Enhancing global SO_2 emission inventories using S5P/ TROPOMI satellite measurements

Max Planck Institute for Chemistry — Satellite Remote Sensing Group

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1. Motivation

- sulfur dioxide (SO_2) is a major air pollutant
- affects atmospheric chemistry, environment, climate, and human health
- SO_2 emission sources:
  - anthropogenic: coal-burning, power plants, oil refineries, and smelters
  - natural: volcanic eruptions, volcanic degassing, and wildfires
- accurate information about SO_2 emissions is required in air quality and climate models

Aims of this study
- identification of anthropogenic SO_2 sources and derivation of a global emission inventory
- comparison of derived emissions with existing emission catalogues
- investigation to other species (e.g. NO_x)
- optimization of emission estimations using new algorithms & methods

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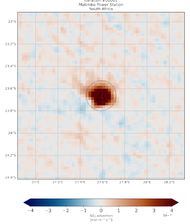
2. Algorithm

1. Data selection
   - COBRA SO_2: decreases noise and biases significantly
   - ERA5 winds: ECMWF atmospheric reanalysis of the global climate
2. Data filtering & merging
   - restriction to QA values above 0.5
   - removal of artifacts due to COBRA algorithm
   - merging of COBRA and DOAS SO_2 datasets
3. AMF correction
   - based on averaging kernel at plume altitude to account for height dependent sensitivity
4. Derivative on TROPOMI grid
   - interpolation of wind fields to 500 m, obs. time and lat/lon of TROPOMI pixel center
   - calculation of gradient of the SO_2 VCD on TROPOMI grid (as proposed by de Foy, 2022)
5. Calculation of advection
   - see section 3
6. Topographic correction
   - systematic artifacts of the divergence map over mountains
   - calculation of topography-corrected advection to account for 3D transport effects (according to Sun, 2023)
7. Gridding and averaging
   - re-gridding to a regular lat/lon grid with 0.025° resolution
   - temporal averages for daily, monthly, and annual periods + complete time series
8. Compilation of point source (ps) catalogue
   1. ps are identified by a fully automated iterative procedure
   2. ps are quantified by spatial integration of the advection map
   3. significant ps are selected by different criteria (e.g. temporal persistence)

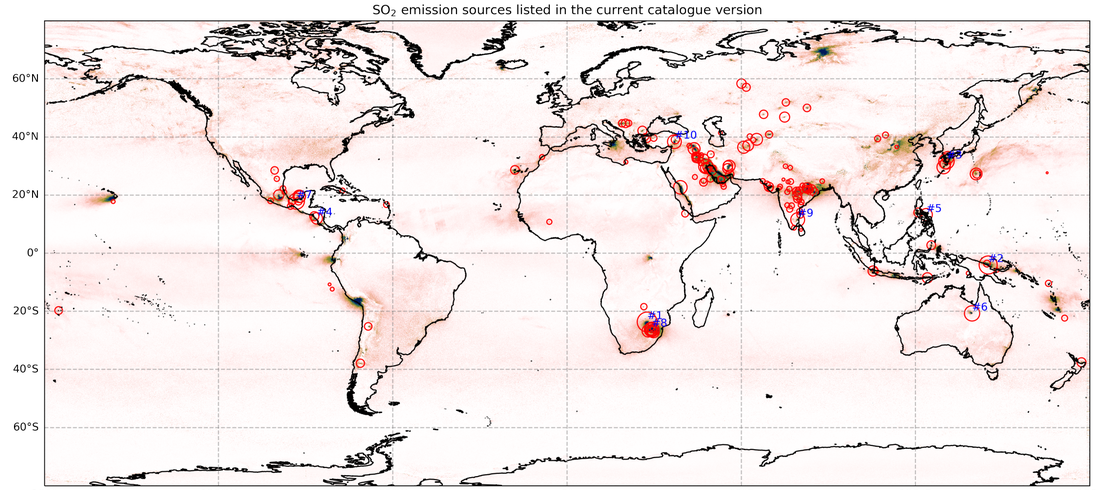
3. Advection method

- starting point: divergence of SO_2 flux based on continuity equation
  - $D = \nabla \cdot \overrightarrow{F} = E - S$
  - $D = \nabla \cdot (\overrightarrow{w} V) = \overrightarrow{w} \cdot \nabla V + V \nabla \cdot \overrightarrow{w}$
- first term is the advection of SO_2
  - $A = \overrightarrow{w} \cdot \nabla V$
- second term: divergence of the wind fields scaled with the SO_2 VCD
- we are interested in flux changes caused by local SO_2 emissions
  - ➡ advection method
- method yields sources/sinks on a map



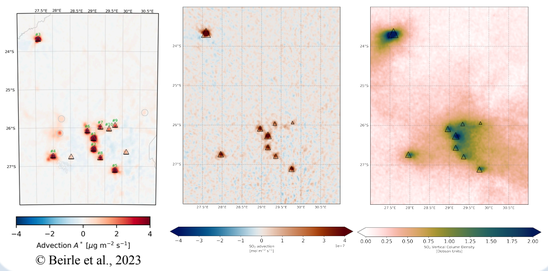
4. Results (global)

- anthropogenic as well as volcanic sources are clearly visible in the total mean SO_2 map
- mostly small and medium emission sources are detected as point sources
- SO_2 sources with very high emission values are not yet classified correctly e.g. volcanoes and strong anthropogenic sources like Norilsk (Russia)
  - due to their spatial extent, some of the sources get classified as “area sources” (not listed yet)
- in case of complex topography or SO_2 sinks in proximity of the source, some SO_2 sources get classified as “negative”
  - this phenomena is often observed near volcanoes



5. Results (regional)

- regions of enhanced SO_2 are already evident from the VCD maps
- exact location is inferred from the advection method
- on local scale: very good agreement with NO_x point source catalogue
- background is much more noisy than for NO_x
  - this makes the weak sources more difficult to distinguish from the background



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6. SO_2 point source catalogue extract (preliminary)

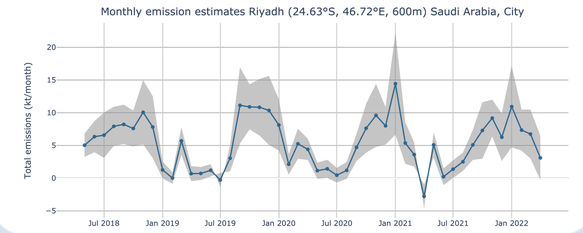
- in addition to emissions, statistics for the point sources will be provided

Top 10 anthropogenic emission sources (global)

Rank	Latitude [°]	Longitude [°]	Emissions [kt/month]	Error [kt/month]
1	-23.69	27.59	35.08	24.83
2	-4.06	145.04	34.69	24.67
3	17.89	-93.19	23.47	16.65
4	31.59	130.66	17.74	12.68
5	-26.26	29.16	17.67	12.68
6	22.66	39.04	16.46	11.65
7	38.36	36.99	16.38	11.6
8	-20.71	139.49	16.29	11.54
9	11.54	79.44	15.65	11.09
10	35.99	43.76	15.05	10.68

7. Timeseries

- monthly time series of SO_2 emission are in line with power plant reports



8. Discussion & Conclusions

- total number of anthropogenic sources is 200+
  - further improvements will probably result in detection of additional point sources
- at some locations, a variety of industrial sources are grouped together close by
  - no simple attribution of sources
- new algorithm allows for accurate identification & localization of point sources
- identification of weak sources due to COBRA SO_2 product
- monitoring of changing SO_2 emissions (time series)

Outlook
- error estimation
- further comparison with existing SO_2 catalogues
- update of ERA5 input dataset to higher spatial and temporal resolution
- include external information about the source

Disclaimer

The presented work has been performed in the frame of the European Space Agency (ESA)-funded World Emission Project (https://www.world-emission.com). Results are preliminary and will still change.

Acknowledgement

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This presentation participates in OSPP
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Sharing is encouraged

Abstract

Supplementary Materials

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