# 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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# Outline

Introduction

Combining GOME and SCIAMACHY time series

Trend analysis

Summary

# 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 | $40 \times 320$ |
| SCIAMACHY | 10h00 | 6 days | 2002/08-now | $30 \times 60$ |

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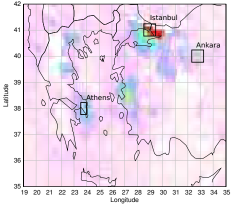
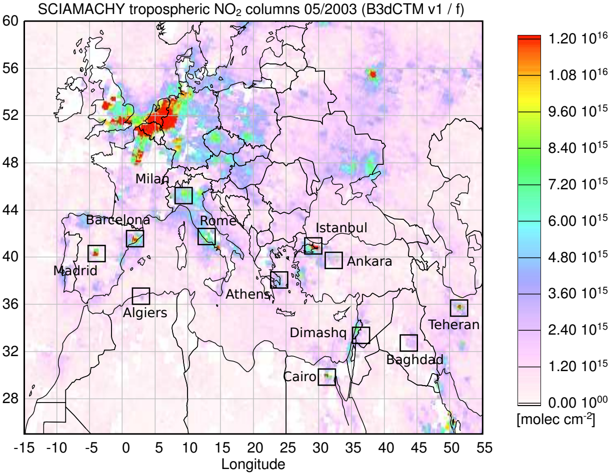
- **D**ifferential **O**ptical **A**bsorption **S**pectroscopy (*Lambert-Beer law*)
- Subtraction of stratospheric $NO_2$ from scaled model data
- Correction for average lightpath in atmosphere
- **Vertical tropospheric column [molec. cm$^{-2}$] $NO_2$**

# Dataset description

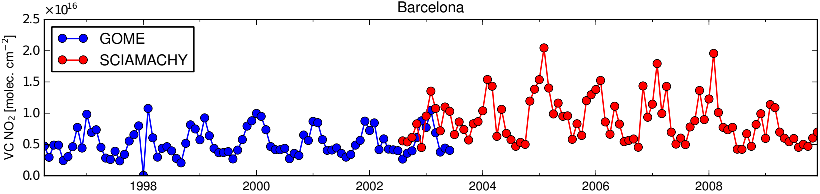
- Grid satellite pixels on 0.125° × 0.125°
- Calculate monthly averages
- Define city regions

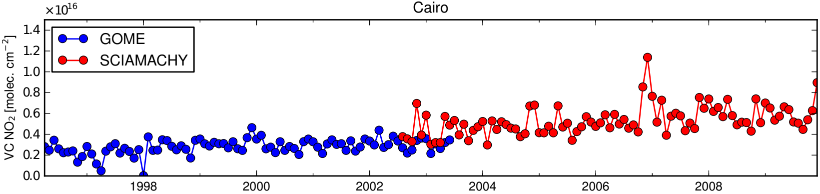



- For each month, calculate the average of each city region individually



# Combined GOME/SCIAMACHY time series



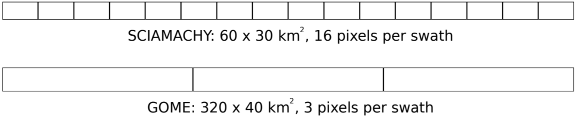




- Most cities investigated show seasonal cycles and a complex increasing pattern
- There are small but significant differences between the GOME and the SCIAMACHY time series
- Challenging to assess the longer term changes and trends

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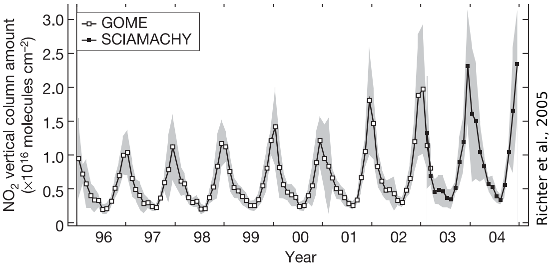
Monthly averages of $NO_2$ $VC_{trop}$ over East Central China



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- GOME and SCIAMACHY have very different spatial resolution:
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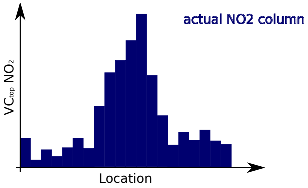
- For very localized sources (like cities), this leads to a relatively diluted signal in the GOME data — the same total amount of $NO_2$ is averaged over a larger area:



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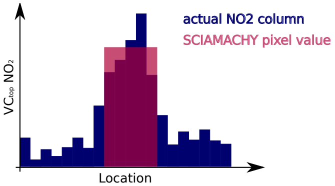

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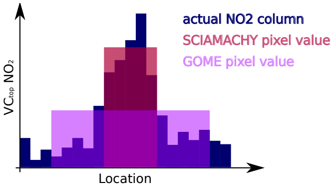

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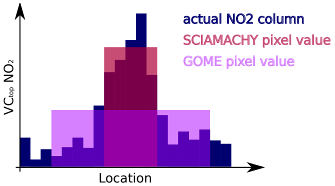
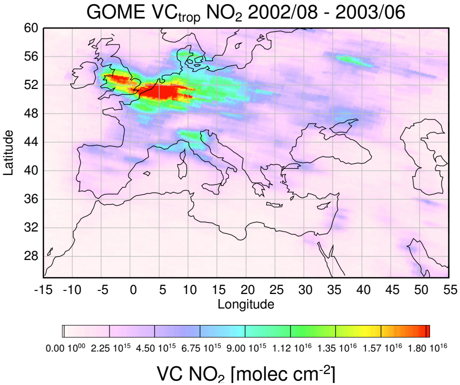
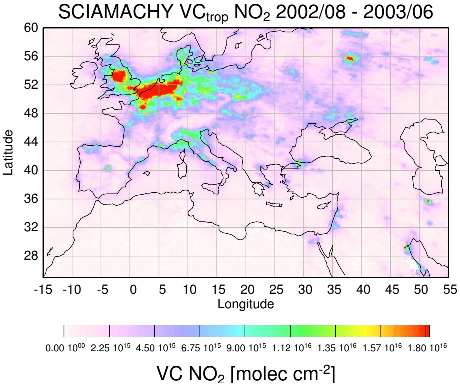



- This leads to inconsistencies in time series spanning both GOME and SCIAMACHY.
- **Any trend study of megacities needs to consider this effect**

# 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 | — | $1.7 \pm 0.7$ |
| Barcelona | — | $3.7 \pm 0.8$ |
| Cairo | $1.3 \pm 1.0$ | — |
| Teheran | $6.5 \pm 1.0$ | $4.0 \pm 0.8$ |

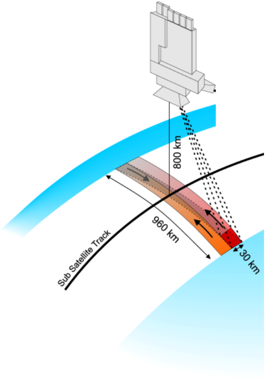
# Solution 1: Averaging over several SCIAMACHY pixels

**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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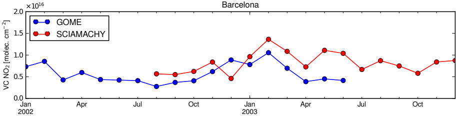


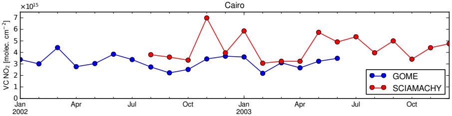


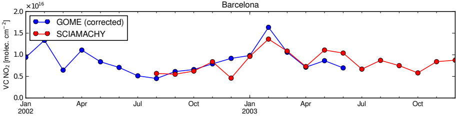


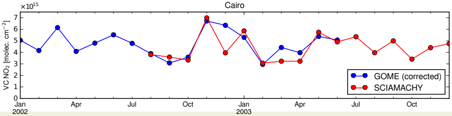


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**Observations:**

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

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This study: determination of annual growth rates by fitting

$$\textit{linear function} + \textit{levelshift} + \textit{seasonal component}$$

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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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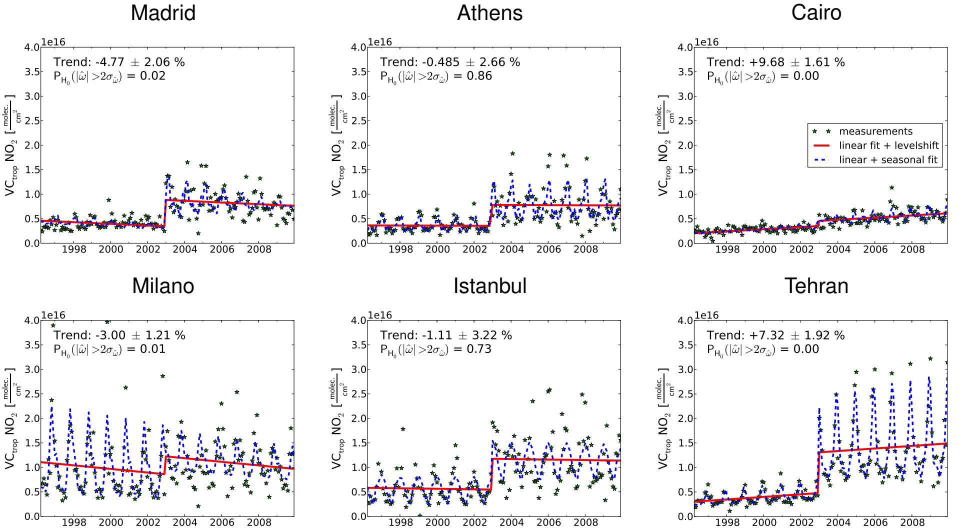
where the seasonal part of the trend is described by

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

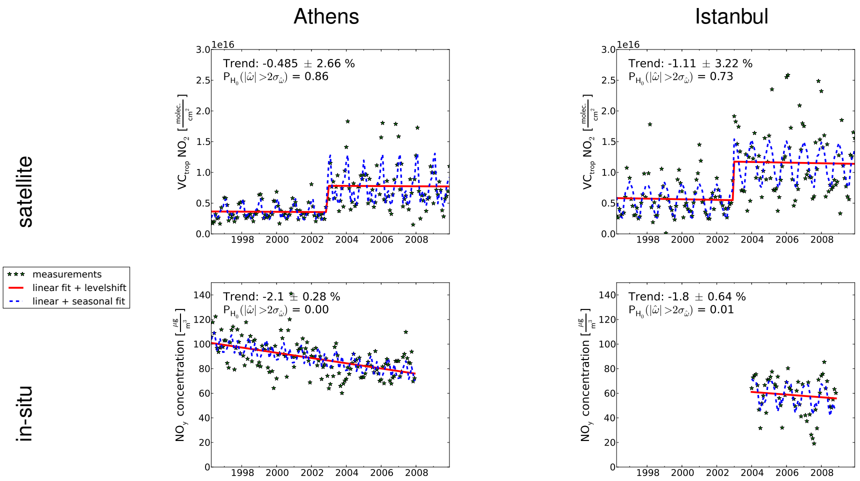
and $\eta = 1 + (\gamma - 1)U_t$ accounts for a possible levelshift in the seasonal component.

# Trend analysis: Results

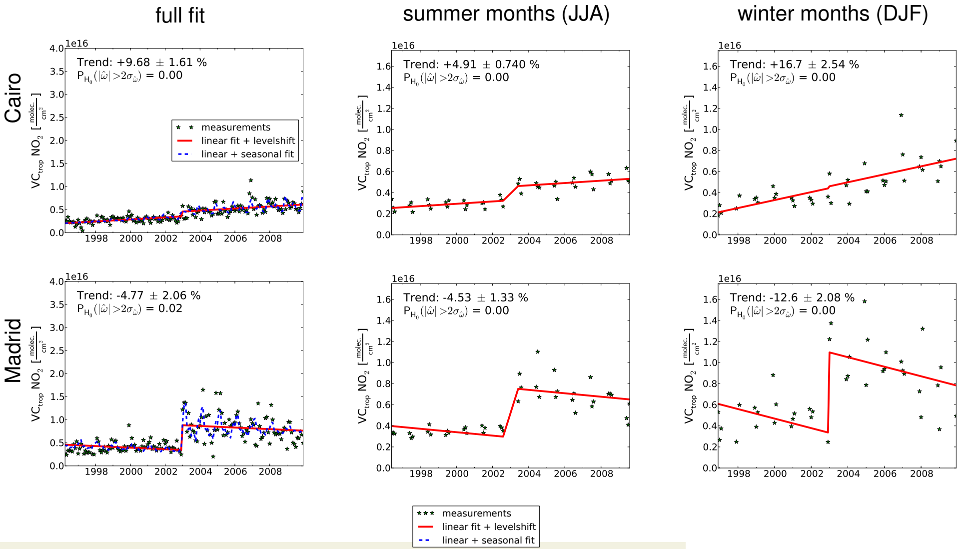
# Annual trends over selected megacities 1996-2002 (GOME) & 2003-2009 (SCIAMACHY)



# Comparison to ground-based measurements



# Seasonal differences



# 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 $\pm$ 1.6 | + 8.8 $\pm$ 1.3 | — |
| Ankara | — | + 1.1 $\pm$ 0.5 | — |
| Athens | — | -4.6 $\pm$ 1.5 | — |
| Baghdad | + 22.3 $\pm$ 2.7 | + 8.0 $\pm$ 1.8 | — |
| Barcelona | -3.4 $\pm$ 1.6 | -4.7 $\pm$ 1.1 | — |
| Cairo | + 9.7 $\pm$ 1.6 | +4.9 $\pm$ 0.7 | +16.7 $\pm$ 2.5 |
| Dimashq | + 20.6 $\pm$ 3.2 | +10.4 $\pm$ 1.4 | +47.4 $\pm$ 5.5 |
| Istanbul | — | — | — |
| Jeddah | + 3.8 $\pm$ 1.2 | +3.0 $\pm$ 0.7 | +4.1 $\pm$ 1.4 |
| Madrid | - 4.8 $\pm$ 2.1 | -4.5 $\pm$ 1.3 | -12.6 $\pm$ 2.1 |
| Milan | -3.0 $\pm$ 1.2 | -1.6 $\pm$ 0.4 | -8.1 $\pm$ 2.0 |
| Riyadh | + 6.3 $\pm$ 1.2 | — | +9.9 $\pm$ 1.2 |
| Rome | — | — | — |
| Teheran | + 7.3 $\pm$ 1.9 | +5.6 $\pm$ 0.8 | +18.9 $\pm$ 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
- IGAC/ACCENT for funding my travel to this conference
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