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Detecting and quantifying NO_x point source emissions from the divergence of the NO_2 flux

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SCIENCE ADVANCES | RESEARCH ARTICLE

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ATMOSPHERIC SCIENCE

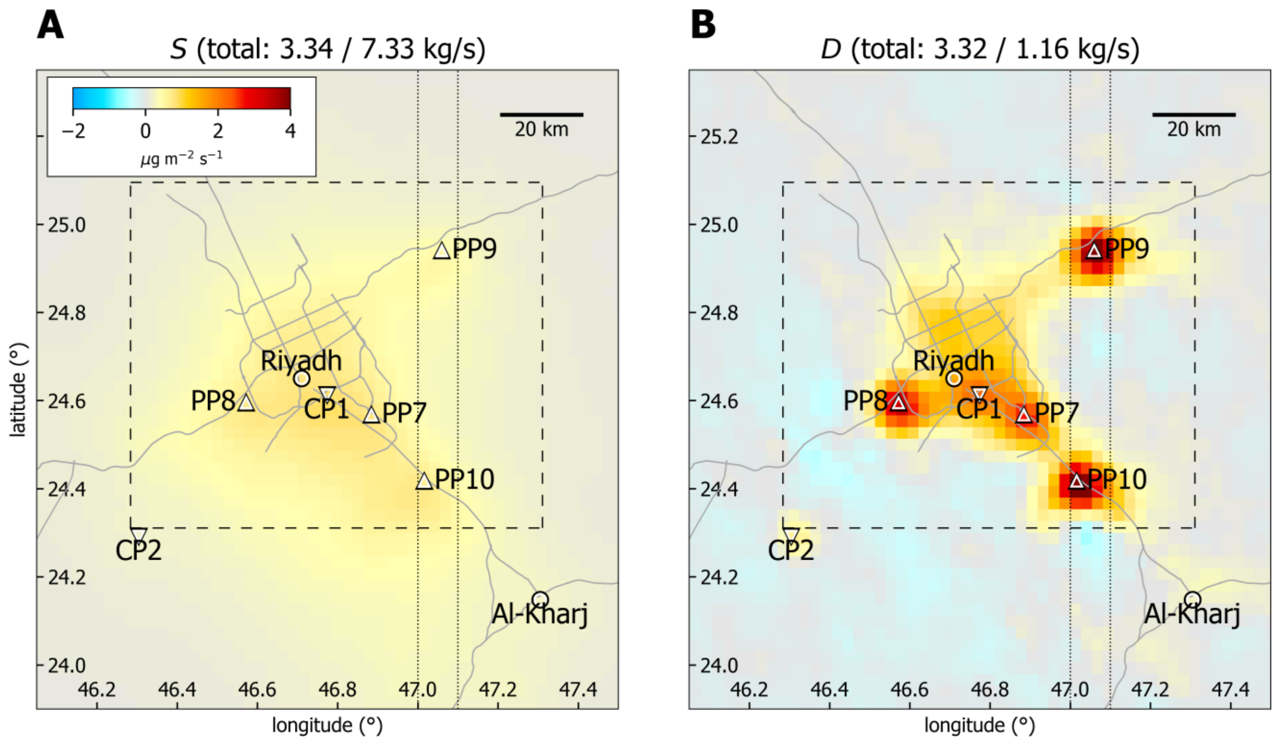
Pinpointing nitrogen oxide emissions from space

Steffen Beirle[1]*, Christian Borger[1], Steffen Dörner[1], Ang Li[2], Zhaokun Hu[2], Fei Liu[3,4], Yang Wang[1], Thomas Wagner[1,5]

Beirle *et al.*, *Sci. Adv.* 2019;**5**:eaax9800 13 November 2019

$S = V/\tau$ $D = \nabla (V\mathbf{w})$

Riyadh



Open Access Earth System Science Data

Catalog of NO_x emissions from point sources as derived from the divergence of the NO_2 flux for TROPOMI

Steffen Beirle[1], Christian Borger[1], Steffen Dörner[1], Henk Eskes[2], Vinod Kumar[1], Adrianus de Laat[2], and Thomas Wagner[1]

https://doi.org/10.5194/essd-13-2995-2021

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- 451 point sources detected by fully automated algorithm (power plants, cement plants, metal smelters, industrial areas, small cities)
- For 242 point sources: match in Global Power Plant Database within 5 km

\+ detection and accurate localization of NO_x point sources

\- low-biased emission estimates (factor 2-8)

Meanwhile: improved version (v2)

Input data

Version 1

- TROPOMI NO_2 from offline product (various versions)
- Meteorology from ECMWF interim & ERA5

Version 2

- TROPOMI NO_2 from reprocessed PAL product
- Meteorology from ERA5

Data selection

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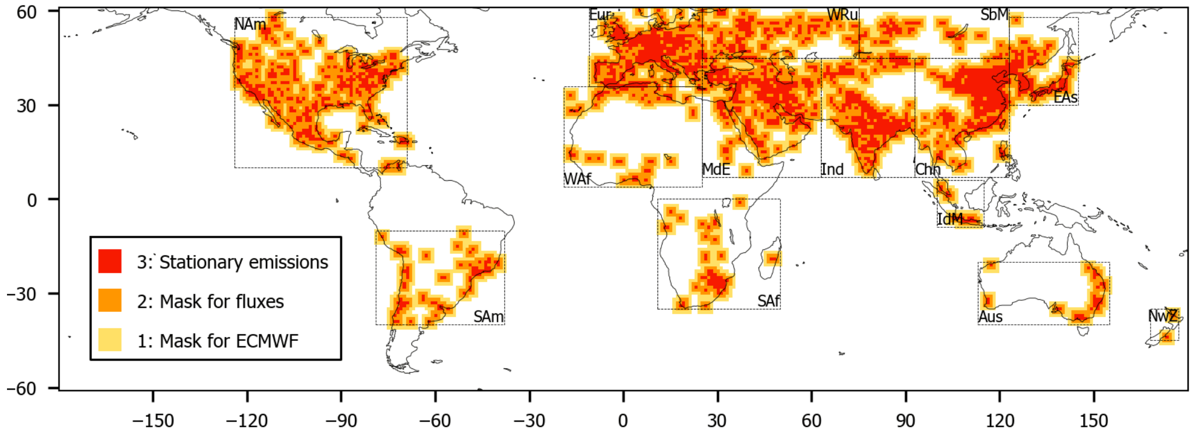
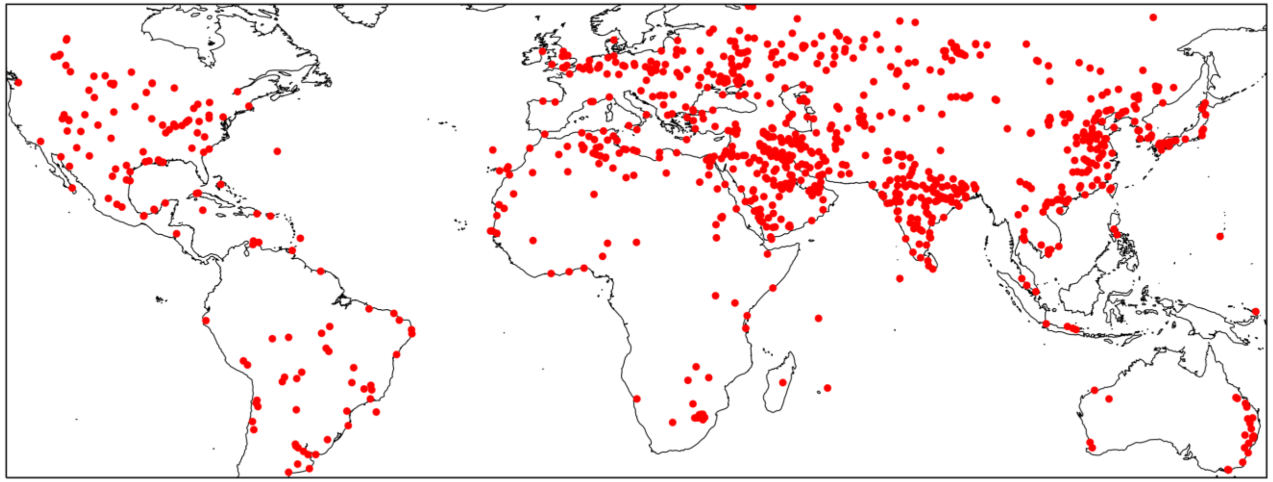
Version 1

- SZA < 65°, qa > 0.75
- -61° < lat < 61°
- Predefined "mask of interest" based on VCD variability

Version 2

- SZA < 65°, qa > 0.75, VZA < 56°
- -50° < lat < 72°
- All orbits are processed
- Gridding done for -40° < lat < 65°, -125° < lon < 155°





NO_2 to NO_x

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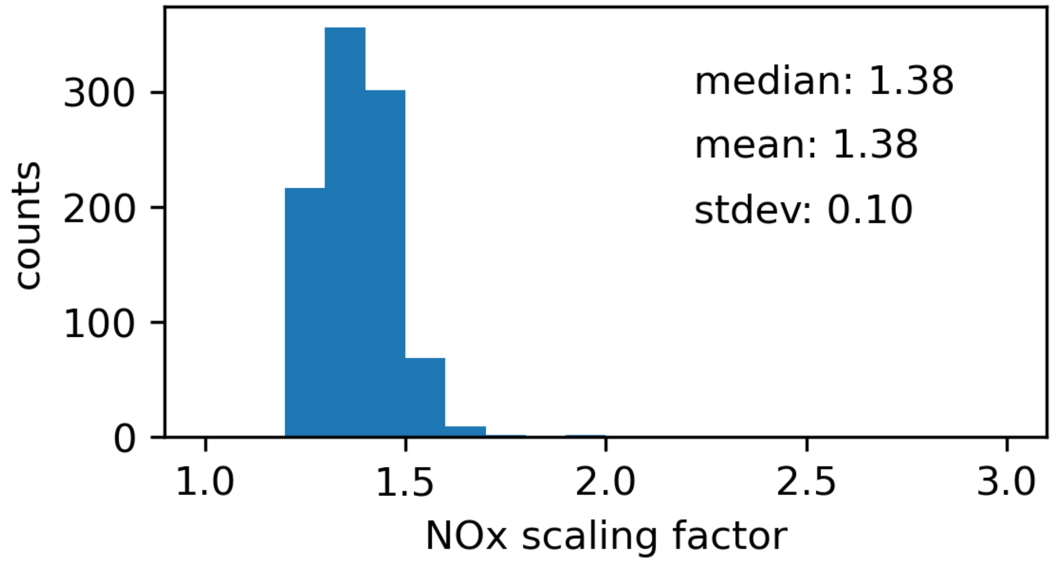
Version 1

- Parameterized from
  - O_3 (from climatology)
  - $J(NO_2) = f(SZA)$
  - $k = f(T)$

Version 2

- Parameterized from
  - O_3 (from climatology)
  - $J(NO_2) = f(SZA)$
  - $k = f(T)$



AMF/AK correction

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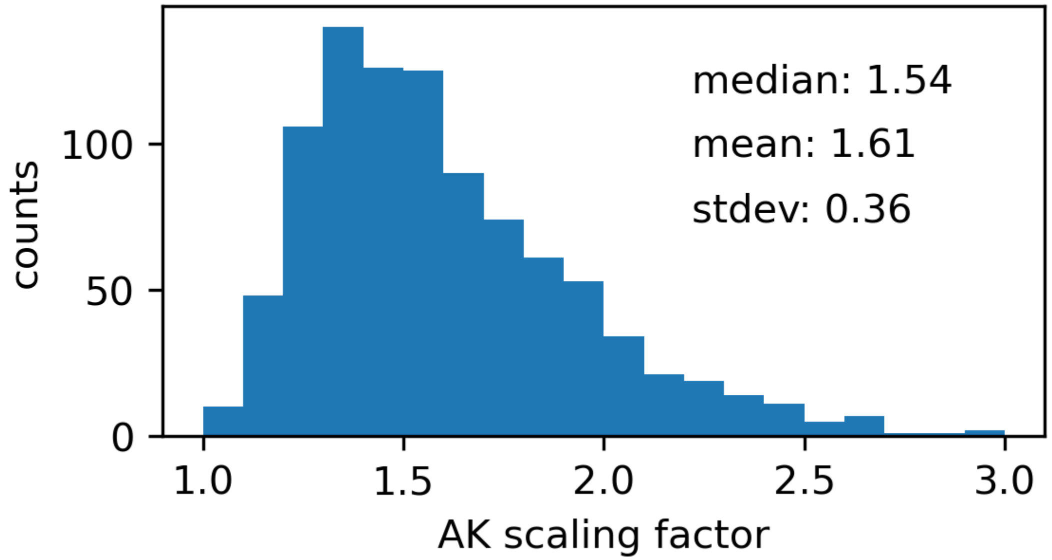
Version 1

- None

Version 2

- Divergence is about NO_2 *excess*, any "background" is intrinsically removed
- For quantifying point source emissions, VCD has to be corrected according to the AK at plume altitude (default: 500 m)



Divergence

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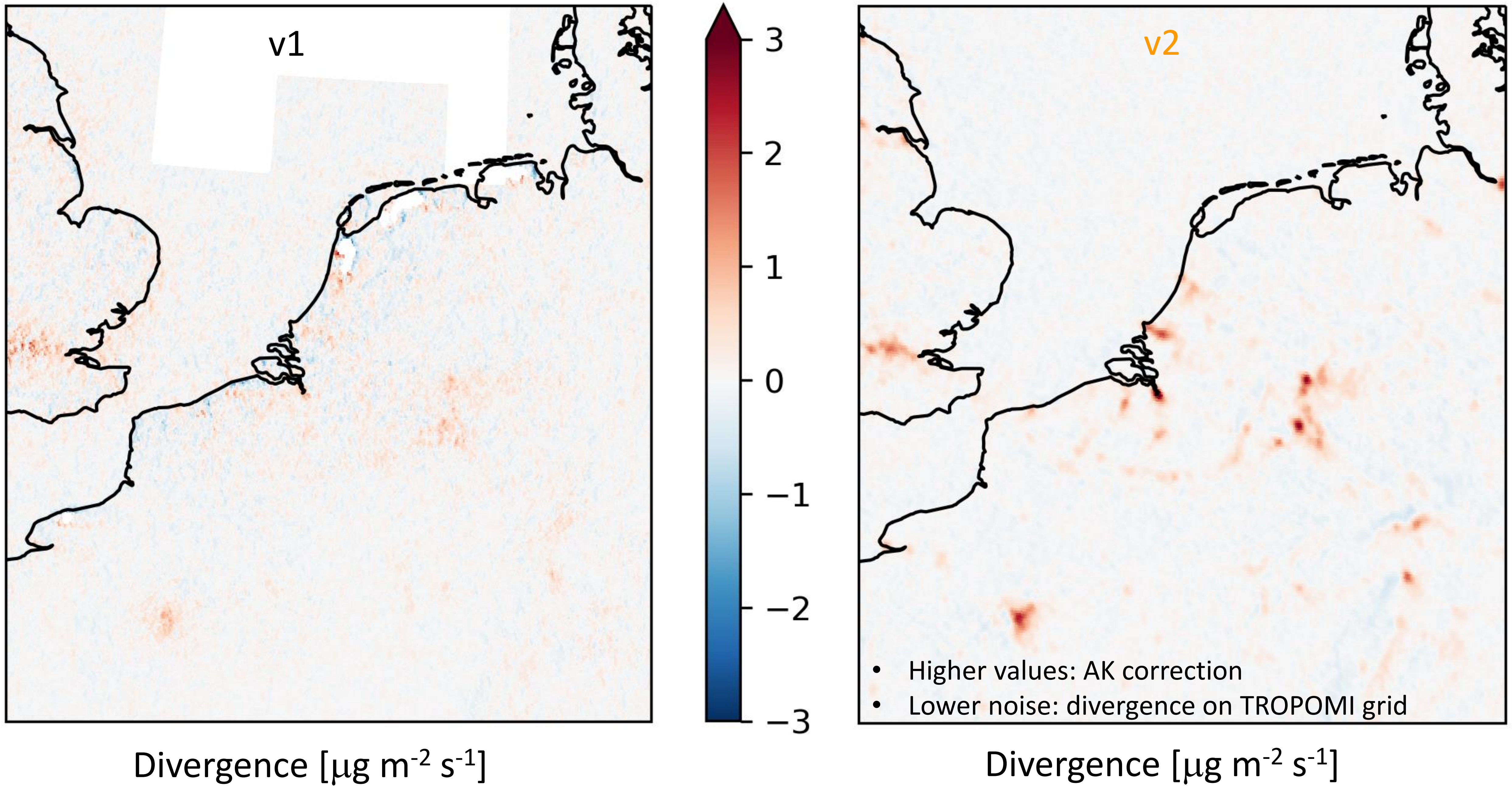
Version 1

- Grid daily VCDs and fluxes (V*w)
- Average fluxes
- Calculate divergence of mean fluxes

Version 2

- Calculate divergence on TROPOMI-"grid" (crosstrack x alongtrack) for each orbit (proposed by de Foy et al., 2022).
- Grid divergence
- Calculate temporal mean.

+ Avoids "steps" due to data gaps
+ Yields smoother divergence maps


v1
v2
3
2
1
0
−1
−2
−3
Higher values: AK correction
Lower noise: divergence on TROPOMI grid
Divergence [μg m-2 s-1]
Divergence [μg m-2 s-1]

Point source detection & quantification

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Version 1

Iterative algorithm:

- Candidate: maximum divergence
- Identify & skip artefacts:
  - Gaps
  - Strong negative divergence
  - Area sources
- Emissions from Gaussian fit to divergence peak within 22 km

- Requires good statistics

Version 2

Iterative algorithm:

- Candidate: maximum divergence
- Identify & skip artefacts:
  - Gaps
  - Strong negative divergence
  - Area sources
  - No peak
- Emissions from spatial integration within 15 km

+ stable & robust

+ works for monthly means

+ smaller area -> less interference

Lifetime correction

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Version 1

- None

Beirle et al., 2019:

- $E = D + S = D + V/\tau$

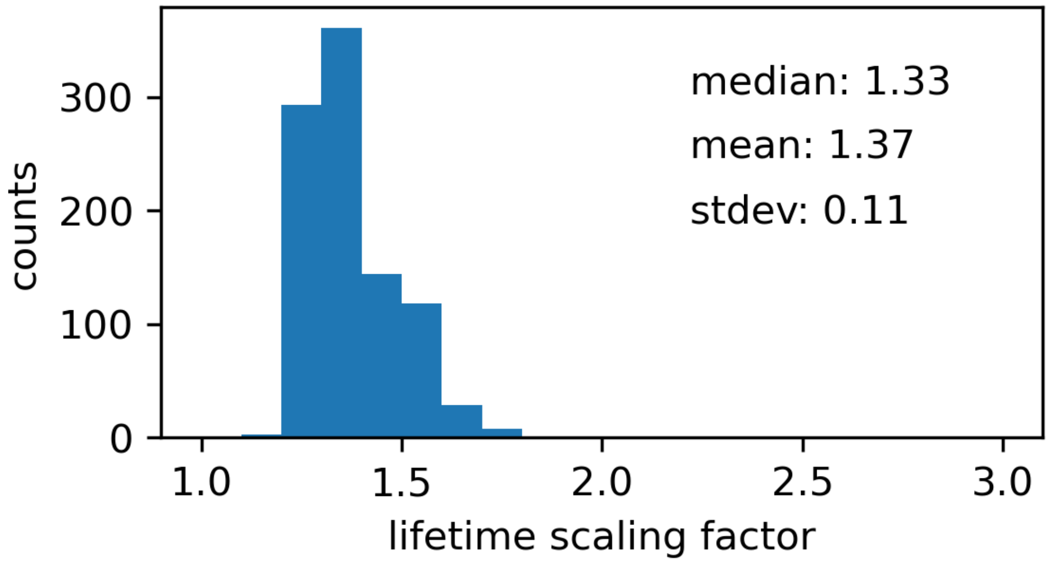
- Peaks smeared out

- Larger area needs to be considered

Version 2

- Emissions: D integrated within 15 km
- Residence time: t_r = 15 km / w
- Correction: $\exp(t_r/\tau)$
- Lifetime: ~2.5 h

  (mean of fitted lifetimes for all point sources)



Added information

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Version 1

- Power plants within 5 km
  from global power plant database

Version 2

- Power plants within 15 km
  from global power plant database
- Cities > 100,000 within 15 km
- Temporal stability:
  fraction of months with significant emissions
  (identifies some point sources as fires)

Summary: Main changes

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	Version 1	Version 2	Effect
Input data	Offline product	PAL product	Corrected cloud height -> appropriate AKs
AK correction	none	According to plume height	Factor ~1.6
Divergence	Calculated for mean of gridded fluxes	Calculated on TROPOMI grid	Reduced noise in divergence map
Emission estimate	Gaussian fit	Spatial integration	Also works for monthly means
Lifetime correction	none	Based on residence time	Factor ~1.4

Results

Version 2: Top 10

	lat	lon	E [kg/s]	power plants	cities
1	-26.2875	29.1625	2.756119	Matla; Kriel	
2	-26.5625	29.1625	2.389643		
3	-23.6875	27.5875	2.341779	Matimba	
4	-27.1125	29.7875	2.036677	Majuba	
5	-26.7375	27.9875	1.953122	Lethabo	
6	22.3875	82.6875	1.795990	Korba	
7	-32.4125	151.0125	1.793726	Bayswater; Liddell	
8	-26.0875	28.9875	1.683661	Kendal	
9	40.6375	109.7375	1.667596	Baotou East Hope	Baotou
10	21.0125	107.1375	1.662897	Quang Ninh	Hạ Long; Cẩm Phả

- Rank 2: Secunda CTL coal liquifier, South Africa (not listed in power plant database)
- Highest emissions for South African power plants (as in version 1)
- Top 10 all related to coal burning

Results

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Version 2: Germany

	lat	lon	E [kg/s]	power plants	cities
46	51.4875	6.7375	0.839792	KW Voerde; KW Walsum; KW West; ...	Duisburg; Oberhausen; Mülheim; Bottrop; Moers
52	51.0125	6.6375	0.820499	Niederaussem; Neurath; ...	
118	53.5125	9.9375	0.557957	Hamburg-Moorburg; Tiefstack; ...	Hamburg
212	49.5125	8.4375	0.392249	GKM Mannheim; Kraftwerk Mitte; ...	Mannheim; Ludwigshafen
304	51.8375	14.4625	0.308875	Jänschwalde	
352	51.4375	14.5625	0.283045	Boxberg	
383	50.8375	6.3375	0.268497	Weisweiler	
520	51.1875	12.3625	0.217118	Lippendorf	
609	49.4375	11.0625	0.190098	Franken 1; HKW Sandreuth	Nuremberg; Fürth
664	53.1125	8.6875	0.176190	Hafen; KW Mittelsbüren; ...	Bremen
680	52.1625	10.3875	0.173030		Braunschweig; Salzgitter
720	51.4125	11.9625	0.165013	Schkopau; HKW Halle Trotha; ...	Halle

Results

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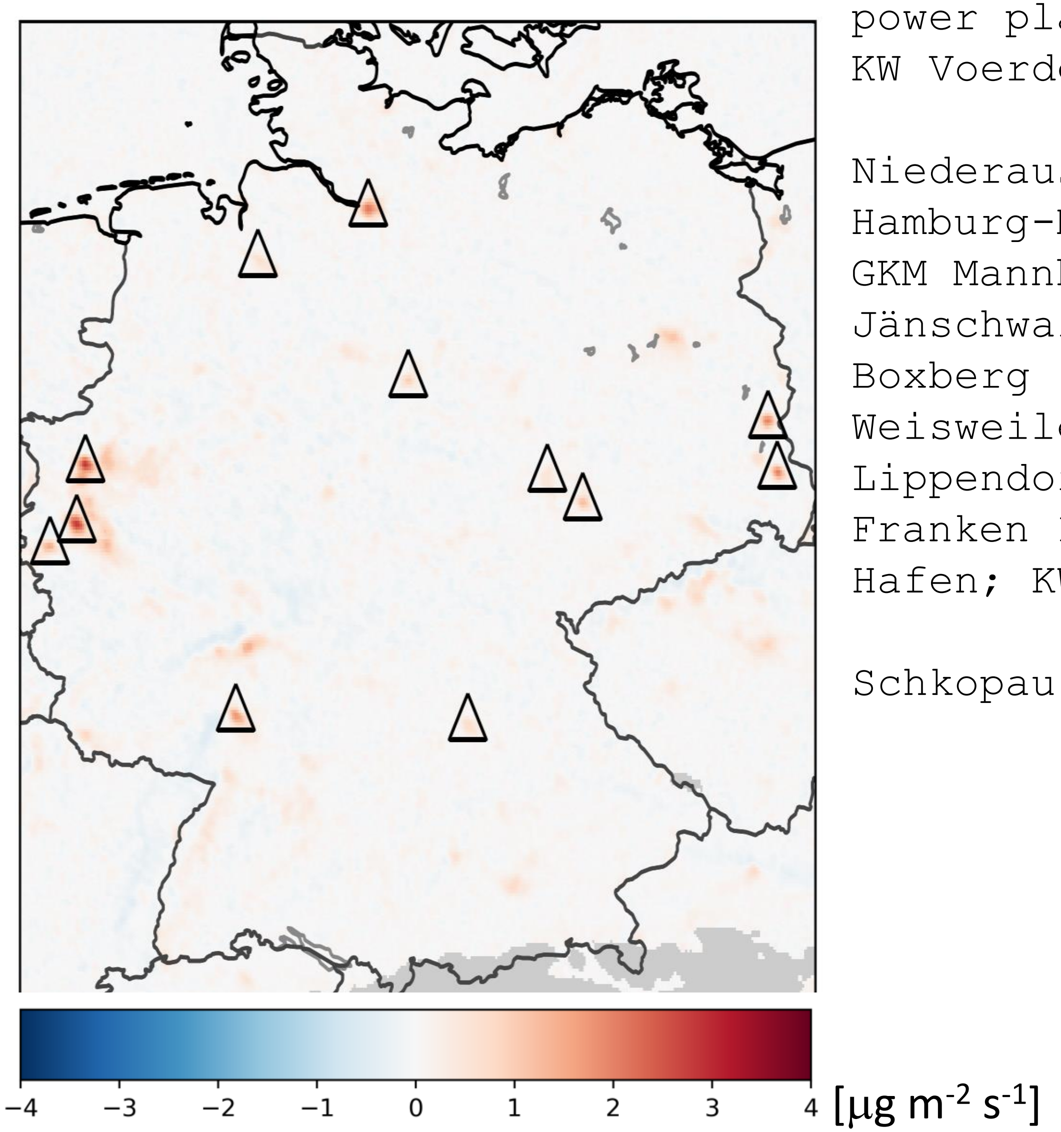
Version 2: Germany



power plants	cities
KW Voerde; KW Walsum; KW West; ...	Duisburg; Oberhausen; Mülheim; Bottrop; Moers
Niederaussem; Neurath; ...	
Hamburg-Moorburg; Tiefstack; ...	Hamburg
GKM Mannheim; Kraftwerk Mitte; ...	Mannheim; Ludwigshafen
Jänschwalde	
Boxberg	
Weisweiler	
Lippendorf	
Franken 1; HKW Sandreuth	Nuremberg; Fürth
Hafen; KW Mittelsbüren; ...	Bremen
	Braunschweig; Salzgitter
Schkopau; HKW Halle Trotha; ...	Halle

Validation

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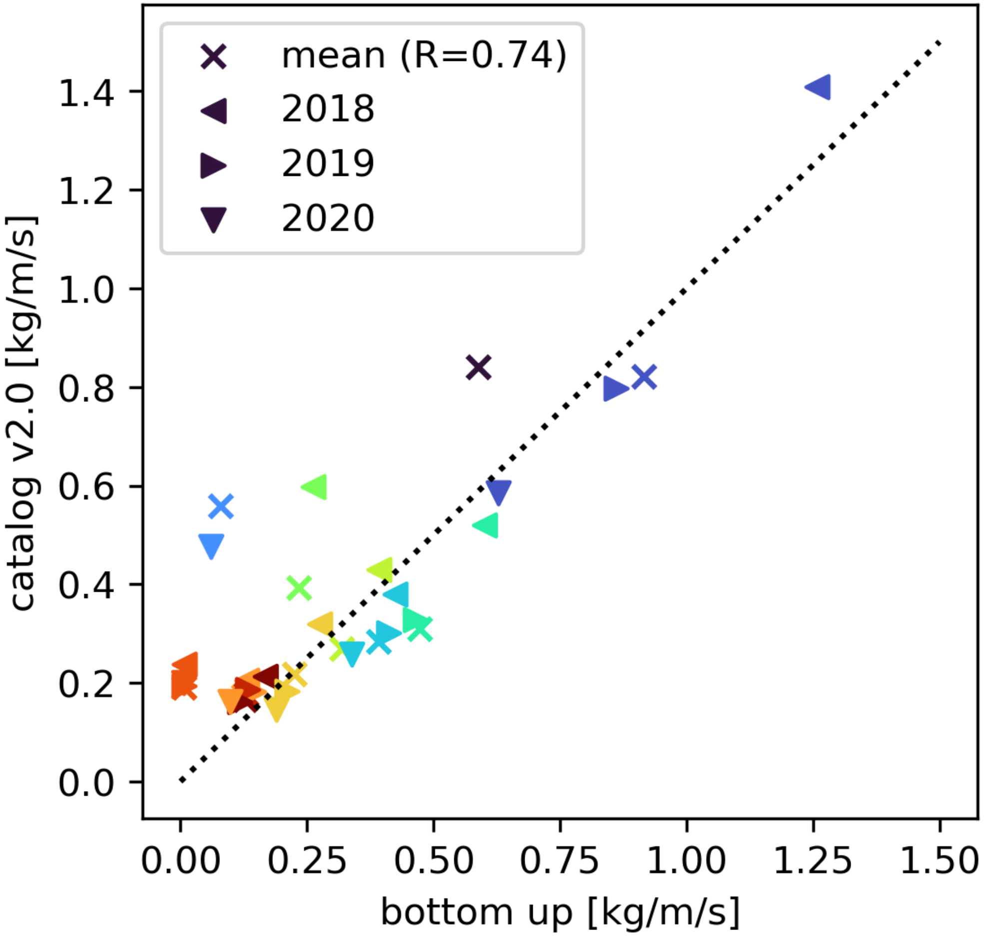
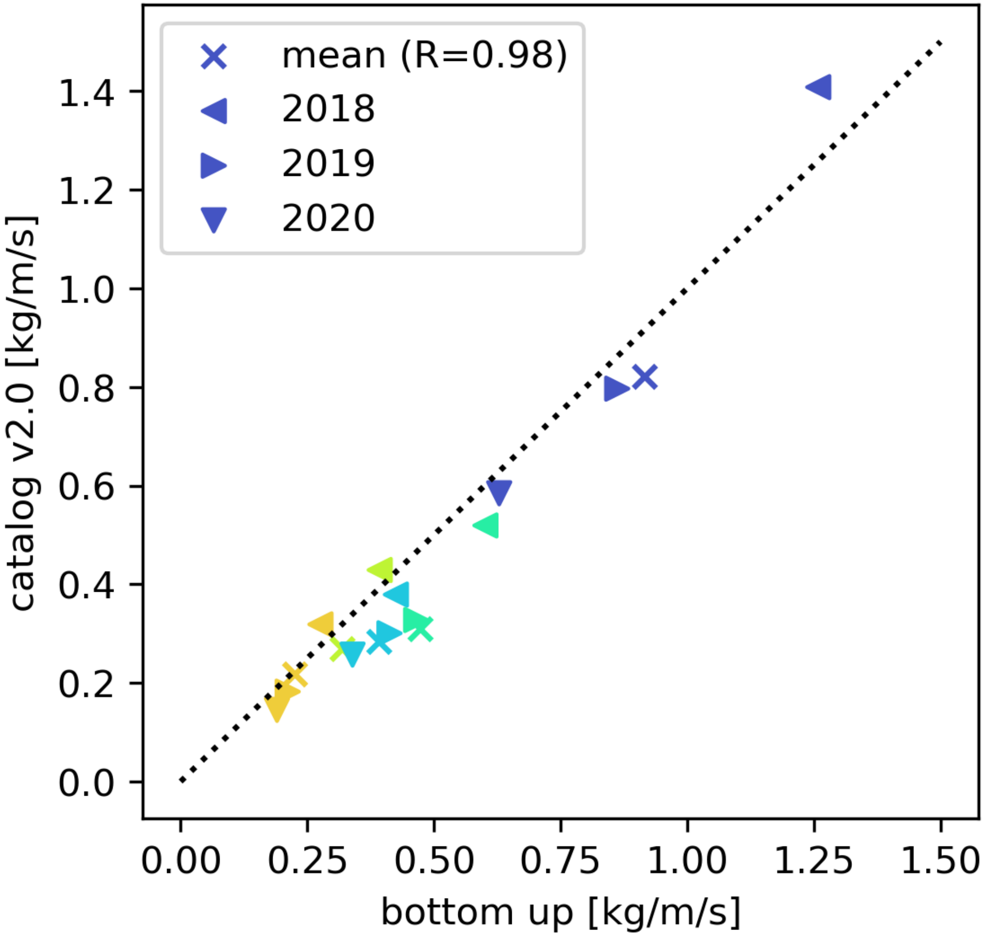
Germany

- Bottom up from PRTR (all sources within 15 km)



Point sources without nearby cities



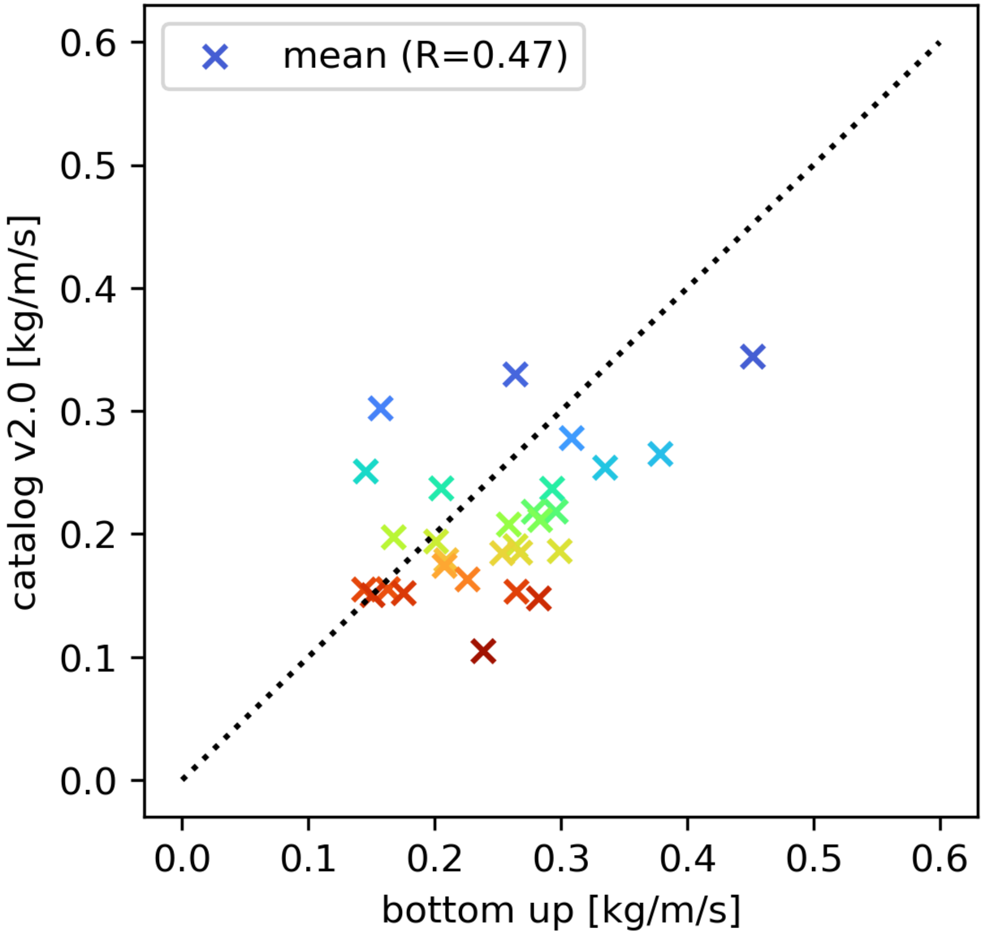
Validation

USA

- Bottom up from EPA EGRID:
  all sources within 15 km
  if sum is above detection limit
  (0.11 kg/s)
- Power plants only!

- https://www.epa.gov/egrid/download-data

Power plants without nearby cities



Remaining issues

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Version 1

- Gaps at desert/ocean transition
- High noise in divergence map over e.g. Europe and China
- Artefacts over mountains
- Low performance over China (too many interfering sources, high background)
- Low bias of emissions

Version 2

- Few gaps at desert/ocean transition
- Artefacts over mountains
- Low performance over China (too many interfering sources, high background)

Outlook

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World Emission

Within the **ESA World Emission** project:

- Compile NO_x point source catalog v2
- Compile SO_2 point source catalog

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