

Improved detection of global NO₂ signals from shipping using TROPOMI observations: advanced filtering and comparison with CAMS



Miriam Latsch¹, Andreas Richter¹, John P. Burrows¹, and Hartmut Bösch¹

¹ Institute of Environmental Physics (IUP), University of Bremen, Germany



poster as pdf

1 Why are we interested in ship emissions?

- Ships emit large amounts of nitrogen oxides, among other air pollutants.
- NO_x (= NO₂ + NO) are important trace gases in the troposphere, affecting the marine boundary layer and human health: “... a surprisingly large fraction of the early mortality – approximately 15%, or 60 000 deaths – were due to air pollution from [...] international ships ...” (ICCT, 2019)
- The aim of this study is to improve the detection of global shipping signals in the TROPOMI NO₂ data, and compare the signals with CAMS model data.

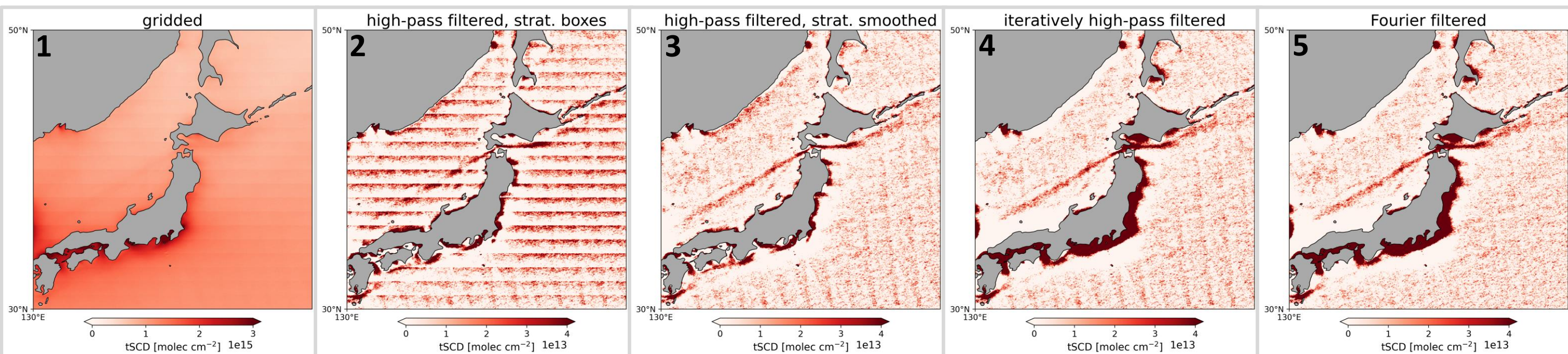


2 TROPOMI data

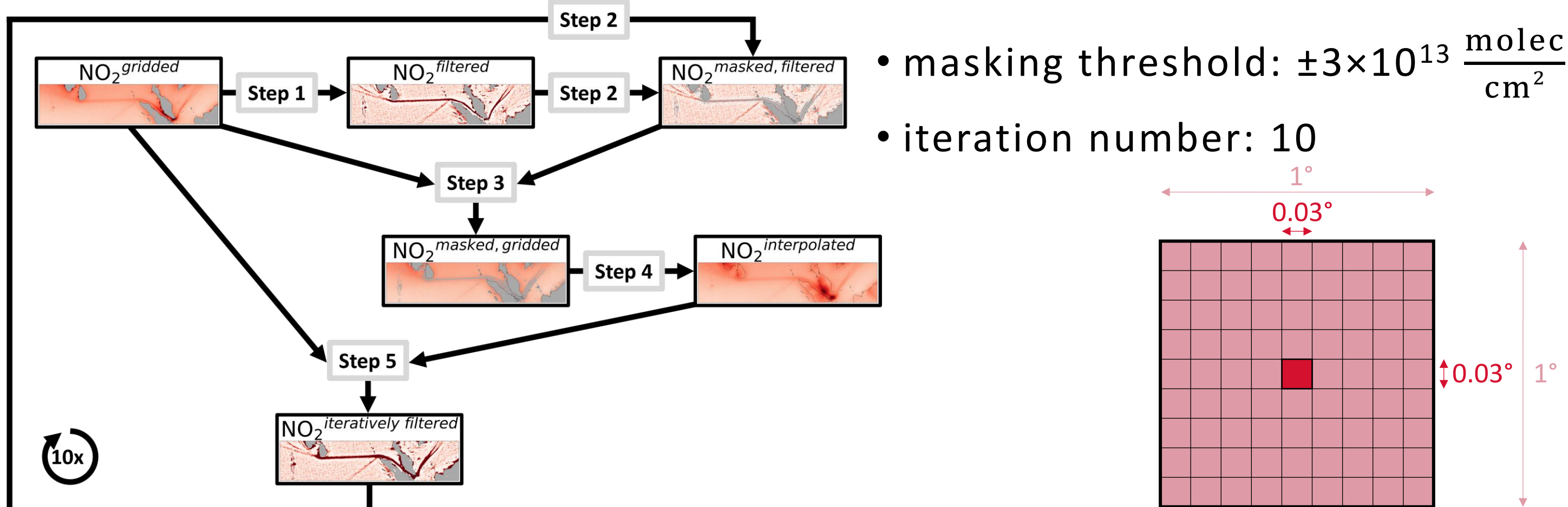
- TROPOMI RPRO and OFFL Level 2 NO₂ data of processor versions 2.4.0-2.6.0
- The tropospheric NO₂ slant column density (tSCD) is used, because the air mass factor (tAMF) is derived using vertical NO₂ profiles from the coarse TM5 model, which contain information over global shipping routes.

3 Advanced filtering method

- Land sources are much larger than shipping sources, therefore we are looking for small signals on a variable background. The following data processing steps allows us to detect global shipping lanes:
- Step 1:** NO₂ tSCDs are averaged on a 0.03° grid from 5/2018 to 4/2024.
- Step 2:** High-pass filtering highlights shipping lanes, but also boxes coming from the stratospheric correction with a tropopause height on a 1° grid.
- Step 3:** Smoothing of the stratospheric VCD removes boxes.
- Step 4:** Iterative high-pass filtering reduces high-pass filter effects.
- Step 5:** Fourier filtering eliminates periodic striped orbit-pattern.



Iterative high-pass filtering scheme:



- high-pass filtering box size: 1°
- masking threshold: $\pm 3 \times 10^{13} \frac{\text{molec}}{\text{cm}^2}$
- iteration number: 10

4 Global NO₂ shipping signals

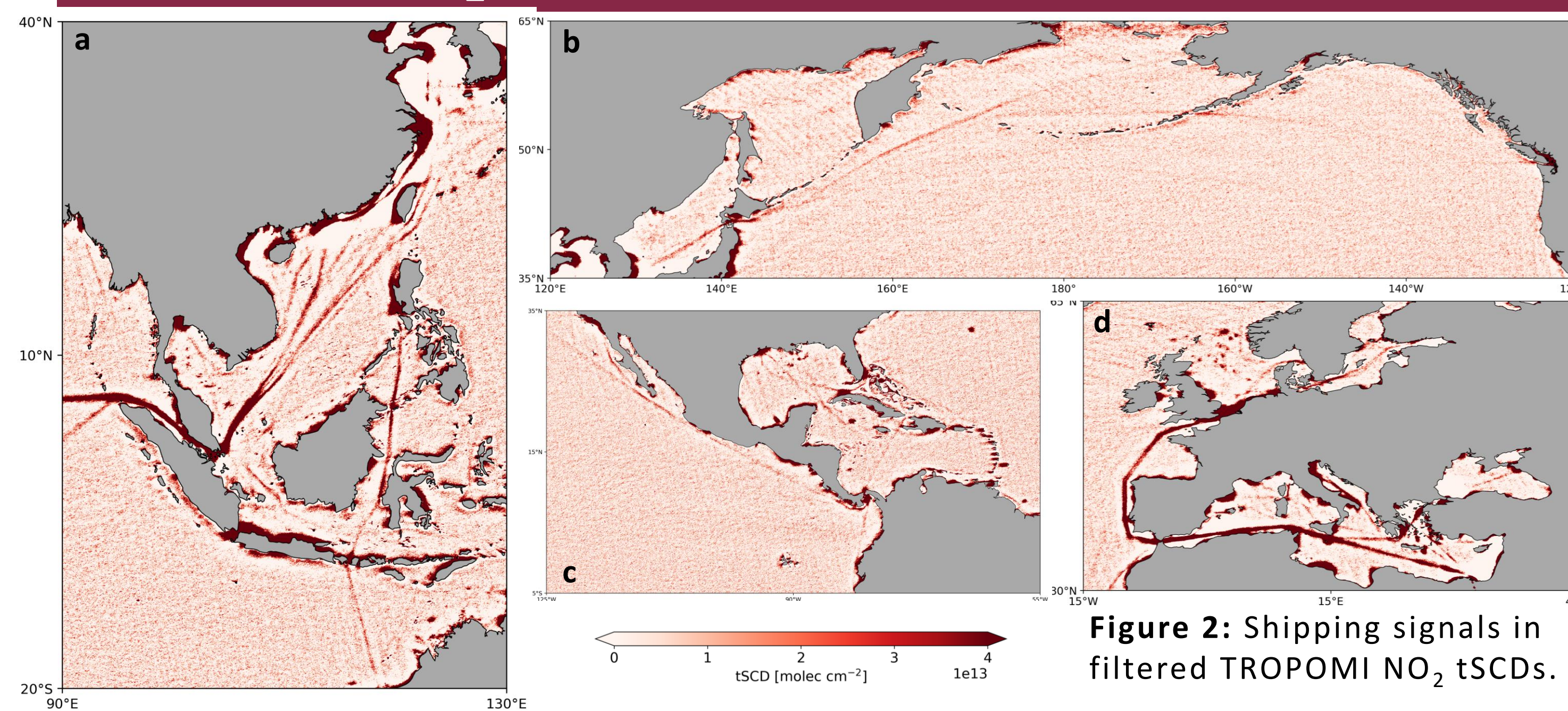


Figure 2: Shipping signals in filtered TROPOMI NO₂ tSCDs.

- The high-pass and Fourier filtering methods enable the detection of
 - known shipping routes with much more details: Asian seas (Fig. 2a) and two Portugal lanes (Fig. 2d and 3a)
 - lanes that have not been detected before: Gulf of Mexico (Fig. 2c)
 - unknown signals: Bering Sea (Fig. 2b)
 - offshore oil and gas platforms: Gulf of Mexico and North Sea (Fig. 2c/d)

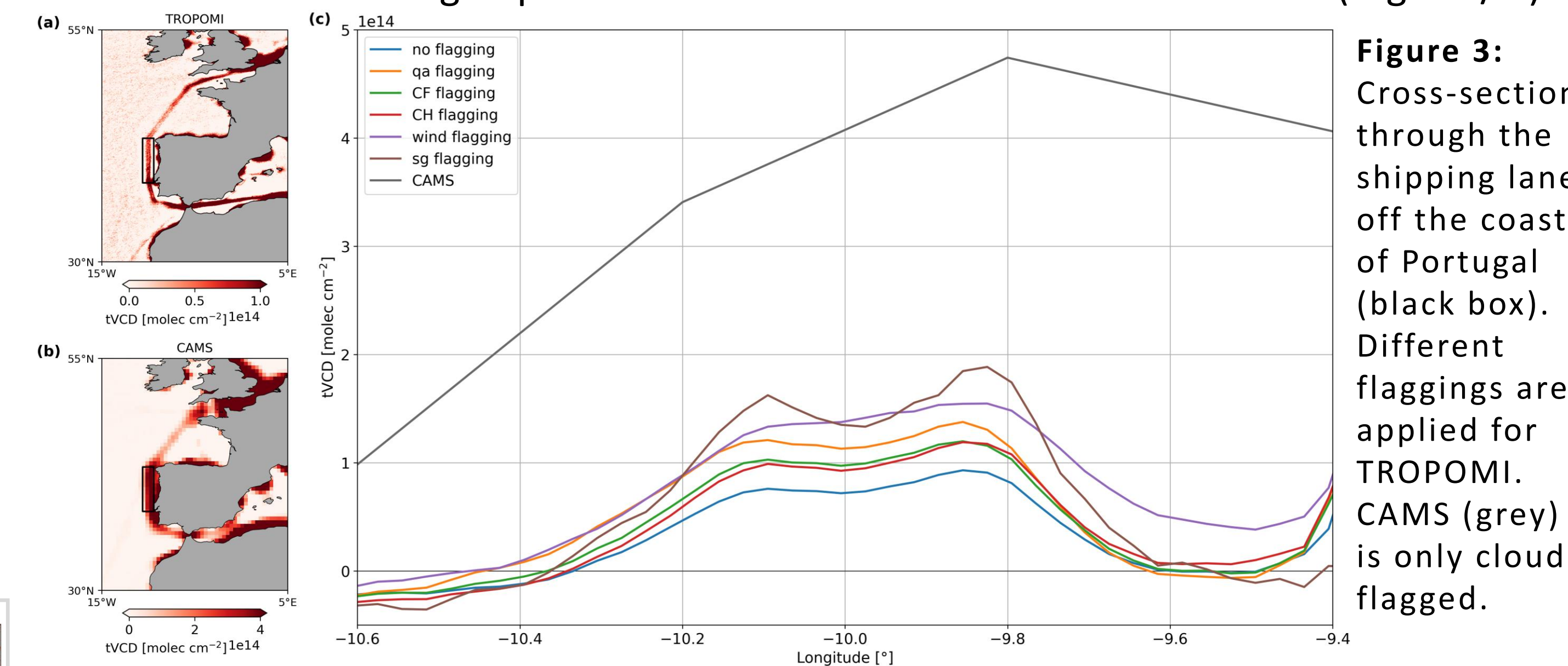


Figure 3: Cross-section through the shipping lane off the coast of Portugal (black box). Different flaggings are applied for TROPOMI. CAMS (grey) is only cloud flagged.

- The distribution of the signal (Fig. 3c) depends on the TROPOMI flagging:
 - no flagging:** lowest NO₂ columns, as expected
 - quality value (qa) > 0.75:** moderate NO₂ columns
 - cloud fraction (CF) < 0.5 and cloud height (CH) < 2km:** similar and smallest effect on the signal
 - wind speed between 0 and 5m/s:** increased, uniform and shifted peak
 - “sun glint (sg) possible”:** highest, pronounced peaks due to the increased sensitivity to detect NO₂ near the sea surfaces
- One issue is that the background noise increases due to the reduced number of available measurements (not shown). Therefore, the standard data in Fig. 2 are not flagged (blue curve in Fig. 3).

Acknowledgements

Parts of this work were funded by the Deutsches Zentrum für Luft- und Raumfahrt (DLR) under contract 50EE1811A (“SSP Datennutzung”) and the University of Bremen.

5 Comparison with CAMS

- CAMS data are included for which a collocated TROPOMI measurement is present, matching both overpass time and cloud filtering (Fig. 3b):
 - 5 years (from 2019 to 2023)
 - a spatial resolution of 0.4°×0.4°
 - high-pass filtered with the same TROPOMI settings, i.e. a 10-fold iteration
- The CAMS curve exceeds the TROPOMI curves by a factor of 2 to 5, depending on the flagging (Fig. 3c). The two peak pattern of the shipping lanes is not as clearly visible due to the coarser resolution of the model.

6 Conclusions

- TROPOMI offers new opportunities to detect NO₂ signals from shipping.
- Using high-pass and Fourier filtering, many shipping routes could be identified that have never been shown in satellite NO₂ data before.
- Smaller box sizes (e.g. 0.25°) enhance the visibility of narrow features (not shown), while a box size of 1° produces overall stronger NO₂ signals and is most consistent with no flagging for a global study.
- TROPOMI and CAMS show good consistency in the positions of the shipping lanes, but larger differences between measured and modelled data result from different spatial resolutions, large land emission outflow in CAMS, and inadequate NO_x chemistry in the CAMS model.

7 Outlook

- More detailed comparison with CAMS global model to better understand the NO_x chemistry in CAMS
- Quantitative estimation of NO_x emissions for the detected shipping tracks, including a conversion from NO₂ SCDs to VCDs using pixel specific AMFs
- overall aim: a global dataset of NO_x emission estimates
- Comparison with geostationary satellites, e.g. Sentinel-4 and GEMS (Fig. 4)
- filtering methods need to be reevaluated

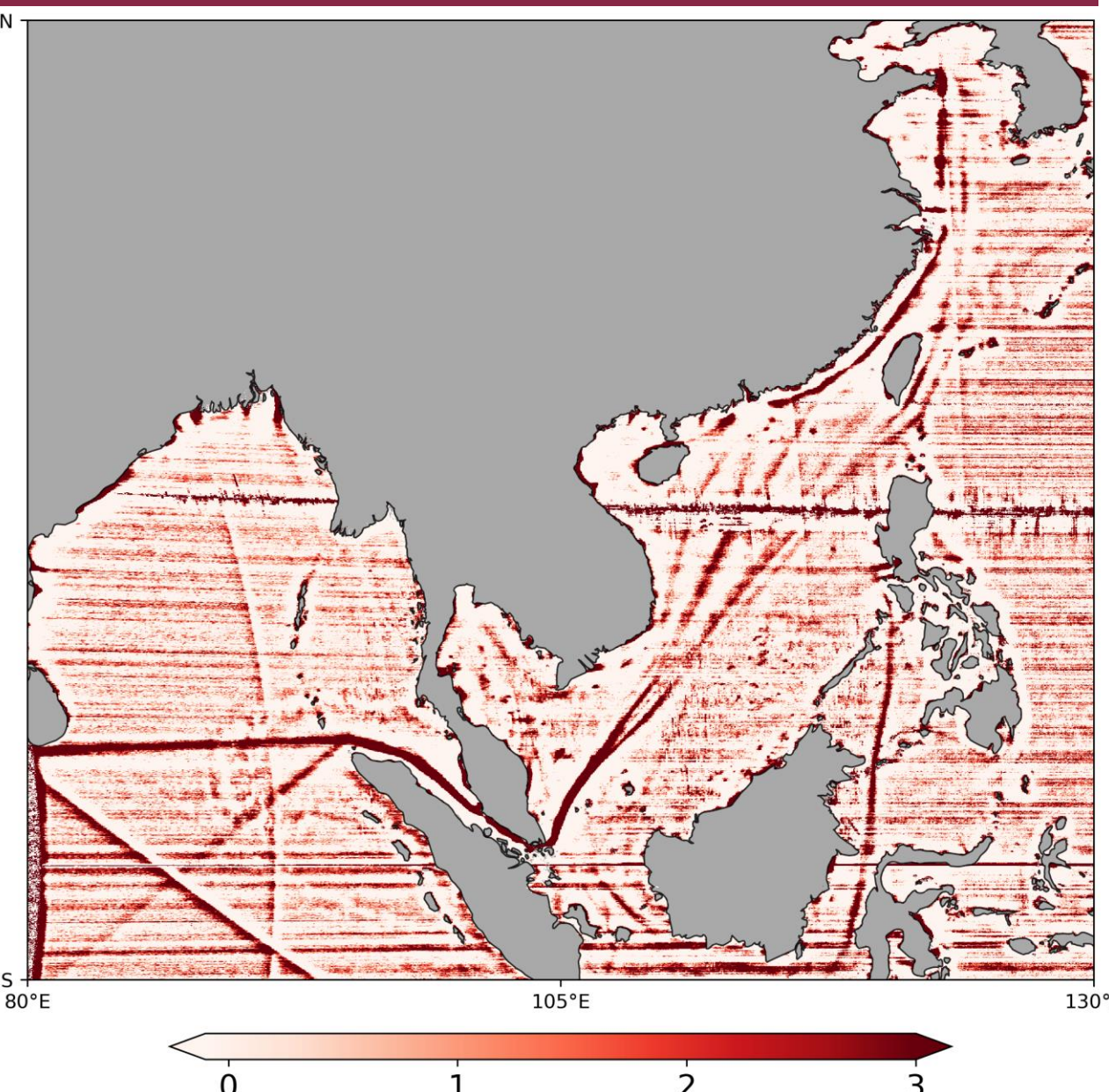


Figure 4: Shipping signals in filtered GEMS NO₂ tSCDs (5-year average).

References

- See also https://www.iup.uni-bremen.de/does/tropomi_ships.htm to explore a high resolved global maps of the filtered TROPOMI NO₂ tSCDs.
- Latsch, M., Richter, A., Burrows, J. P., and Bösch, H.: Improved detection of global NO₂ signals from shipping in Sentinel-5P TROPOMI data, *Atmos. Meas. Tech.*, 18, 17, 4373–4395, <https://doi.org/10.5194/amt-18-4373-2025>, 2025.
- Latsch, M., Richter, A., Burrows, J. P., and Bösch, H.: Global filtered tropospheric NO₂ slant column densities derived from 6-year averages of TROPOMI measurements over water for shipping signal detection [data set], PANAGEA, <https://doi.org/10.1594/PANGAEA.982514>, 2025.