

# GOME-2 satellite observations of NO<sub>x</sub> emissions from ships

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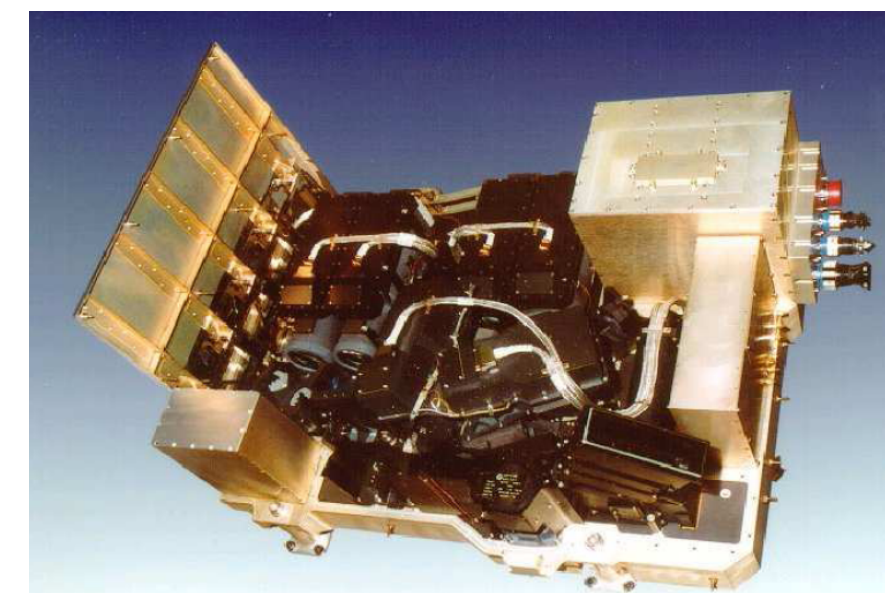


## Why measure shipping NO<sub>x</sub>?

- Nitrogen oxides (NO<sub>x</sub> = NO<sub>2</sub> + NO) are important trace gases in the troposphere.
- They are a key component in tropospheric ozone formation.
- Through reaction with OH, they form HNO<sub>3</sub> 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.



## GOME-2 Instrument



### 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<sup>2</sup> pixel size
- global coverage in 1.5 days
- 09:30 LT equator crossing

## Retrieval of shipping NO<sub>2</sub>

### 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<sub>2</sub>
- 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 triangular smoothing over +/- 2.5° latitude and longitude
- masked to data over water only

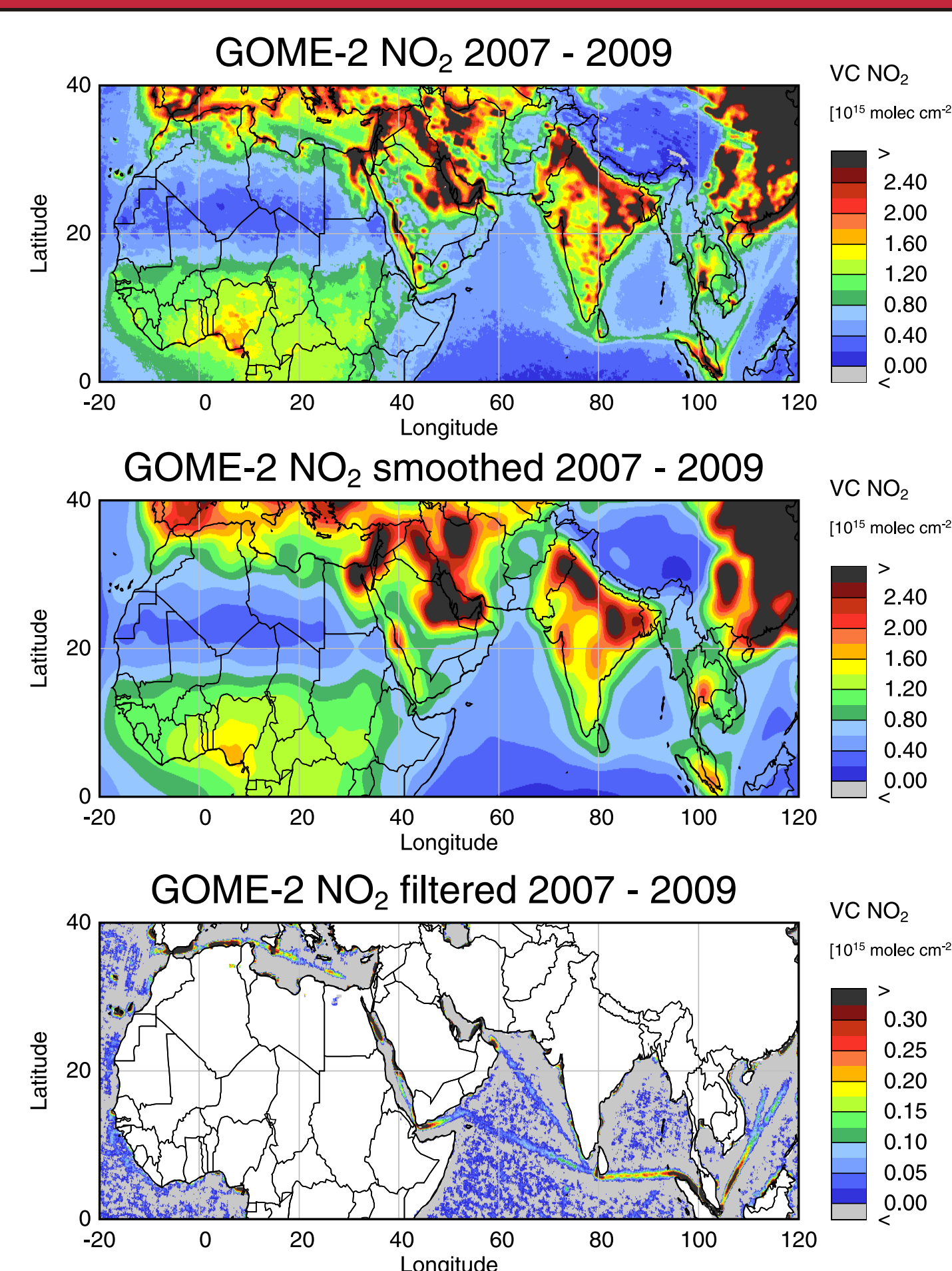


Figure: Illustration of data analysis steps

## Temporal Changes in shipping NO<sub>2</sub>

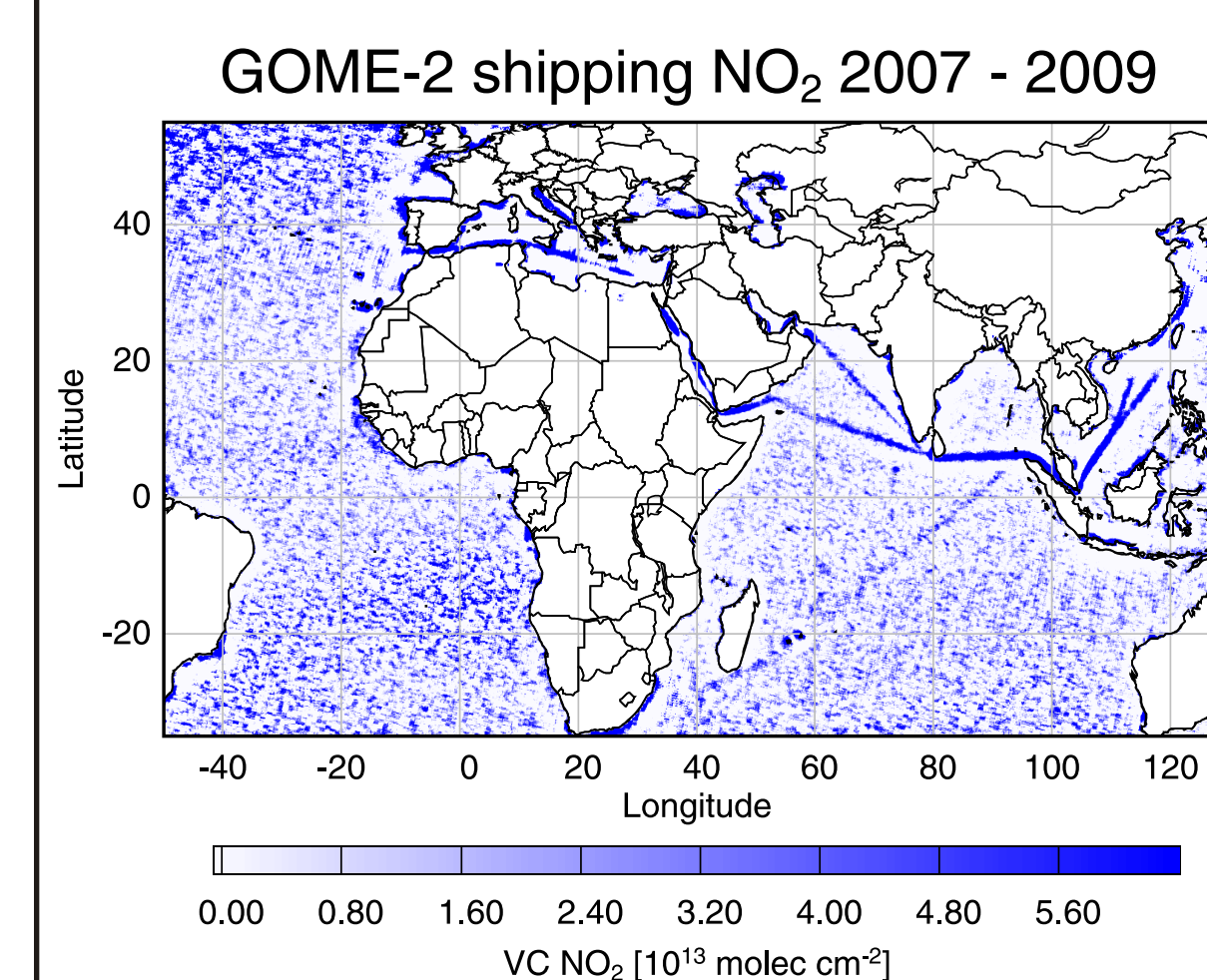
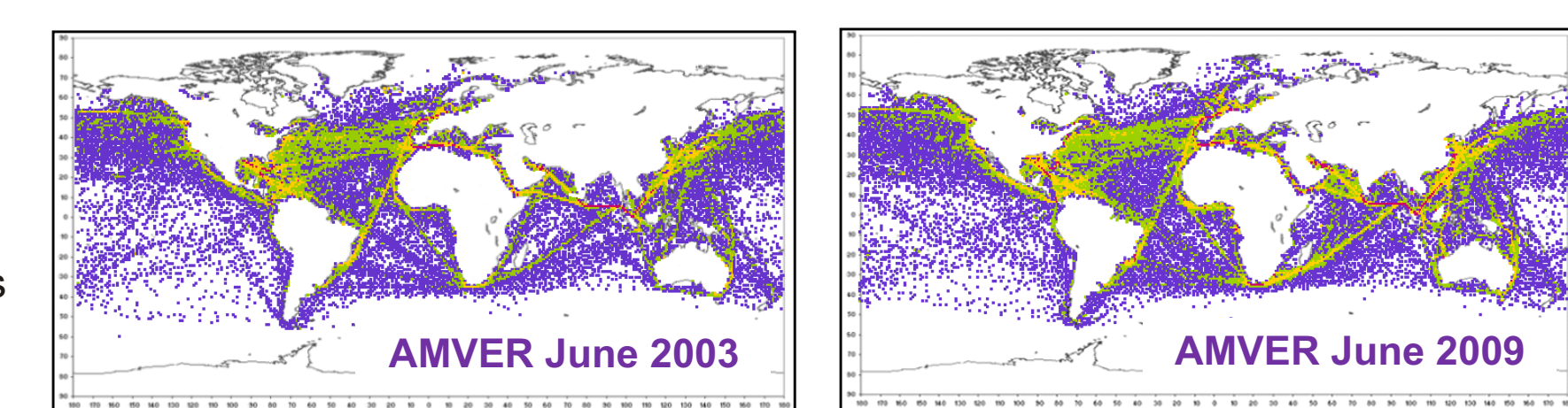


Figure top: Three year average of filtered GOME-2 NO<sub>2</sub>, showing enhanced values along several shipping routes

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

### Observations:

- In GOME-2 NO<sub>2</sub>, an additional shipping line is apparent from South Africa to Indonesia. This is the result of
  - improved signal to noise ratio (as compared to SCIAMACHY)
  - increased vessel density and thus emissions on this route (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)
- There are also hints of other shipping lines but they are not as clearly detected.



### Comparison with SCIAMACHY data:

- GOME and SCIAMACHY shipping NO<sub>2</sub> 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 to the right: Comparison of shipping NO<sub>2</sub> 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.

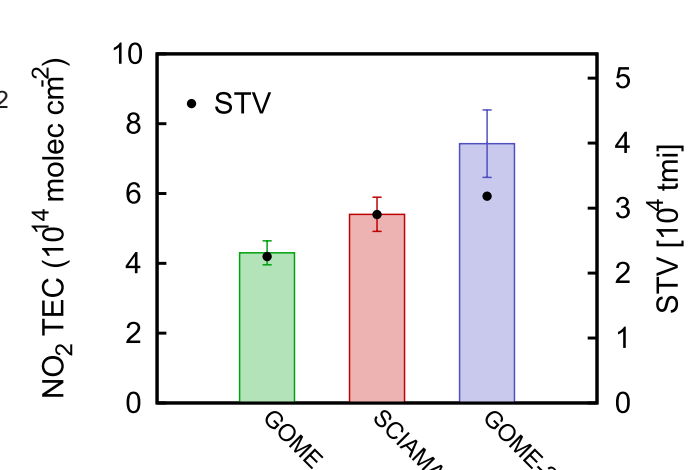
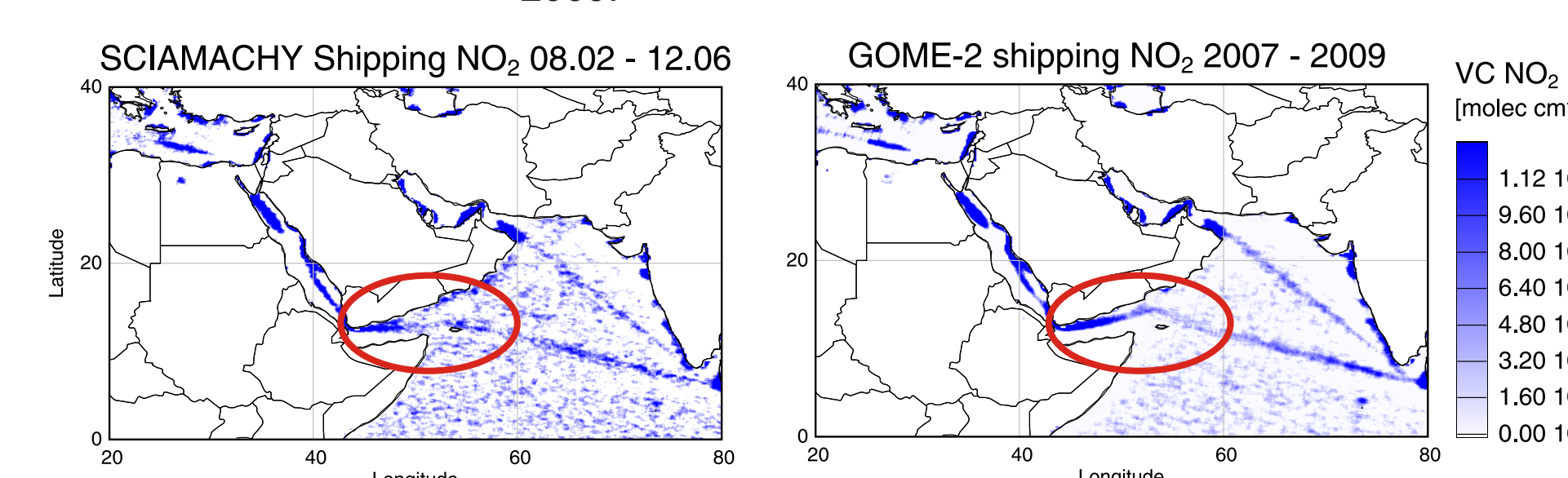


Figure: Comparison of shipping NO<sub>2</sub> averages as observed by SCIAMACHY from August 2002 to December 2006 (left) and by GOME-2 from 2007 - 2009. In addition to the better signal to noise of GOME-2 measurements, there is a clear change in route off Yemen and around the islands of Sokotra (see red circle), probably to avoid pirates operating from the coast of Somalia.



## Cloud effects

### Expectation:

Clouds are expected to have a large impact on the shipping NO<sub>2</sub> 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. This is confirmed from the statistics of the raw data (see below)

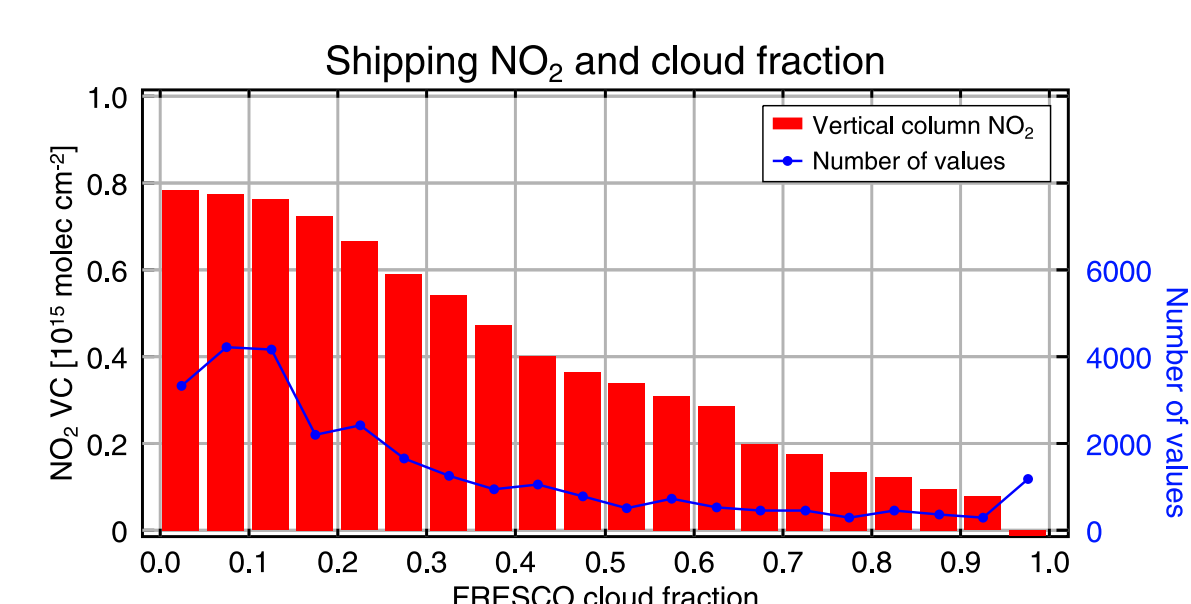
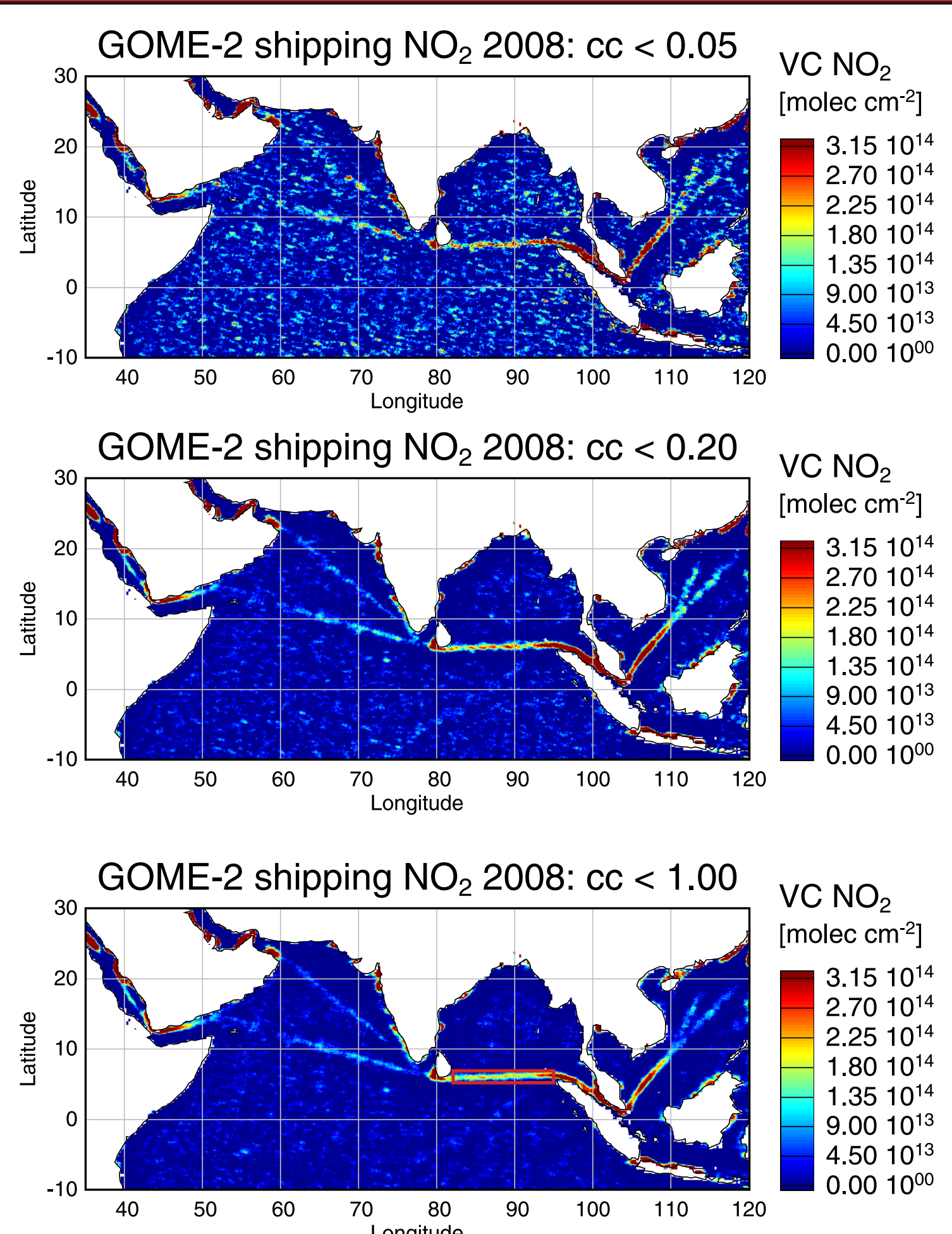


Figure: Average NO<sub>2</sub> columns in main shipping line in 2008 as function of cloud fraction as well as number of measurements for each bin. Raw data is plotted (no high pass filter applied).



Figures: GOME-2 shipping NO<sub>2</sub> for different cloud fraction thresholds. Red box indicates region used for cloud statistics in left figure.

## Acknowledgements

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## Conclusions and future work

### Conclusions

- GOME-2 NO<sub>2</sub> 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 South Africa to Indonesia could be detected
- 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 shipping NO<sub>x</sub> 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%

### Future work

- The cloud impact needs more detailed analysis by using the new FRESCO version and including cloud top heights in the considerations

## Selected References

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see also: [www.iup.uni-bremen.de/doas](http://www.iup.uni-bremen.de/doas)