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# Satellite observations of Ship emitted $NO_2$


A. Richter, F. Wittrock and J. P. Burrows

Institute of Environmental Physics/Remote Sensing, University of Bremen,
FB 1, P.O. Box 330440, D-28334 Bremen, Germany
Email: Andreas.Richter@iup.physik.uni-bremen.de


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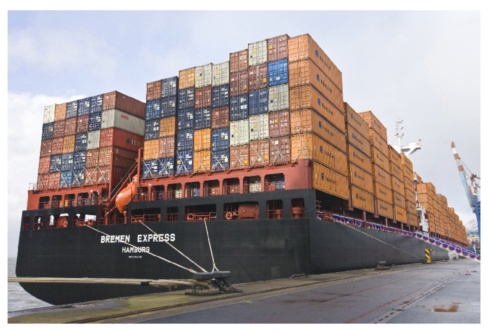
## Why measure shipping NOx?

- Nitrogen oxides (NOx = $NO_2$ + NO) are important trace gases in the troposphere.
- They are a key component in tropospheric ozone formation.
- Through reaction with OH, they form $HNO_3$ contributing to acidification.



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- Ships emit large amounts of nitrogen oxides into the marine boundary layer.
- They change the chemistry in remote regions and create health hazards when operating close to coasts.
- As the amount of goods transported increases, so do emissions from ships.
- Ship emissions are currently not strongly regulated but legislation will change in the coming years.

## Instruments and Retrieval

**SCIAMACHY:**

- data since August 2002
- 60 x 30 km$^2$ pixel size
- global coverage in 6 days
- 10:00 LT equator crossing

**GOME-2:**

- data since January 2007
- 80 x 40 km$^2$ pixel size
- global coverage in 1.5 days
- 09:30 LT equator crossing

**OMI:**

- data since October 2004
- 13 x 24 km$^2$ min. pixel size
- global coverage in 1 days
- 13:40 LT equator crossing

**DOAS Analysis:**

- 425 - 450 nm (SCIAMACHY) and 425 - 497 nm (GOME-2) fitting window

**Stratospheric Correction:**

- reference sector over the Pacific (180° - 220° E)

**Airmass Factors:**

- assumption of a 600 m well mixed boundary layer with $NO_2$
- no correction for aerosol impacts

**Cloud treatment:**

- only filtering for values with cloud fraction below 20% using FRESCO data, no further correction

**Filtering:**

- high pass filter using boxcar smoothing over +/- 1.8° latitude and longitude
- masked to data over water only

## Cloud effects

**Expectation:**
Clouds are expected to have a large impact on the shipping $NO_2$ signal, mainly by shielding it from the satellite view

**Analysis:**
Data sets with different cloud fraction thresholds have been compared. FRESCO cloud fraction from the operational GOME-2 lv1 data was used

**Observations:**
There is a clear effect but it is not very large for small cloud fractions. Individual measurements are larger without clouds but the average is not much affected.

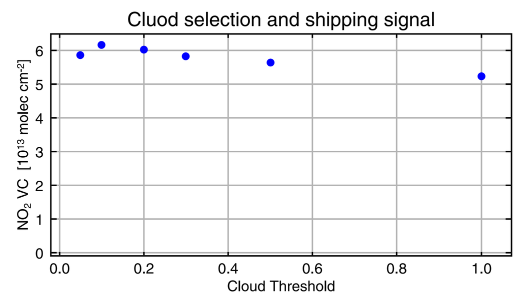



**Figure left:** Cloud threshold dependence of area marked in red in figure on the right. The reduction in $NO_2$ when using all data is only 20%, much less than expected from cloud shielding.

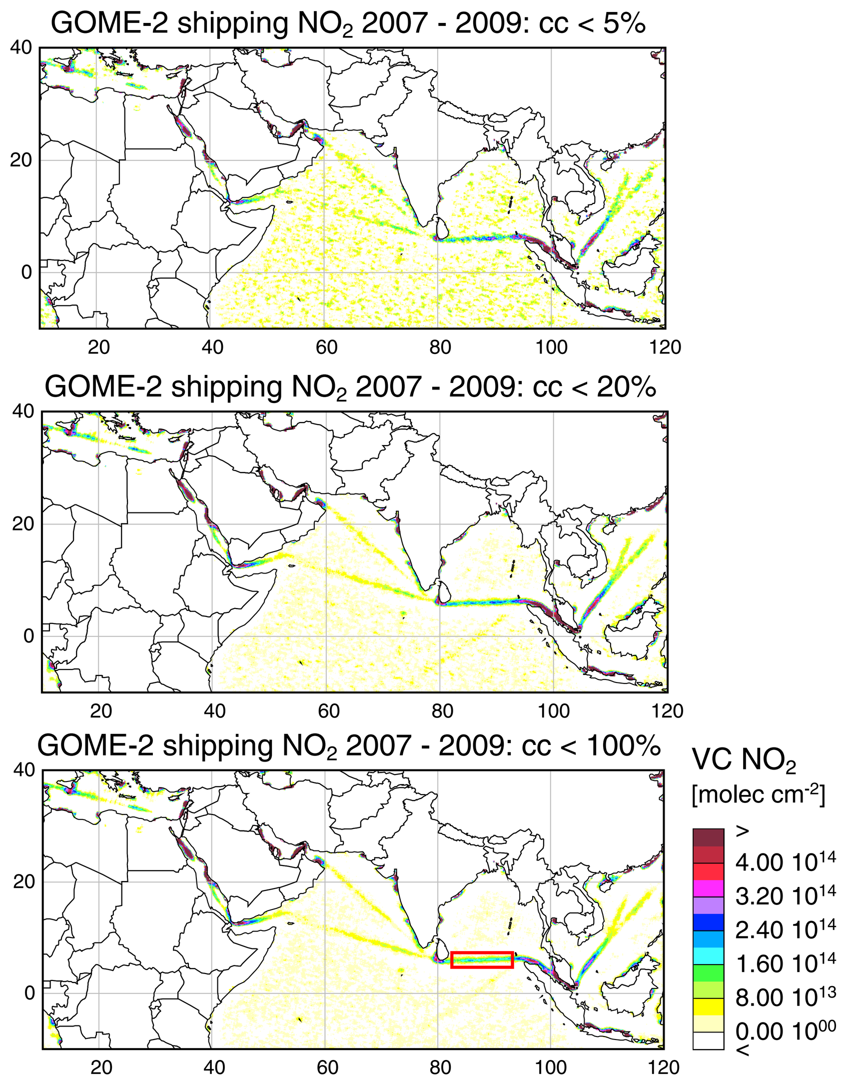
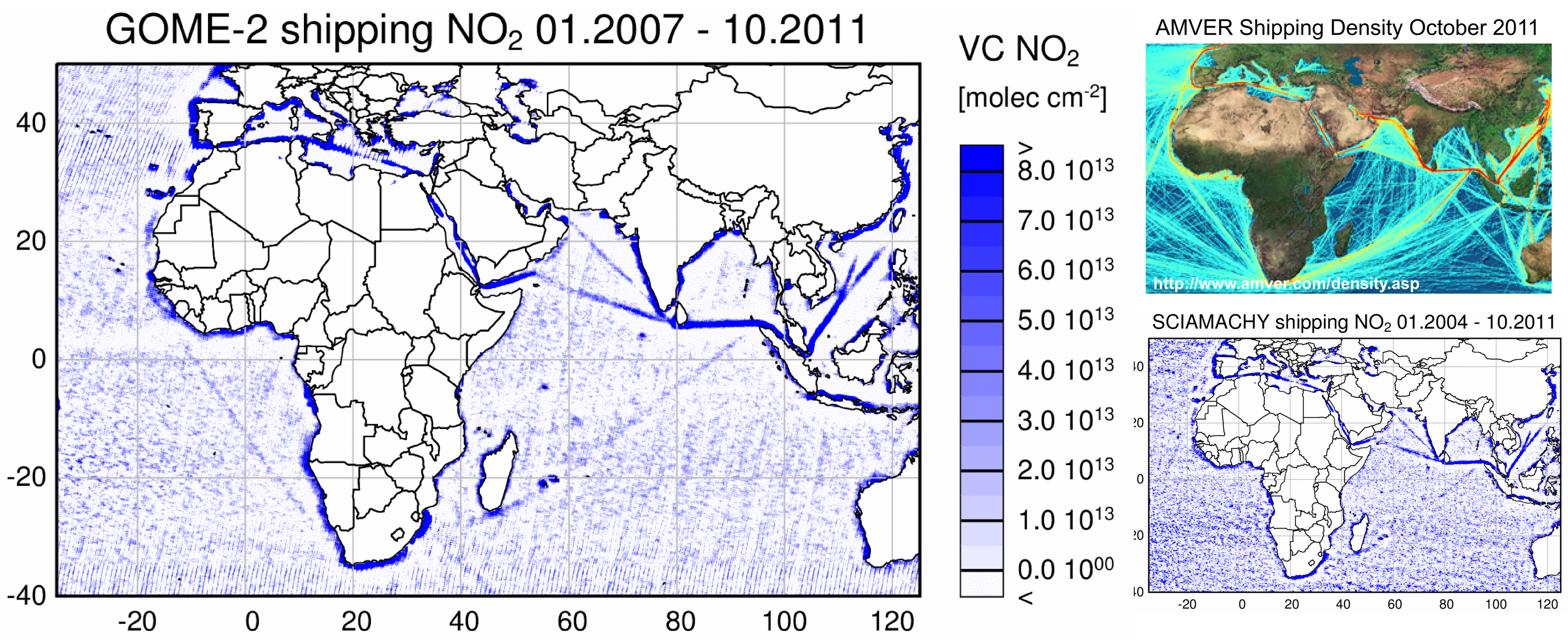



**Figure top:** GOME-2 shipping $NO_2$ for different cloud thresholds (< 5%, < 20%, no cloud screening). While the improvement in SNR is evident, there is no large reduction in $NO_2$ signal.

## Results



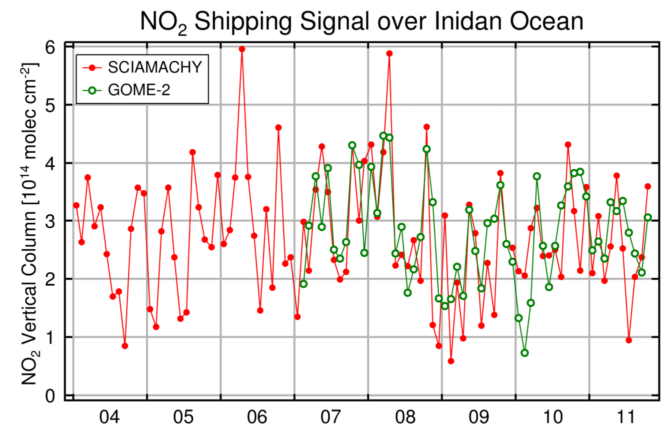

**Figures:** GOME-2 shipping signal (no cloud filtering applied) compared to AMVER ship densities (top right) and SCIAMACHY shipping $NO_2$ (bottom right).

**Observations:**

- $NO_2$ from international shipping can be detected as distinct lines of enhanced $NO_2$ in the GOME-2 observations from Europe through the Mediterranean, the Suez Channel, the Red Sea towards India, Indonesia and then China and Japan. The shipping lane around Africa can also be distinguished as well as shipping emissions in the Black Sea.
- Similar patterns are found in SCIAMACHY (and OMI) data but with larger noise.
- The observed pattern is similar to that reported from the AMVER shipping density. However, interestingly in the most recent AMVER data, the shipping lane to the Persian Gulf is much closer to the coast than suggested by the long-term average of the satellite data

**Temporal Changes:**

- Changes in shipping emissions are expected in response to varying ship transport volume
- Monthly shipping $NO_2$ observations in the strongest shipping lane in the Indian Ocean show large variations but good consistency between SCIAMACHY and GOME-2
- A 12 month running average suggests a slow increase from 2004 to 2008 with a sharp decrease towards mid 2009 and a subsequent increase
- This could be related to reduced shipping activities during the economic crisis
- The temporal evolution agrees with OMI data, the latter having smaller absolute values, presumably as result of the noon overpass time



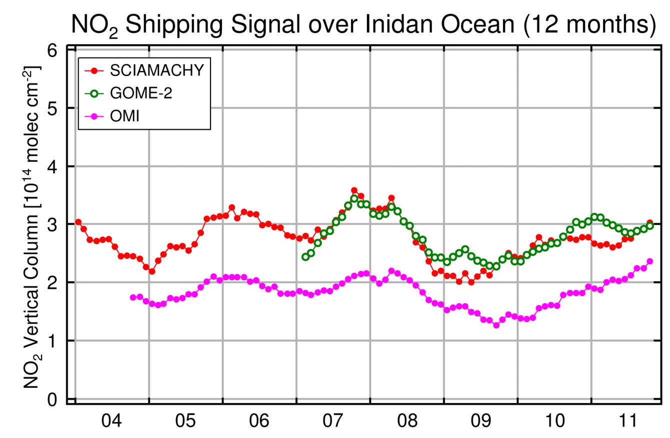




**Figure:** Shipping $NO_2$ in the Indian Ocean. The difference in $NO_2$ tropospheric columns between the region from 82°E - 95°E, 5°N - 7°N and the same longitude range but from 4°N - 5°N is shown. OMI data are based on NASA collection 3 total slant columns followed by the same analysis as described for SCIAMACHY and GOME-2 data.
In the lower figure, a 12 month moving average was applied to the data.

## Conclusions and future work

**Conclusions**

- GOME-2 $NO_2$ provides excellent signal to noise for studying ship emissions
- In addition to the ship tracks reported from GOME, SCIAMACHY, and OMI data, the shipping lane from Europe around Africa to Indonesia can now be detected
- There is indication for changes in shipping NOx emissions linked to overall increased transport volume and reduction during the economic crisis but uncertainties are still large
- The effect of clouds on the retrieval appears to be relatively small for cloud fractions below 30%

**Future work**

- More shipping lanes need to be analysed quantitatively, the impact of meteorology and transport needs to be investigated and the striping in GOME-2 and OMI data should be further reduced

## Acknowledgements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- OMI Slant Columns have been provided by NASA
- AMVER shipping densities have been provided by the US Coast Guard
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see also: www.iup.uni-bremen.de/doas