Study of the hemispheric difference in observed NO_2 trends

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Pictures of the four primary NDACC stations included in this study (from left: Jungfraujoch, Lauder, Mauna Loa (top), Arrival Heights (bottom)

Background

As summarized in the WMO 2006 report, Chapter 3 (Global Ozone), evidence suggested that the NO_2 (nitrogen dioxide) trends in the Southern Hemisphere (SH) are significantly larger than in the Northern Hemisphere (NH). This finding was based on the trend analysis of long-term observation of NO_2 made at Lauder (45.0ºS), New Zealand using UV-visible spectroscopy and at the Jungfraujoch (46.5ºN), Switzerland using Fourier transform spectroscopy.

A linear increase of 6.2 ± 1.8% per decade (am) and 5.7 ± 1.1% per decade (pm) was inferred for Lauder, while the trend analysis using the same algorithm for the Jungfraujoch data set produced a linear trend of only 1.5 ± 1.0% per decade. While the trend at Jungfraujoch is consistent with the 2.4% per decade increase in tropospheric N_2O (nitrous oxide), the WMO 2003 report concluded that both the observed N_2O increase and the decrease in ozone explained a trend in NO_2 of 5 ± 1% per decade.

Method

To investigate this hemispheric difference further, we present a statistical analysis of long-term time series of NO_2 from ground-based measurements made at several locations in the NH and SH (including Lauder and Jungfraujoch), using two independent ground-based techniques (UV-visible spectroscopy and FTIR) and one satellite data set (SAGE II).

All the monthly time-series were fitted by multi-linear regression with the same model, as used in our past work (Liley et al, JGR, 2000). In addition to the linear (decadal) trend, basis functions include three sine-cosine pairs for annual, semi-annual, and 4-month periods, 10.7 cm solar flux, Quasi-Biennial Oscillation, Southern Oscillation Index, and volcanic aerosol terms if the measurements date back to the aftermath of Pinatubo or El Chichon. Monthly means are used because there is still substantial autocorrelation in the residuals at that time resolution, showing that there are other effects not accounted for by the statistical model. Higher time resolution would compound these effects even more, meaning that any apparent improvement in statistical confidence would be spurious. To allow for the non-independence of residuals, standard errors of the fitted terms are increased by the autocorrelation-dependent factor adopted by Weatherhead et al. (JGR, 1998).

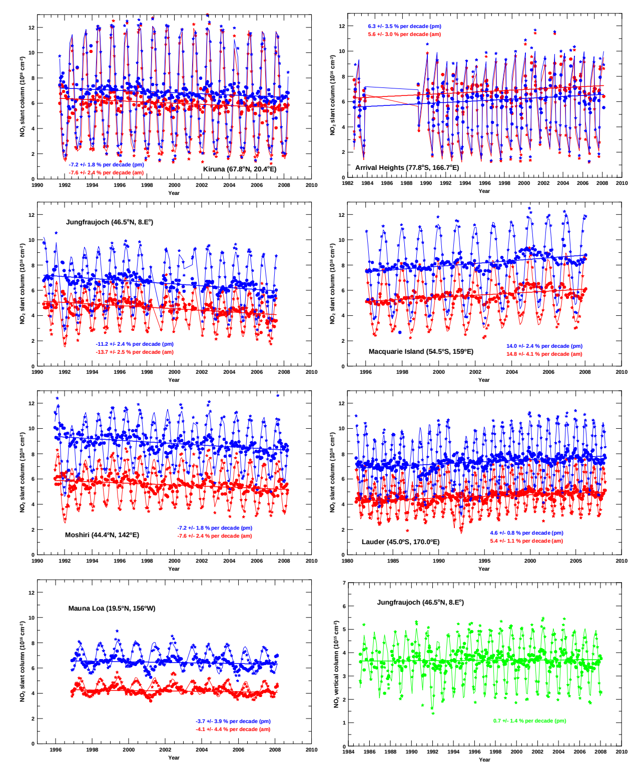

Figure 1: NO_2 long-term time series of UV-visible spectroscopy measurements from seven ground-based stations are shown together with the FTIR NO_2 data from Jungfraujoch. Displayed is the trend analysis for the longest time series available for each of the locations. The four Northern Hemisphere stations are shown on the left, the three Southern Hemisphere stations on the right; the bottom right panel shows the Jungfraujoch FTIR data (green).

The monthly mean values are displayed as red (sunrise) and blue (sunset) stars, the thin solid line is the fitted model, the filled circles are the trend plus residual, and the thick solid line the linear trend. The reference date for the percentage change is the start of year 2000.

	Trend 1984.8 – 2005.6		Trend 1991 – 2005.6		Trend 1996 – 2005.6	
Site	sunrise	sunset	sunrise	sunset	sunrise	sunset
Kiruna (67.8ºN)			-3.7 ± 4.3	-2.6 ± 3.5	-0.2 ± 5.0	-0.5 ± 4.0
Jungfraujoch (46.5ºN)			-9.8 ± 2.9	-7.8 ± 2.7	-18.0 ± 4.3	-7.5 ± 3.9
Moshiri (44.4ºN)			-7.1 ± 3.4	-6.4 ± 2.2	-0.2 ± 5.8	-0.9 ± 3.9
Mauna Loa (19.5ºN)					-1.6 ± 5.9	-0.5 ± 5.2
Lauder (45.0ºS)	8.3 ± 1.6	7.1 ± 1.3	7.5 ± 2.7	6.2 ± 1.8	-2.2 ± 3.2	2.1 ± 2.3
Macquarie Island (54.5ºS)					20.4 ± 4.5	19.3 ± 3.1
Arrival Heights (77.8ºS)			15.8 ± 5.3	17.2 ± 6.2	33.9 ± 10.2	37.6 ±12.2
Jungfraujoch FTIR	3.1 ± 1.5		0.9 ± 2.5		0.1 ± 3.3	
SAGE II (50º-60ºN)		4.4 ± 1.5		-2.9 ± 3.8		-16.9 ± 2.7
SAGE II (40º-50ºN)		3.5 ± 1.9		-2.4 ± 5.8		-18.5 ± 3.5
SAGE II (20º-40ºN)		3.1 ± 1.4		-2.7 ± 4.7		-20.6 ± 2.6
SAGE II (0º-20ºN)		5.9 ± 2.2		-8.9 ± 7.7		-25.7 ± 4.8
SAGE II (0º-20ºS)		7.9 ± 3.0		-1.9 ± 8.5		-17.3 ± 5.3
SAGE II (20º-40ºS)		6.3 ± 1.8		4.0 ± 4.6		-16.9 ± 1.8
SAGE II (40º-50ºS)		6.5 ± 2.0		1.4 ± 5.4		-14.5 ± 1.8
SAGE II (50º-60ºS)		5.5 ± 1.6		10.8 ± 3.9		-5.9 ± 6.7

Table 1 lists the fitted trend in percent (%) per decade in monthly mean NO_2 relative to the intercept at year 2000.0 for all ground-based stations and instruments, and the SAGE II sunset data. End date for all calculated trends is 2005.6. Trends in yellow are assumed real with a 95% confidence level when the ratio between the trend and its standard deviation is > 2. The SAGE II sunrise data are omitted because they have been corrected for a number of instrumental effects that might introduce a trend with time with the 'Thermal Shock' correction being the most important one.

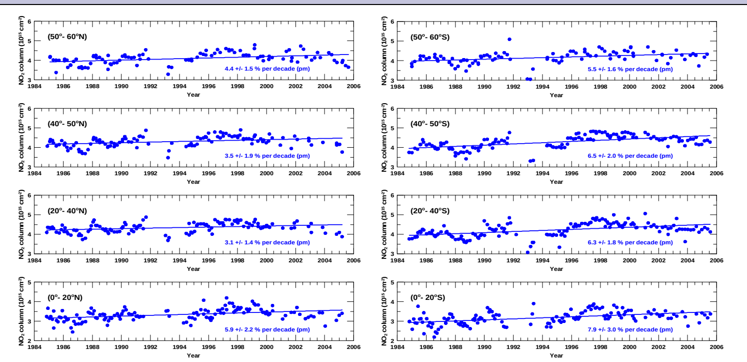

Figure 2: SAGE II sunset NO_2 monthly mean trends for NH and SH zonal means over 20 years (1985 – 2005). The filled circles show the linear trend plus residual and the solid line shows the linear trend.

Discussion

Our analysis highlights that the calculated NO_2 trends can depend strongly on the chosen time period and in some cases on the season (not shown here). For this study, we took care to only include ground-based data sets from stations for which we know that the data analysis is done consistently over the whole time period. All data series used in this study seem to be long enough for reasonable orthogonality between basis functions, so that the trends as quoted are sufficiently robust against variations in the model, and statistically significant within the model used.

Summary

➢ The Lauder UV/visible (7.1%) and Jungfraujoch FTIR (3.1%) trends agree very well with the SAGE II 40-50ºS and 40-50ºN trends respectively (see table) for the longest overlapping time period (> 20 years). These trends are the most reliable ones and show for the ground-based stations as well as for SAGE II only positive trends with considerably higher positive trends in the SH.

➢ The SAGE II data seem to show an increase in NO_2 from the mid-80s to mid-90s, a turn-around in the mid- to late 90s and possibly a thereafter.

➢ The hemispheric difference seen at the ground-based stations for NO_2 trends calculated for 1991 – 2005.6 is not confirmed as clearly by SAGE II for 2 reasons: firstly, most of the calculated SAGE II trends are not statistically significant within the 95% level and secondly, since the start date is so close to the Pinatubo eruption and the SAGE NO_2 measurements have not been carefully evaluated for the impact of lingering volcanic aerosols, the trends have to be viewed with some caution.

➢ There is a distinct difference between the strong negative trends seen in the UV-visible data at the Jungfraujoch station and the statistically not significantly different from zero trends seen in the FTIR data set for the same time period. This will be investigated further.

➢ This study shows a more complicated picture than anticipated and we will continue to investigate the difference in the trends between hemispheres and different data sets in more detail.

We would like to acknowledge the use of the NDACC data base for the ground-based column NO_2.