ANALYSIS OF TROPOSPHERIC NO_2 BASED ON SATELLITE MEASUREMENTS

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ABSTRACT:

The distribution and changes of tropospheric nitrogen dioxide (NO_2) are analyzed using the satellite measurements data from GOME (Global Ozone Monitoring Experiment) and SCIMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY). We produced global maps of tropospheric NO_2 for 4 seasons using GOME measurements from January 1997 to June 2003. The global distribution shows high values in regions with dense population and high industrialization. Tropospheric NO_2 shows obvious seasonal changes depending on its emission and lifetime. Based on the good agreement between two instruments in the time period of overlapping measurements (January 2003-June2003), we linked SCIAMACHY data to the GOME time series. The combined time series over the past decade indicate that NO_2 levels over China are rapidly increasing while those over Europe are decreasing. We also discussed potential application of spaceborne instruments in detecting and characterizing long-distance transport of NO_2.

KEY WORDS: Tropospheric NO_2, GOME, SCIAMACHY, Distribution and Changes, Transport

1. INTRODUCTION

Nitrogen dioxide (NO_2) is a direct indicator of anthropogenic pollution and is a key species in atmospheric chemistry. In the troposphere, its amount and distribution is of significance directly for air quality and human health and indirectly for ozone formation and radiative forcing. Sources of NO_2 are both natural (soil emissions, lightning) and anthropogenic (fossil fuel combustion, biomass burning). Although the estimation of the strengths for the different NO_2 sources still has high uncertainties, it is estimated that more than two third of the total NO_2 emissions are anthropogenic, dominated by the burning of fossil fuels for transportation and industrial activities (Leue et al., 2001).

Satellite measurements allow a new and independent approach to the determination of trace gas emissions. The global NO_2 distribution can be monitored with a single instrument under the same conditions and over long periods of time. Satellite instruments, GOME (Global Ozone Monitoring Experiment) and SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY) allow the retrieval of tropospheric NO_2 column densities from space. The combined time series of the two instruments provides a unique dataset of the global tropospheric NO_2 that now covers over one decade.

This paper will present some special features of tropospheric NO_2 in global distribution, seasonal changes and regional trends as observed by the spaceborne instruments. We also discussed potential application of remote sensing data in detecting and characterizing NO_2 transport.

2. GOME AND SCIAMACHY

The GOME instrument is a 4 channel UV/visible spectrometer which was launched on ERS-2 (European Remote Sensing-2) satellite in April 1995 into a Sun-synchronous orbit. The GOME observes the atmosphere in nadir view with a spatial resolution of 40 km latitude by 320 km longitude in forward scan, using a scanning mirror to measure three such scenes across the flight track. Global coverage at the equator is achieved every three days through its swath of 960 km.

The SCIAMACHY was launched on ENVISAT (ENVIronmental SATellite) in March 2002. In comparison to GOME, the wavelength range has been expanded to the infrared and therefore the retrieval of greenhouse gases and CO is allowed. With respect to the NO_2 retrieval, SCIAMACHY has two major improvements. One is the better spatial resolution of 30 km latitude by 60 km longitude, and the other is a introduction of new viewing geometries (limb, occultation) that allow direct measurements of the stratospheric columns. Global coverage at the equator is achieved within 6 days when using the alternating limb/nadir scan option.

We used tropospheric NO_2 vertical column densities based on BIRA-IASB (Belgian Institute for Space Aeronomy) slant column NO_2 retrievals with the DOAS (Differential Optical Absorption Spectroscopy) technique and the KNMI (Royal Netherlands Meteorological Institute) combined modelling/retrieval/assimilation approach (Eskes and Boersma, 2003; Boersma et al., 2004). TEMIS (Tropospheric Emission Monitoring Internet Service) provides tropospheric trace gas concentrations (O_3, NO_2, SO_2, BrO) and aerosol and UV products, derived from observations of the nadir-viewing satellite instruments GOME and SCIAMACHY.

3. ANALYSIS RESULTS

3.1 Global Distribution and Seasonal Cycle

Figure 1 shows the seasonally averaged tropospheric NO_2 vertical column densities retrieved from GOME for January 1997-June 2003. High vertical column distributions of NO_2 are associated with major cities across North America, Europe and Northeast Asia, along with other sites such as Mexico City in Central America and South African coal-fired power plants located close together in the eastern Highveld plateau of that country.

The NO_2 vertical column densities over industrial regions are lowest in summer and highest in winter due to the changes in lifetime dominated by reaction with OH. The NO_2 persists longer in the atmosphere at less sunny time of year, lasting around a day rather than hours.

On the other hand, the seasonal changes of the tropospheric NO_2 in areas of biomass burning are dominated by changes in emissions. Seasonal enhancements from biomass burning are observed over India during MAM (March-April-May), central Africa during JJA (June-July-August), central South America from June to October and northern Africa during DJF (December-January-February).

3.2 Comparison of GOME and SCIAMACHY

As the GOME and SCIAMACHY nadir measurements are very similar, the SCIAMACHY data are well suited to continue the GOME time series that basically ended in June 2003. The main differences of the two nadir measurements are in sampling (coverage difference because of alternating limb/nadir mode) and resolution.

Tropospheric NO_2 retrieved from GOME and SCIMACHY for the time period of overlapping measurements from January 2003 to June 2003 are compared in Figure 2. The global comparison of tropospherc NO_2 from the two instruments generally shows good agreement in both distribution and strength. In detail, the comparison reveals the benefit of higher spatial resolution that can detect several localized sources consistent with large cities. The benefit can be used to simplify the separation between transport and local emission of NO_2.

The agreement between GOME and SCIAMACHY improves further when GOME data are used for narrow swath mode (NSM) with a spatial resolution of 80×40 km^2 (Beirle et al., 2004) and for which SCIAMACHY data exist within a certain radius (Richter et al., 2004).

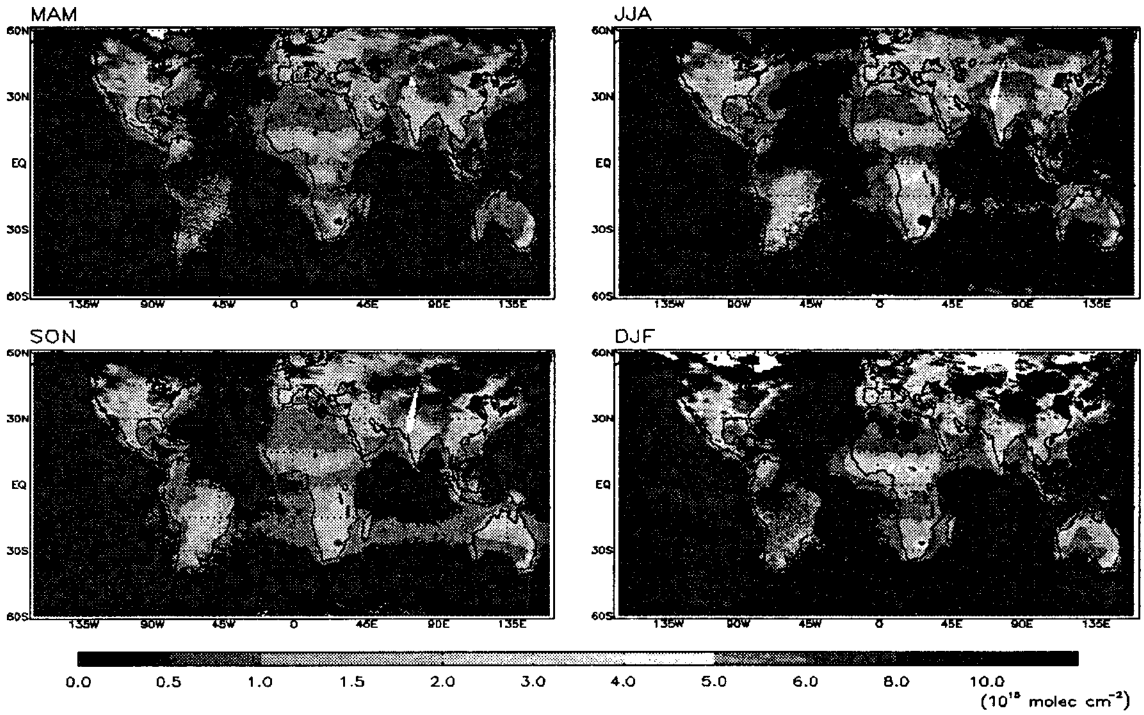

Figure 1. Seasonal mean tropospheric NO_2 vertical column densities from January 1997 to June 2003 (MAM: March-April-May, JJA: June-July-August, SON: September-October-November, DJF: December-January-February).

3.3 Regional Trends

The NO_2 trends can be readily extracted from the satellite data because satellite allows the measurements of global atmosphere with a single instrument under the same conditions. The combined time series from GOME and SCIAMACHY provides a unique dataset of the global tropospheric NO_2 that now covers over one decade.

Figure 3 shows the regional trends of NO_2 vertical column densities over China (30°N-40°N, 112°E-122°E) and over Europe (44°N-56°N, 6°W-24°E) from April 1996 to July 2005. We plotted monthly averaged values and linked SCIAMACHY data to the GOME time series. GOME and SCIAMACHY time series match well in the time of overlapping measurements in spite of the reduced coverage of SCIAMACHY.

In China, NO_2 levels have rapidly risen over the past decade and are continuing to increase. The drastically increased emissions of NO_2 are thought to be a result of spectacular economic growth and industrialization. On the other hand, NO_2 levels over Europe are continuously decreasing although the rate is not so rapid as that of China is.

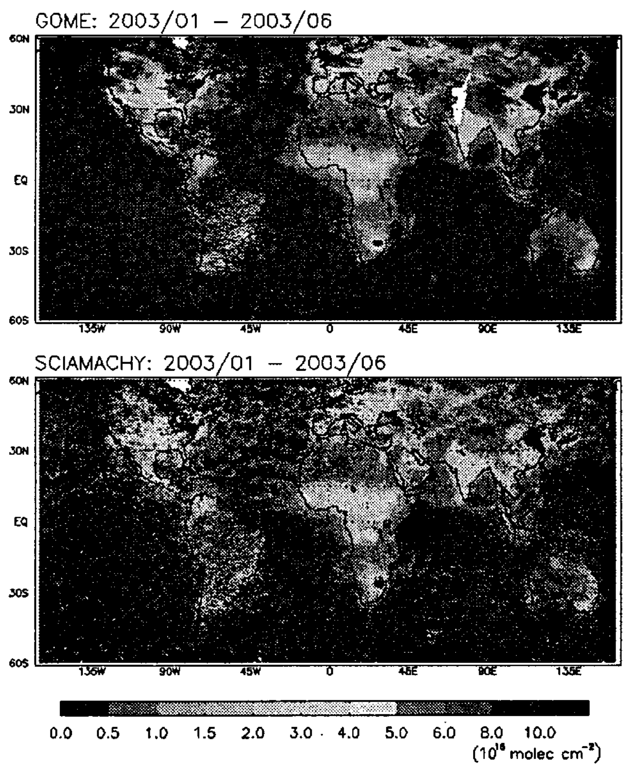

Figure 2. The comparison of GOME and SCIAMACHY tropospheric NO_2 vertical column densities for the time period of overlapping measurements from January 2003 to June 2003.

3.4 Potential Application in Detecting NO_2 Transport

NO_2 is a short-lived trace gas in the atmospheric boundary layer with life time of about a day and therefore NO_2 is highly concentrated in its major source regions. In the upper troposphere, however, its lifetime is of the order of 5-10 days, which sufficient even for intercontinental transport. That means NO_2 can be transported over long distance only when strong lift to the upper troposphere and high wind speeds in the upper troposphere are provided.

In the previous researches (Spichtinger et al., 2001; Wenig et al., 2003; Stohl et al., 2003), GOME measurements were used to observe intercontinental transport events of NO_2 and demonstrated the potential of spaceborne instruments. Since high wind speeds are more frequent in winter than other seasons, it is appropriate focusing on winter events to study long-distance transport of NO_2. Higher resolution of SCIAMACHY will be useful in separation between transport and emission in spite of its reduced coverage.

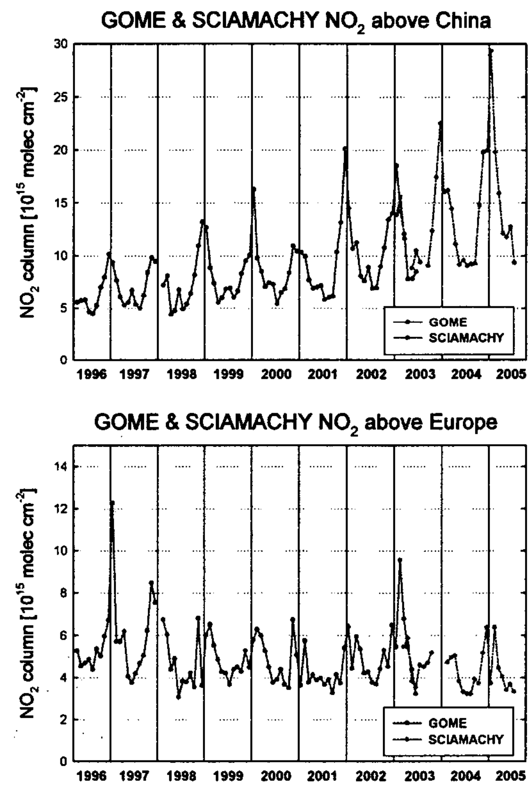

Figure 3. Trends in tropospheric NO_2 vertical column densities over China (30°N -40°N, 112°E -122°E) and Europe (44°N -56°N, 6°W -24°E) from April 1996 to July 2005. Monthly averaged NO_2 vertical column densities from GOME and SCIAMACHY are linked.

4. SUMMARY AND CONCLUSIONS

We studied global distribution, seasonal cycle and regional trends of tropospheric NO_2 using the satellite measurements from GOME and SCIMACHY. Tropospheric NO_2 shows significantly enhanced values in regions with dense population and high industrialization. Seasonal changes of tropospheric NO_2 are obvious depending on those emissions and lifetime. Tropospheric NO_2 columns from SCIMACHY agree well with GOME data in the time period of overlapping measurements and thus it is reasonable linking SCIMACHY data to the GOME time series. The combined time series from the two instruments show increasing trend over China and decreasing trend over Europe.

The large area, strong intensities and increasing trend of NO_2 in China reinforce the necessity of studies on long-distance transport of tropospheric NO_2 over the Northeast Asia affected by westerly winds. We will continue the analysis of tropospheric NO_2 using satellite measurements for the detection and characterization of long-distance NO_2 ransport over the Northeast Asia.

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