Trends in tropospheric nitrogen dioxide (NO_2) over megacities and large conurbations in the Mediterranean and Middle East from GOME and SCIAMACHY

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11th IGAC Science Conference / 12th ICACGP Symposium

July 14th 2010

Outline

Introduction

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- Megacities: pollution hot spots due to high energy use
- NO_2: ozone smog, acid rain, hazardous to human health
- Satellite instruments: long time series, global coverage

Instrument	**Equator crossing**	**Global coverage**	**Available period**	**Pixel [km^2]**
GOME	10h30	3 days	1995/10-2003/06	40×320
SCIAMACHY	10h00	6 days	2002/08-now	30×60

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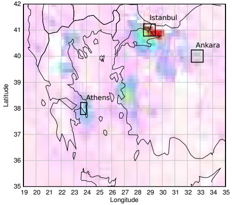
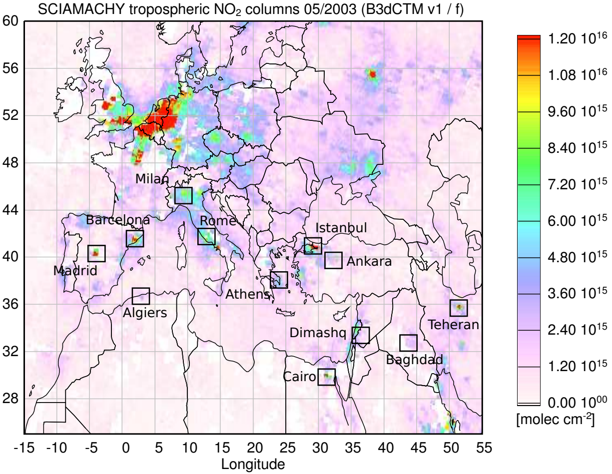
- **D**ifferential **O**ptical **A**bsorption **S**pectroscopy (*Lambert-Beer law*)
- Subtraction of stratospheric NO_2 from scaled model data
- Correction for average lightpath in atmosphere
- **Vertical tropospheric column [molec. cm^{-2}] NO_2**

Dataset description

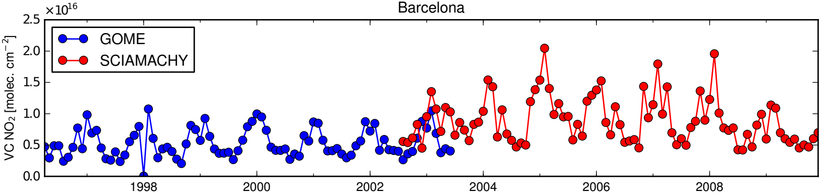
- Grid satellite pixels on $0.125^\circ \times 0.125^\circ$
- Calculate monthly averages
- Define city regions

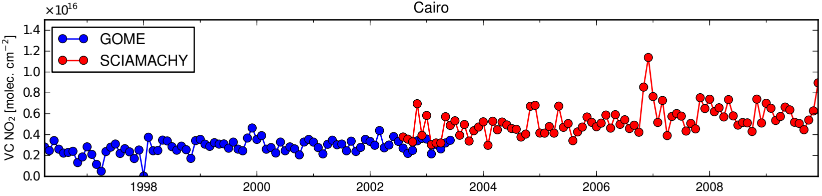


- For each month, calculate the average of each city region individually



Combined GOME/SCIAMACHY time series



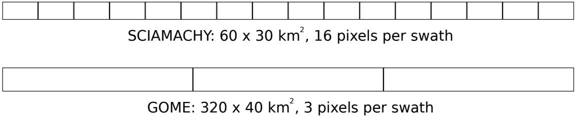


- Most cities investigated show seasonal cycles and a complex increasing pattern
- There are small but significant differences between the GOME and the SCIAMACHY time series
- Challenging to assess the longer term changes and trends

Constructing one consistent time series from GOME and SCIAMACHY

The problem of differing pixel sizes

- GOME and SCIAMACHY have very different spatial resolution:



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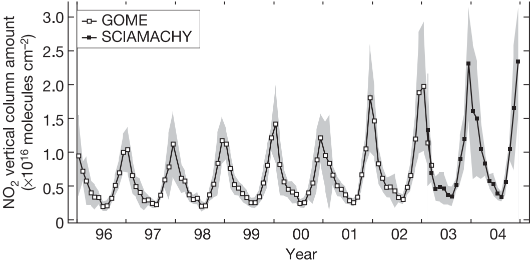
Monthly averages of NO_2 VC_{trop} over East Central China



Richter et al., 2005

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- GOME and SCIAMACHY have very different spatial resolution:
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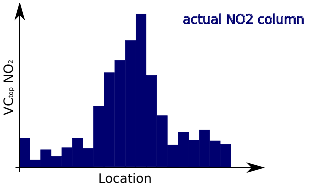

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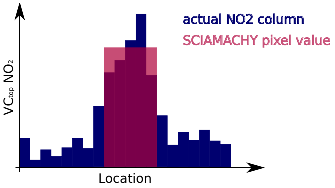

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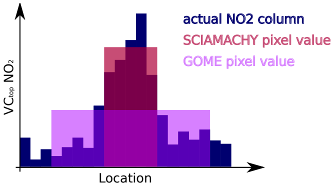

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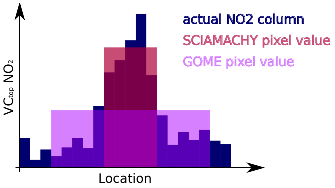
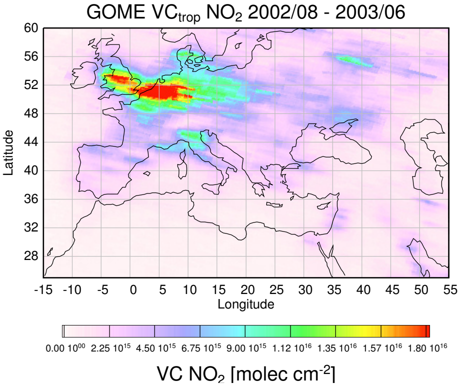
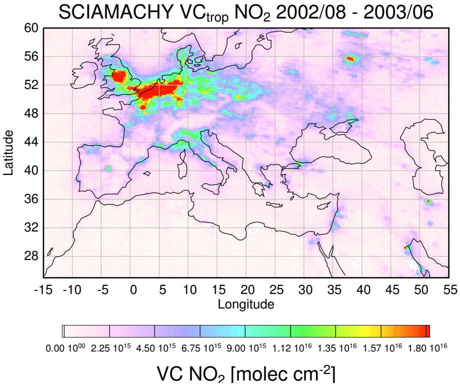


- This leads to inconsistencies in time series spanning both GOME and SCIAMACHY.
- **Any trend study of megacities needs to consider this effect**

Comparison: GOME and SCIAMACHY measurements 2002/08 – 2003/06





How to derive consistent trends?

Previous studies artificially reduced the resolution of SCIAMACHY measurements:

Publication	*Time period covered*
van der A et al., 2008	1996-2006
Konovalov et al., 2010	1996-2008 (summer months)

or calculated a correction factor for GOME measurements by convolving SCIAMACHY measurements (Konovalov et al., 2006)

Derived annual trends [% / yr]

City	*van der A.*	*Konovalov (2010)*
Baghdad	—	1.7 ± 0.7
Barcelona	—	3.7 ± 0.8
Cairo	1.3 ± 1.0	—
Teheran	6.5 ± 1.0	4.0 ± 0.8

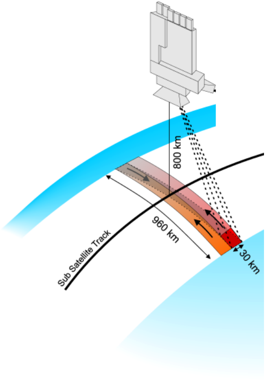
Solution 1: Averaging over several SCIAMACHY pixels

The simplest approach:

average 5 neighboring SCIAMACHY pixels. But:

- non-linearities in the retrieval
- what to do with clouds
- ...

Solution 2: SCIAMACHY backscan measurements



Idea:

- SCIAMACHY scans 16 $\times$ 60x30km / forward scan
- 4 $\times$ 240x30km / backward scan
- backscan pixels close in size to GOME
- physically comparable to GOME measurement
- create climatology GOME $\times$ $SCIA_{forw}$ / $SCIA_{back}$ for each grid cell

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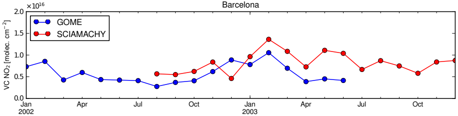

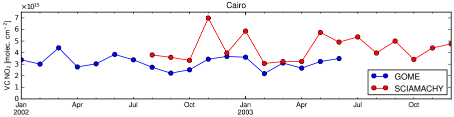

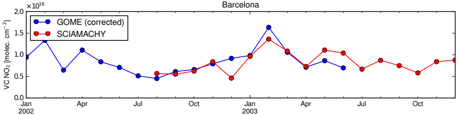

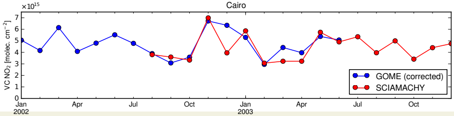

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Observations:

- Actually works quite well
- Difficult to see overall picture from individual trends
- Different trends per season
- Error quantification and significance analysis are difficult

Solution 3: Fitting a trend using the levelshift method

This study: determination of annual growth rates by fitting

linear function + *levelshift* + *seasonal component*

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$$\underbrace{Y_t}_{\text{monthly avg.}} = \underbrace{\mu}_{\text{offset}} + \underbrace{\omega \cdot X_t}_{\text{linear trend}} + \underbrace{\delta \cdot U_t}_{\text{levelshift}} + \underbrace{(1 + \xi X_t) \cdot \eta \cdot S_t}_{\text{seasonality}} + \underbrace{N_t}_{\text{noise}}$$

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where the seasonal part of the trend is described by

$$S_t = \sum_{j=1}^{4} \left(\beta_{1,j} \cdot \sin\left(\frac{2\pi t}{12}\right) + \beta_{2,j} \cdot \cos\left(\frac{2\pi t}{12}\right)\right)$$

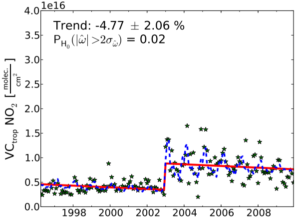
and $\eta = 1 + (1 - \gamma)U_t$ accounts for a possible levelshift in the seasonal component.

Universität Bremen

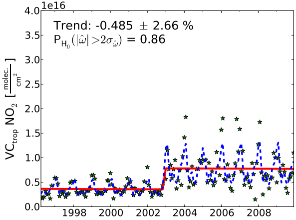
Trend analysis: Results

Annual trends over selected megacities 1996-2002 (GOME) & 2003-2009 (SCIAMACHY)

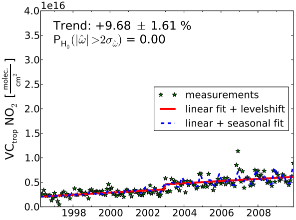
Madrid



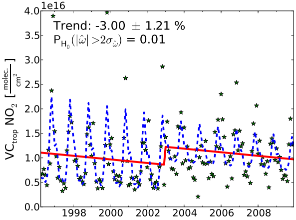
Athens



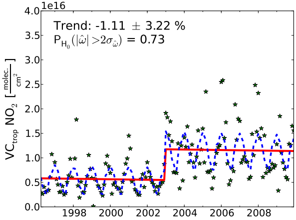
Cairo



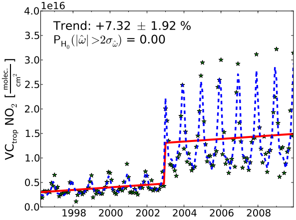
Milano



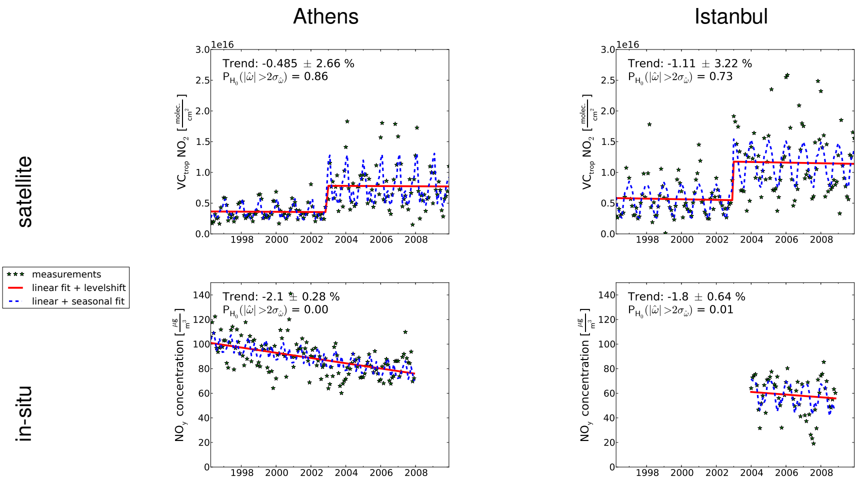
Istanbul



Tehran

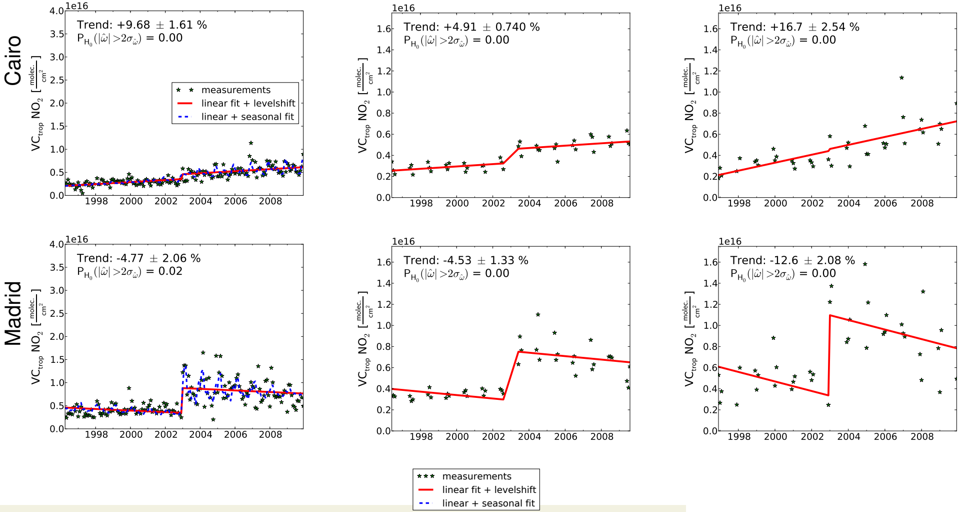


Comparison to ground-based measurements



Seasonal differences

full fit | summer months (JJA) | winter months (DJF)



Seasonal differences

Observations:

- Winter trends are stronger than summer trends
- Winter values generally show more scattering (due to sampling)

Possible explanations:

- Different chemistry in summer and winter (non-linearities?)
- Seasonal differences in
  - industrial / traffic / energy NO_2 emissions
  - agricultural NO_2 emissions
  - aerosol amount / size distribution / vertical distribution

Observed trends for the MedME region 1996–2009

City	annual trend [% / yr]	summer trend [% / yr]	winter trend [% / yr]
Algiers	+ 8.3 ± 1.6	+ 8.8 ± 1.3	—
Ankara	—	+ 1.1 ± 0.5	—
Athens	—	-4.6 ± 1.5	—
Baghdad	+ 22.3 ± 2.7	+ 8.0 ± 1.8	—
Barcelona	-3.4 ± 1.6	-4.7 ± 1.1	—
Cairo	+ 9.7 ± 1.6	+4.9 ± 0.7	+16.7 ± 2.5
Dimashq	+ 20.6 ± 3.2	+10.4 ± 1.4	+47.4 ± 5.5
Istanbul	—	—	—
Jeddah	+ 3.8 ± 1.2	+3.0 ± 0.7	+4.1 ± 1.4
Madrid	- 4.8 ± 2.1	-4.5 ± 1.3	-12.6 ± 2.1
Milan	-3.0 ± 1.2	-1.6 ± 0.4	-8.1 ± 2.0
Riyadh	+ 6.3 ± 1.2	—	+9.9 ± 1.2
Rome	—	—	—
Teheran	+ 7.3 ± 1.9	+5.6 ± 0.8	+18.9 ± 4.7

Summary

Summary

- Long-term changes in tropospheric NO_2 from satellite
- Different spatial resolutions of GOME and SCIAMCHY result in differences in the behaviour of the two datasets.
- Here, we accounted for the differences between the two instruments by including an offset in the fitting procedure.
- Strong differences between summer and winter trends
- Significant upward trends for most developing cities
- Significant downward trends for most developed cities

Acknowledgements

- Sebastian Mieruch (IUP/Uni-HB)
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- TEMIS for providing FRESCO+ data
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