Long-term evolution of satellite derived tropospheric NO_2 fields

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Why measure NO_2 from Space?

- NO_x (NO_2 + NO) is an important precursor for tropospheric ozone
- NO_x levels are changing, mainly as result of anthropogenic activities
- consistent global long-term measurements are needed to monitor and understand these changes
- surface in-situ measurements provide local long-term data sets but lack spatial coverage
- air-borne in-situ measurements provide vertical resolution but also lack coverage
- satellite measurements lack vertical and spatial resolution but provide good coverage

Atmospheric composition change can result from
- changes in emissions (e.g. pollution)
- changes in air chemistry (e.g. OH concentration)
- changes in dynamics (e.g. strat-trop exchange)
- any combination of the above

How to measure from Space?

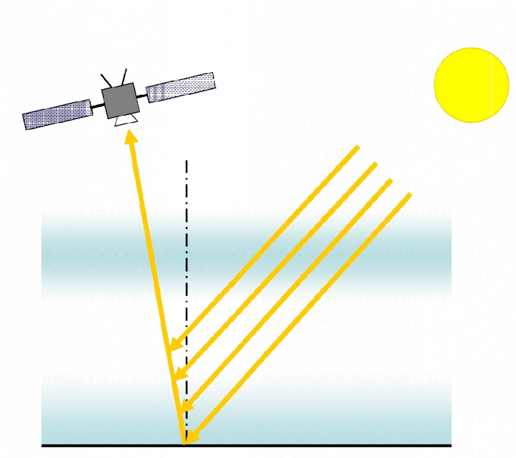

Fig 1: Cartoon of the measurement geometry. The light observed by the satellite is either reflected on the surface or scattered back from the atmosphere. Not all photons probe the lowest layers which reduces the sensitivity of the measurements, in particular in the UV where Rayleigh scattering is more effective.

Measurement Technique:
- Differential Optical Absorption Spectroscopy on UV/visible sun light scattered back and reflected from the atmosphere and surface
- use of Lambert-Beer's law to determine the absorption along the effective light path
- use of radiative transfer simulations to determine the effective light path
- separation of tropospheric and stratospheric components by making assumptions on zonal homogeneity of the stratospheric fields

Instruments used:

GOME
- data from 9.95 - 6.2003
- 320 x 40 km^2 pixels
- global coverage 3 days
- 10:30 LT equator crossing

SCIAMACHY
- data since 8.2002
- 60 x 30 km^2 pixels
- global coverage 6 days
- 10:00 LT equator crossing

GOME-2
- data since 3.2007
- 80 x 40 km^2 pixels
- global coverage 1.5 days
- 09:30 LT equator crossing

Global tropospheric NO_2 changes

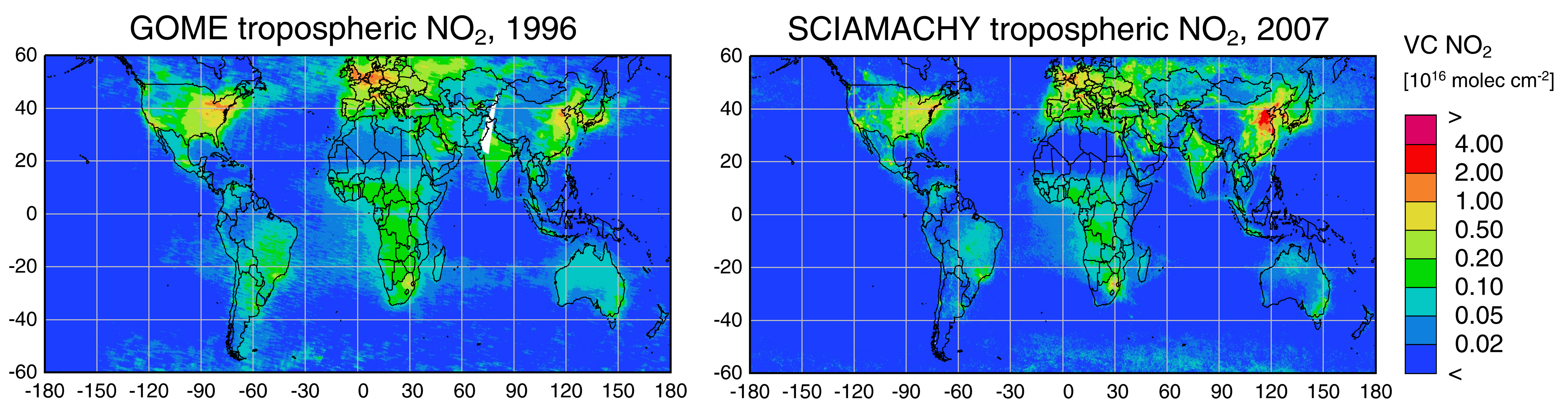

Fig.2: Annual averages of tropospheric NO_2 columns from GOME for 1996 (left and SCIAMACHY for 2007 (right)
- the overall patterns in the two measurements agree very well
- the range of observed columns is very large (note the logarithmic colour scale)
- SCIAMACHY measurements provide more detail as result of the better spatial resolution
- NO_2 columns over large parts of China are much larger in 2007 than in 1996
- NO_2 columns over Europe and the US are somewhat smaller in 2007 than in 1996

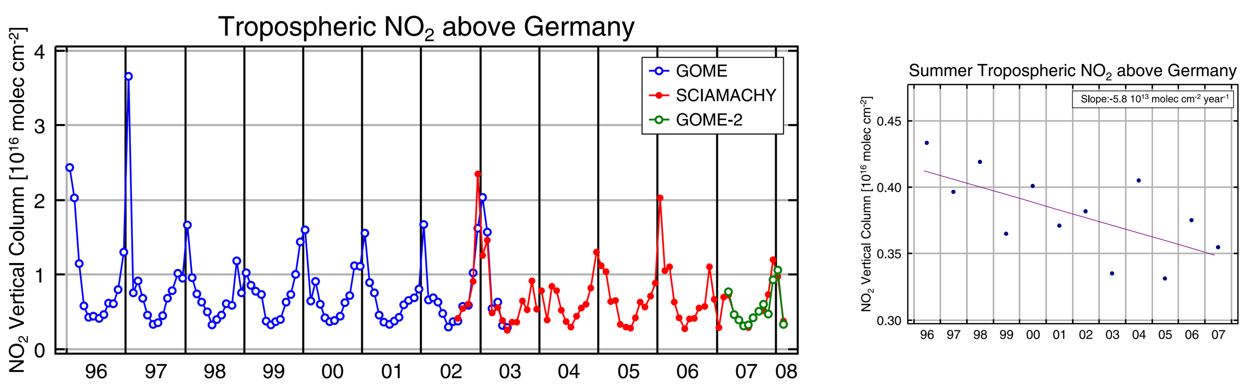

Fig. 3: Monthly averages of tropospheric NO_2 above Germany (left) and evolution of the summer values (May - August, right). The area used for averaging is (46 - 55°N, 6 - 15°E)
- there is a clear seasonal cycle with higher values in winter than in summer
- the winter values are dominated by large variability which is linked to poor sampling in the cloudy season in combination with pollution events
- the agreement between the three sensors is very good in the periods of overlapping measurements
- there is a downward trend in the summer values of about 17% over the 12 years which appears to level off in the last years

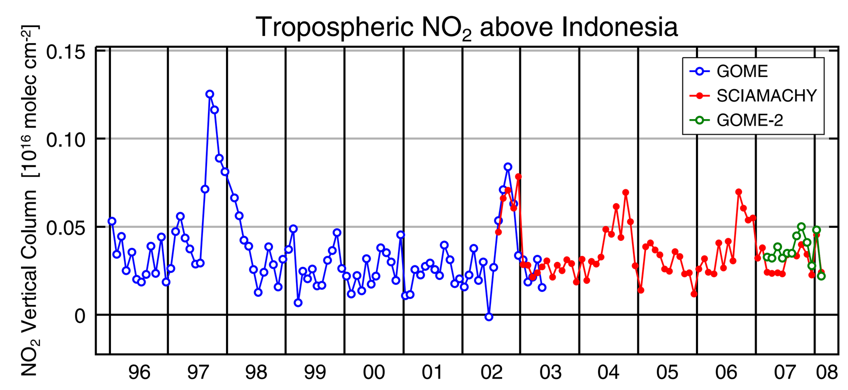

Fig. 4: Monthly averages of tropospheric NO_2 above the area around Watukosek (15 - 0°S, 110 - 115°E) derived from GOME, SCIAMACHY, and GOME-2 measurements.
- the agreement between the different sensors is good (note the different scale)
- there is no conceivable seasonal variation and no apparent trend
- El Nino years are associated with large increases in NO_2 columns which affect a wide area. This is the result of intense biomass burning in dry years and the resulting smog.

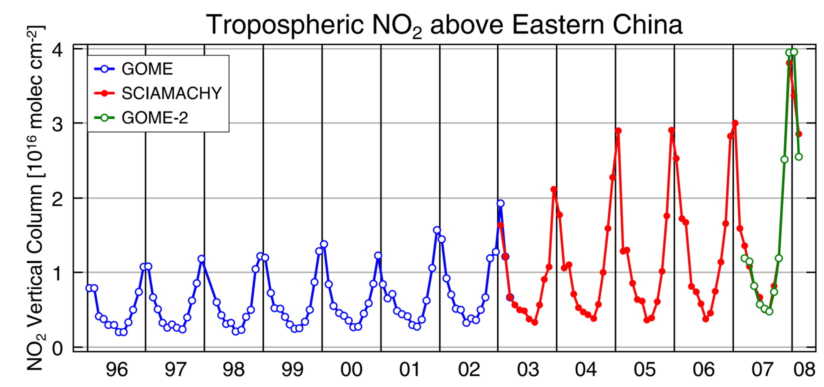

Fig.5: Monthly averaged tropospheric NO_2 above Eastern China (30 - 40°N, 110 - 123°E)
- the agreement between the different sensors is very good
- there is a clear seasonal cycle with higher winter values
- the variability is much smaller than over Germany, mainly as result of larger averaging area
- there is a clear upward trend with very large winter values in the latest years but also clearly increasing summer columns
- this is mainly due to increased emissions but changes in aerosol load and associated changes in sensitivity may also contribute

How consistent are different sensors?

Several aspects can contribute to differences:

Instrument differences
- instrumental errors (e.g. polarisation sensitivity) vary between sensors
- spatial resolution differs
- cloud retrievals differ and may lead to different results

NO_2 field differences
- time of overpass varies between sensors (10:30 LT for GOME, 10:00 LT for SCIAMACHY, 09:30 LT for GOME-2, 13:00 LT for OMI) and therefore NO_2 concentrations change as result of emissions, transport and photochemistry

Sampling differences
- as the tropospheric NO_2 field is heterogeneous, the exact position and distribution of measurements has a large

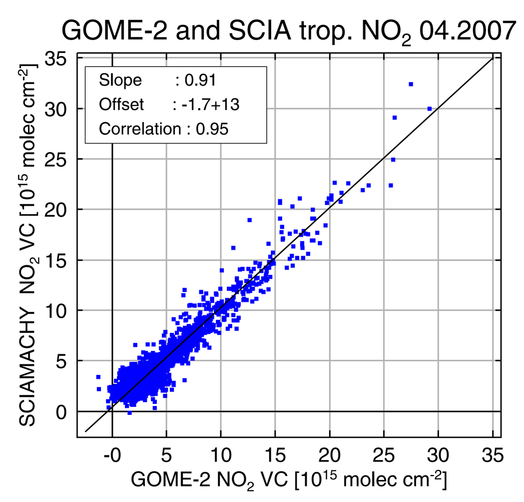

Fig. 6: Scatter plot of monthly NO_2 fields from SCIAMACHY and GOME-2 for April 2007. Only those data are used, where both instruments have measurements on the same day. Data have been binned on 1 x 1°

Conclusions

- UV/visible satellite measurements of tropospheric species provide valuable long-term data sets
- the data can be used to monitor emission changes
- the consistency between measurements from different sensors (GOME, SCIAMACHY, GOME-2) is good but standard deviations of about $1x10^{15}$ molec cm^{-2} remain for individual 1x1° grid cells
- differences are mainly to sampling differences of the heterogeneous NO_2 field
- the increase in NO_2 above China continues
- some reductions occurred over Europe and the US but with large year-to-year variability
- biomass burning signals, in particular over Indonesia vary with meteorology and no clear trend can is observed

Acknowledgements

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