



The global economic cycle and satellite-derived NO₂ trends overshipping lanes

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Project: IMPOSE (Impact Of Shipping Emissions), 2009-2010

Goal: set-up of system for monitoring of shipping emissions over North Sea (modelling, remote sensing with data assimilation, advanced computational methods)

Partners: BMT-ARGOSS, environmental consultancy company
VORtech, scientific computing company
KNMI KS-CK

- KNMI tasks:
- supply of OMI measurements of NO2
 - improvement of quality of OMI data
 - provide independent modelling chain for validation of results from ARGOSS (ARGOSS: CHIMERE; KNMI: LOTOS-EUROS)
 - study feasibility of remote sensing of shipping signals over North Sea (i.e. at high latitudes)
 - study feasibility of remote sensing of shipping trends





Shipping emissions: some general facts

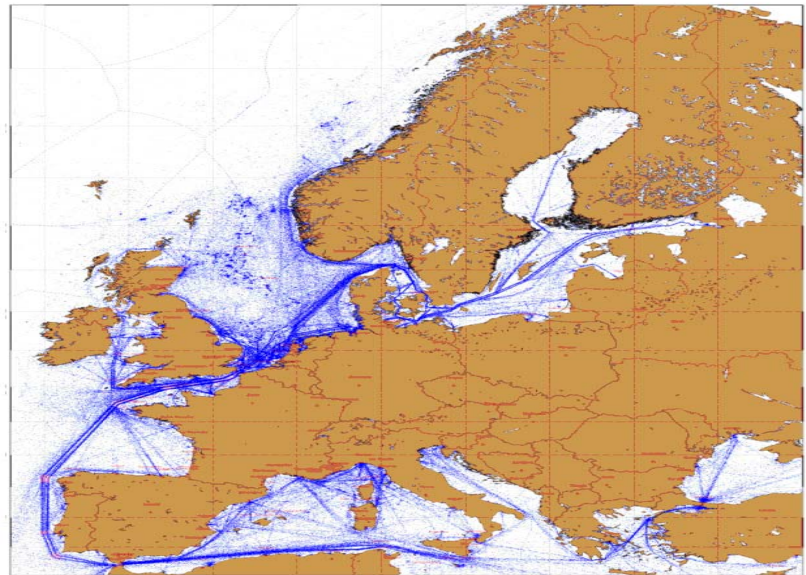
- ⇒ shipping: 15% of global anthropogenic NO_x emissions and 4–9% of SO₂ emissions
- ⇒ last decades: average rising trend of 3%/year in global shipping emissions
- ⇒ only growing source of sulfur emissions (no regulation on emissions in open water, very low-grade fuels like used motor-oil)
- ⇒ >70% of shipping emissions occurs within 400 km from land
- ⇒ globally: ~60,000 deaths annually due to shipping emissions of PM (3%-8% of all casualties due to anthropogenic emissions of PM_{2.5})



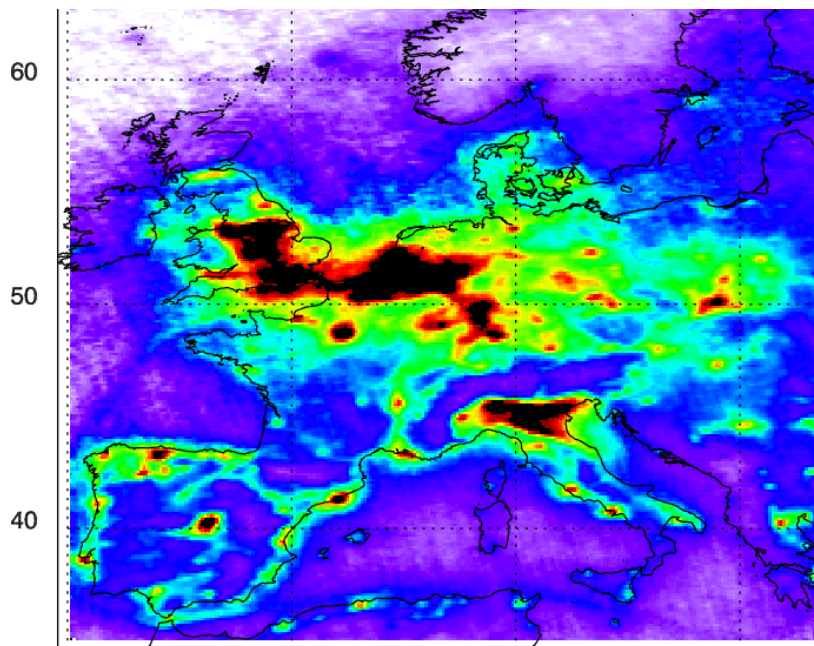
Remote sensing of ship traffic: examples

- ⇒ several shipping features visible in NO2 data
- ⇒ North Sea: shipping emissions close to continental emissions, difficult to separate
- ⇒ therefore: study other regions

Cumulated ship detection reports
Using ENVISAT/ASAR Products



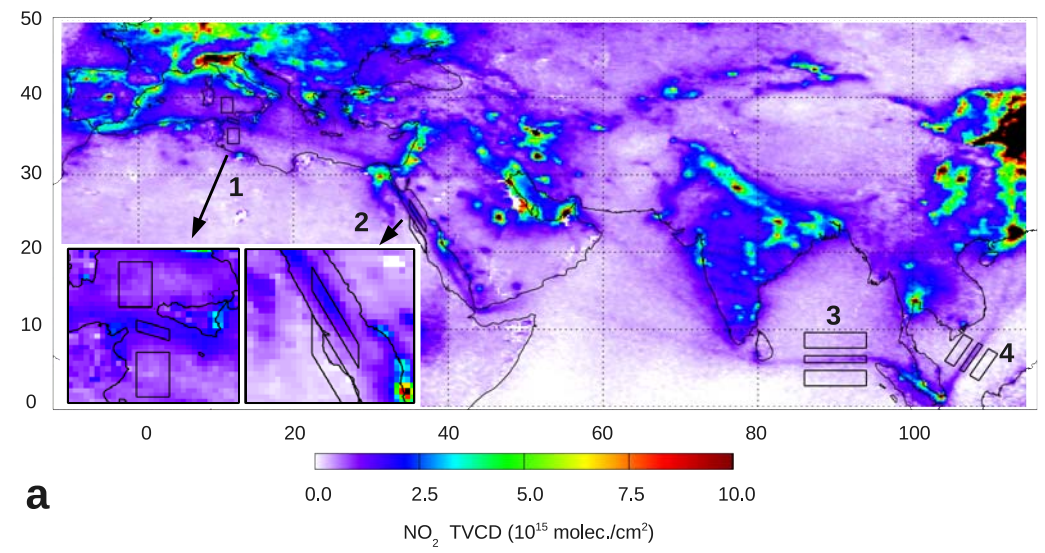
Generated by (c) CLS
Powered by (R) SARTool
Using ENVISAT ASAR products, (c) ESA (2002-2009)



Vertical Column Densities of NO2, measured by
OMI (Oct. 2004 - Dec. 2009)

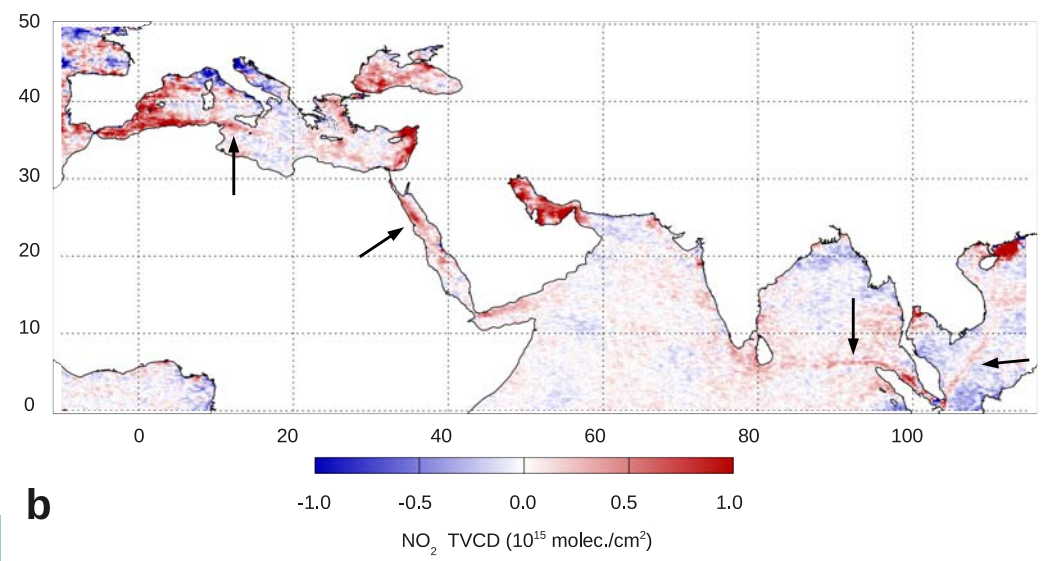


NO₂ VCD, SCIAMACHY (Jan. 2007 – Dec. 2008)



a

NO₂ VCD, SCIAMACHY difference between Jan. 2007 – Dec. 2008 and July 2002 – July 2004



b

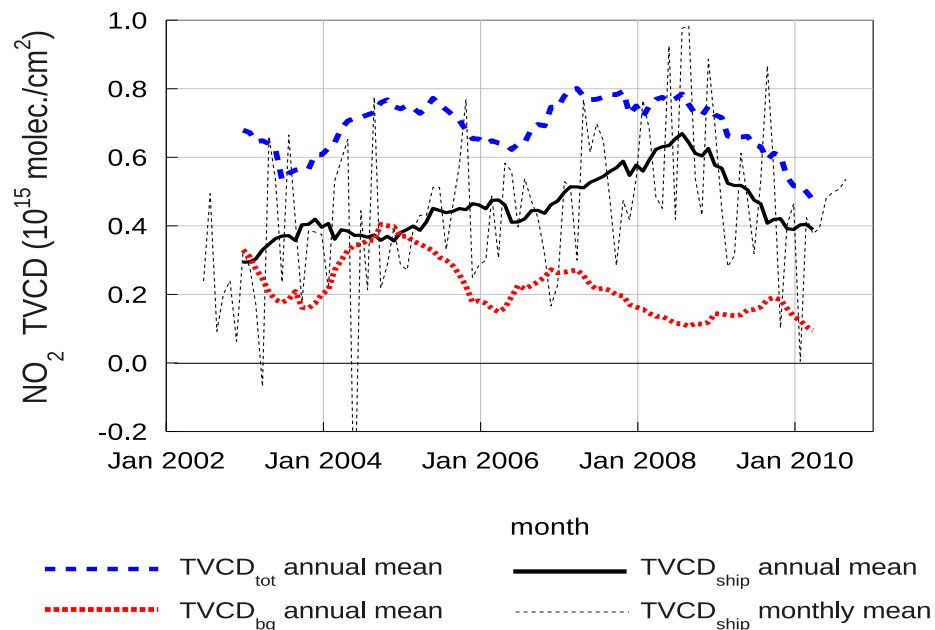


Extraction of NO₂ shipping signal from satellite data

Shipping signal in NO₂ VCDs is not very strong, trends and noise are of same order of magnitude \Rightarrow signal enhancement necessary:

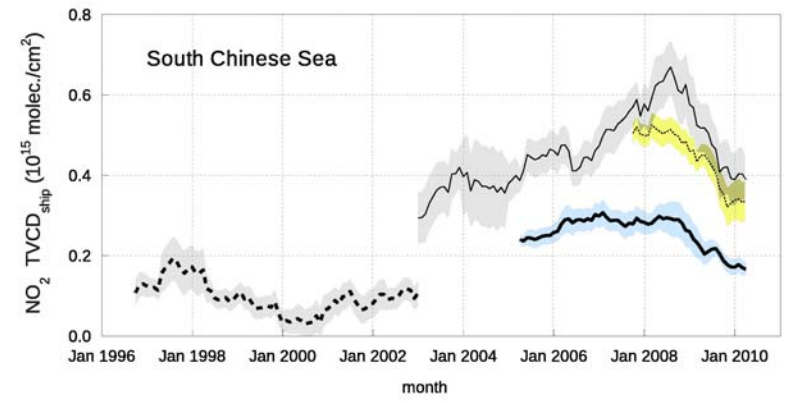
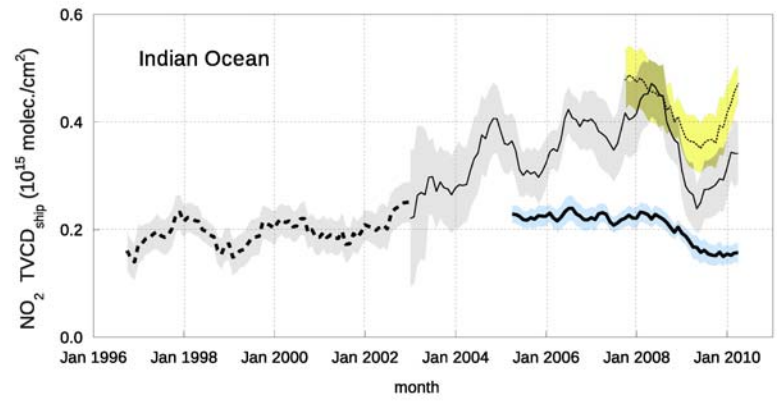
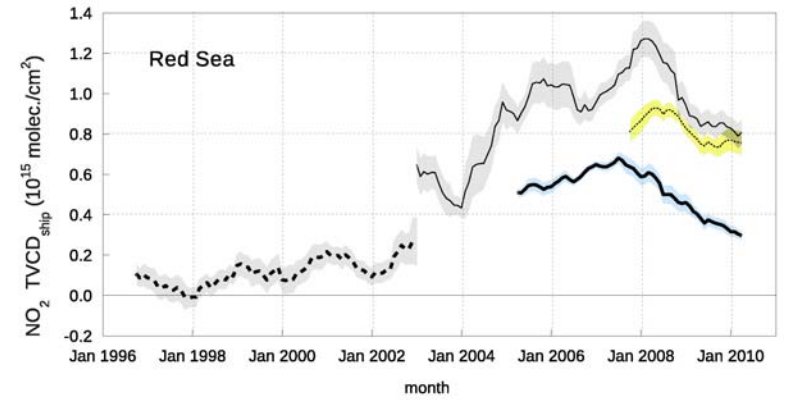
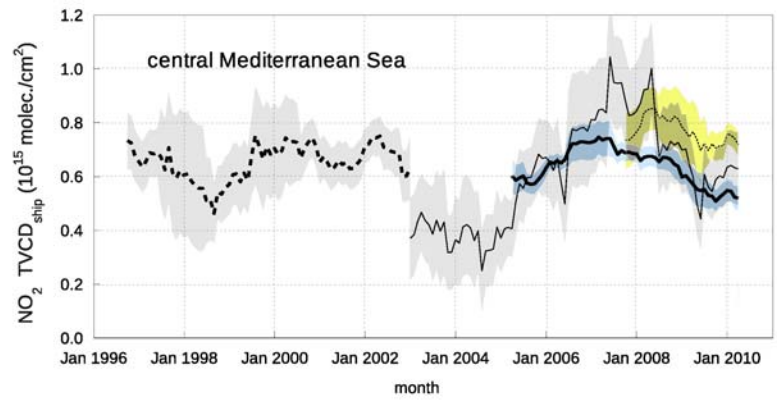
1. compute monthly means
2. subtract signal over background region from signal over shipping lane
3. compute running mean over 12 months

Example:
SCIAMACHY measurements
over the South Chinese Sea





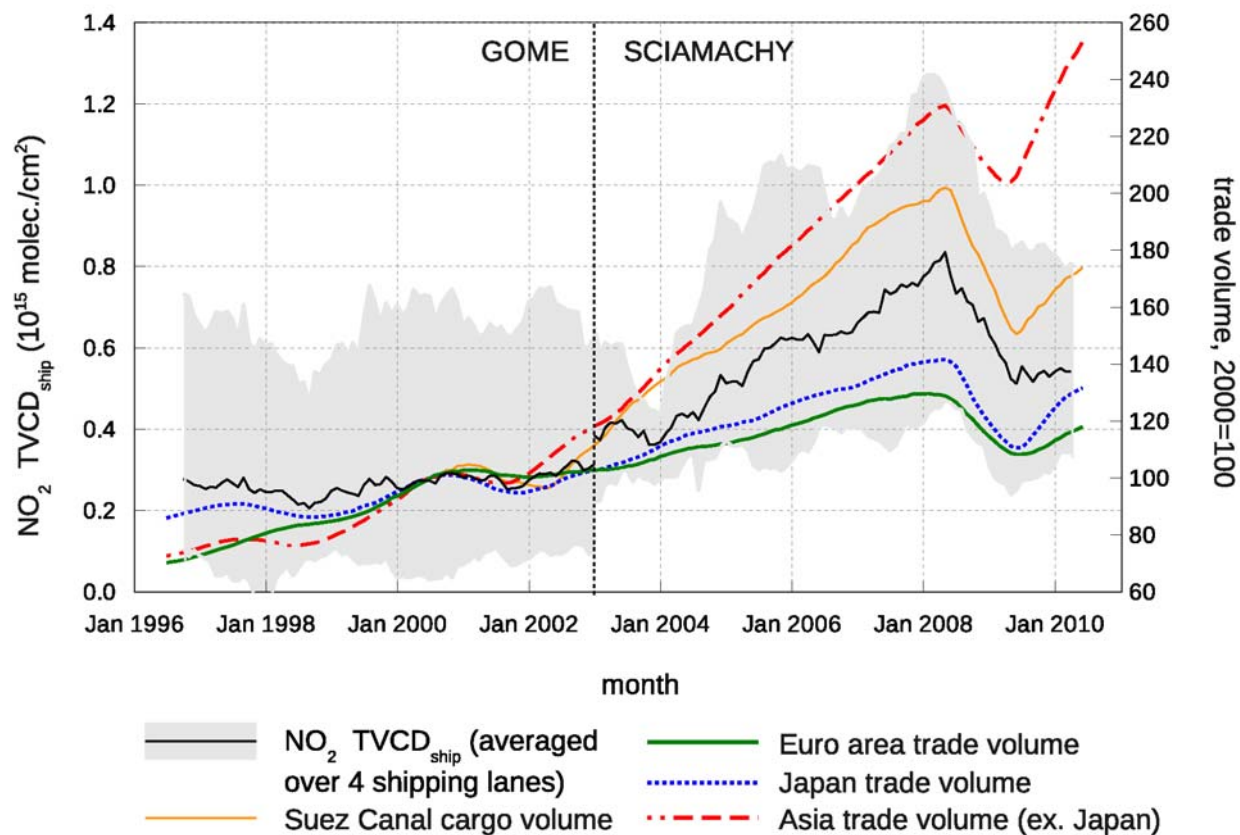
Time-series of NO₂ shipping signal 12-month running means





Comparison of NO₂ shipping signal with economic data

Satellite measurements: equal to previous plot (12-month running means of NO₂ shipping signal), but only GOME and SCIAMACHY are shown.





Correlations between satellite-derived shipping emissions and trade volumes

Based on the twelve-month running means that were shown in the last plot.

	Mediterranean Sea			Red Sea			Indian Ocean			South Chinese Sea		
	OMI	SCIAM.	GOME-2	OMI	SCIAM.	GOME-2	OMI	SCIAM.	GOME-2	OMI	SCIAM.	GOME-2
Mediterranean Sea OMI	x	0.73	0.72	0.89	0.55	0.89	0.77	0.74	0.67	0.91	0.40	0.92
Mediterranean Sea SCIAM.		x	0.68	0.67	0.79	0.78	0.43	0.57	0.78	0.62	0.75	0.68
Mediterranean Sea GOME-2			x	0.59	0.67	0.91	0.74	0.75	0.45	0.73	0.79	0.68
Red Sea OMI				x	0.67	0.78	0.88	0.62	0.66	0.88	0.30	0.89
Red Sea SCIAM.					x	0.87	0.68	0.70	0.74	0.70	0.75	0.85
Red Sea GOME-2						x	0.90	0.87	0.60	0.89	0.88	0.82
Indian Ocean OMI							x	0.66	0.70	0.85	0.27	0.91
Indian Ocean SCIAM.								x	0.87	0.73	0.54	0.66
Indian Ocean GOME-2									x	0.50	0.36	0.42
South Chinese Sea OMI										x	0.54	0.96
South Chinese Sea SCIAM.											x	0.95
South Chinese Sea GOME-2												x
Suez canal cargo volume	0.72	0.90	0.71	0.60	0.87	0.86	0.45	0.76	0.88	0.65	0.83	0.71
Japan trade volume	0.74	0.86	0.60	0.70	0.87	0.76	0.62	0.83	0.95	0.67	0.71	0.56
Euro area trade volume	0.87	0.88	0.64	0.84	0.86	0.82	0.72	0.82	0.90	0.81	0.73	0.73

Notes: OMI has later overpass-time than other instruments, measures weaker signal
GOME-2 data only for ~2.5 years



Percentage changes in mean annual VCDdiff

Based on a polynomial fit to the twelve-month running means that were shown in the last plot.

	Sept. 2005 - Sept. 2008 OMI	June 2003 - Sept. 2008 SCIAMACHY	Sept. 2008 – Dec. 2009			
			OMI	SCIAMACHY	GOME-2	average
Mediterranean Sea	13	94	-16	-33	-14	-21
Red Sea	8	109	-37	-27	-18	-27
Indian Ocean	2	79	-28	-38	-21	-29
South Chinese Sea	22	103	-23	-19	-20	-21
Average	11	96	-26	-29	-18	

economic growth

economic contraction

Data from several economical/statistical sources:

- worldwide seaborne trade: +39% between 2002 and 2008
- shipped trade volume east-Asia – Europe: +30% between May 2007 and July 2008
- shipped trade volume east-Asia – Europe: -25% between Aug. 2008 and Jan. 2010.
- fewer ships
- average shipping speeds: -30% (to reduce fuel costs)



Conclusions

- high correlation between monthly NO₂ VCDs measured by different sensors over different shipping routes
- high correlation between monthly NO₂ VCDs and economic data
- it is possible to observe from space, on a monthly to annual time scale, the economic cycle of boom and bust in shipping
- the period 2002-2010 was suitable for detection of trends because of the large variations in global economic growth and shipping

Paper:

De Ruyter de Wildt, M. S., H. Eskes and K. F. Boersma. The global economic cycle and satellite-derived NO₂ trends over shipping lanes. *Geophys. Res. Lett.*, 39, 1, doi:10.1029/2011GL049541, 2012.