Tropospheric Composition Change observed from Space

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Why from Space?

- atmospheric composition is 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?

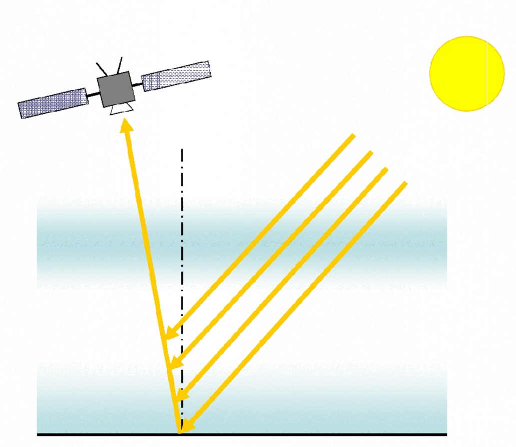


Fig 1: Cartoon of the measurement geometry. The light observed by the satellite is either reflected on the surface or scattered back from the atmosphere. Not all photons probe the lowest layers which reduces the sensitivity of the measurements, in particular in the UV where Rayleigh scattering is more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

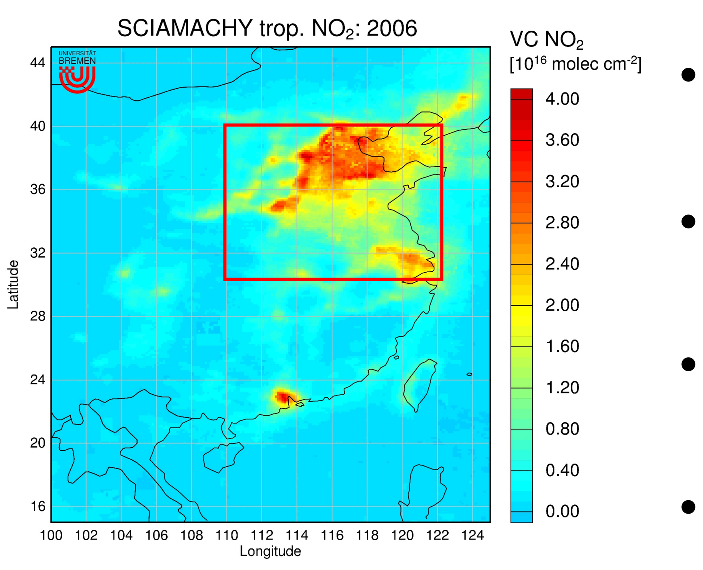
- data since 8.2002
- 60 x 30 km^2 pixels
- global coverage 6 days
- 10:00 LT equator crossing

GOME-2

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

Some Examples

NO_2 Increase above China



- NO_2 is mainly emitted from cars, power plants and cement industry
- rapid industrialisation leads to rapid increase in emissions
- increase seen by satellite is slightly larger than in recent emission estimates
- winter increase much larger in satellite data but only moderately larger in emission estimate

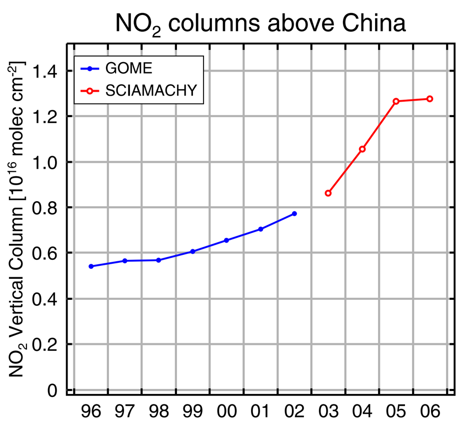
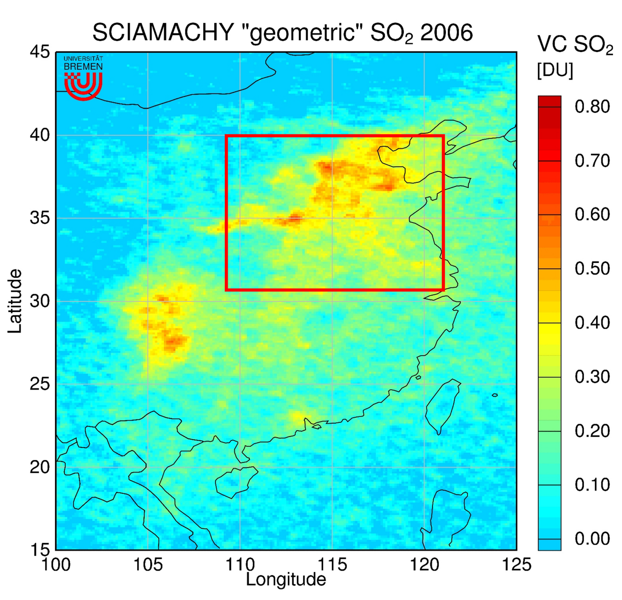


Fig. 2. Annual averages of tropospheric NO_2 above the indicated region in China as seen by GOME and SCIAMACHY. Data for 2006 are still preliminary.

SO_2 Increase above China



- SO_2 is mainly emitted from power plants and domestic heating
- increased coal use in power plants increases emissions
- reduced household use decreases emissions
- improved emission controls reduce emissions
- change in viewing conditions might contribute to satellite signal (see Fig. 6)

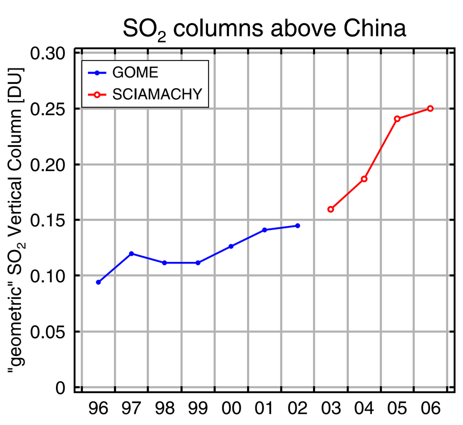
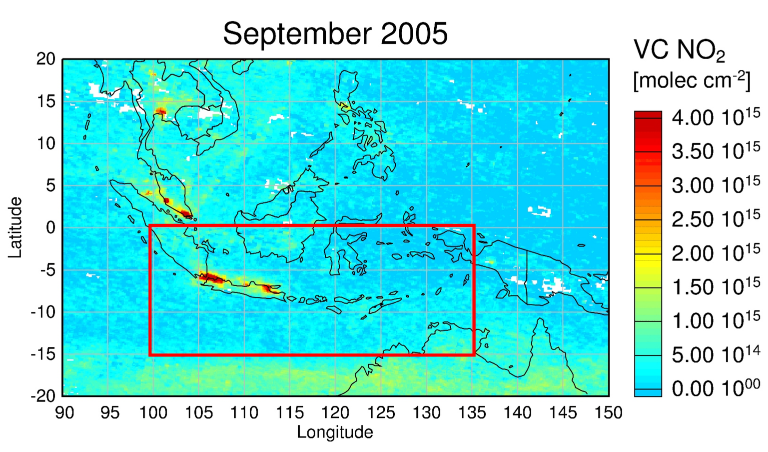
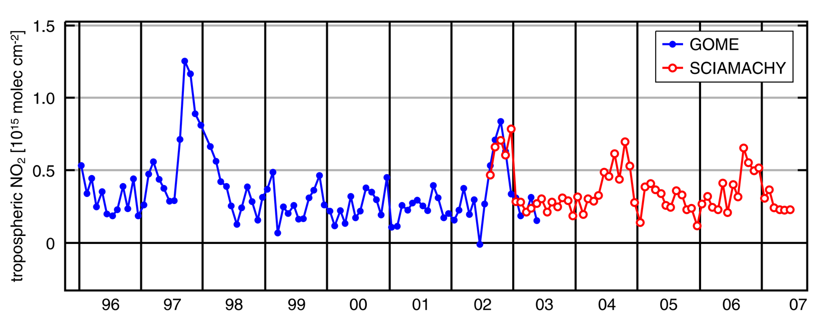
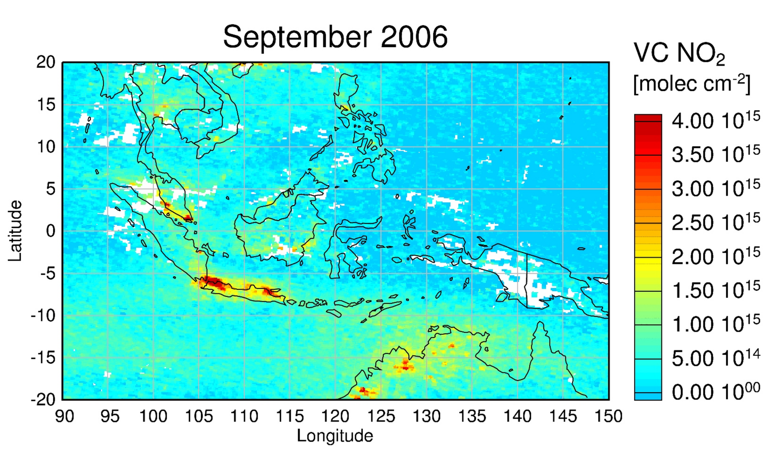


Fig. 3: Annual averages of tropospheric SO_2 above the indicated region in China as seen by GOME and SCIAMACHY. Data have not yet been fully corrected for light path effects. 2006 point is still preliminary.

El Nino and NO_2 above Indonesia and Australia







- dryness during el Nino years such as 2006 lead to large scale wild fires in Indonesia and Australia
- air quality is affected in large region
- smoke and haze from fires reduces number of good satellite measurements (see gaps in SCIAMACHY September 2006 map)

Fig. 4: Monthly averages of tropospheric NO_2 above the indicated area around Watukosek (8°S, 118°E) derived from GOME and SCIAMACHY measurements. El Nino years are associated with large increases in NO2 columns which affect a wide area (see SCIAMACHY maps to the left)

Problems and possible Solutions

Instrument Changes

- any instrument may change over time introducing artificial changes
- long-term data sets rely on data from different sensors which may differ for several reasons:
  - instrument characteristics
  - spatial resolution differences
  - local time of measurement differences

=> *verification using overlapping time series (see Figure 5)*

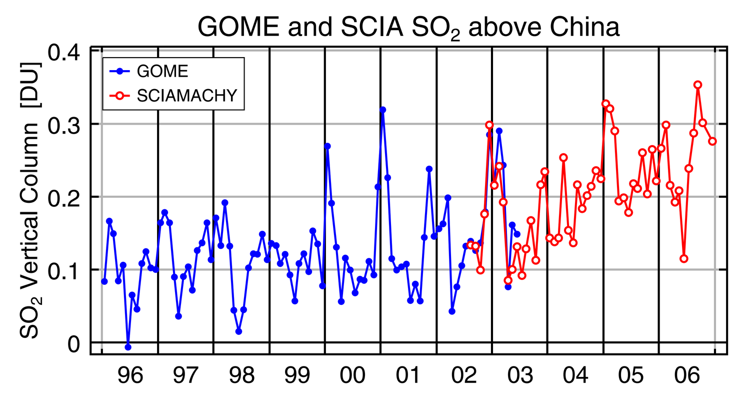


Fig. 5: Monthly averages of GOME and SCIAMACHY SO_2 above China showing the excellent agreement in the overlapping months.

Viewing Condition Changes

- over a longer time series, the observation conditions may change, e.g. through:
  - systematic cloud changes
  - changes in surface albedo (e.g. deforestation)
  - changes in aerosol loading, possibly linked to emission changes (e.g. SO_2)
  - changes in emission height (see figure)

=> *validation with external data needed*

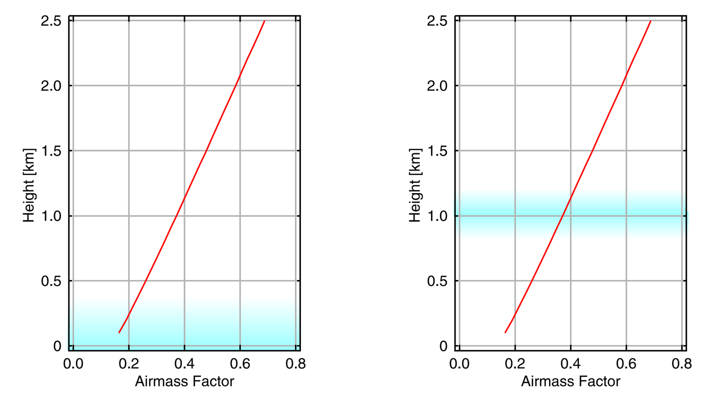


Fig. 6: Vertical sensitivity of SO_2 measurement and the effect of different emission types (domestic fires: low emission, power plants: high altitude emissions and possibly export into free troposphere). A change in emission type will lead to a signal change at the same

Separation of Effects

- the measurements provide atmospheric column amounts, which have to be transferred to emission strengths or local concentrations
- external information or models are often needed to make the link
- selection of appropriate case studies can also help (e.g.: only power plant emissions change, see Figure 7)

=> *data are best used synergistically*

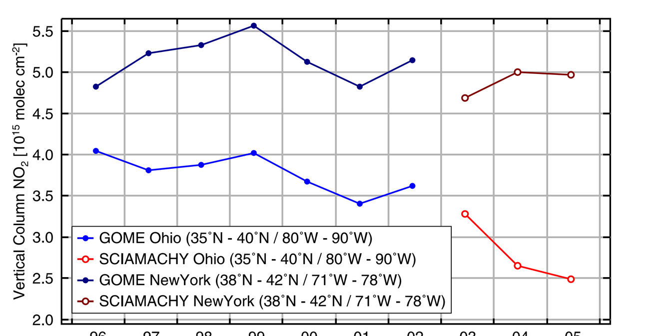


Fig.7: Change in NO_2 column amount over two regions in the Eastern US. During this time, in the Ohio River Valley, mostly NO_x emissions from power plants changed in response to legislation changes while the column over New-York remained more or less stable.

Conclusions

- UV/visible satellite measurements of tropospheric species provide valuable long-term data sets
- the data can be used to monitor emission changes
- examples are increases in anthropogenic emissions of NO_x and SO_2 in China, reductions in NO_x emissions in power plants in the US, as well as NO_x emissions from fires in Indonesia
- use of multi-sensior time series necessitates careful instrument cross-verification
- possible changes in observation conditions (e.g. change in vertical profile) have to be considered

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