Long-term changes of tropospheric NO_2 over megacities derived from multiple satellite instruments

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Background

Why NO_2 ?

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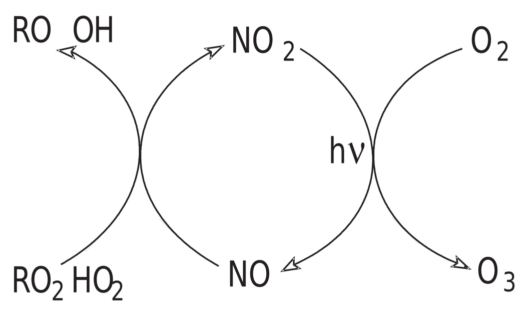
– important precursor of ozone
– cause of acid rain
– hazardous to human health



Why Megacities ?

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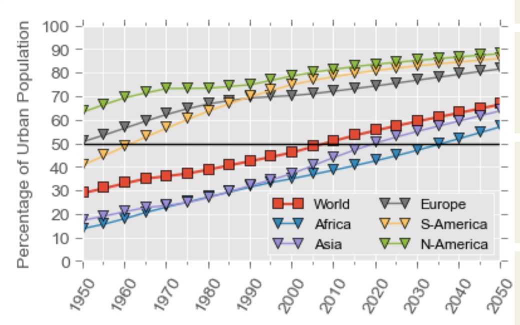
– more than 50% of human population lives in cities
– urbanization still stronly increasing
– pollution hot spots due to high energy use
– large number of people affected by air quality in megacities



Why Satellites ?

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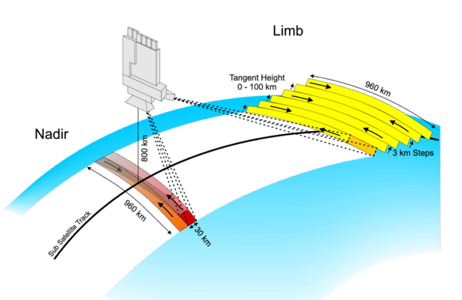
– long timeseries
– global coverage
– consistent measurement conditions



Different satellite instruments:

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GOME:	1995/10–2003/06	10:30LT
SCIAMACHY:	2002/08–2012/04	10:00LT
OMI:	2004/10–...	13:45LT
GOME-2:	2007/01–...	09:30LT

Different spatial resolutions:

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320 x 40 km²	GOME
60 x 30 km²	SCIAMACHY
24 x 13 km²	OMI(*)
80 x 40 km²	GOME-2

(*) at nadir point

Methods

The problem:

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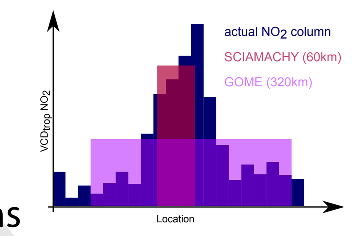
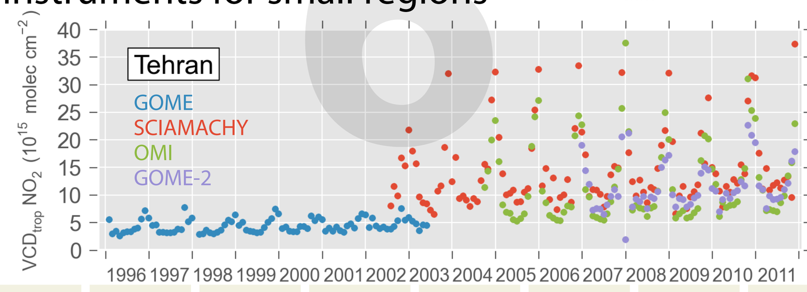
– different spatial resolutions result in different sampling of fine-scale pollution structure
– large differences between the four instruments for small regions





The data:

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– VCD_{trop} NO_2 from IUP/Uni-HB scientific retrieval v4
– stratospheric correction with Bremen 3d CTM
– climatological tropospheric AMFs from MOZART
– gridded to 0.0625°
– monthly averages

The idea:

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Account for instrumental differences in trend model:
– common among all instruments:
  – linear growth rate
  – seasonality 'shape'
– instrument-dependent:
  – offset
  – seasonality amplitude
  – noise

Trend model:

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X_{trend} monthly avg.
t time
i instrument

$$X_{trend}(t,i) = \omega \cdot t + \mu_i + \eta_i \cdot \Psi(t) + N(t,i)$$

linear growth rate ($\omega \cdot t$); offset (μ_i); seasonal cycle ($\eta_i \cdot \Psi(t)$); noise ($N(t,i)$)

Seasonality:

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

Uncertainty / significance assessment

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via Bootstrap analysis:
– 2000 replications
– shuffle trend fit residuals, repeat analysis
– compute histogram & 95% confidence interval
– trend is significant $\Longleftrightarrow$ 0.0 is outside of 95%-interval

Results

Global trend patterns

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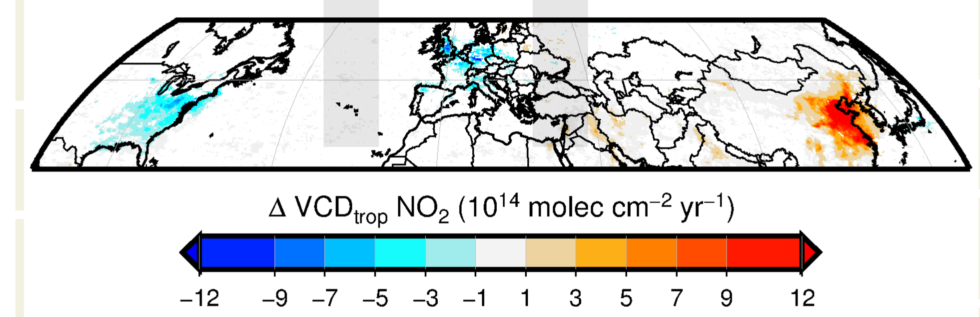
– strong decreases over U.S., Europe, Japan
– strong increases over E-China and Middle East
– no significant changes in the rest of the World



Megacitiy comparison

(SCIAMACHY only)

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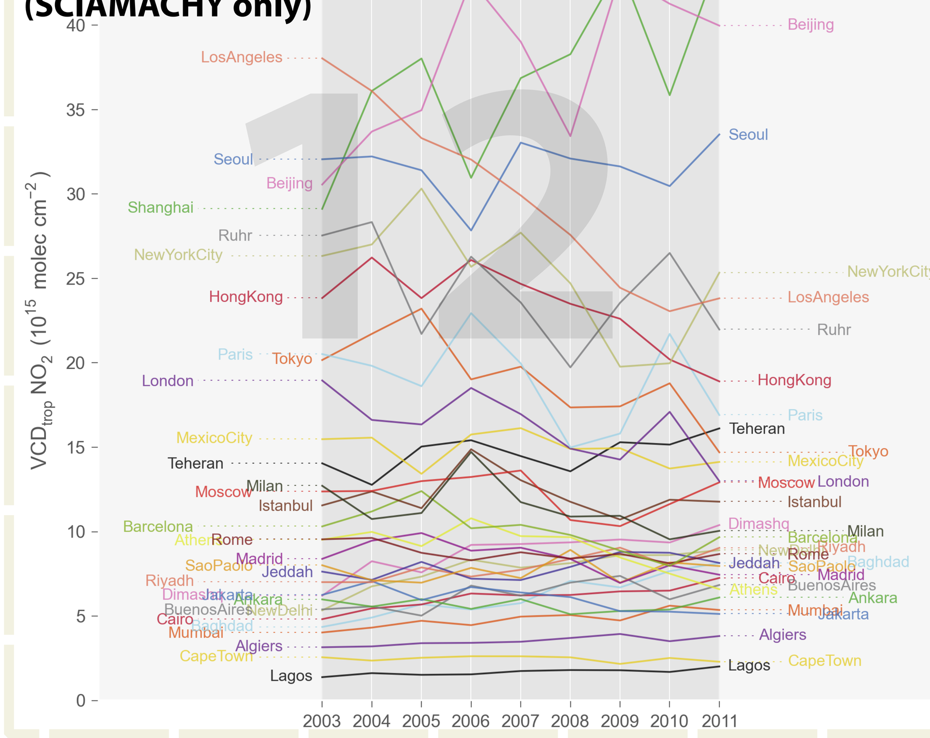

Megacity timeseries

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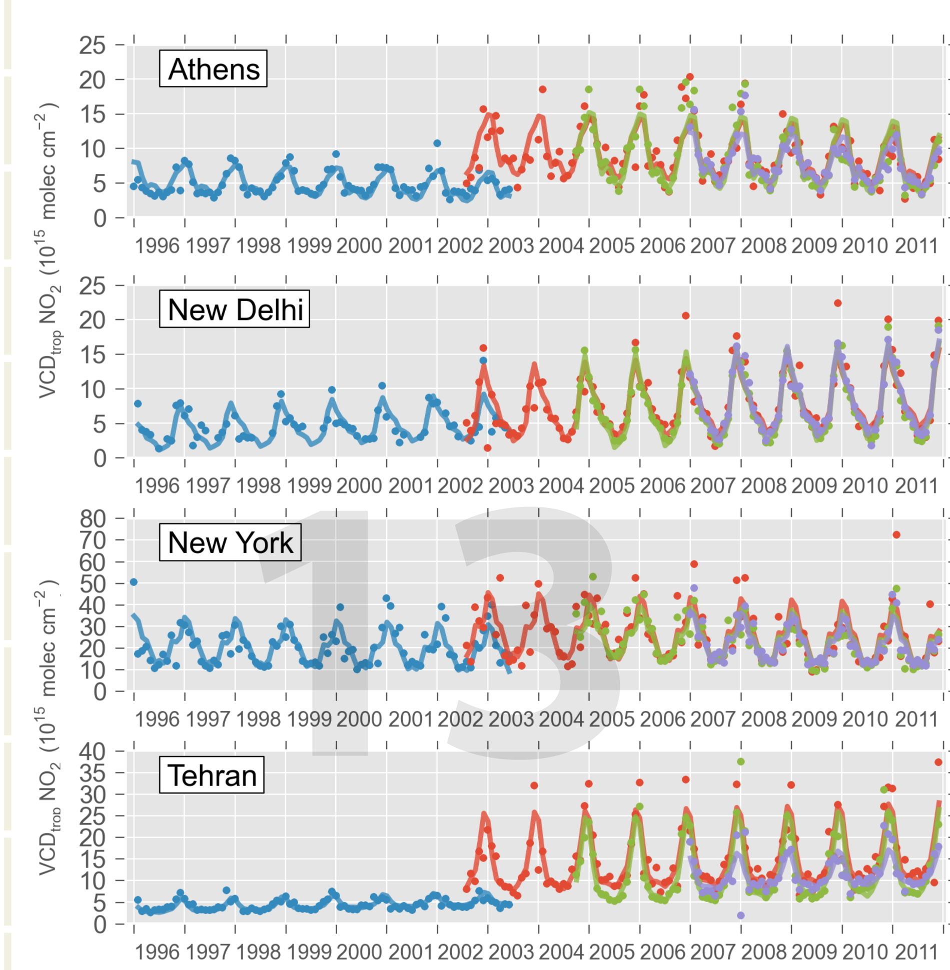

Megacity NO_2 trends

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City	(10^{14} molec cm^{-2} yr^{-1})	(% yr^{-1})
Athens	-2.09 ± 0.83	-3.7 ± 1.5
Baghdad	+3.24 ± 0.37	+18.0 ± 2.1
Beijing	+9.5 ± 2.9	+7.3 ± 2.2
Buenos Aires	*+0.55 ± 0.51*	*+1.7 ± 1.6*
Cairo	+1.73 ± 0.28	+6.4 ± 1.0
Dhaka	+3.41 ± 0.54	+24.0 ± 3.8
Hong Kong	*-1.1 ± 2.3*	*-1.0 ± 2.1*
Istanbul	*-0.4 ± 1.1*	*-0.5 ± 1.5*
Jakarta	-1.19 ± 0.41	3.3 ± 1.1
Karachi	+0.85 ± 0.25	+6.0 ± 1.8
Lagos	+0.33 ± 0.12	+2.68 ± 0.95
London	*-3.0 ± 1.6*	*-1.66 ± 0.91*
Los Angeles	-13.2 ± 2.6	-5.8 ± 1.2
Mexico City	*+0.51 ± 0.82*	*+1.0 ± 1.6*
Moscow	*-1.4 ± 1.6*	*-1.6 ± 1.9*
Mumbai	+0.70 ± 0.21	+3.6 ± 1.1
New Delhi	+2.57 ± 0.60	+7.4 ± 1.7
New York	-5.7 ± 2.3	-2.6 ± 1.0
Paris	-5.2 ± 2.5	-3.3 ± 1.6
Riyadh	+2.05 ± 0.38	+6.9 ± 1.3
São Paolo	*+0.37 ± 0.52*	*+0.9 ± 1.3*
Seoul	*+1.0 ± 1.8*	*+0.7 ± 1.2*
Shanghai	+9.4 ± 3.0	+9.2 ± 2.9
Shenzhen	*-2.2 ± 1.7*	*-1.8 ± 1.3*
Tehran	+2.68 ± 0.93	+7.8 ± 2.7
Tokyo	-5.4 ± 1.4	-3.77 ± 0.97

magenta = not significant

Reasons for instrument-dependence

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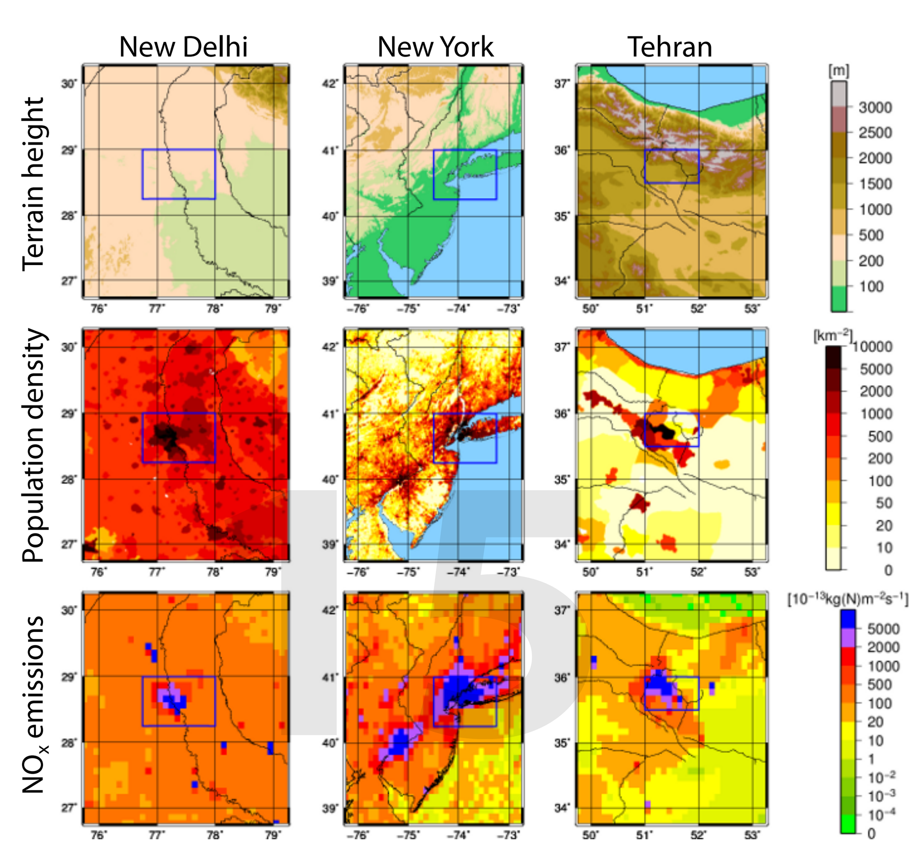

Homogeneous, high-emission areas with no topographic boundaries:
– ground pixel size has negligible effect

Areas with inhomogeneous, partly high emissions and no topographic boundaries: NO_2 can spread
– small impact of instrument resolution

Emission "point sources" with topographic barriers (e.g., mountaints): NO_2 cannot spread throughout area
– instrument resolution is very important

Non-linear changes in Athens

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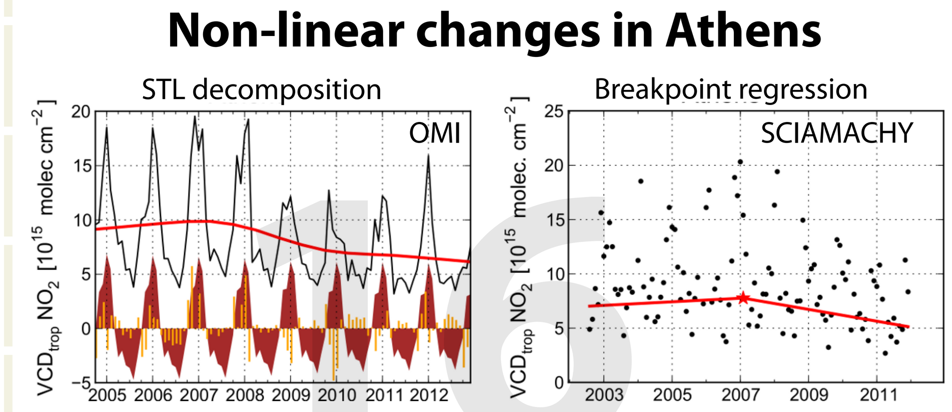

– Linear trend model does not reflect reality
– Trend needs to be decomposed into several periods

Summary / Conclusions

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– Investigation of long-term changes in tropospheric NO_2 columns using multiple satellite instruments
– Different instruments' spatial resolutions result in differences in the behaviour of the four datasets
– Effect of spatial resolution strongly depends on local surroundings of the city
– Development of a trend model which uses all available data
– Positive trends in emerging regions, negative trends in developed regions
– Assumption of linear changes is not optimal for long timeseries: non-linear methods needed for quantification

Publication:
Hilboll A, Richter A, and Burrows JP. Long-term changes of tropospheric NO2 over megacities derived from multiple satellite instruments.
Atmospheric Chemistry and Physics, 13(8):4145–4169, doi:10.5194/acp-13-4145-2013, 2013.

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*EXZELLENT.

Andreas Hilboll's PhD work was partly funded by the *Earth System Science Research School (ESSReS)*, an initiative of the Helmholtz Association of German research centres (HGF) at the Alfred Wegener Institute for Polar and Marine Research.
The authors would like to acknowledge the European Union Seventh Framework Programme (FP7/2007-2013) project *CityZen* (Grant Agreement no. 212095).