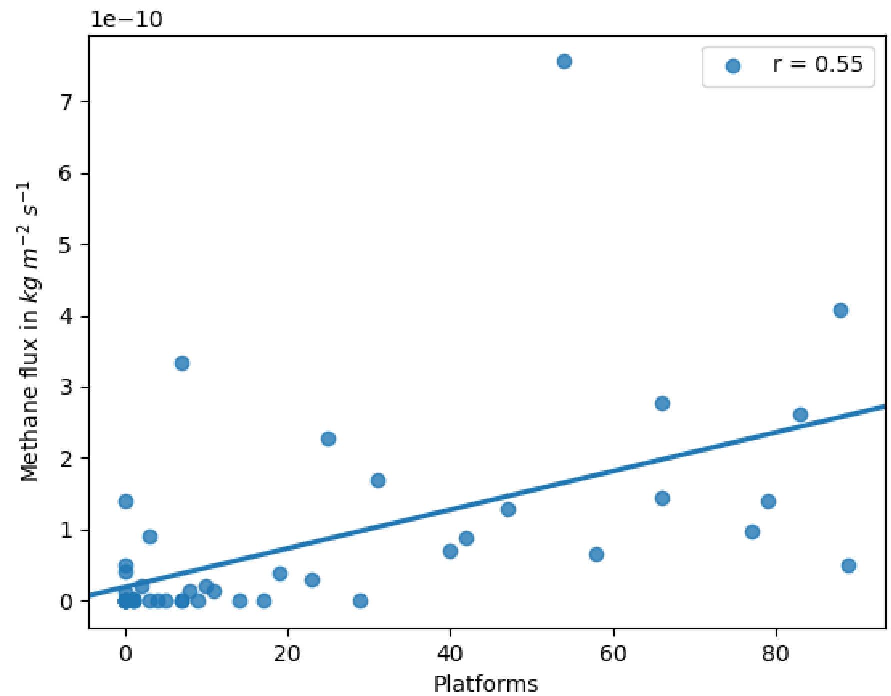
Grid resolution: 1° x 1°

r = 0.55

Janssens-Maenhout et al., NAS, 2010 and OSPAR, 2011

Correlation of fluxes and platforms



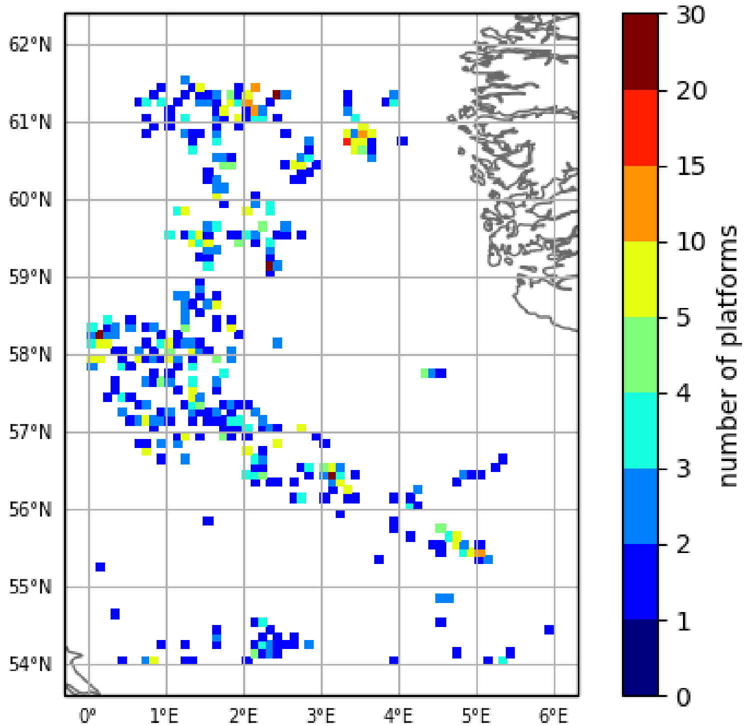


- Correlation of methane fluxes and number of platforms is fine
- Pearsons r is increasing with lower grid resolution
- Is there a mismatch of the datasets?

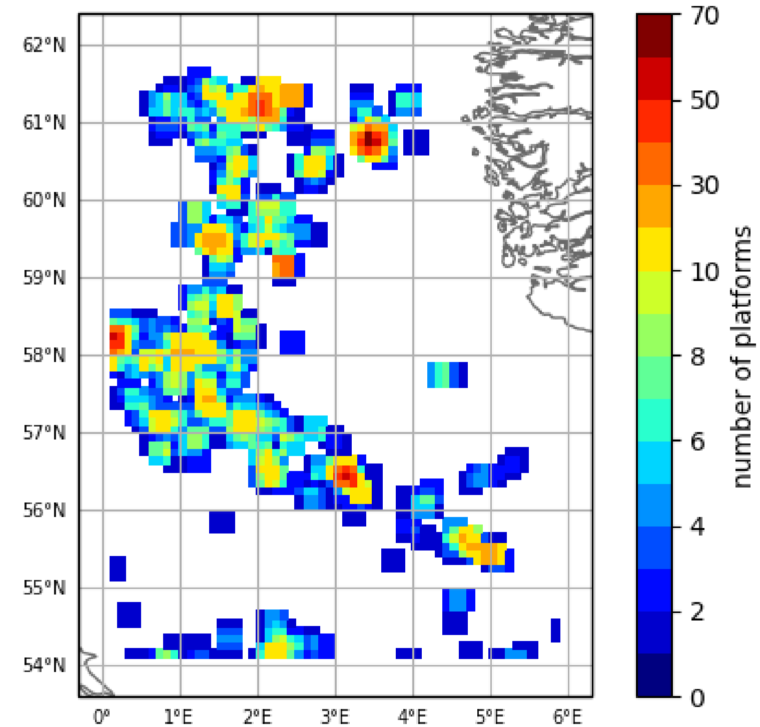
0.1° x 0.1°	r = 0.205
0.2° x 0.2°	r = 0.381
0.5° x 0.5°	r = 0.548
1° x 1°	r = 0.55

Janssens-Maenhout et al., NAS, 2010 and OSPAR, 2011

Investigating the mismatch



Including the eight grid cells around



OSPAR, 2011

Investigating the mismatch

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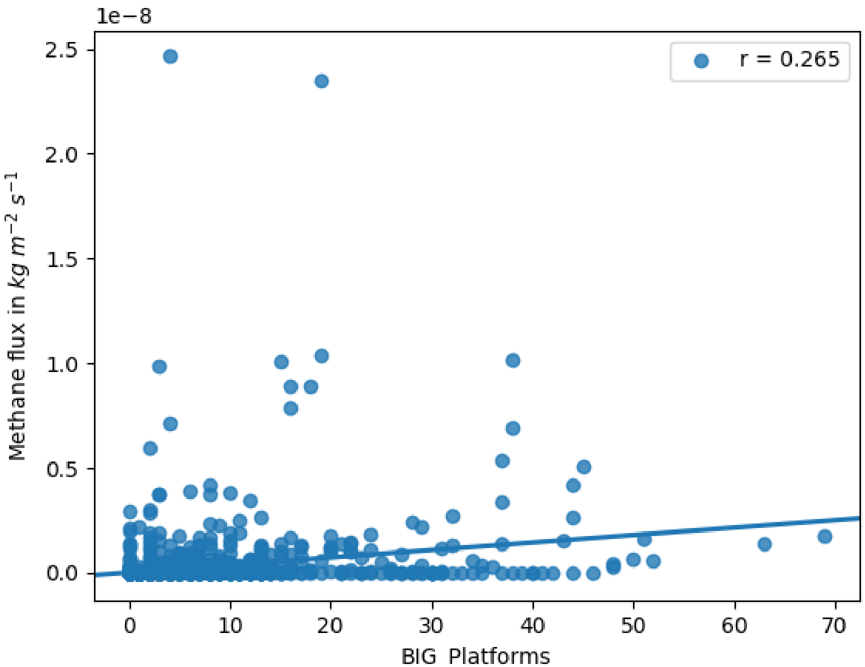
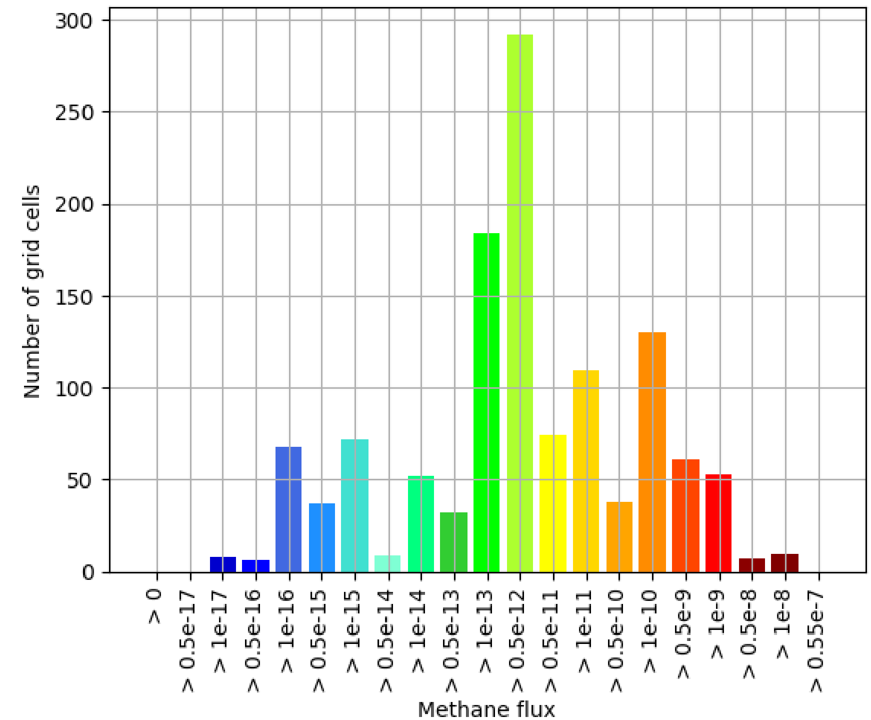
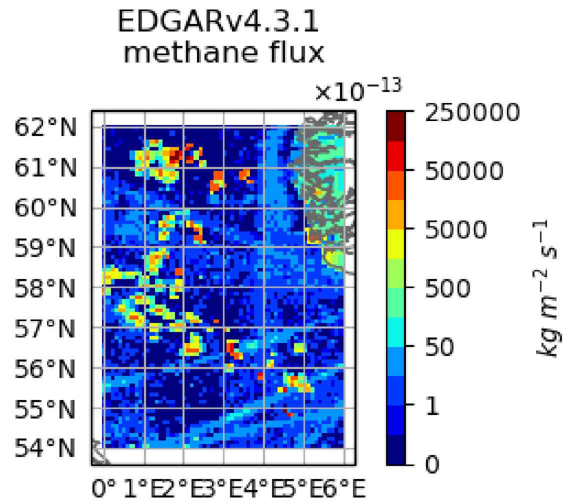
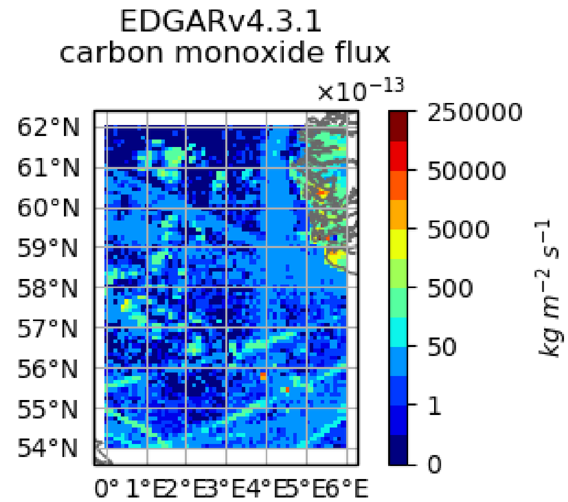


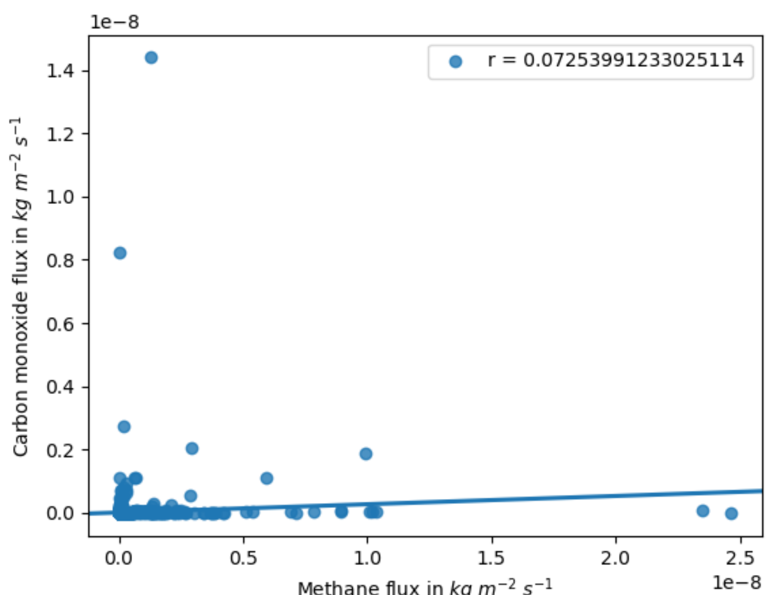


- Correlation of methane fluxes and number of platforms is better than without the new method
- The distribution of the methane fluxes in the new method suggests to be trimodal and maybe country specific
- Can we think of another approach that is independent of platform locations and the mismatch?

Correlation of methane and carbon monoxide



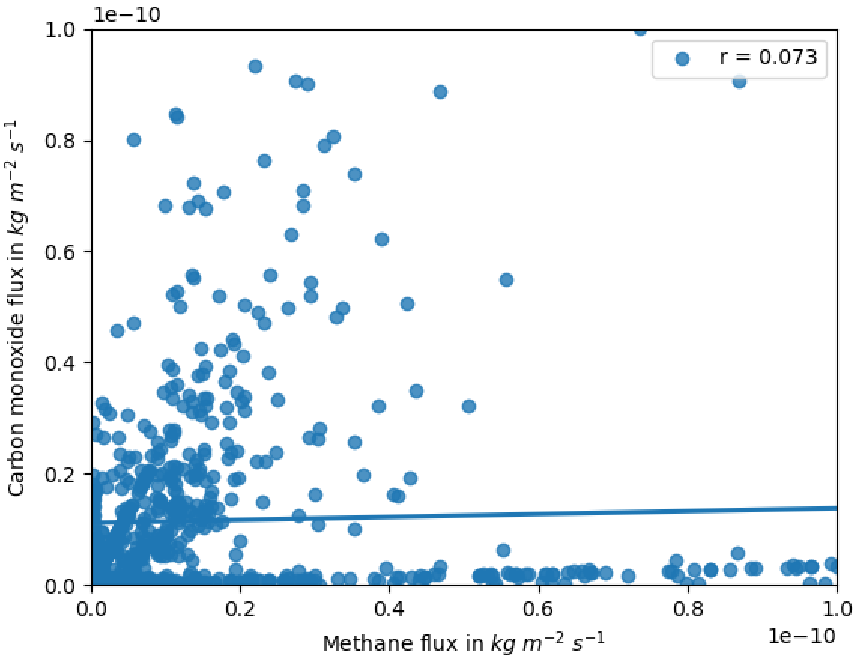


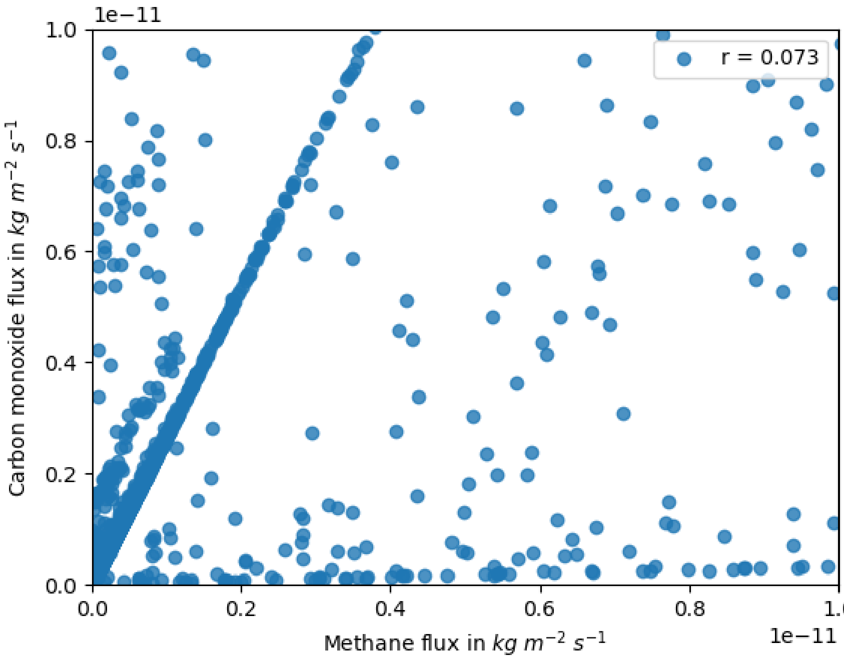


No correlation between CH_4 and CO

Janssens-Maenhout et al., NAS, 2010

Correlation of methane and carbon monoxide

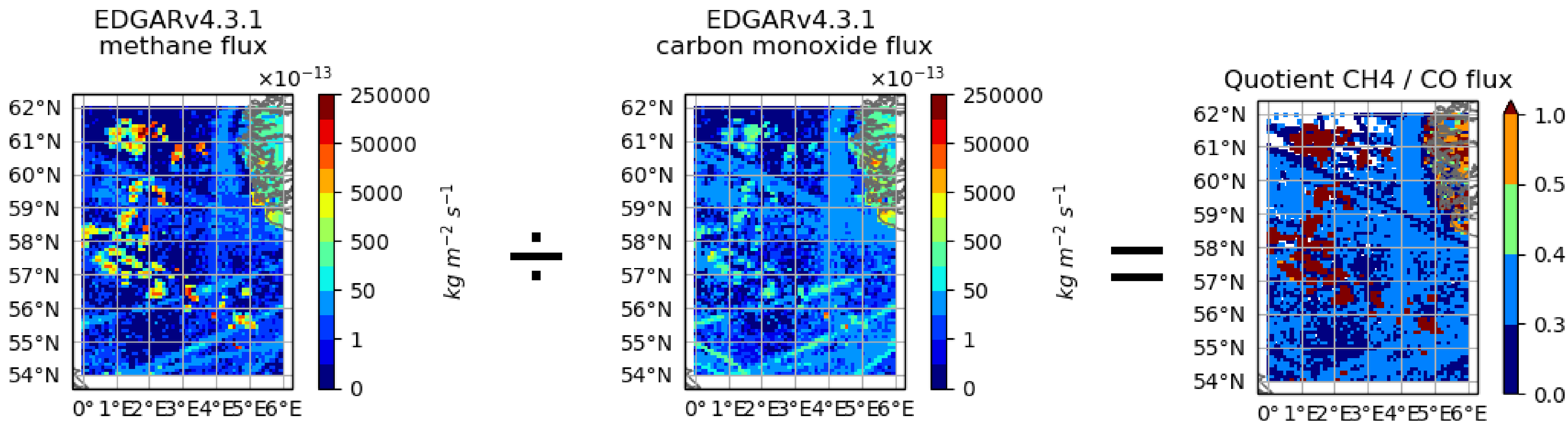




- Some values between the noise seem to be very well correlated
- How can we learn more about them?

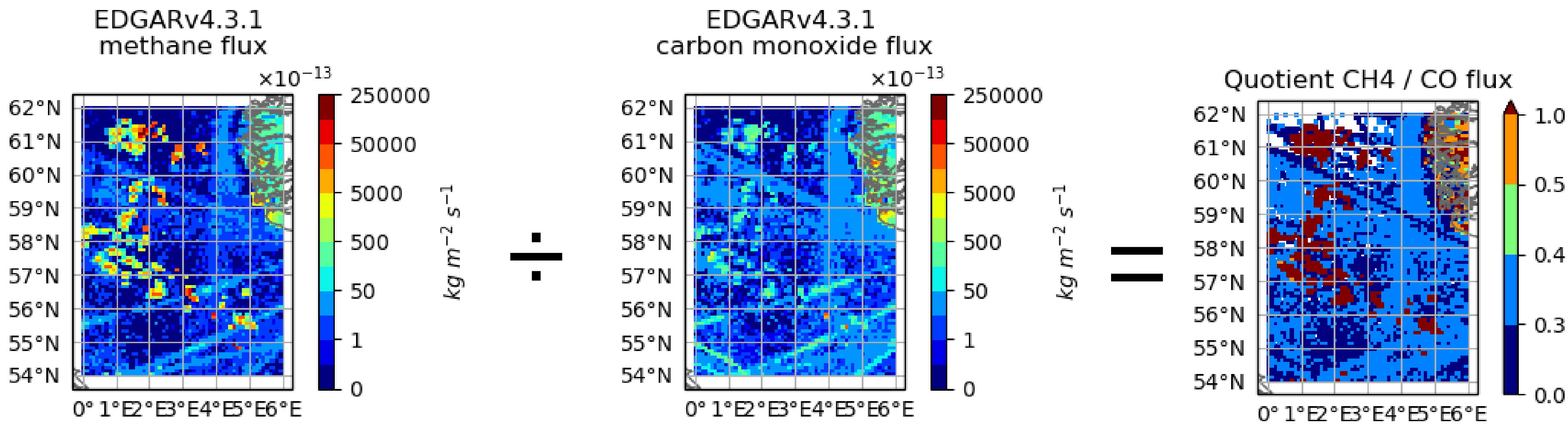
Janssens-Maenhout et al., NAS, 2010

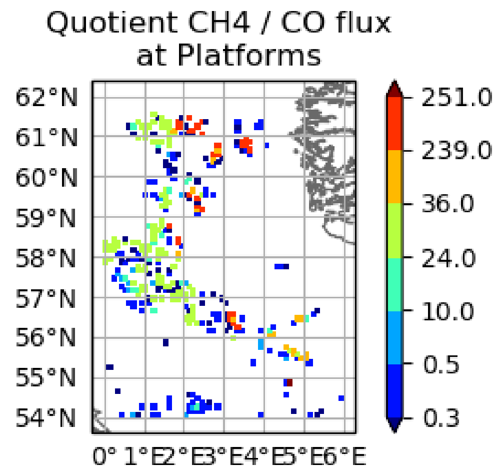
Correlation of methane and carbon monoxide



Janssens-Maenhout et al., NAS, 2010

Correlation of methane and carbon monoxide





Janssens-Maenhout et al., NAS, 2010 and OSPAR, 2011

Correlation of methane and carbon monoxide

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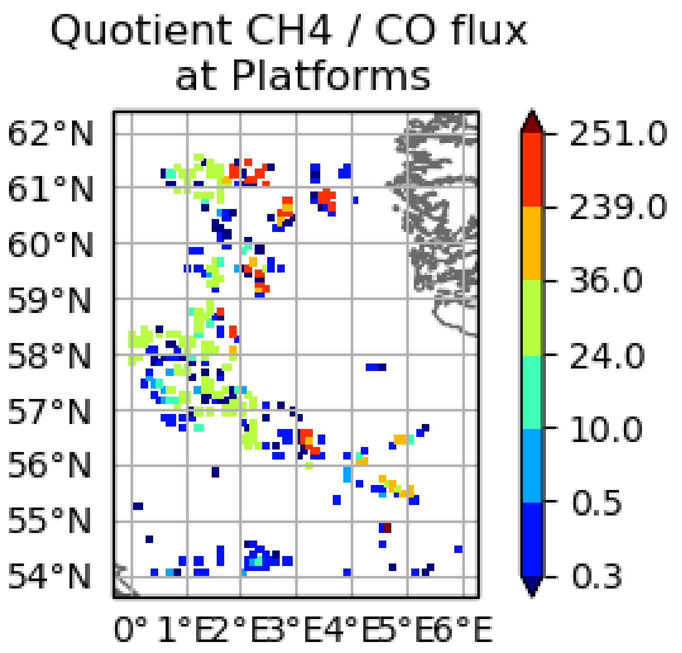

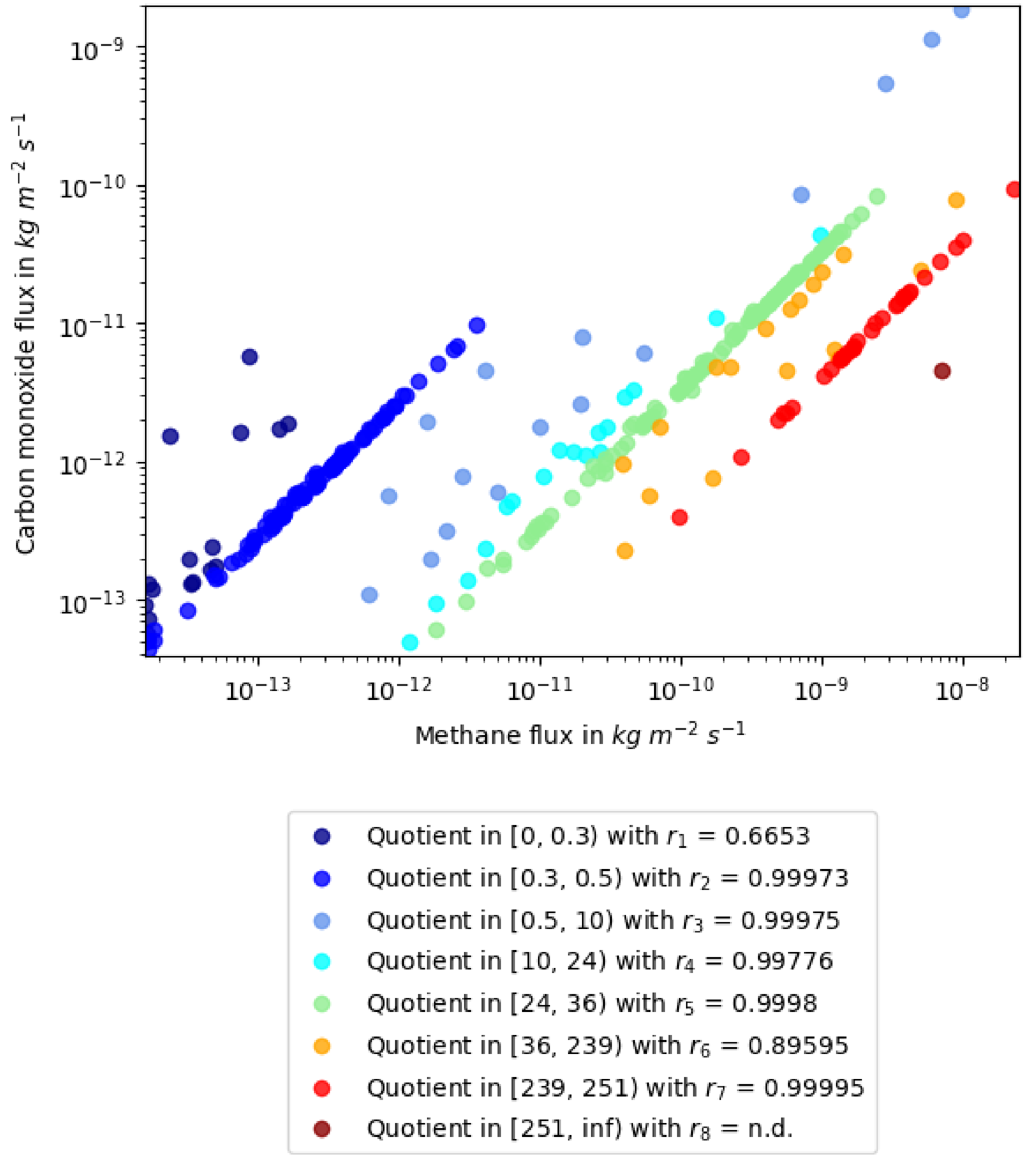

Janssens-Maenhout et al., NAS, 2010 and OSPAR, 2011

Correlation of methane and carbon monoxide

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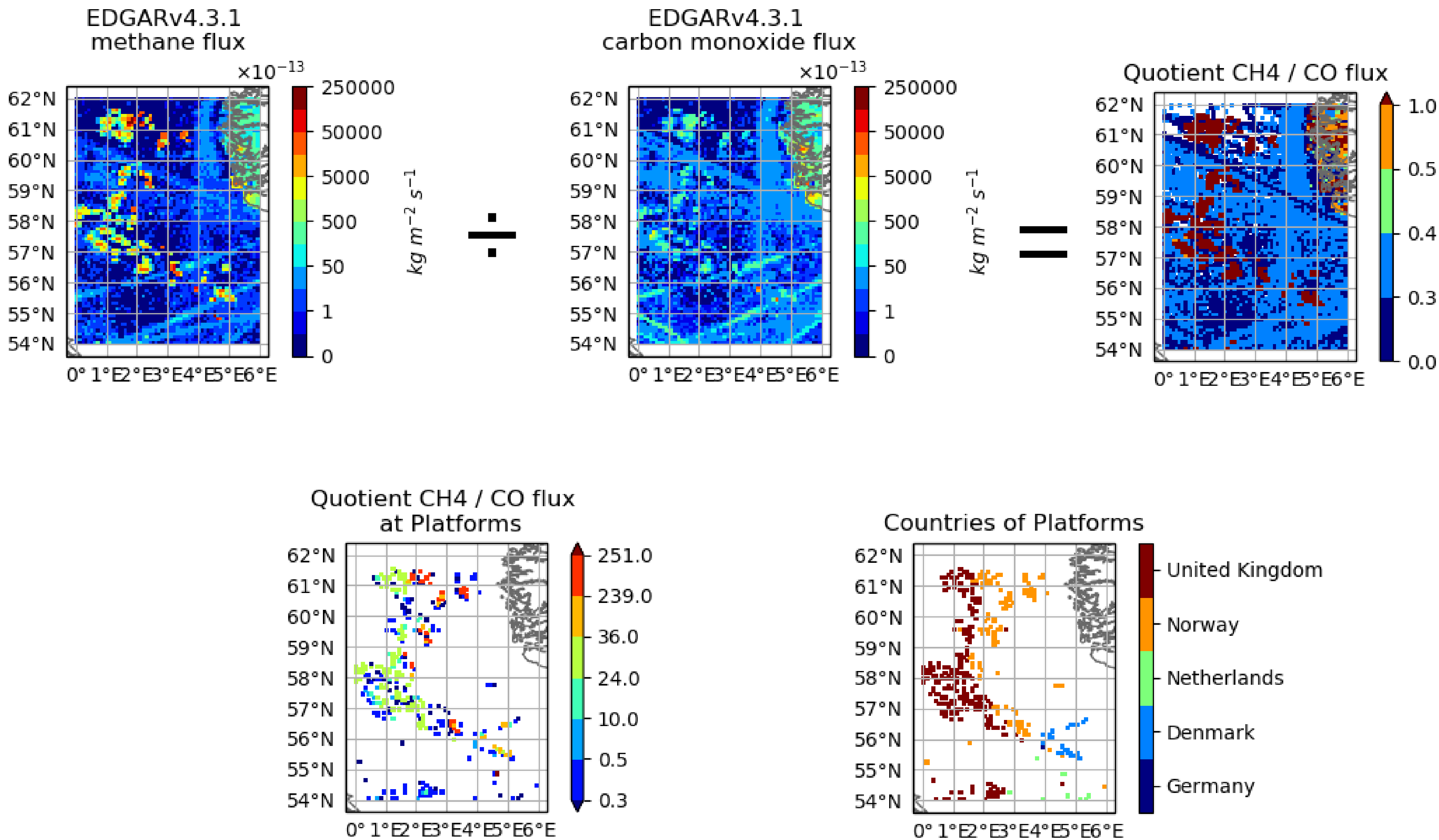
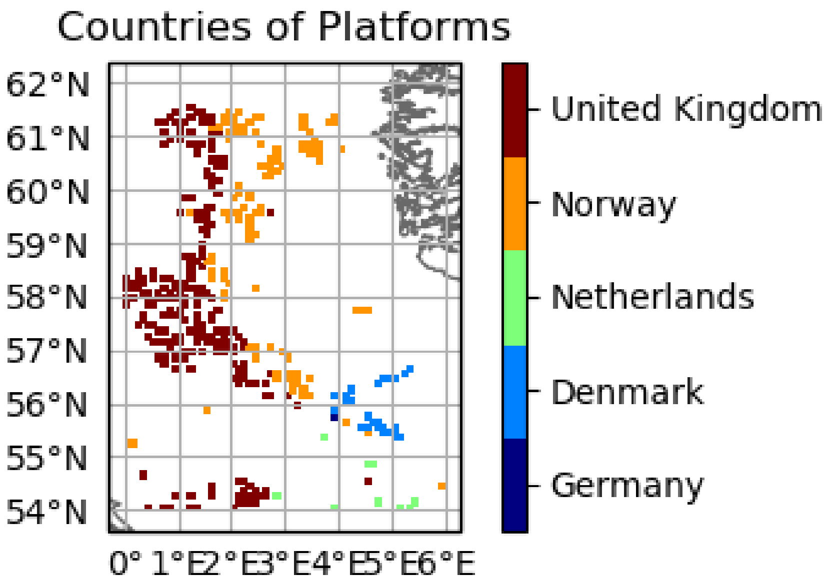
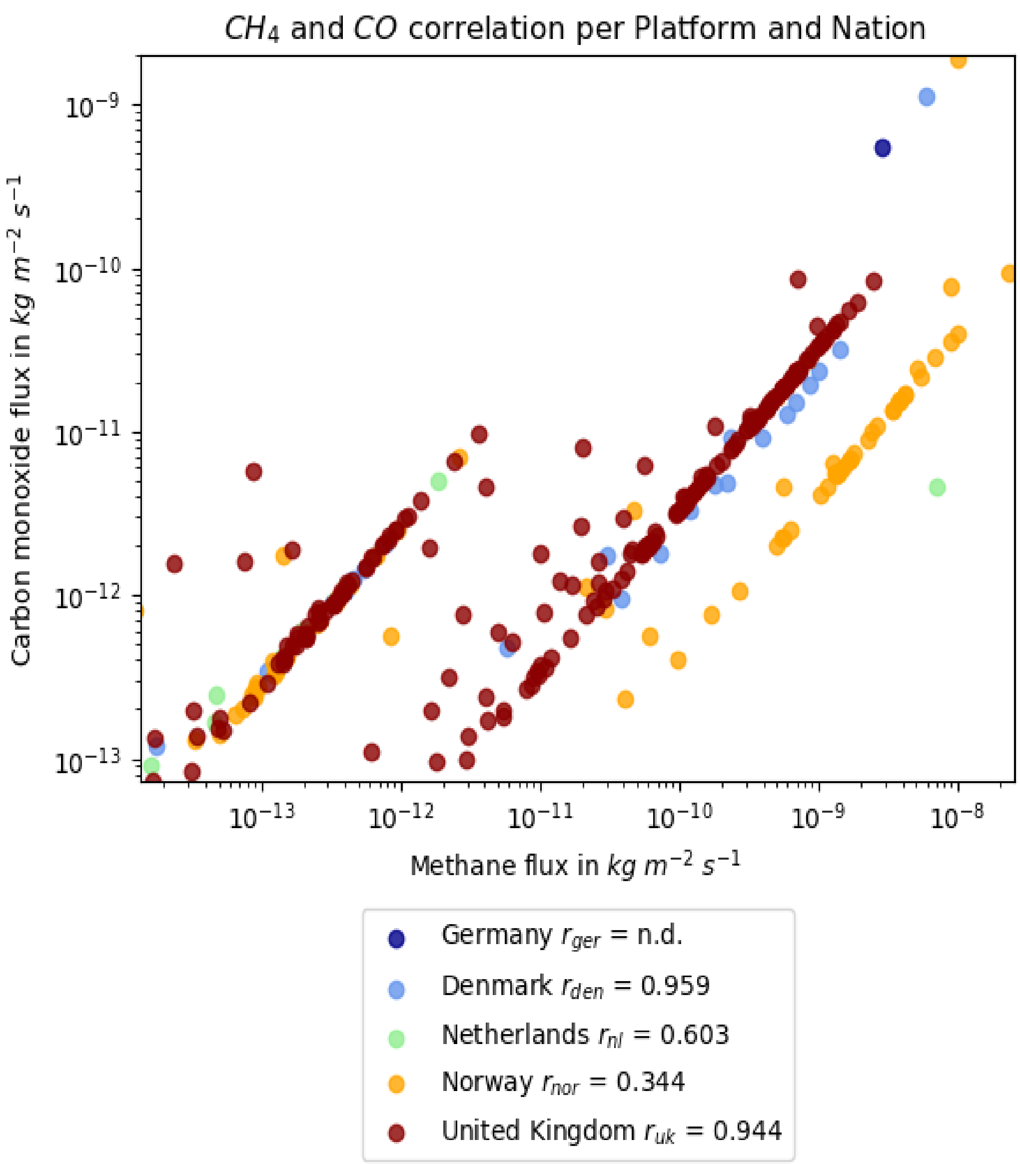


Janssens-Maenhout et al., NAS, 2010 and OSPAR, 2011

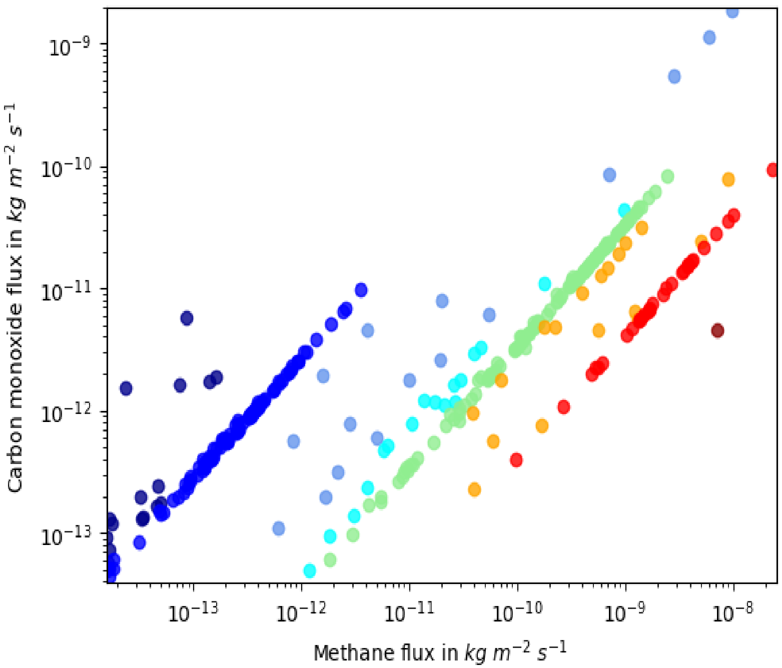
Correlation of methane and carbon monoxide

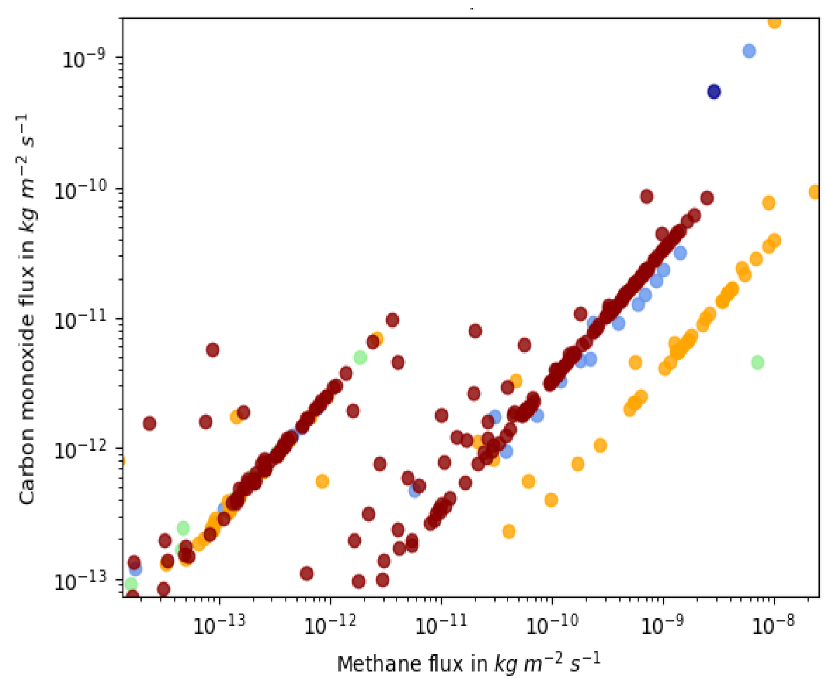




Janssens-Maenhout et al., NAS, 2010 and OSPAR, 2011

Correlation of methane and carbon monoxide





- CH_4 and CO are correlated in EDGAR at platform locations
- The quotient of CH_4 and CO seems to be related to the nation of a platform
- Adjust the missing emissions with the nation-specific quotient of CH_4 and CO (estimate CH_4 emissions through CO satellite measurements)

Janssens-Maenhout et al., NAS, 2010 and OSPAR, 2011

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1) Motivation and Scientific Goals

2) Correlation of fluxes and platforms

3) **ICON-ART sensitivity studies**

4) The pointsource module of ART

5) Sentinel-5P satellite measurements

6) Summary

ICON-ART sensitivity studies

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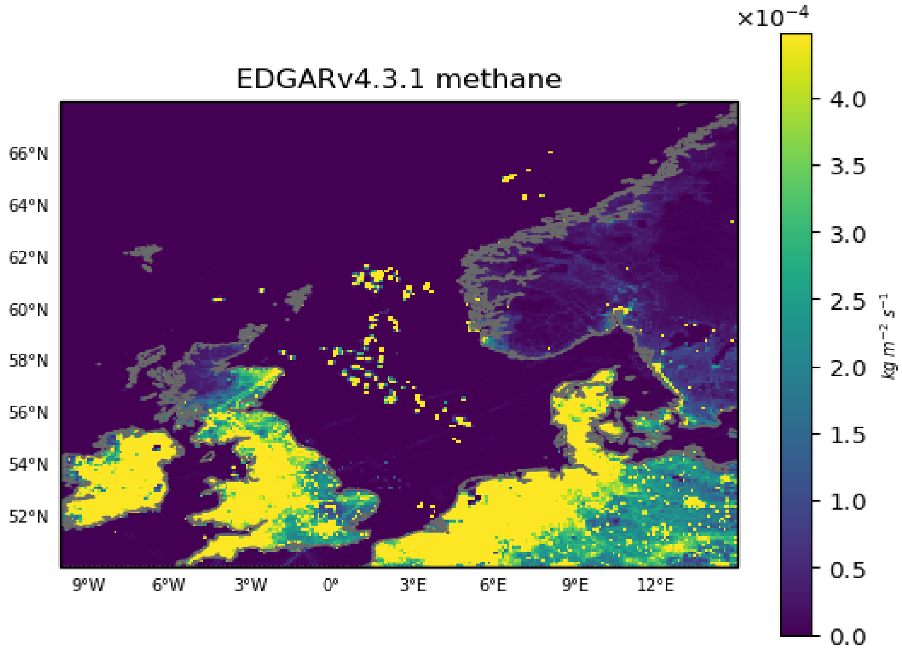
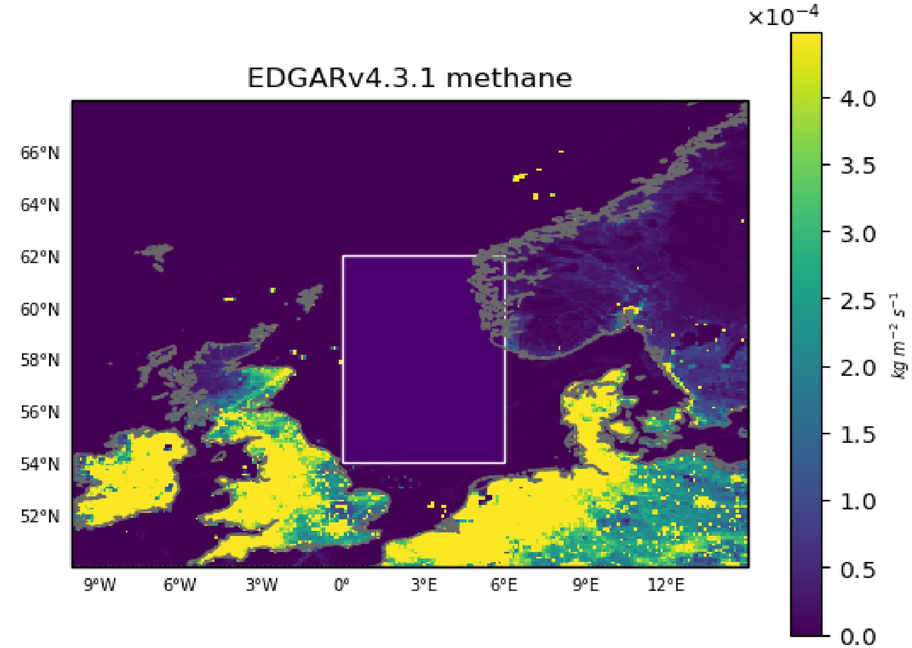
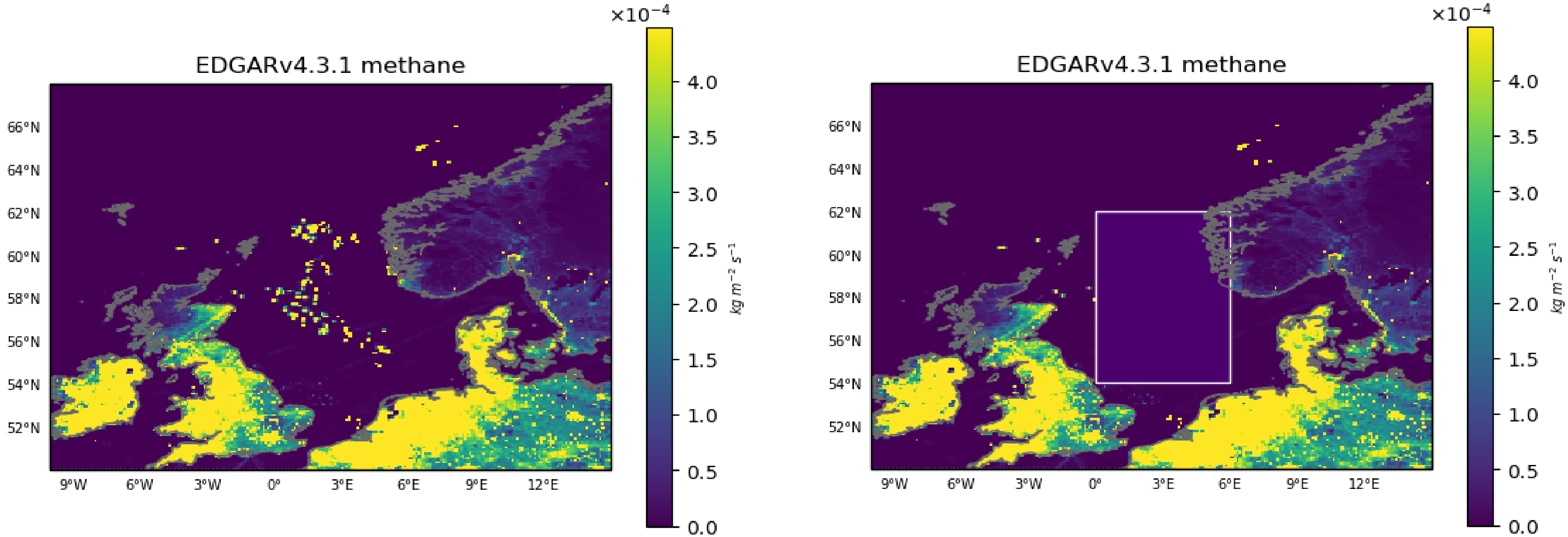




- EDGAR as anthropogenic methane emissions
- Second simulation without emissions in the North Sea Region

Janssens-Maenhout et al., NAS, 2010

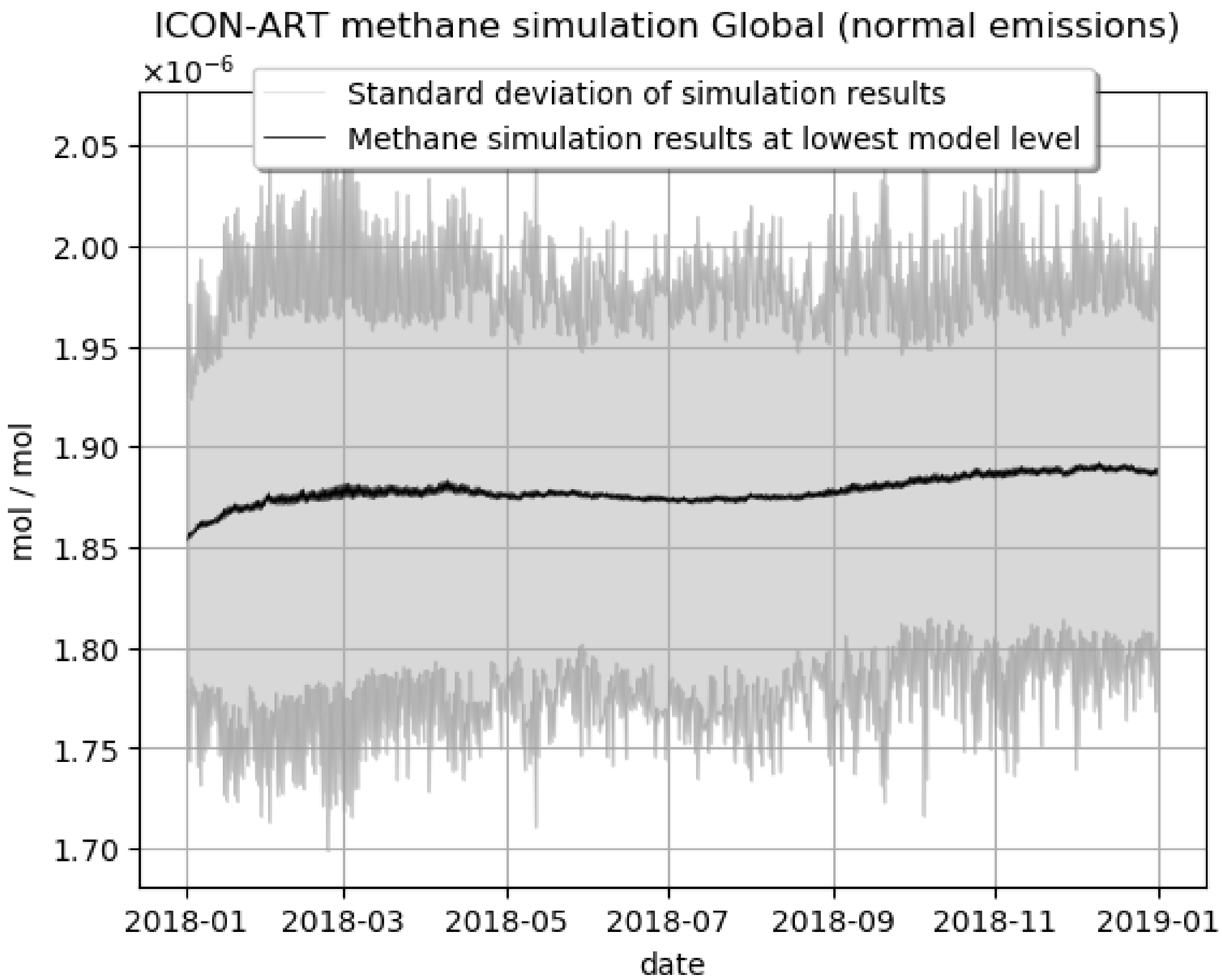
ICON-ART sensitivity studies



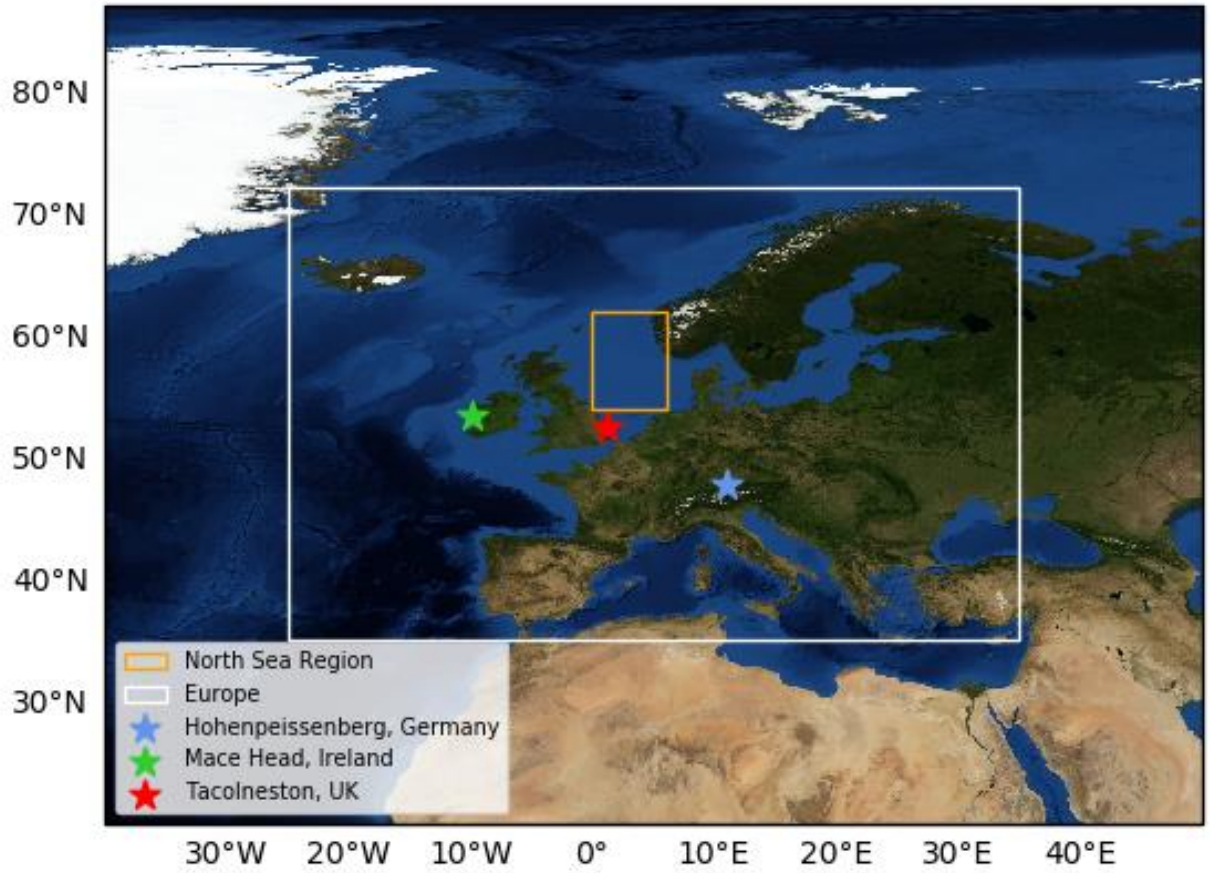
Initialisation values	NH: 1900 ppbv CH_4 (at lowest model level) SH: 1800 ppbv CH_4 (at lowest model level)
Simulation period	2018-01-01 to 2019-01-01
Global grid resolution	R2B05: Δx ~80 km
Input emission inventory	EDGARv4.3.1 (monthly mean, 0.1°x0.1°)
Output	0.5°x0.5°, Δt= 12 hours
ICON-ART chemistry mode	Tracers with simplified OH chemistry

Janssens-Maenhout et al., NAS, 2010

ICON-ART sensitivity studies



ICON-ART sensitivity studies



- Compare the model data with three NOAA measurement sites in Europe
- Weekly measurement data

NOAA, Earth System Research Laboratory and NASA visible earth, 2019

ICON-ART sensitivity studies

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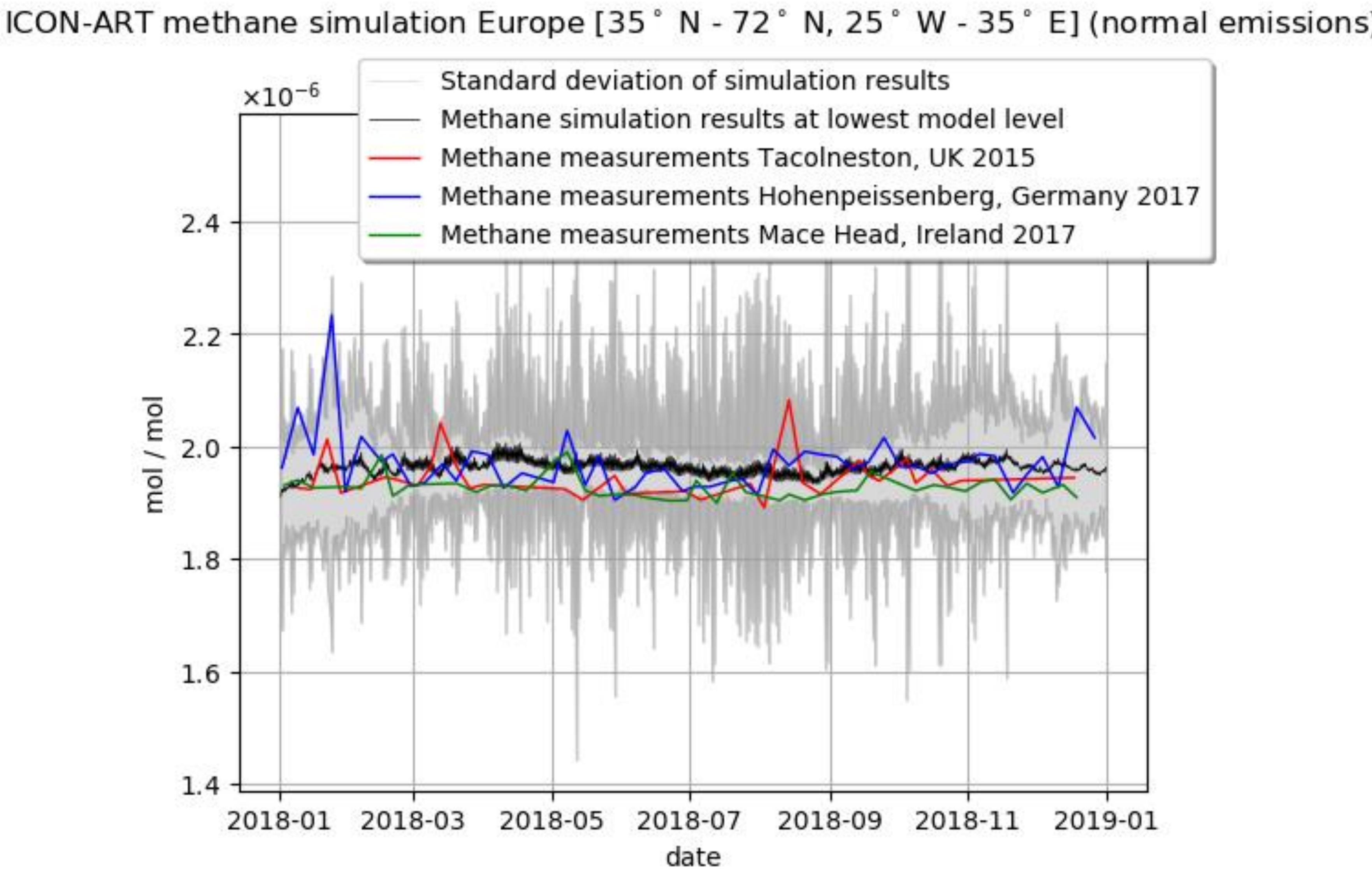
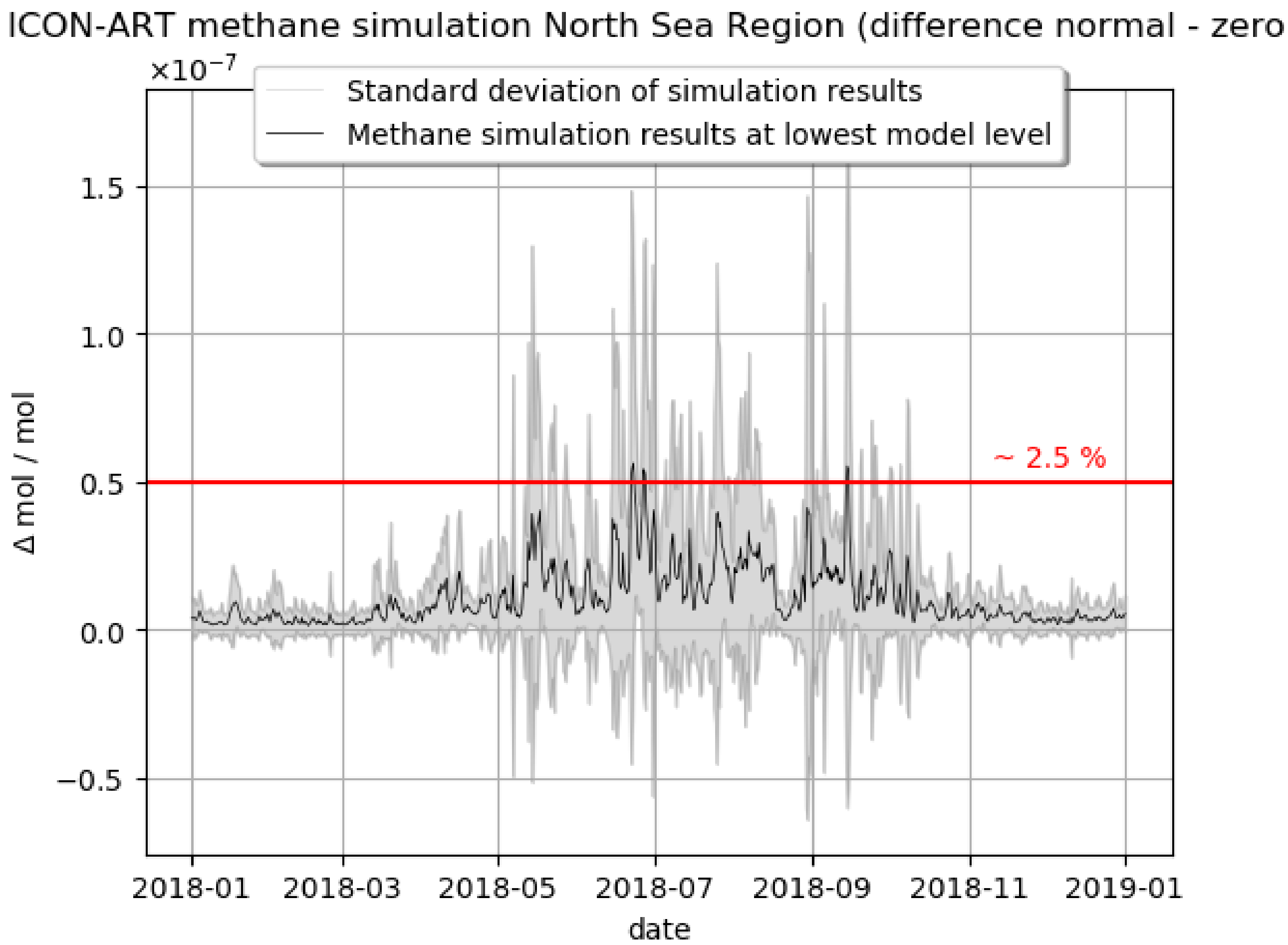


NOAA, Earth System Research Laboratory

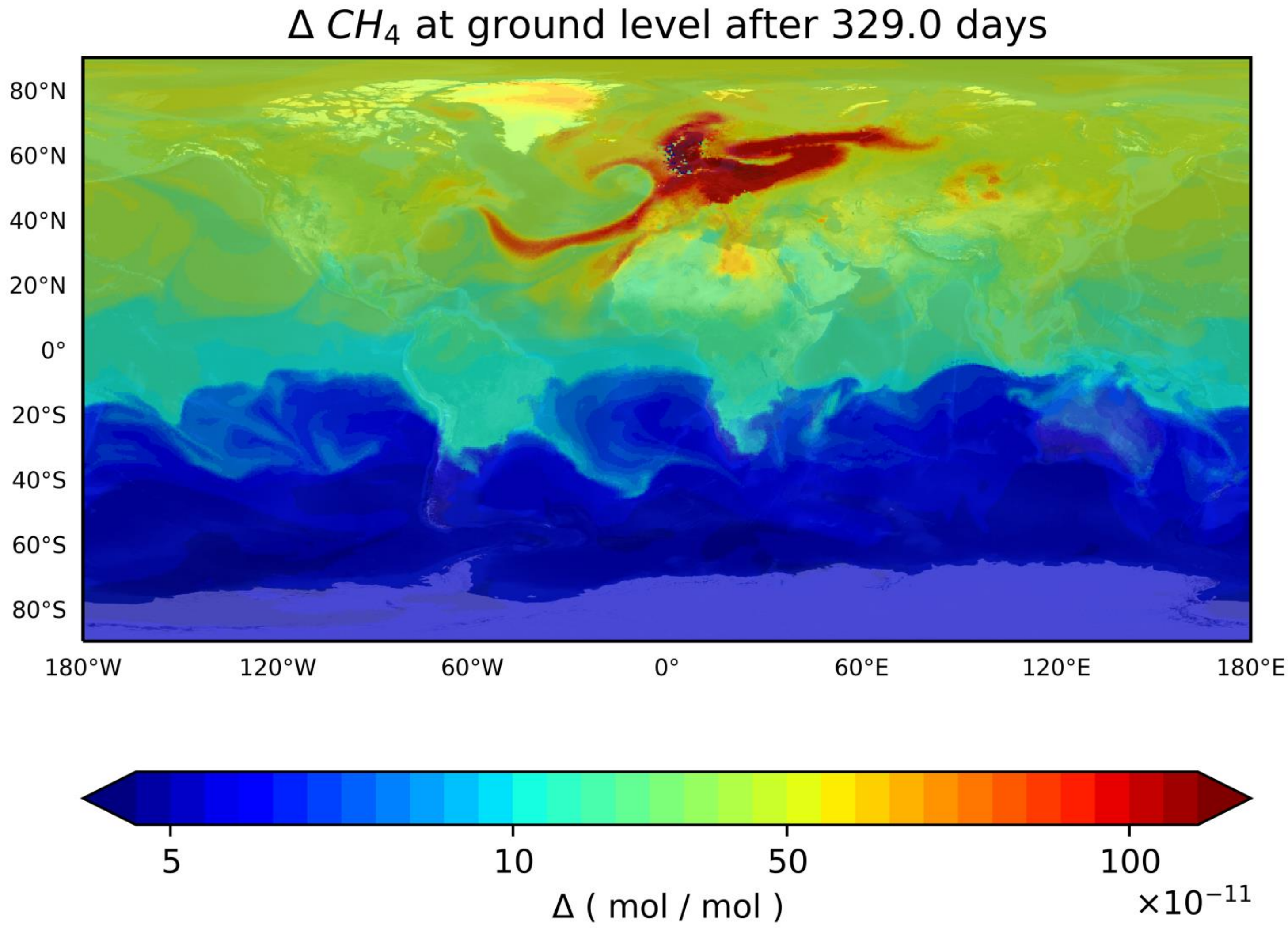
ICON-ART sensitivity studies

Difference of the two simulations



ICON-ART sensitivity studies

Difference of the two simulations

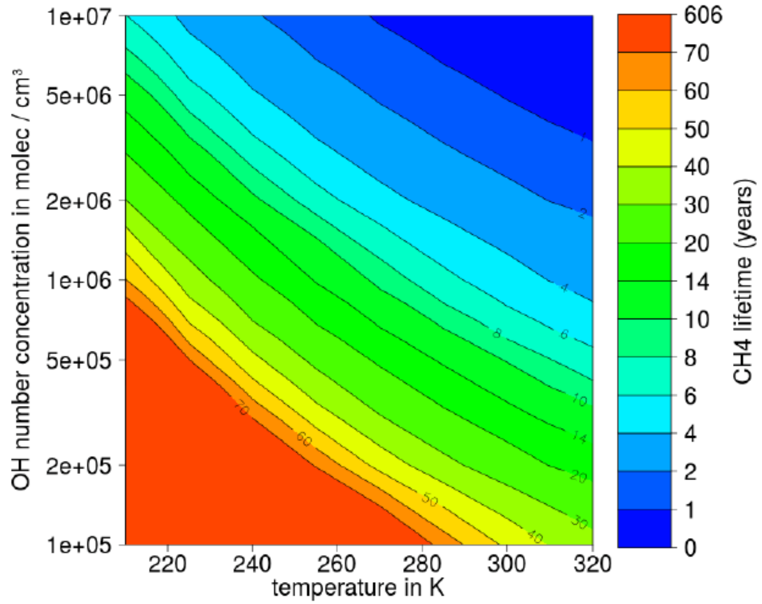


The effect of OH on CH_4

$$OH + CH_4 \xrightarrow{k_{CH_4}} H_2O + CH_3 \longrightarrow \ldots \longrightarrow CO + HO_2$$

$$k_{CH4} = 2.45 \cdot 10^{-12} \cdot \exp\left(\frac{-1775}{T}\right)$$

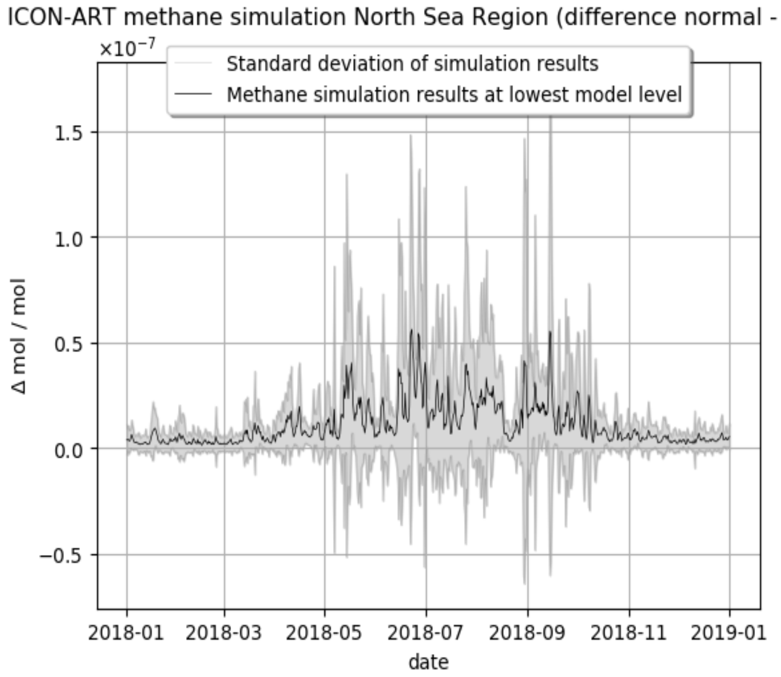
$$\tau_{CH4} = \frac{1}{k_{CH4} \cdot [OH]}$$



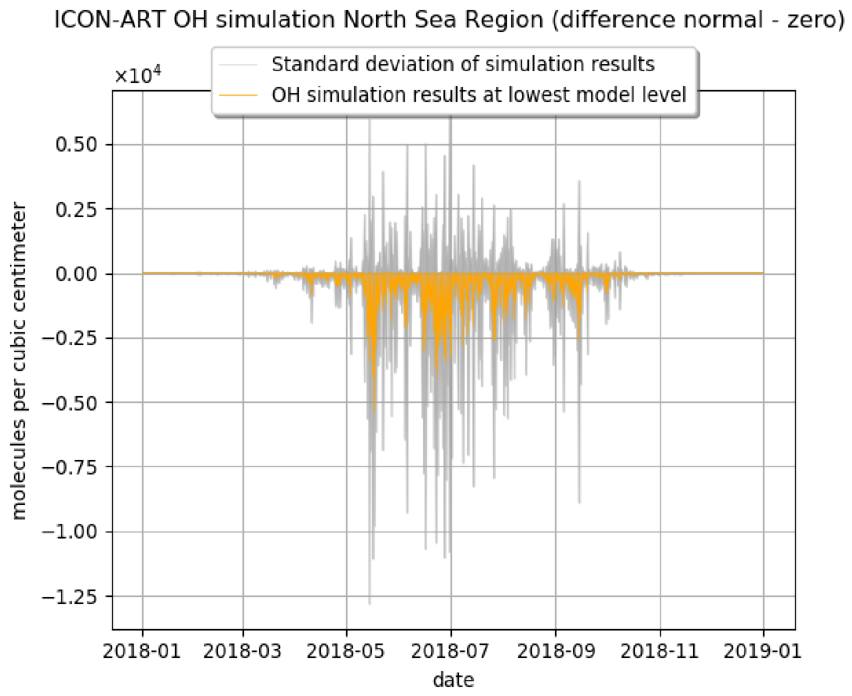
Weimer et al., 2017
Weimer, 2015
Sander et al., 2011

The effect of OH on CH_4

CH_4



OH



- The anticorrelation between CH_4 and OH is visible in the simulation results

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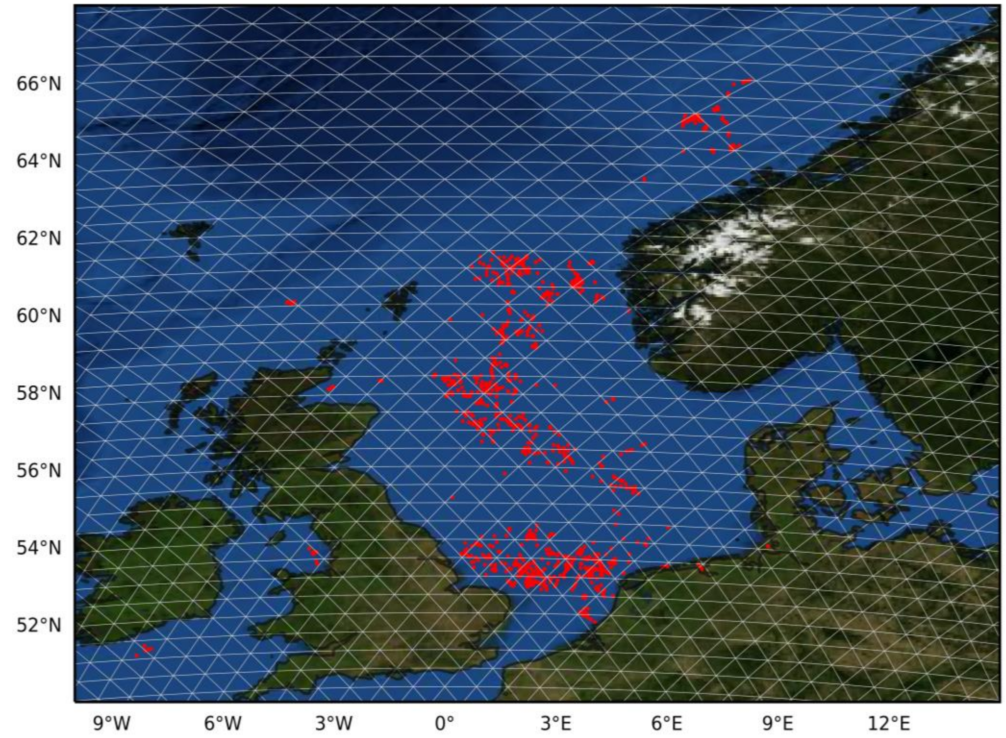
Problems and Tasks

- Translating point measurements and sources of methane to triangular grid of ICON-ART
- Handling different amount of points per gridcell
- How good are the points represented by the grid?

40 km grid point distance



NASA visible earth, 2019 and OSPAR, 2011

Point Source .xml files in ICON-ART

```xml
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE tracers SYSTEM "sources_selTrnsp.dtd">

<sources>
  <pntSrc id="Campus_Nord_Office">
    <lon type="real">8.435538</lon>
    <lat type="real">49.095056</lat>
    <substance type="char">cstracer</substance>
    <source_strength type="real">1.0</source_strength>
    <height type="real">10.</height>
    <unit type="char">kg s-1</unit>
    <startTime type="char">2018-01-01T00:00:00</startTime>
    <endTime type="char">2018-01-03T00:00:00</endTime>
  </pntSrc>
</sources>
```

From Point Source .xml to ICON-ART tracer

Emission factor: $$emiss = \frac{source\_strength}{cell\_area} \cdot dtime \qquad \left[\frac{kg}{m^2}\right]$$

Tracer value: $$tracer = tracer + \frac{h \cdot emiss}{(\rho \cdot dz)} \qquad \left[\frac{kg}{kg}\right]$$

$cell\_area$: area of triangular grid cell in ICON $[m^2]$

$dtime$: basic time step used for tracer transport in ICON $[s]$

h: height factor ρ: density of air $\left[\frac{kg}{m^3}\right]$ dz: height of layer $[m]$

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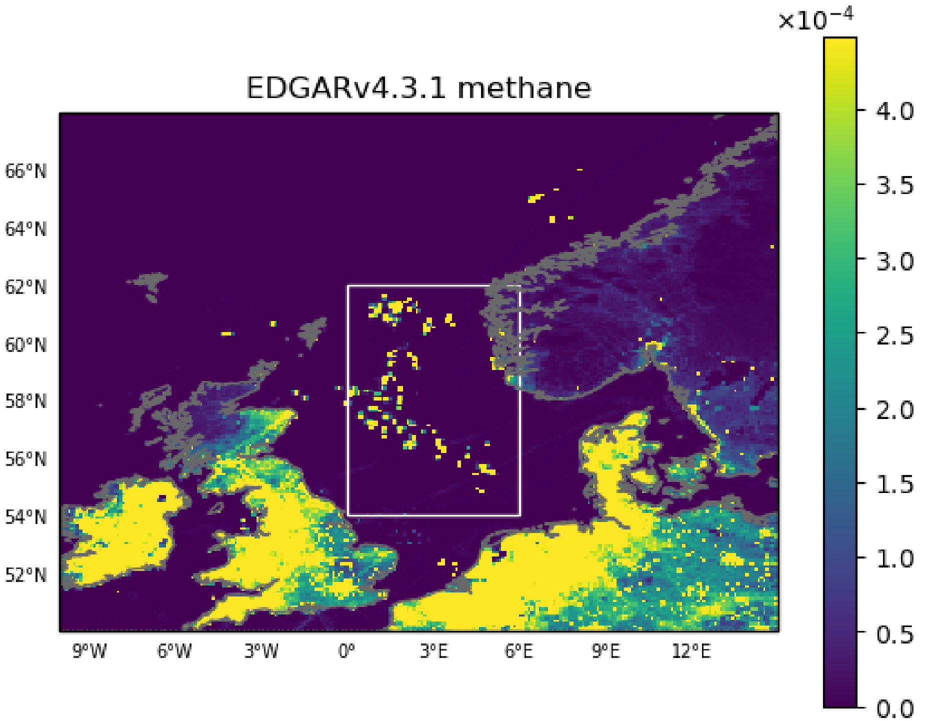
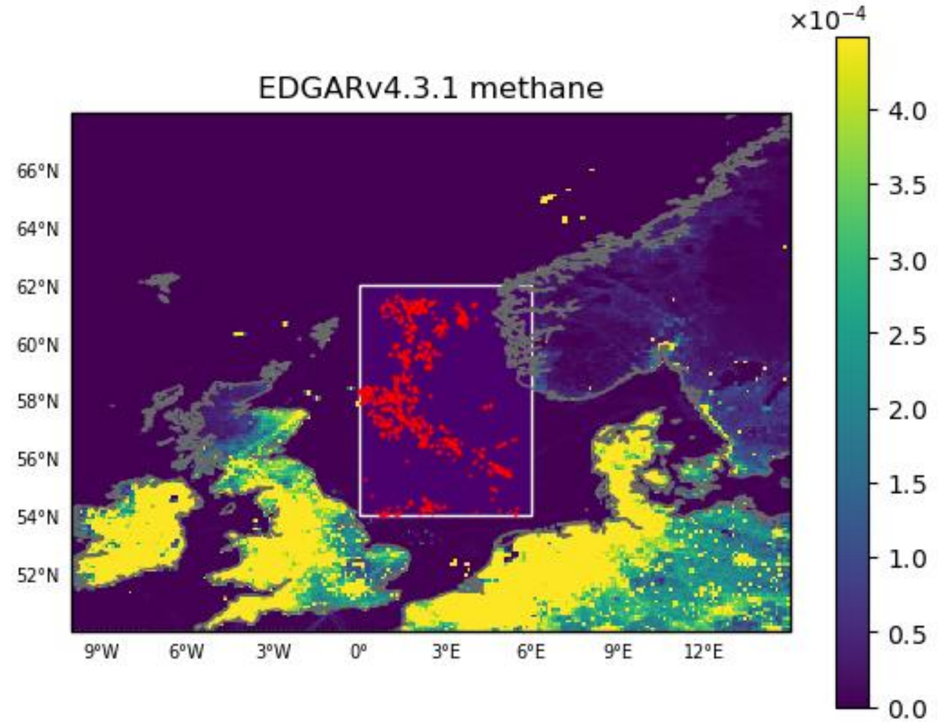
Compare *gridded* and *pointsource* simulation with ICON-ART



0.1° x 0.1° input

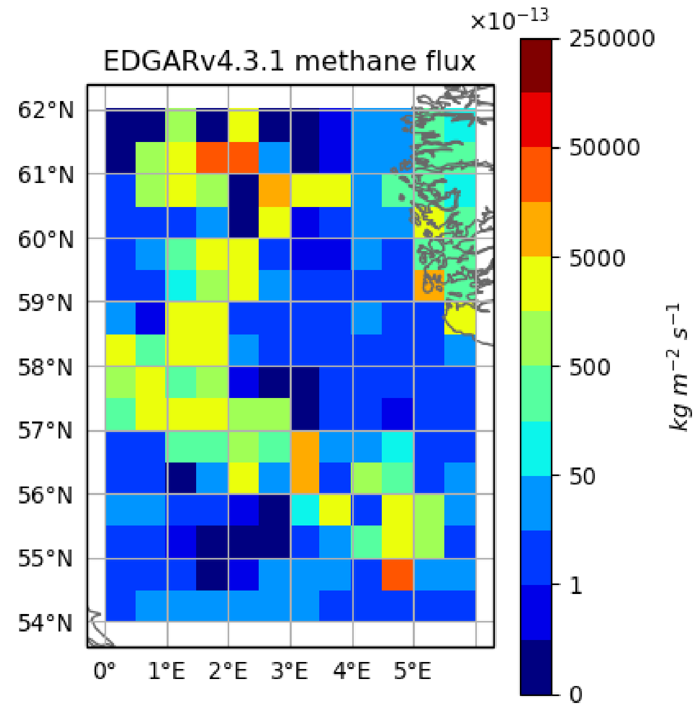


pointsources

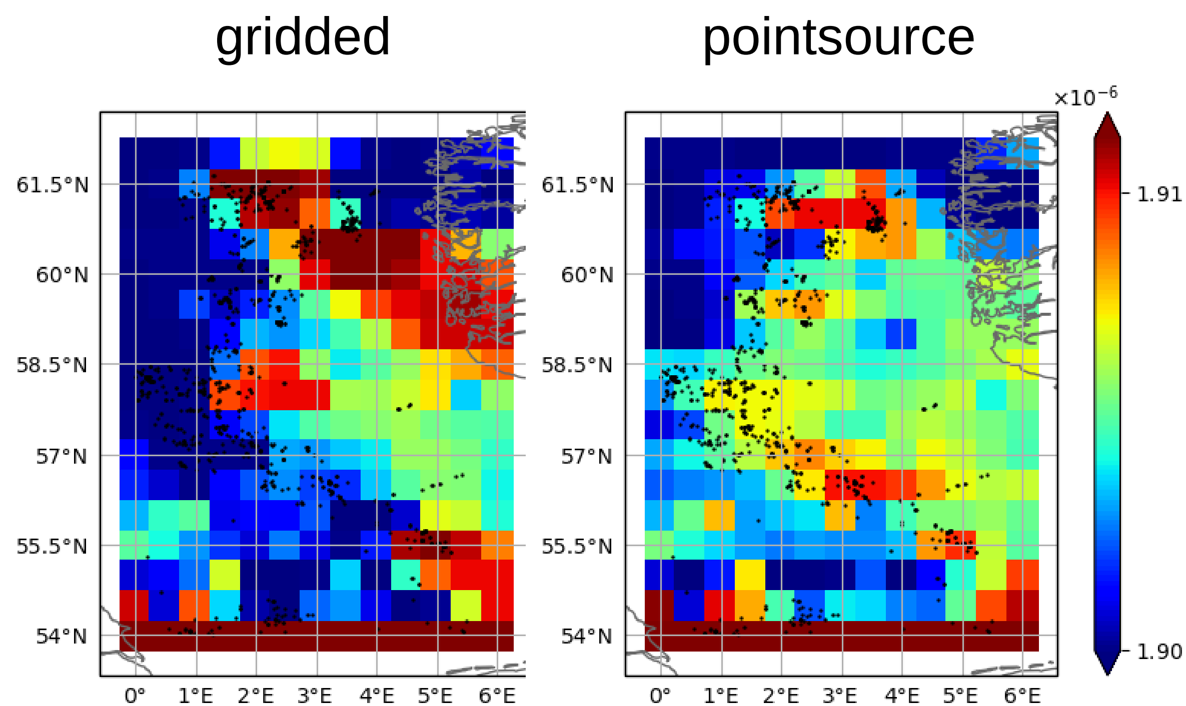
The emission sum of EDGAR was distributed to 956 pointsources in the North Sea Region and replaces the *gridded* emissions

Janssens-Maenhout et al., NAS, 2010 and OSPAR, 2011

Compare *gridded* and *pointsource* simulation with ICON-ART



INPUT



OUTPUT

In the 0.5° x 0.5° output the pointsource simulation seems to be more accurate

Janssens-Maenhout et al., NAS, 2010 and OSPAR, 2011

Compare *gridded* and *pointsource* simulation with ICON-ART

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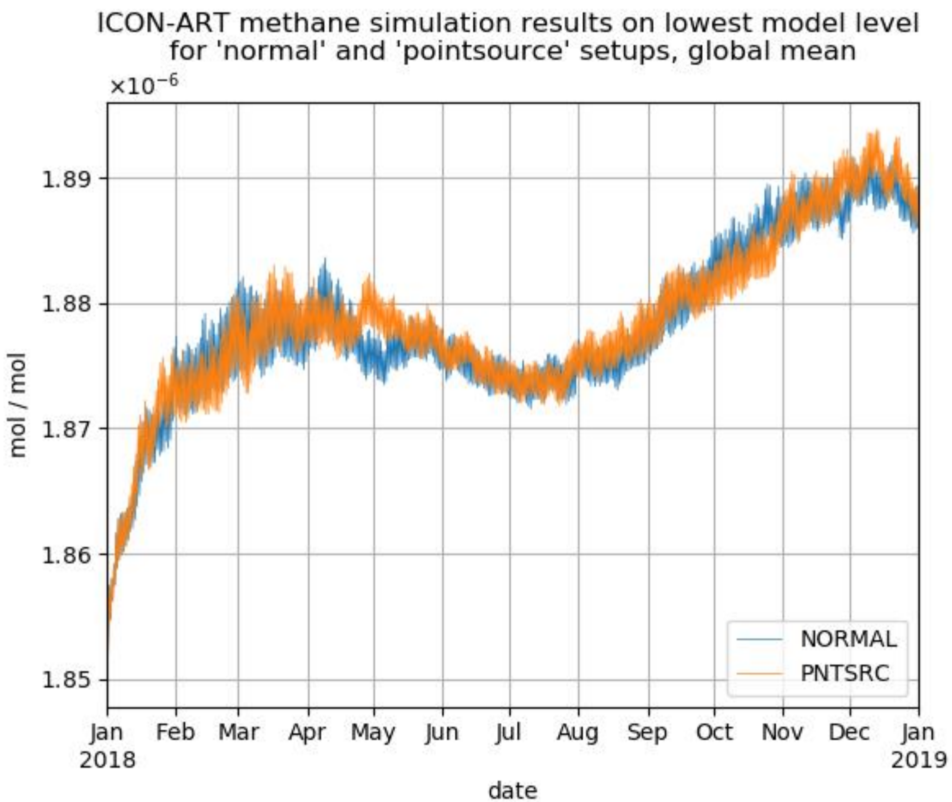

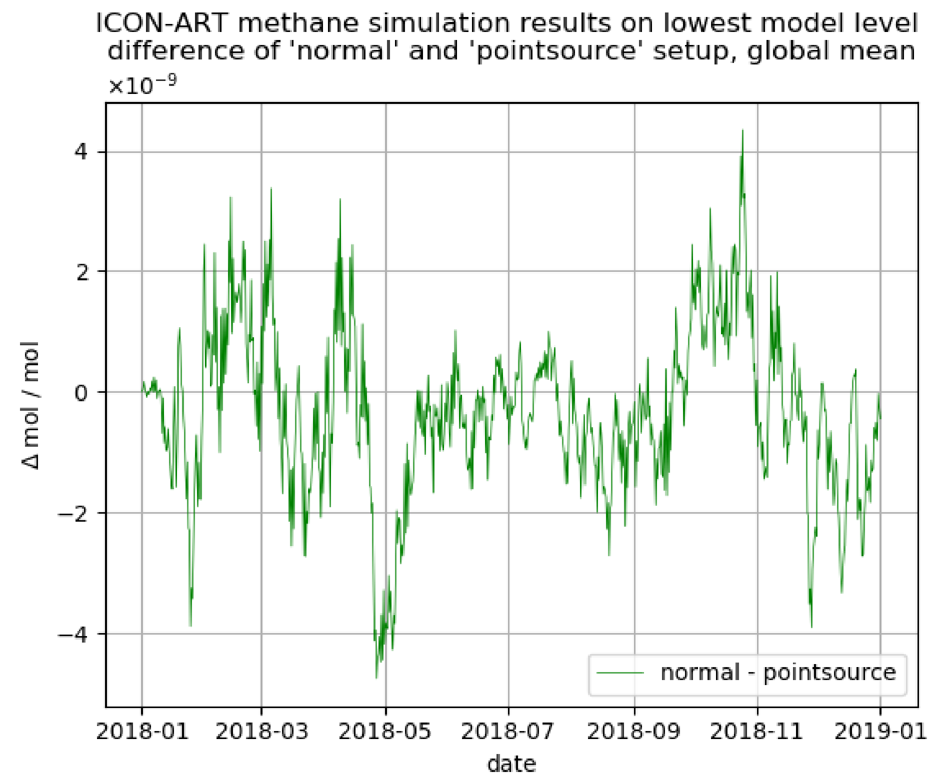

The pointsource module fits the original EDGAR emission quite well with

$$|\Delta_{max}| = 4.755\ ppbv \qquad \Delta_{mean} = -0.342\ ppbv$$

Agenda

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Sentinel-5P and Tropomi

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- Copernicus mission dedicated to monitoring our atmosphere (started in October 2017)

- Carries the Tropomi instrument to map trace gases such as
  - nitrogen dioxide
  - ozone
  - formaldehyde
  - sulphur dioxide
  - methane
  - carbon monoxide
  - aerosols

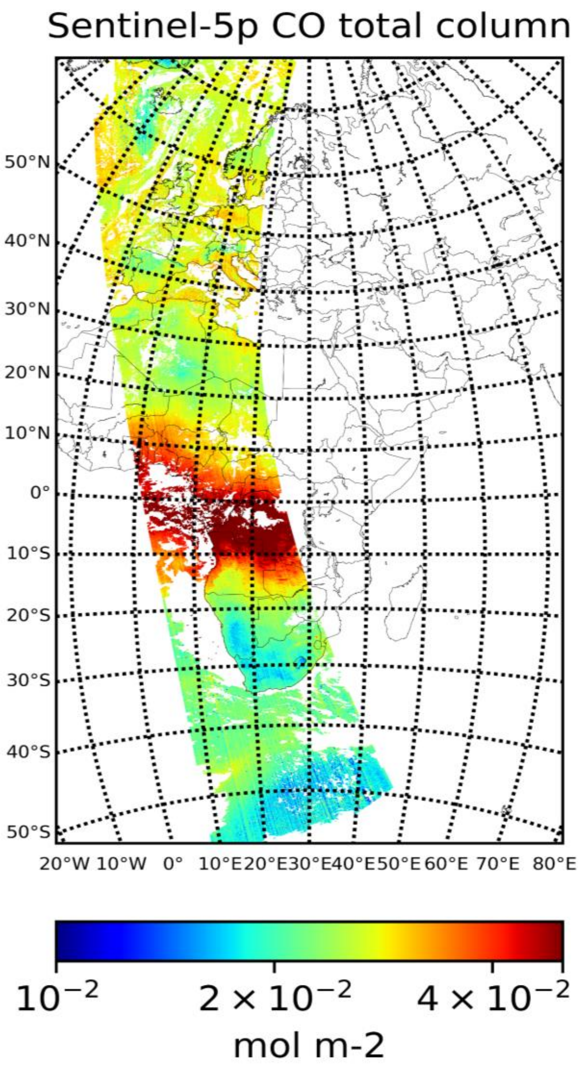
Kramer, 2020

Problems and Tasks

- Satellite measurements are unstructured *Level 2* data
- In 2019 more than 5000 single orbits of each substance have been recorded

Main question:

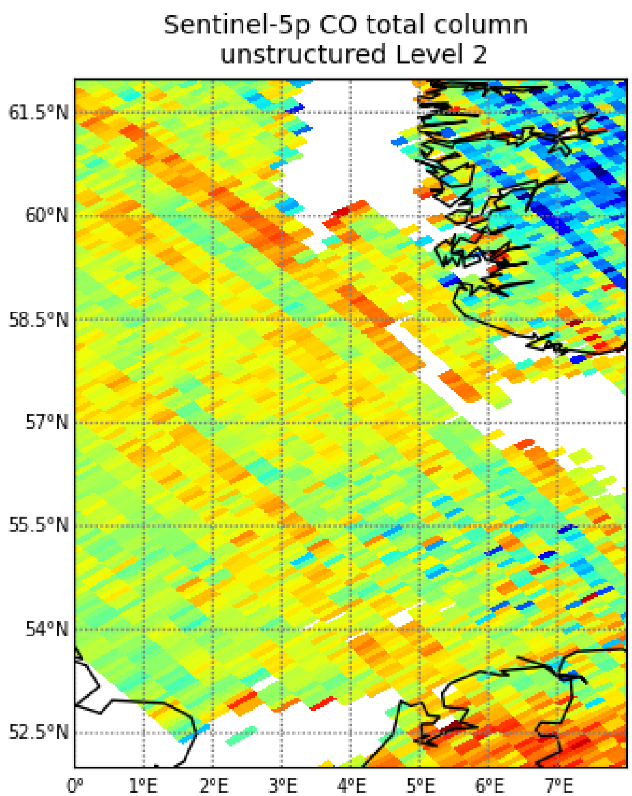
Is it possible (and reasonable) to determine methane emission from carbon monoxide satellite measurements?

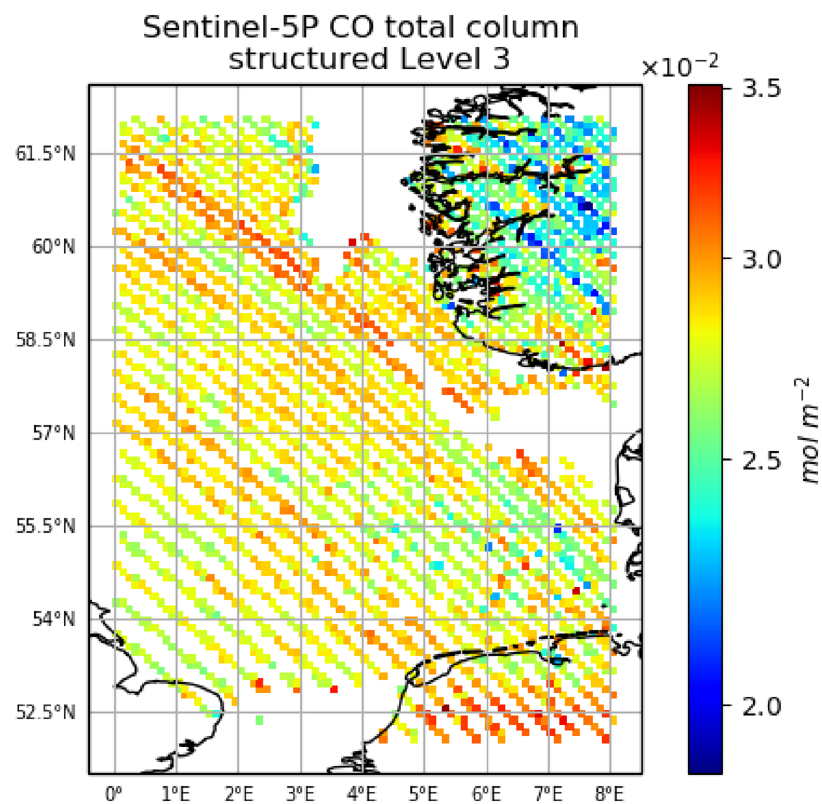


European Space Agency - ESA, Sentinel-5P Tropomi produced from ESA remote sensing data

Level 2 and Level 3 data

Unstructured Level 2 and gridded Level 3 data are mapping in a satisfying way when using the S5P-Level3 processor written in python

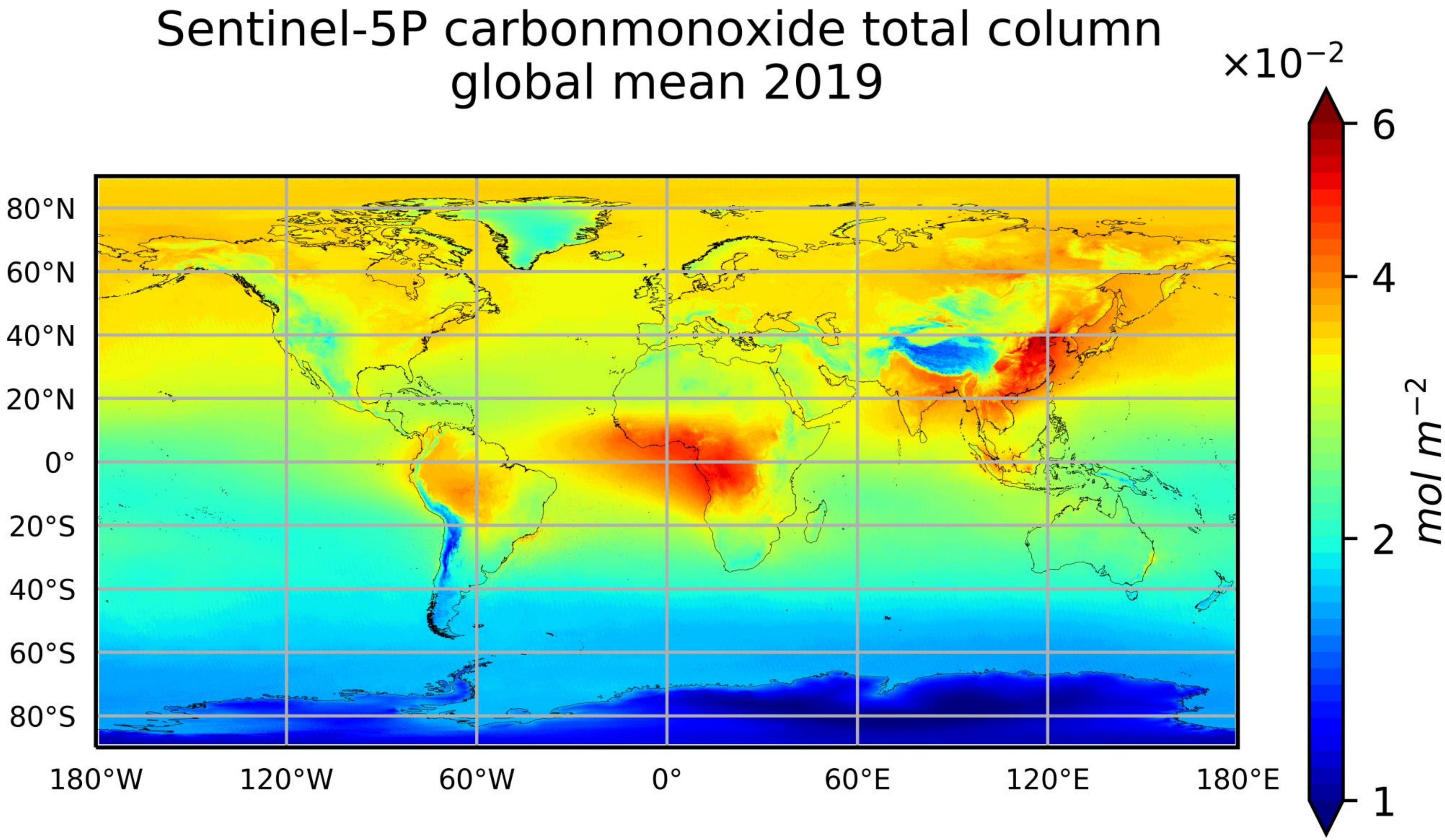




0.1° x 0.1° grid

European Space Agency - ESA, Sentinel-5P Tropomi produced from ESA remote sensing data

Level 3 data global



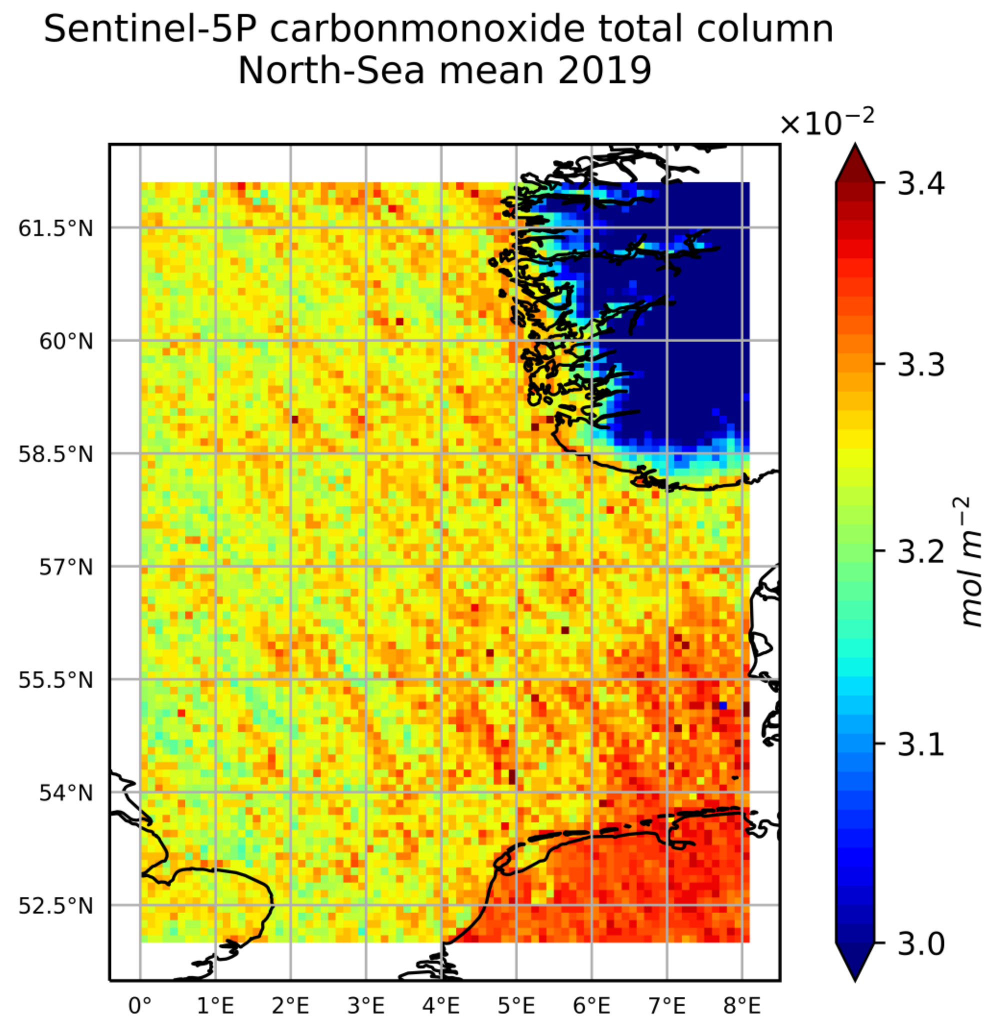
European Space Agency - ESA, Sentinel-5P Tropomi produced from ESA remote sensing data

Correlation of EDGAR and Sentinel-5P

Main question:

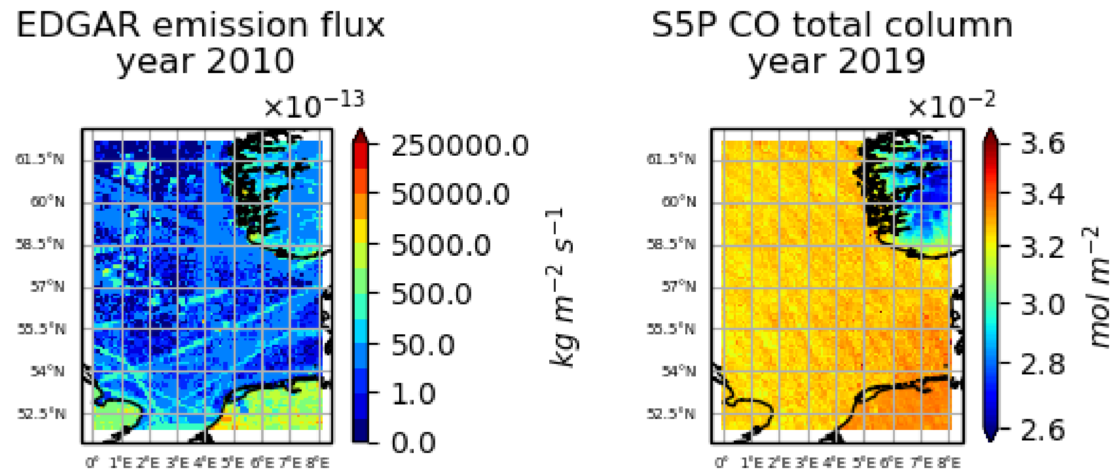
Is it possible (and reasonable) to determine methane emission from carbon monoxide satellite measurements?

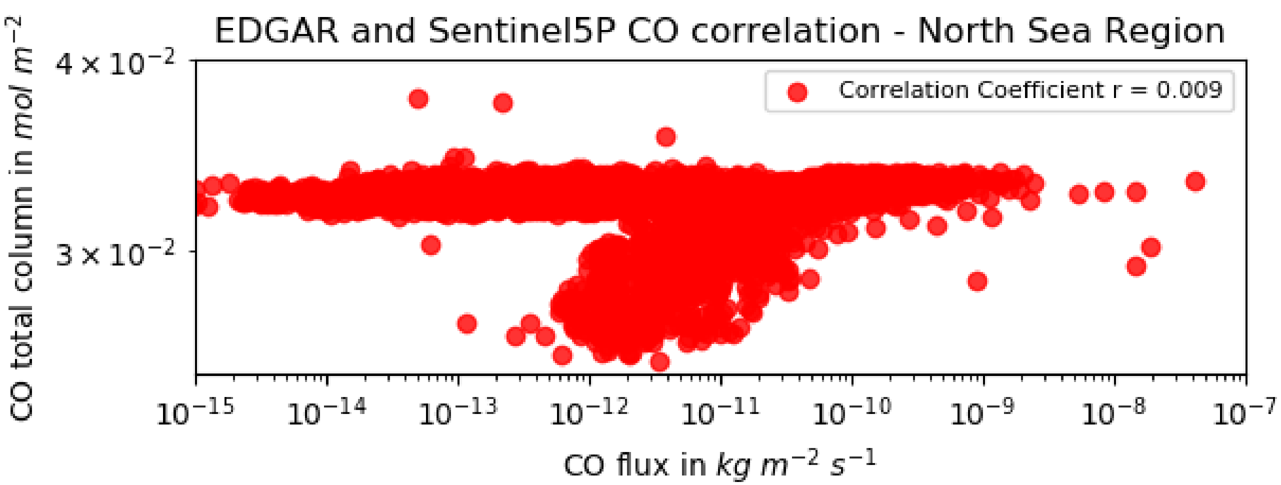
- Correlate EDGAR carbon monoxide and S5P measurements
- If this correlation is good we can try to determine methane from it as seen in Section 2



European Space Agency - ESA, Sentinel-5P Tropomi produced from ESA remote sensing data

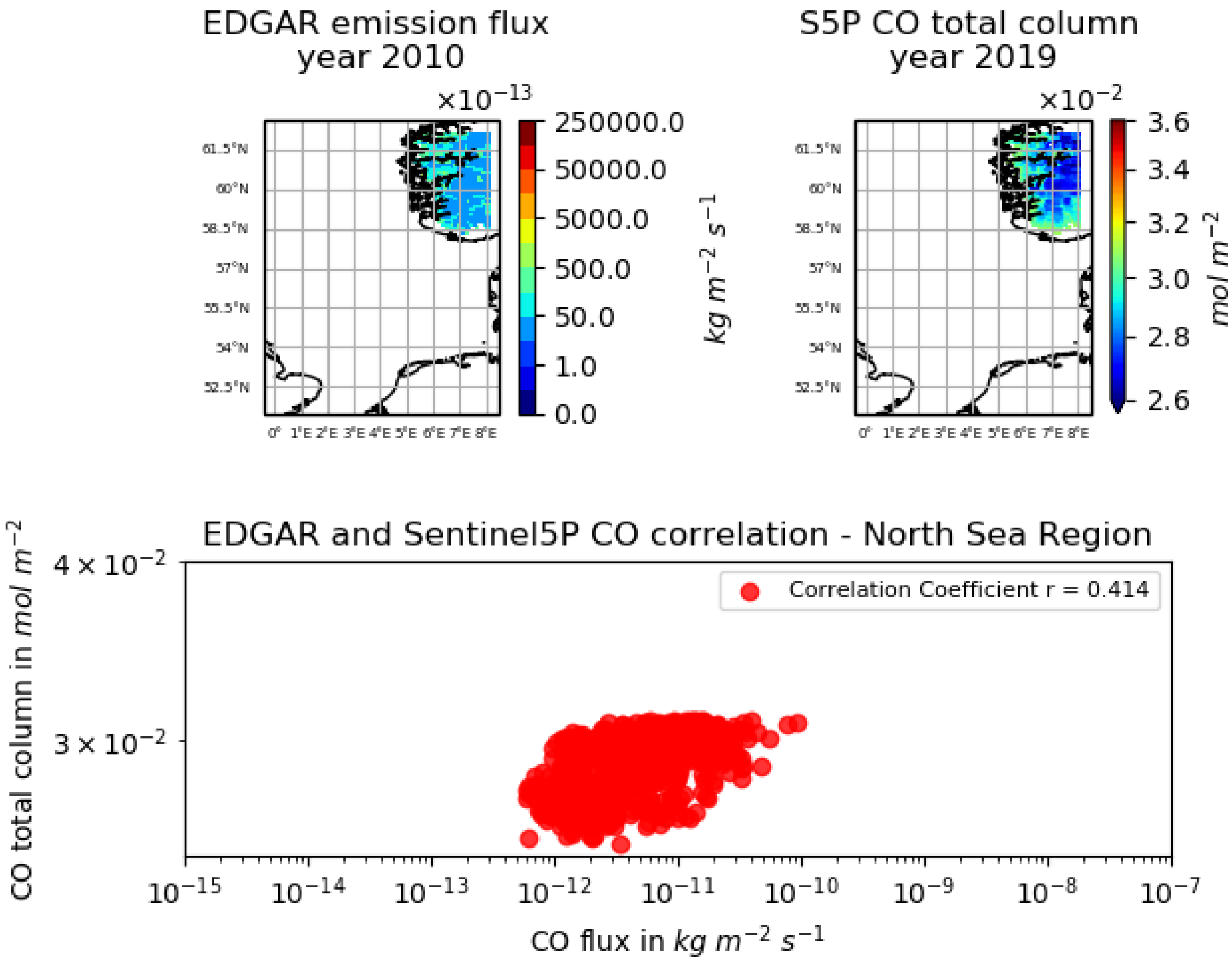
Correlation of EDGAR and Sentinel-5P





Janssens-Maenhout et al., NAS, 2010
European Space Agency - ESA, Sentinel-5P Tropomi produced from ESA remote sensing data

Correlation of EDGAR and Sentinel-5P



Janssens-Maenhout et al., NAS, 2010
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Correlation of EDGAR and Sentinel-5P

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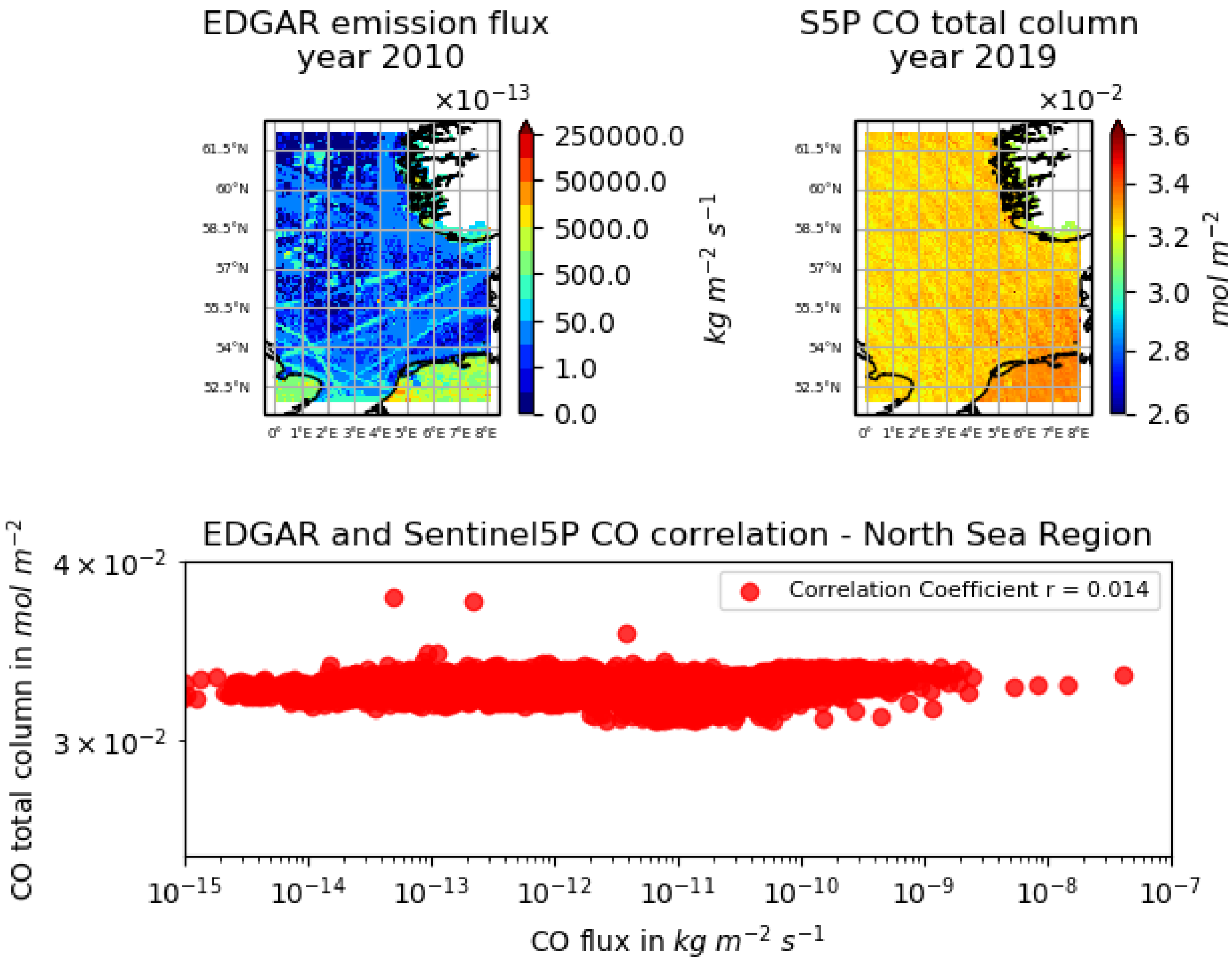

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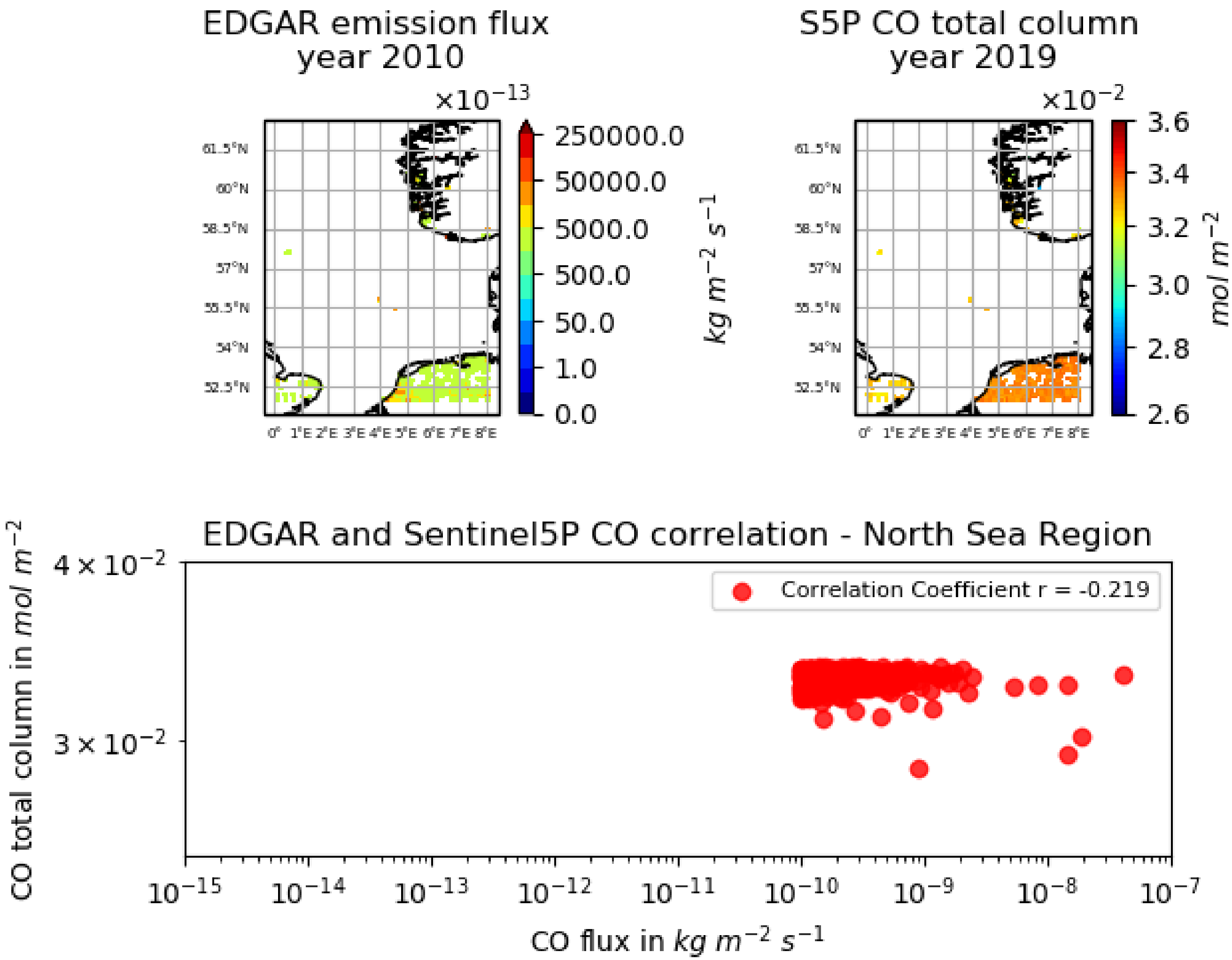
Correlation of EDGAR and Sentinel-5P



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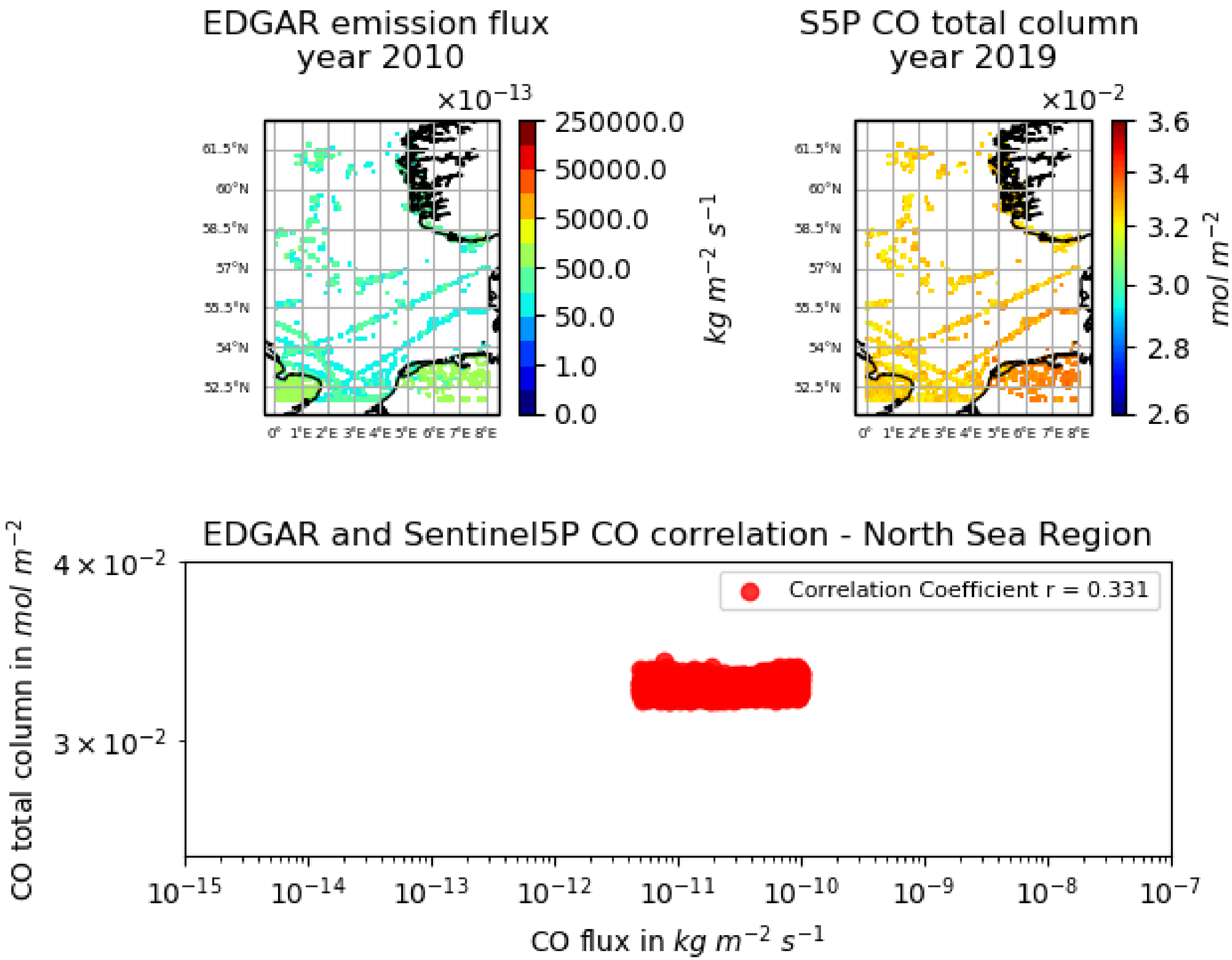

Janssens-Maenhout et al., NAS, 2010
European Space Agency - ESA, Sentinel-5P Tropomi produced from ESA remote sensing data

Agenda

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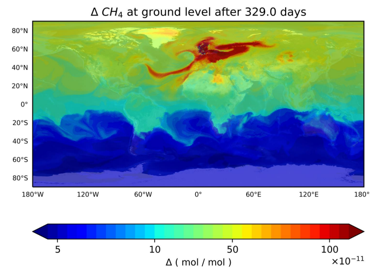
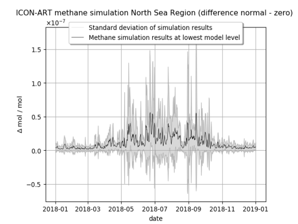
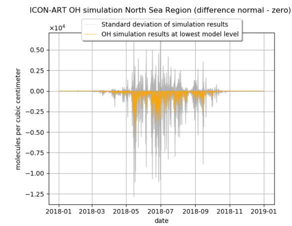
1) Motivation and Scientific Goals
2) Correlation of fluxes and platforms
3) ICON-ART sensitivity studies
4) The pointsource module of ART
5) Sentinel-5P satellite measurements
6) **Summary**

Summary





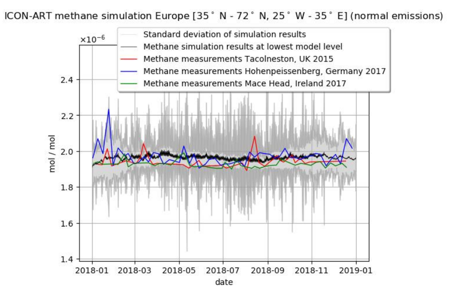


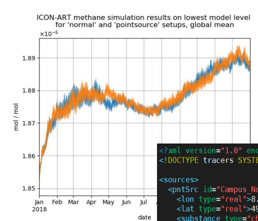
ICON-ART ⟷ Simulation ⟷ EDGAR

ICON-ART ⟷ Validation ⟷ MEASURE-MENTS

EDGAR ⟷ Adjustment ⟷ PLATFORMS

MEASURE-MENTS ⟷ Connection ⟷ PLATFORMS



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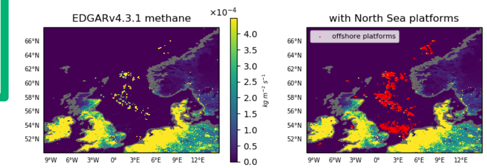

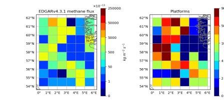

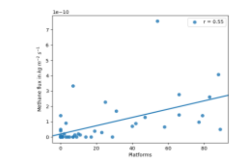

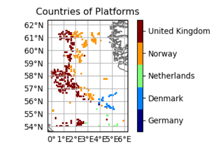

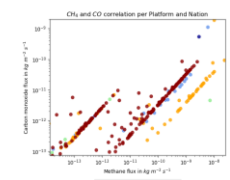

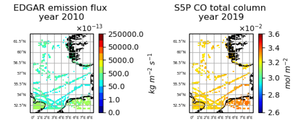

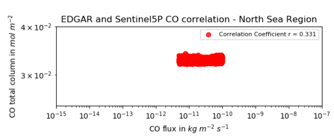

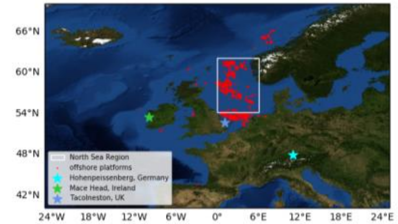

Thank you for reading!

Are there some questions or remarks?

Acknowledgement

Karlsruhe Institute of Technology

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SCC

Steinbuch Centre for Computing

In addition to that the Large Scale Data Facility (LSDF) operated by the SCC was used to store research data of this project.

Please find more information on HPC at KIT here and the LSDF here.

SCC, 2020

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