GOME-2 satellite observations of NOx emissions from ships

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Introduction

- 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.

- 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.

Instrument and Retrieval

GOME-2 Instrument:

- launched on MetOp-A in October 2006
- data since January 2007
- 4 channel nadir viewing UV/visible spectrometer
- similar to GOME and SCIAMACHY
- first in a series of three identical instruments
- 80 x 40 km^2 pixel size
- global coverage in 1.5 days
- 09:30 LT equator crossing

DOAS Analysis:
- 425 - 497 nm fitting window
- spectral spike correction to reduce scatter
- liquid water cross-section to remove interference from water absorption

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
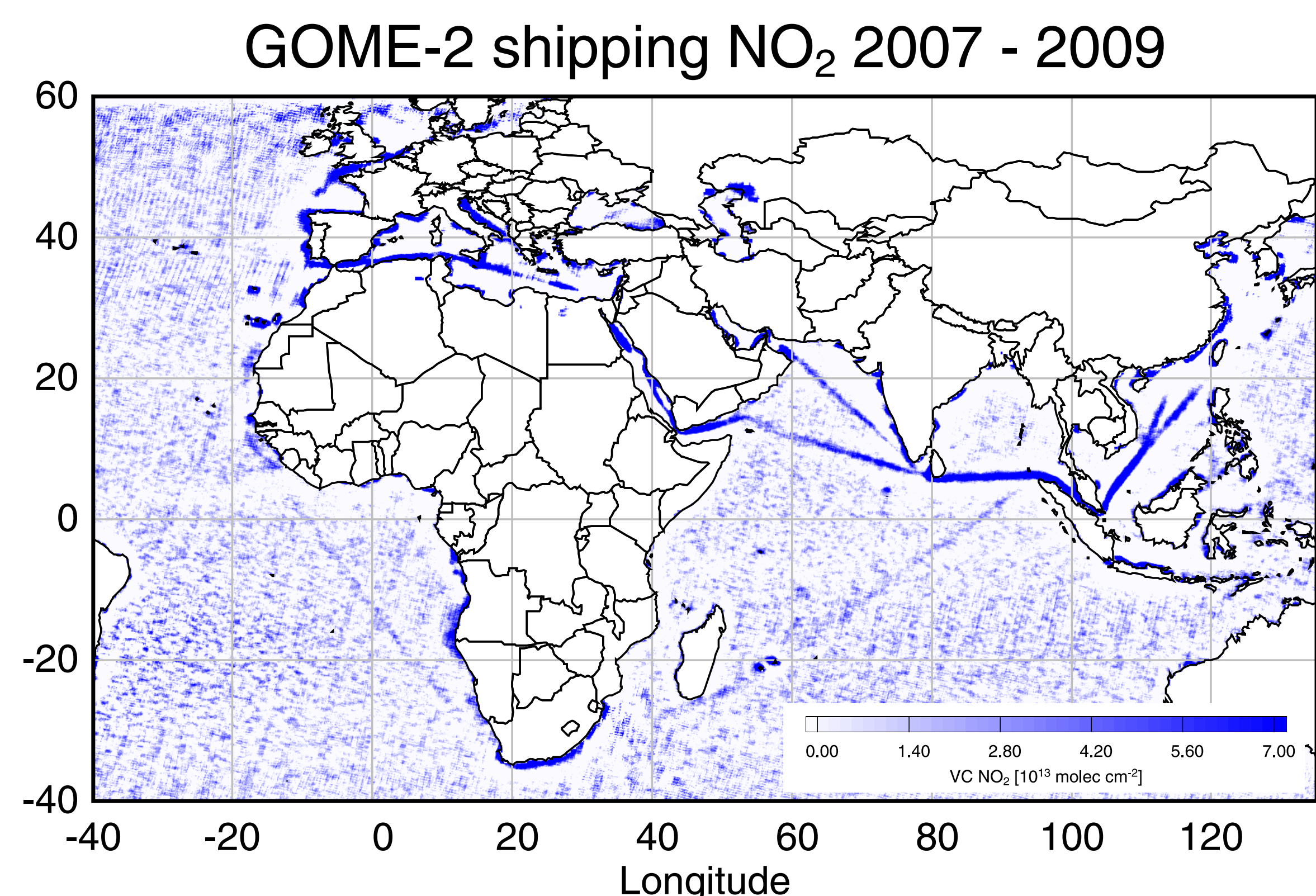
Cloud treatment:
- no cloud filtering for main figure but different filtering thresholds investigated using FRESCO data, see box to the right

Filtering:
- high pass filter using triangular smoothing over +/- 2.5° latitude and longitude
- masked to data over water only

Acknowledgements

GOME-2 shipping NO_2 2007 - 2009

Comparison to SCIAMACHY data

Observations:
In GOME-2 NO_2, several shipping lines are discernible:
- from Europe through the Mediterranean and the Suez Channel towards india, Indonesia and China / Japan
- from the Persian Gulf towards Indonesa
- from Europe around Africa towards Indonesia
- from Europe towards South America (very weak)

Only part of these signals could be seen in earlier data for several reasons:
- improved signal to noise ratio in GOME-2 data (as compared to SCIAMACHY)
- increased vessel density and thus emissions on some routes (compare AMVER data. Reasons: ships do no longer use the Suez Channel as they grow too large and as they try to avoid pirates (see below)

AMVER June 2003

AMVER June 2009

Figure top: AMVER vessel densities for June 2003 and 2009 from http://www.amver.com/density.asp

Comparison with SCIAMACHY data:
- GOME and SCIAMACHY shipping NO_2 signals are smaller than those from GOME-2
- This is in agreement with increases in shipping volume
- Changes in local time of measurement and retrieval uncertainties may also impact the comparison

Figure top: Comparison of shipping NO_2 between India and Indonesia from GOME, SCIAMACHY and GOME-2. Also shown is the seaborne trade volume (STV) as dots, averaged over the corresponding measurement periods. From Franke et al., 2009.

Figure: Comparison of shipping NO_2 averages as observed by SCIAMACHY from August 2002 to December 2006 (left) and by GOME-2 from 2007 - 2009. In addition to the better signal to noise of GOME-2 measurements, there is a clear change in route off Yemen and around the islands of Sokotra (see red circle), probably to avoid pirates operating from the coast of Somalia.

SCIAMACHY Shipping NO_2 08.02 - 12.06 | GOME-2 shipping NO_2 2007 - 2009

Shipping signal and clouds

Expectation:
Clouds are expected to have a large impact on the shipping NO_2 signal, mainly by shielding it from the satellite view. Some clouds could be formed from ship exhausts.

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 measure-ments are larger without clouds but the average is not much affected.
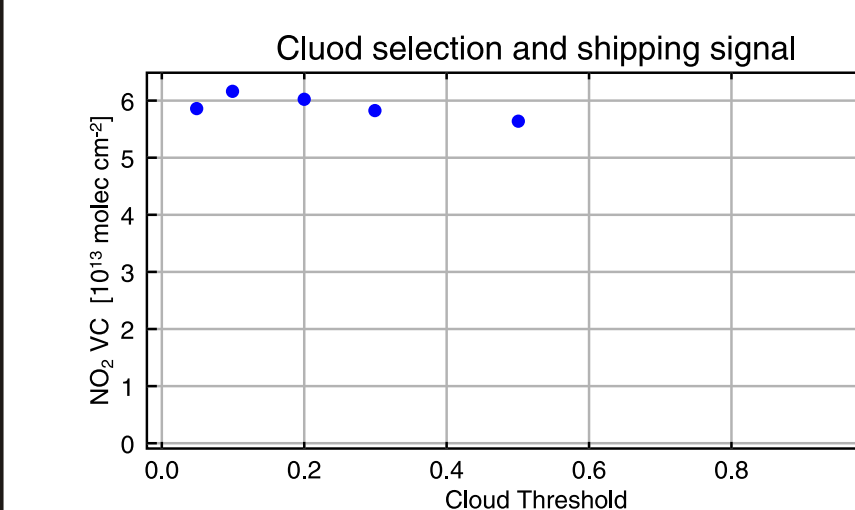

Figure left: Cloud threshold dependence of area marked in red in figure on the right. The reduction in NO_2 when using all data is only 20%, much less than expected from cloud shielding.
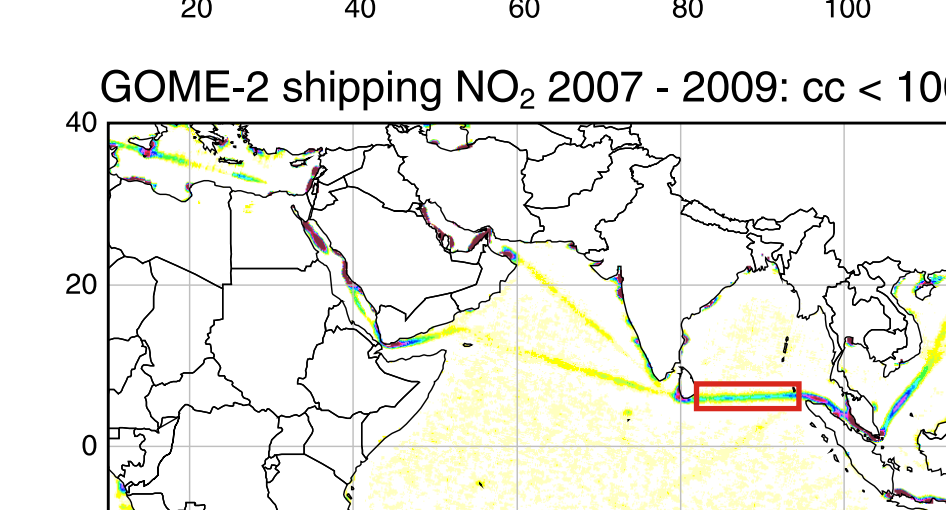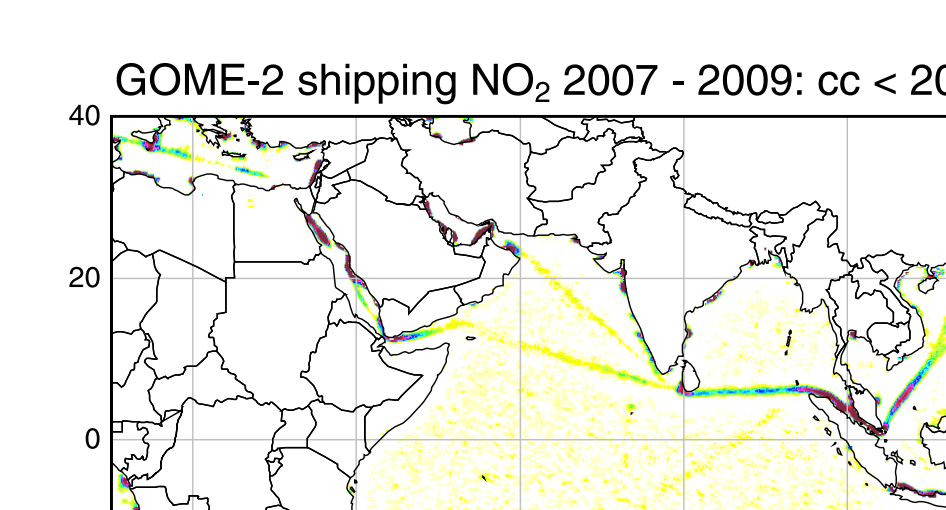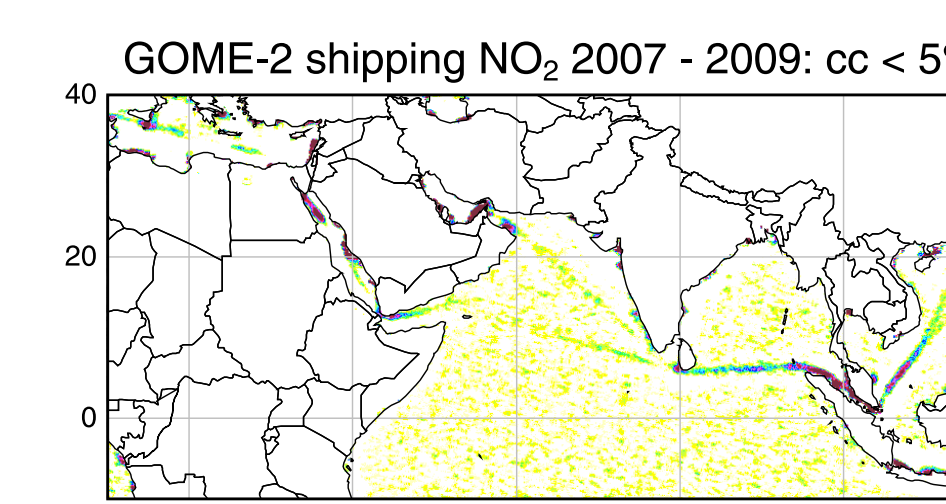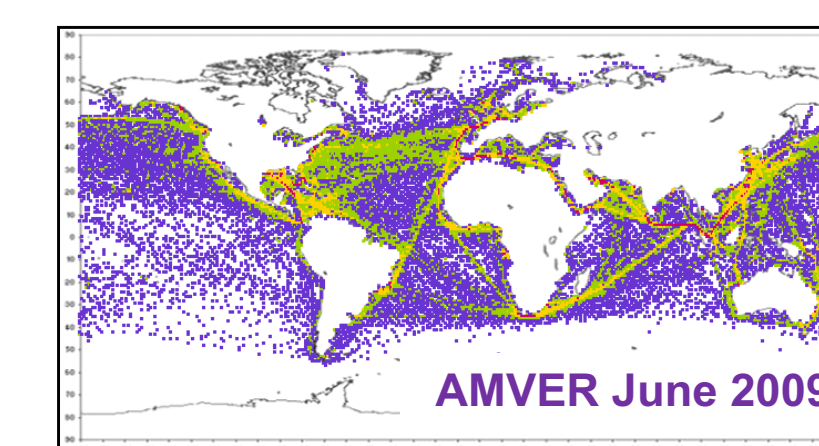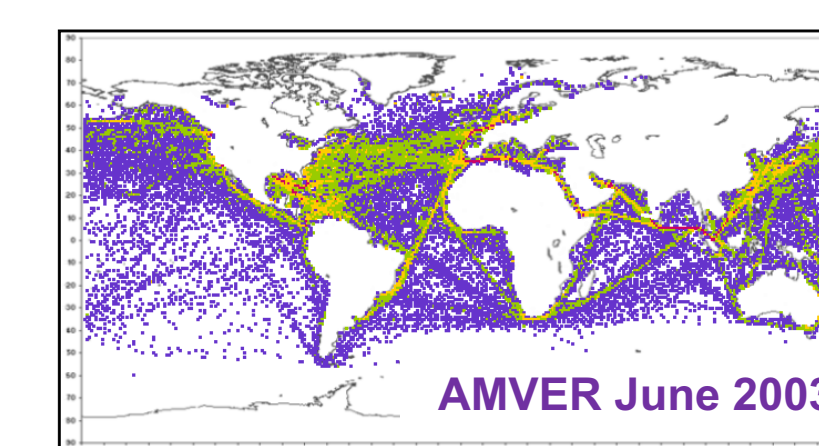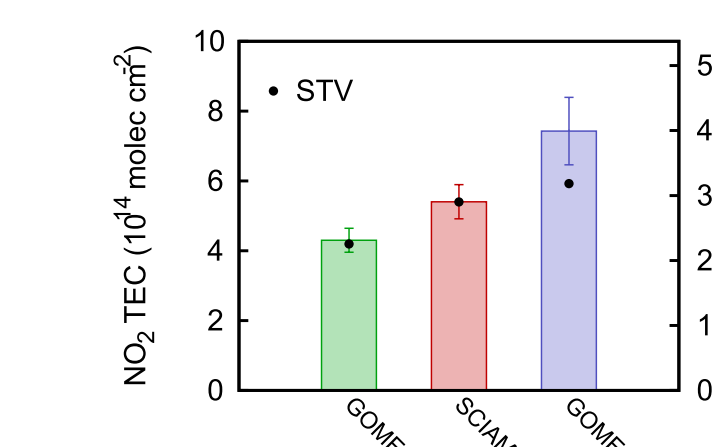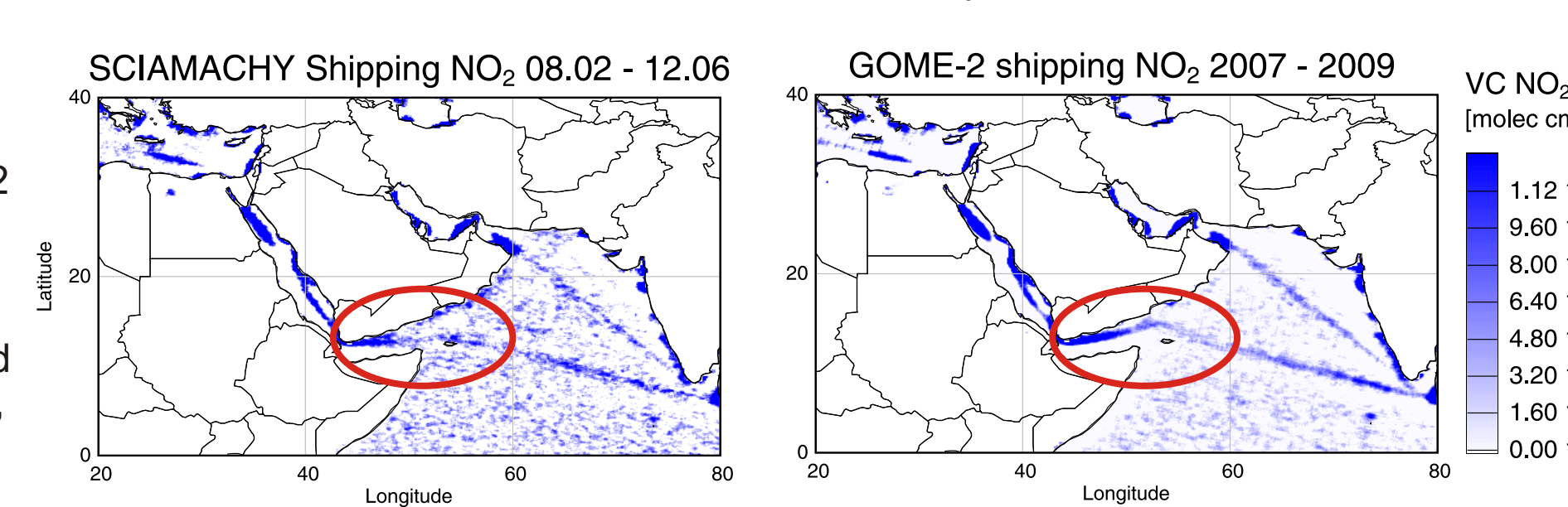
Figure top: GOME-2 shipping NO_2 for different cloud thresholds (< 5%, < 20%, no cloud screening). While the improvement in SNR is evident, there is no large reduction in NO_2 signal.

Conclusions

- GOME-2 NO_2 provides excellent signal to noise for study of ship emissions.
- In addition to the ship tracks reported from GOME, SCIAMACHY and OMI data, the shipping lane from Europe to South Africa to Indonesia could be detected and hints of the lane from Europe to South America.
- Changes in ship tracks off the coast of Yemen have been observed since 2006 which are a result of attempts to evade pirates operating from Somalia.
- There is indication for an increase in sipping NOx emissions linked to increased transport volume but uncertainties are still large.
- The effect of clouds on the retrieval appears to be relatively small for cloud fractions below 30%, probably because of cancellations of shielding and enhancement effects. Thus cloud screening is not as important as expected but reuslts could still be affected by clouds.

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