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

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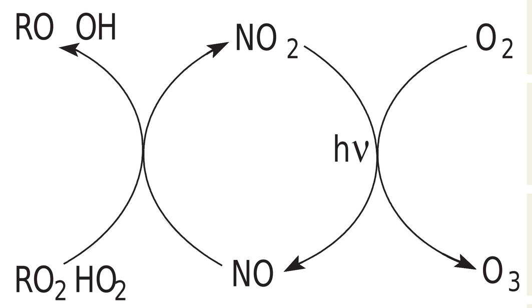
Background

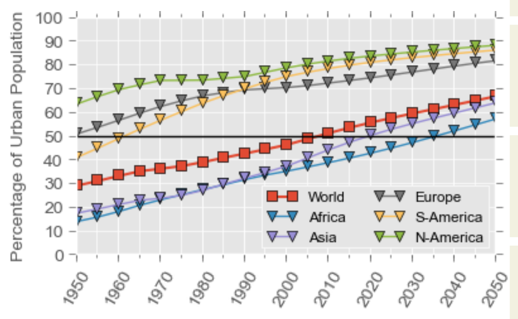
Why NO_2 ?

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



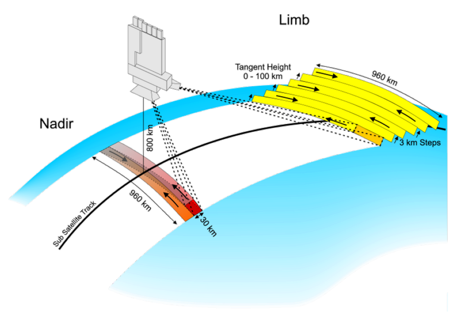
Why Megacities ?

- 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 ?

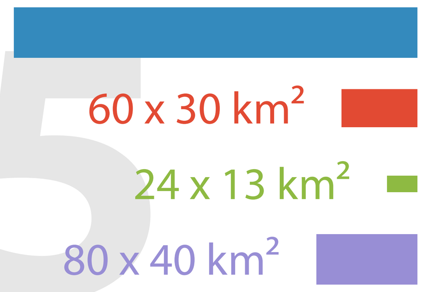
- long timeseries
- global coverage
- consistent measurement conditions



Different satellite instruments:

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

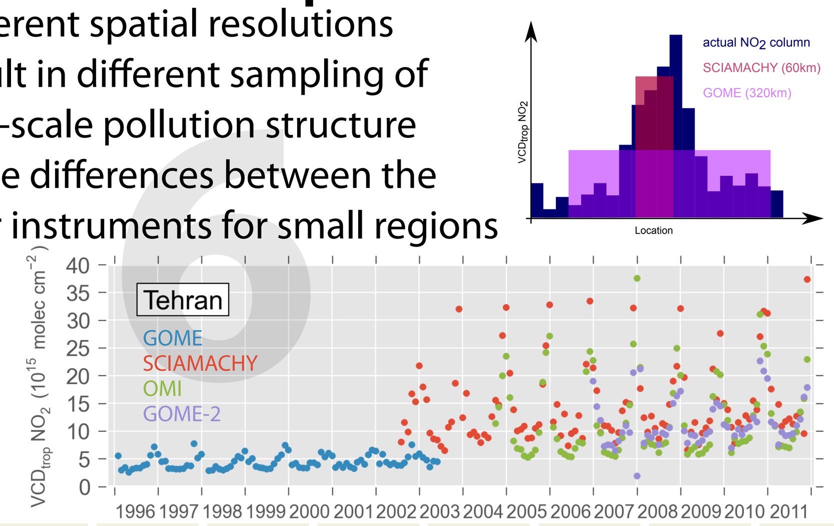
Different spatial resolutions:



Methods

The problem:

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



The data:

- 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:

Account for instrumental differences in trend model:

- common among all instruments:
  - linear growth rate
  - seasonality 'shape'
- instrument-dependent:
  - offset
  - seasonality amplitude
  - noise

Trend model:

X_{trend} monthly avg.
t time
i instrument

$$X_{trend}(t,i) = \omega \cdot t \quad \text{linear growth rate}$$
$$+ \mu_i \quad \text{offset}$$
$$+ \eta_i \cdot \Psi(t) \quad \text{seasonal cycle}$$
$$+ N(t,i) \quad \text{noise}$$

Seasonality:

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

Uncertainty / significance assessment

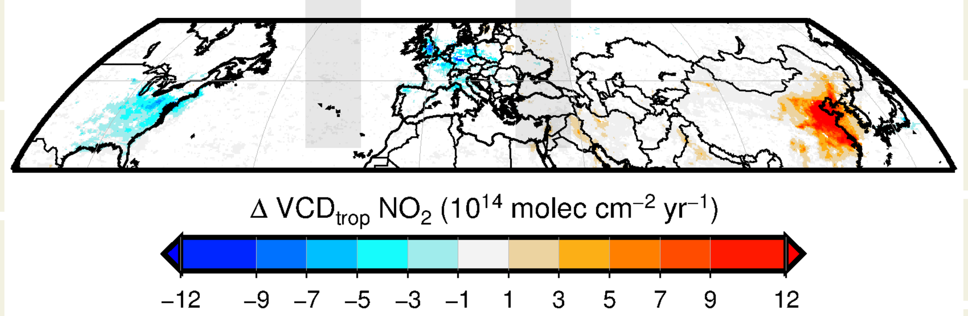
via Bootstrap analysis:

- 2000 replications
- shuffle trend fit residuals, repeat analysis
- compute histogram & 95% confidence interval
- trend is significant ⟺ 0.0 is outside of 95%-interval

Results

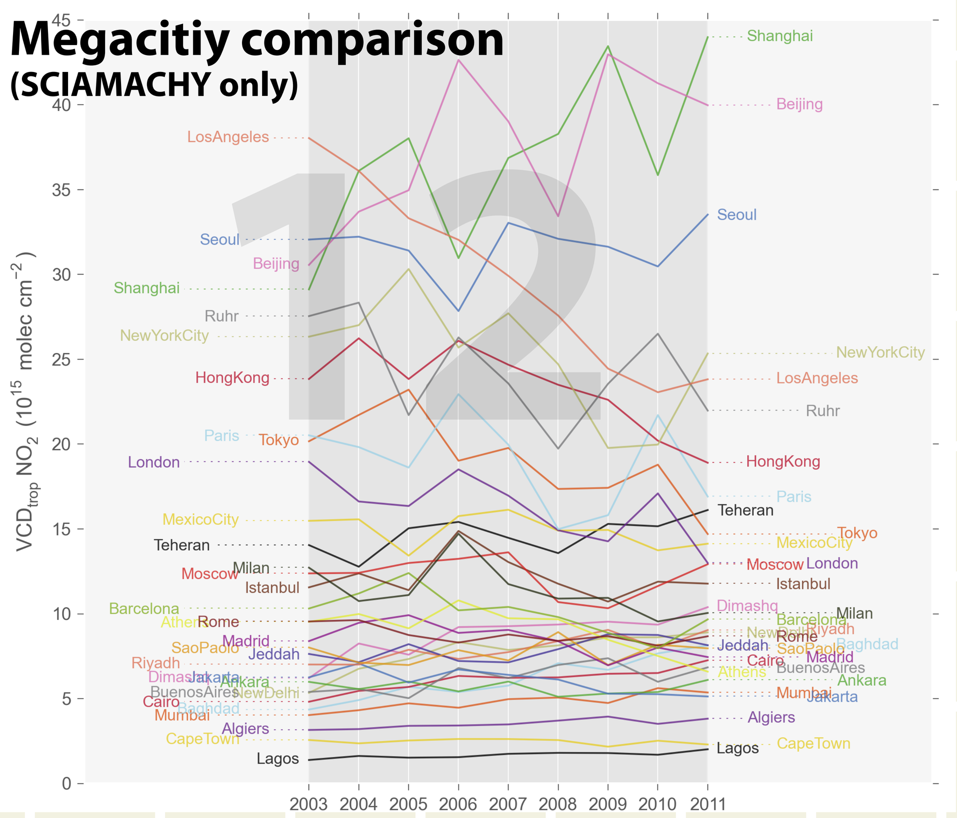
Global trend patterns

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

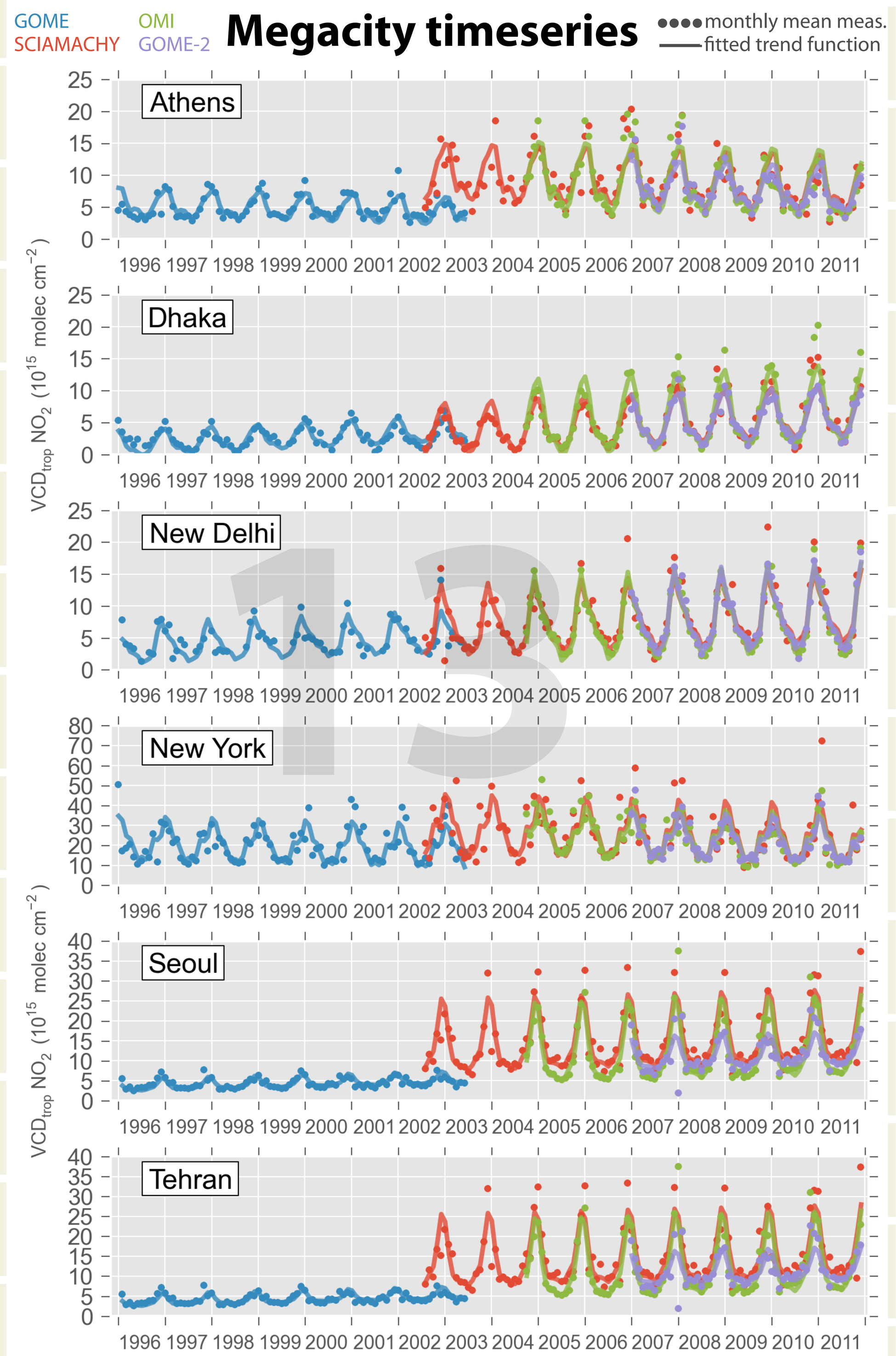


Megacitiy comparison

(SCIAMACHY only)



Megacity timeseries

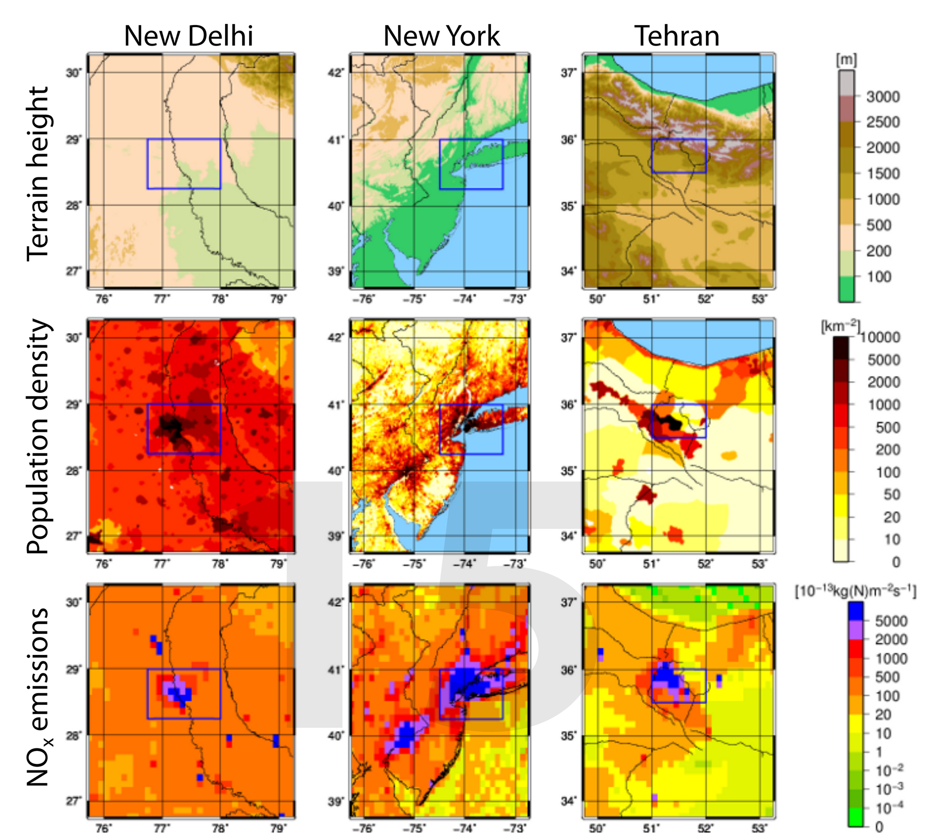


Megacity NO_2 trends

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

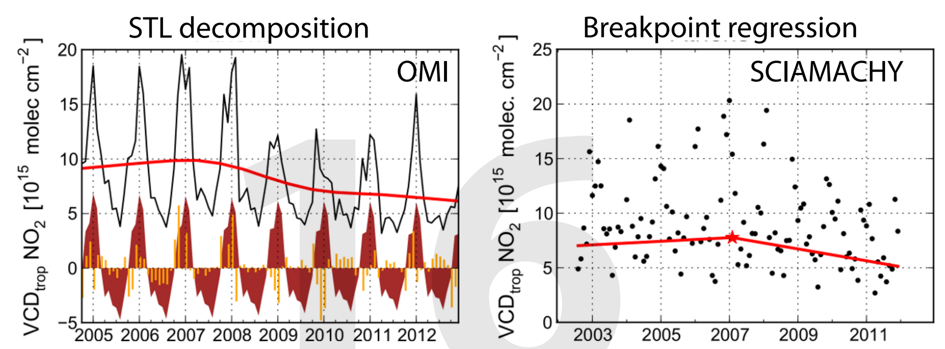


Homogeneous, high-emission areas with no topographic boundaries:
– ground pixel size has negligible effect

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



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

Summary / Conclusions

- 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

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