Khosrawi et al.: Assessment of the interannual variability and impact of the QBO and upwelling on tracer-tracer distributions of N_2O and O_3 in the tropical lower stratosphere

Electronic supplement

Latitudinal occurrence of N_2O > 320 ppbv:
In Figure 1 the N_2O mixing ratios 650±25 K that are larger than 320 ppbv are plotted on a map for January, April, July and October 2003. These high N_2O mixing ratios occur solely in the tropics.

Odin/SMR:
Considering the maximum N_2O mixing ratios of the averaged bins for the years 2003 to 2010 a higher occurrence of these high N_2O values is found in 2003, 2004, 2007 than in the other years (Table 1). High N_2O mixing ratios are found in 2003 during all winter months (January to March and October to November), but in 2004 only at the begin of the year (January to March), in 2005 and 2007 only at the end of the year (November to December), in 2006 and 2010 only in two months (January and October and January and March, respectively) and 2008 and 2009 only in one month (February and November, respectively). Lowest maximum N_2O values are found during summer months (June and July in 2004-2005, June to August in 2006, May to July 2007, May to August 2008 and 2009 and July to August 2010). One exception, however, of this scheme is found in 2007, when the lowest value was found in January.

Aura/MLS:
Though the highest N_2O averages from Aura/MLS are ∼ 20 ppbv lower than the monthly averages from Odin/SMR, a similar structure of higher N_2O values during winter months is found (Table 2). The summer minima, however, are not as strongly pronounced in the Aura/MLS data as in Odin/SMR data (see paper for more details).

ENVISAT/MIPAS:
In 2003 and 2004, before the intermission in the ENVISAT/MIPAS operation, maximum N_2O mixing ratios of 330 ppbv are found between February and April. From 2005 onwards when ENVISAT/MIPAS continued its operation with a lower spectral resolution much lower N_2O mixing ratios (Table 3) are found than in 2003 and 2004 due to measures in the adjusted retrieval approach to reduce the high bias which had been identified for the 2002 - 2004 data set.

SD-WACCM:
No structure as pronounced as in the satellite data sets showing higher maximum N_2O mixing ratios of the averaged bins during winter months are found Table 4. However, higher values are found during Mai 2007, February 2009 and from January to June 2010. The QBO in SD-WACCM is realistically simulated and in good agreement with the QBO derived from Odin/SMR (not shown). However, in WACCM the QBO does not propagate as far down as in Odin/SMR. This may explain why we do not see the structure of higher N_2O values in winter than in summer that pronounced in SD-WACCM than in the satellite data.

Sensitivity studies:
Sensitivity studies on the effect of the bias/noise error on the interannual variability. The following cases were considered:

1. Monthly averages have only been calculated up to 320 ppbv.

2. Monthly averages were calculated for the entire Odin/SMR data set being reduced by 20 ppbv.

Both figures (Figure 2 and 3) are identical to the figure shown in the paper. The only difference is that the last bin (330 ppb) is missing. Thus, the noise error in the Odin/SMR data does not have any influence on the interannual variability or on the application of the method for a model evaluation/satellite intercomparison. In the first figure where the bins are only calculated up to 320 ppb, the variation due to the QBO in N_2O is not visible anymore. This is due to the fact that the values are simply cut-off. The second case which is more realistic for a considering a bias/noise error in a data set, the variation in the last bin is exactly visible as in the tables in electronic supplement, with the only exception that the absolute values are 20 ppb lower and that the curves are shifted 20 ppb to the left.

QBO Amplitudes:
The fact, that the seasonal and interannual variability of higher/lower N_2O values is real can be seen from the figures showing the time series and QBO amplitudes (Figure 4 and 5). The QBO amplitudes were calculated with a linear regression model. That model consisted of an offset, a linear term, sine and cosine functions with periods of 6 and 12 months to represent the semi-annal and annual variation as well two QBO proxies in form of the Singapore winds at 50 hPa and 30 hPa. Those two proxies are approximately orthogonal and therefore allow an estimation of the QBO phase.

Although the absolute values from Odin/SMR may be too high, the strength of the amplitude agrees with what is found from the ENVISAT/MIPAS data (Figure 6 and 7). Further, from the time series and QBO amplitudes we derive a variation of N_2O of the order of ±10-15 ppbv (Odin/SMR) and ±10 ppbv (ENVISAT/MIPAS) and of ±1 ppmv in O_3 (Odin/SMR) in absolute values at 25 km. The corresponding amplitudes in N_2O are ±6 ppbv (Odin/SMR) and ±4 ppbv (ENVISAT/MIPAS) and in O_3 ±0.5 ppmv. The variation in N_2O and O_3 due to the QBO is in the order of the variations we see in the monthly averages and can thus be attributed to the QBO (see Figure 4-9).

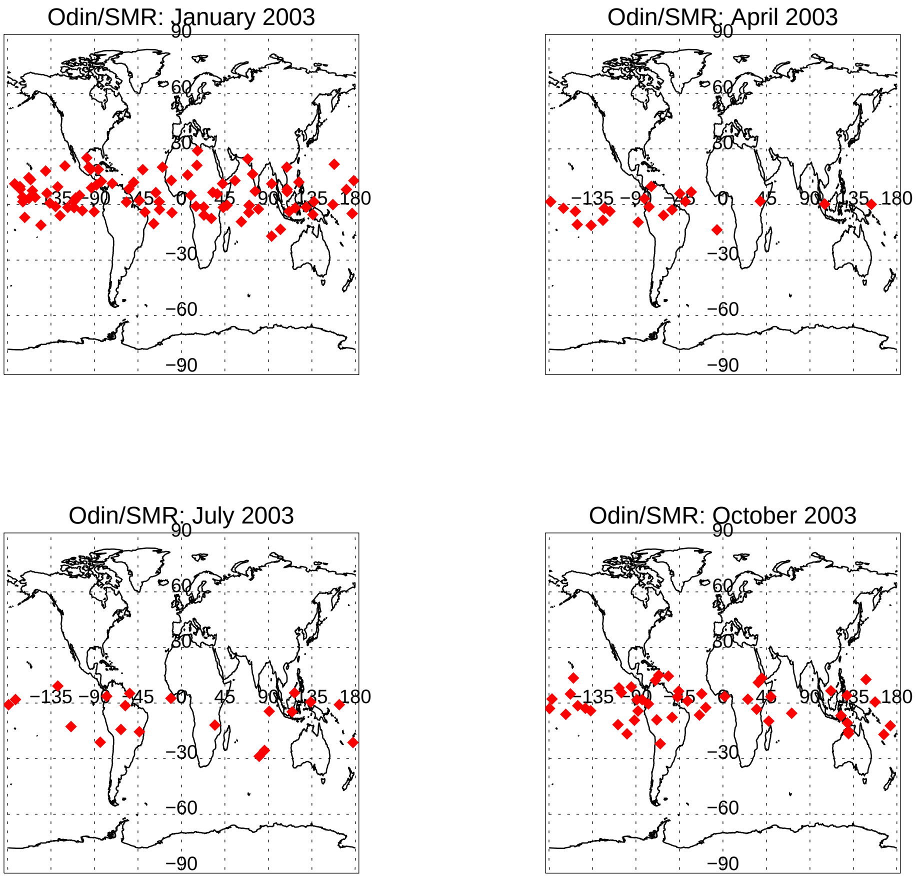

Figure 1: Locations where Odin/SMR N_2O mixing ratios greater 320 ppbv are observed at 650±25 K during 2003 (NH). Shown is every third month, thus January (top, left), April (top, right), July (bottom, left) and October (bottom, right).

Table 1: Odin/SMR: Maximum monthly averaged N_2O mixing ratios (averaged mixing ratio of the last N_2O bin) at 650±25 K. Maxima and Minima are marked in bold face.

Month/Year	2003	2004	2005	2006	2007	2008	2009	2010
January	**330**	**330**	310	**330**	**290**	310	310	**330**
February	**330**	**330**	310	310	310	**330**	310	310
March	**330**	**330**	310	310	310	310	310	**330**
April	310	310	310	310	310	310	310	310
May	310	310	310	310	**290**	**290**	**290**	310
June	310	**290**	**290**	**290**	**290**	**290**	**290**	310
July	310	**290**	**290**	**290**	**290**	**290**	**290**	**290**
August	310	310	310	**290**	310	**290**	**290**	**290**
September	310	310	310	310	310	310	310	310
October	**330**	310	310	**330**	**330**	310	310	310
November	**330**	310	**330**	310	**330**	310	**330**	310
December	**330**	310	**330**	310	**330**	310	310	310

Table 2: Aura/MLS: Maximum monthly averaged N_2O mixing ratios (averaged mixing ratio of the last N_2O bin) at 650±25 K. Maxima and Minima are marked in bold face.

Month/Year	2003	2004	2005	2006	2007	2008	2009	2010
January	-	-	**310**	**310**	**310**	290	**310**	**310**
February	-	-	**310**	**310**	**310**	290	**310**	**310**
March	-	-	**310**	290	**310**	290	**310**	**310**
April	-	-	290	290	290	290	290	**310**
May	-	-	290	-	290	290	290	**310**
June	-	-	290	**270**	290	290	290	-
July	-	-	290	**270**	290	290	290	-
August	-	-	290	290	290	290	290	-
September	-	290	290	290	290	290	290	-
October	-	290	290	290	290	290	**310**	-
November	-	290	290	-	**310**	290	**310**	290
December	-	290	290	290	290	290	**310**	290

Table 3: ENVISAT/MIPAS: Maximum monthly averaged N_2O mixing ratios (averaged mixing ratio of the last N_2O bin) at 650±25 K. Maxima and Minima are marked in bold face.

Month/Year	2003	2004	2005	2006	2007	2008	2009	2010
January	310	310	**250**	270	270	**290**	**290**	-
February	**330**	310	270	-	270	**290**	270	-
March	**330**	310	270	270	270	**290**	270	-
April	**330**	-	**250**	-	270	270	270	-
May	310	-	**250**	270	270	270	270	-
June	310	-	270	**250**	270	270	270	-
July	310	-	**250**	270	270	270	**290**	-
August	310	-	270	270	**290**	270	**290**	-
September	310	-	-	270	270	270	**290**	-
October	310	-	-	270	270	270	**290**	-
November	310	-	-	270	270	270	**290**	-
December	310	-	270	270	**290**	270	**290**	-

Table 4: WACCM: Maximum monthly averaged N_2O mixing ratios (averaged mixing ratio of the last N_2O bin) at 650±25 K. Maxima and Minima are marked in bold face.

Month/Year	2003	2004	2005	2006	2007	2008	2009	2010
January	-	-	270	270	280	270	280	**290**
February	-	-	280	270	280	270	**290**	**290**
March	-	-	280	270	280	280	280	**290**
April	-	-	280	270	280	270	280	**290**
May	-	-	280	270	**290**	280	280	**290**
June	-	-	280	270	280	280	280	**290**
July	-	-	280	270	280	280	270	280
August	-	-	280	270	280	280	**260**	270
September	-	-	280	270	280	270	270	270
October	-	-	270	270	270	270	270	-
November	-	-	280	270	270	270	280	-
December	-	-	270	280	270	280	280	-

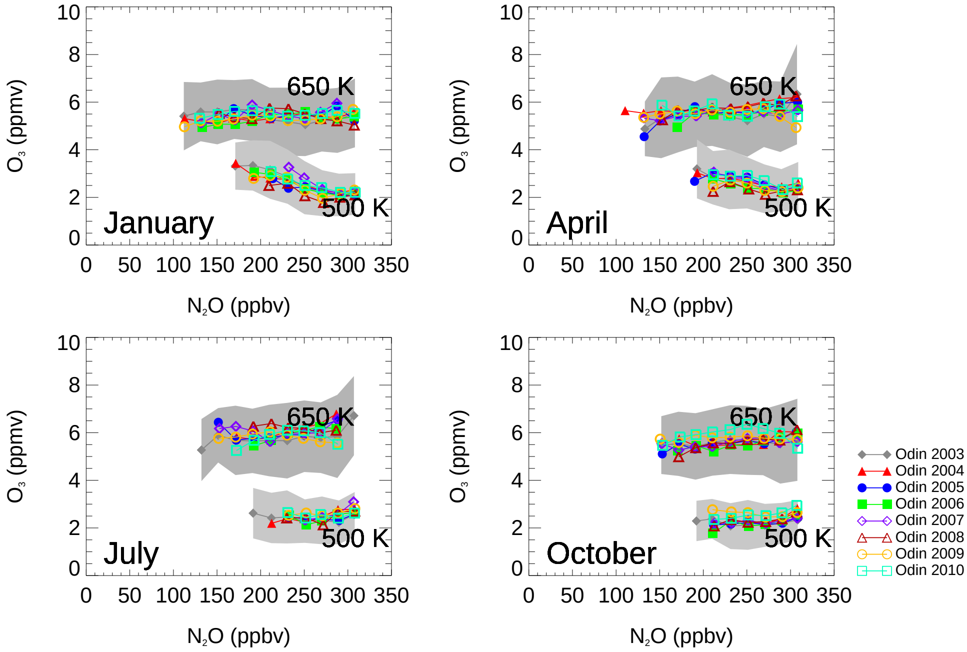

Figure 2: Odin/SMR climatology for 2003. Averages were calculated only up to 320 ppb.

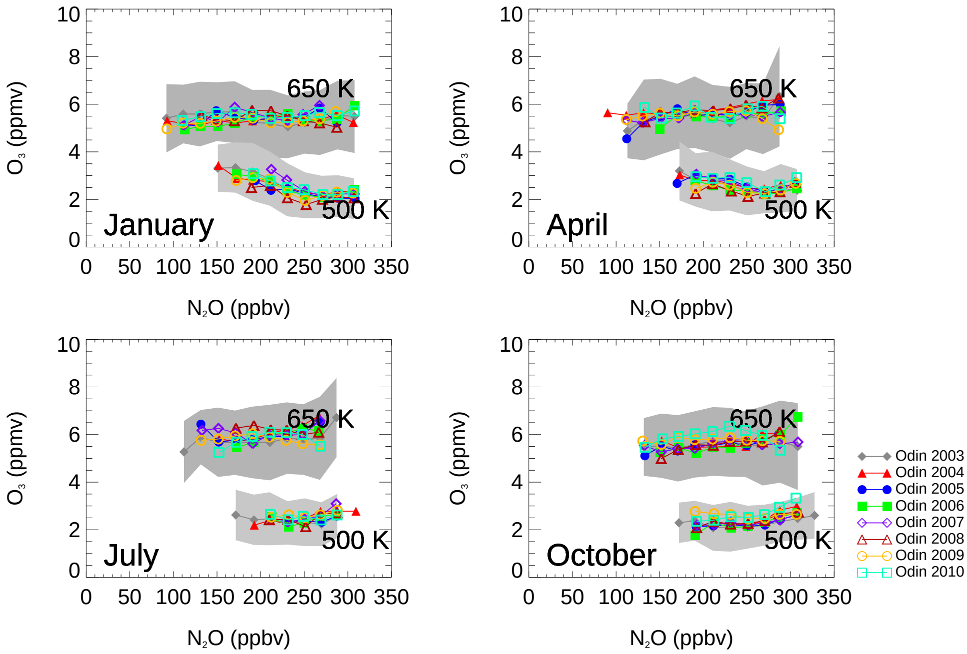

Figure 3: Odin/SMR climatology for 2003. The Odin/SMR data has been reduced by 20 ppb.

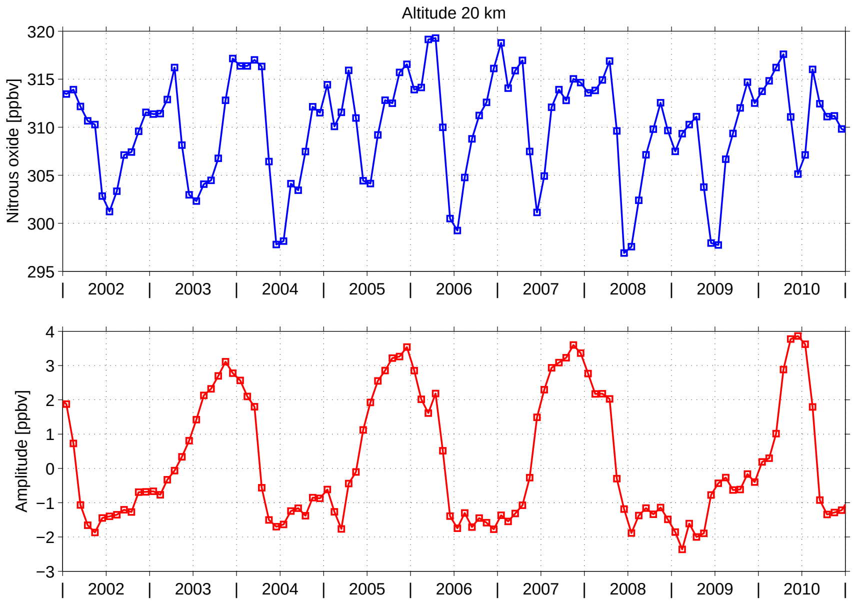

Figure 4: N_2O time series (top) and QBO N_2O amplitude (bottom) derived from Odin/SMR at 20 km.

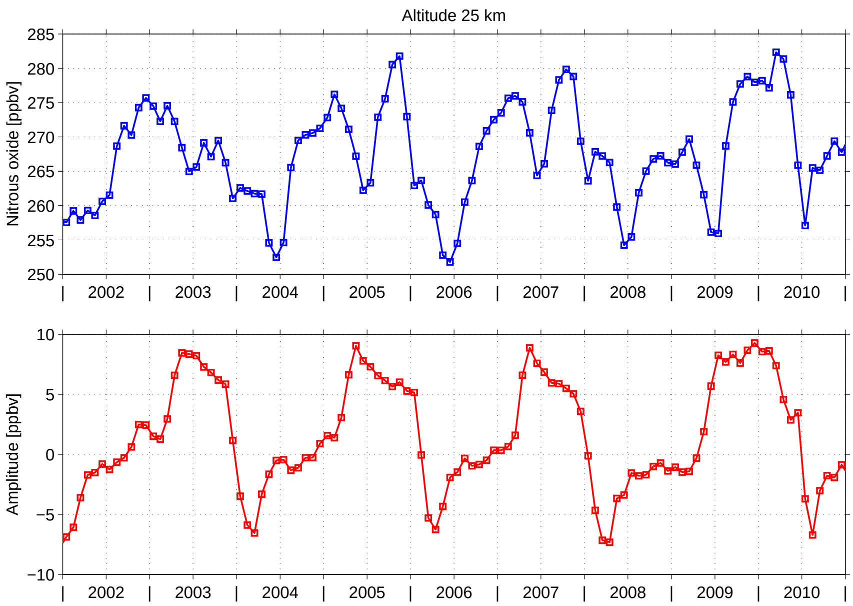

Figure 5: N_2O time series (top) and QBO N_2O amplitude (bottom) derived from Odin/SMR at 25 km.

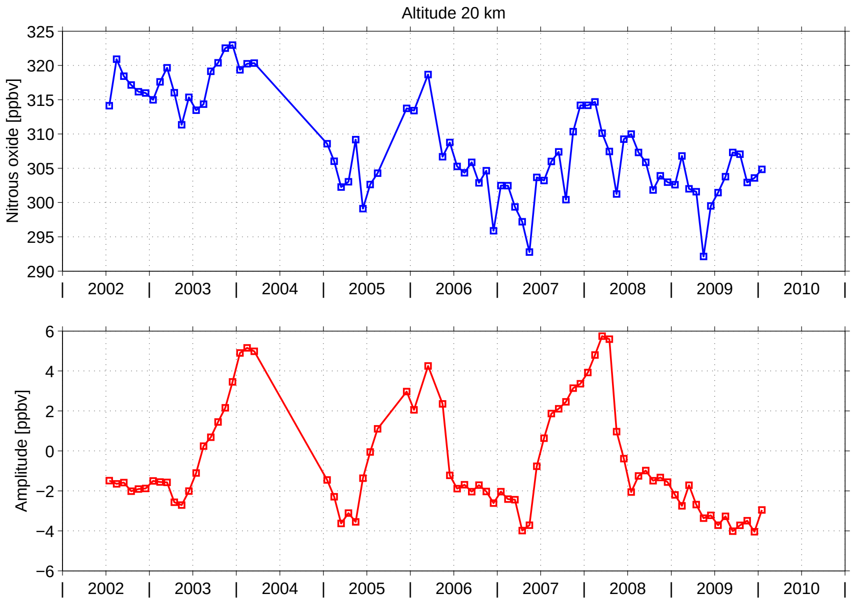

Figure 6: N_2O time series (top) and QBO N_2O amplitude (bottom) derived from ENVISAT/MIPAS at 20 km.

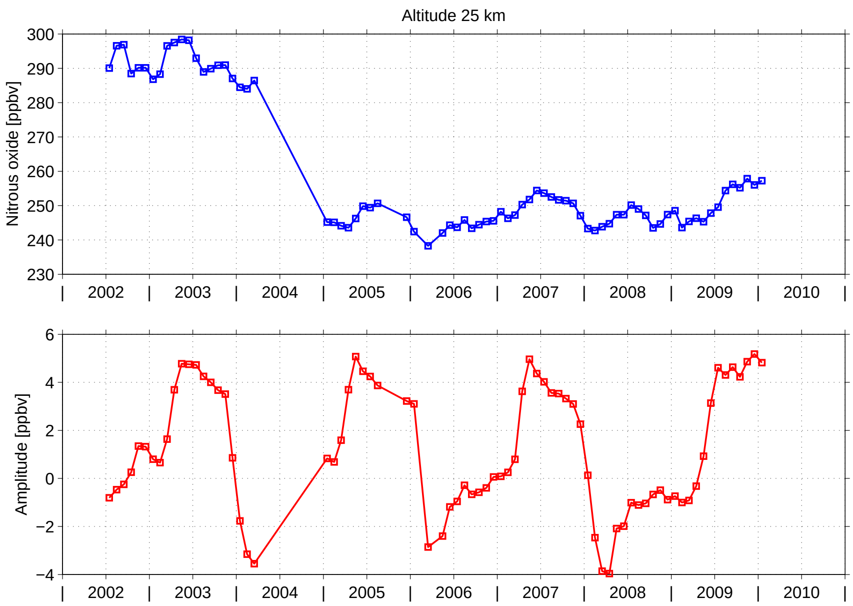

Figure 7: N_2O time series (top) and QBO N_2O amplitude (bottom) derived from ENVISAT/MIPAS at 25 km.

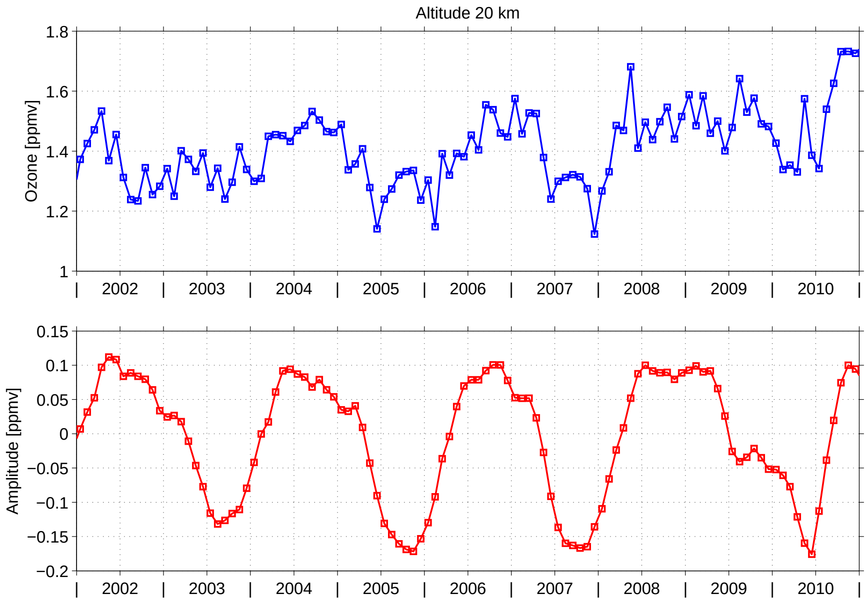

Figure 8: O_3 time series (top) and QBO O_3 amplitude (bottom) derived from Odin/SMR at 20 km

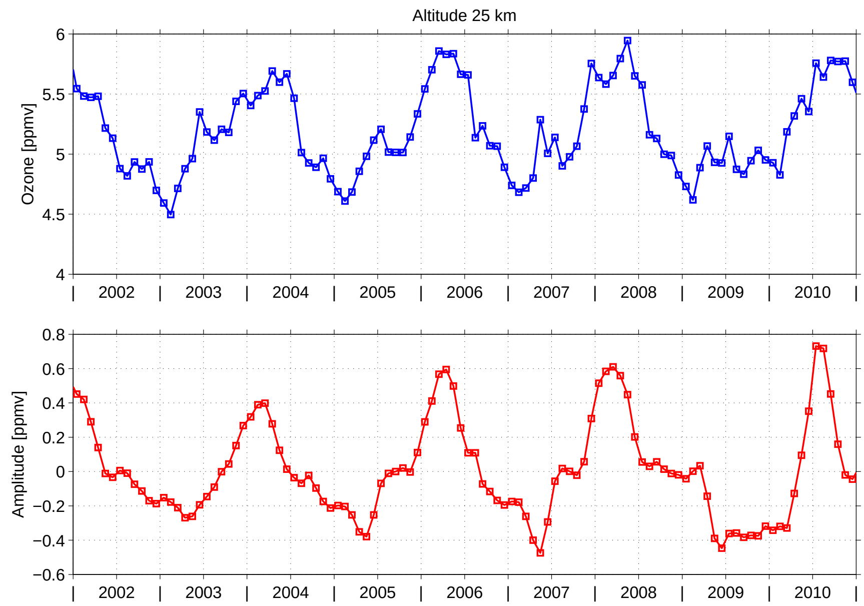

Figure 9: O_3 time series (top) and O_3 QBO amplitude (bottom) derived from Odin/SMR at 25 km.