

We thank the reviewer for the thoughtful comments and helpful suggestions. We have made changes to address the reviewer's comments.

In addition to those changes, we note that we have removed discussion of the NO₂ lifetime from the observations over Dubai (Section 6). In subsequent research motivated by these observations, we were able to establish that the land/sea-breeze that we had assumed constant in our calculation of NO₂ lifetime had reversed direction and thus that the shape of the plume was dominated not by chemical effects but by the meteorology. We still believe that the super-zoom dataset greatly enhances the ability to calculate the NO_x lifetime downwind of individual power plants and urban centers and are working toward a more robust method.

Responses to Reviewer #1

Major Issue 1: Method to assess uncertainty.

Both reviewers posed particular concern about the method we selected to assess the uncertainty of the super-zoom slant column NO₂ observations. Both reviewers believe that the uncertainty should be discussed in terms of the variability observed over a remote ocean in a region where NO₂ and viewing parameters are assumed not to vary.

Response

As suggested by both reviewers, we have assessed uncertainty in terms of observational precision over remote ocean in a method adapted from Boersma et al. (2007). We present an image of a swath that includes the remote Arabian Desert and the nearly cloud-free Indian Ocean to replace the series of SNR images in the original AMTD manuscript.

As part of the clarification we reordered some of the sections of the paper (4 and 5) so that discussion of the uncertainty precedes discussion of the atmospheric variability.

Text: Figure 2 shows slant column NO₂ retrieved over the Arabian Peninsula and the Indian Ocean from a super-zoom mode orbit on 21 November 2004. To assess the uncertainty in retrieved slant column NO₂, we use a method similar to Boersma et al (2007). We find that slant column NO₂ retrieved at operational resolution is normally distributed with 1 σ variability of 0.8×10^{15} molecules cm⁻² over the remote ocean and 0.6×10^{15} molecules cm⁻² over the remote desert (Fig. 2c), well within the range of values determined previously (Boersma et al., 2007). The precision of slant column NO₂ retrieved from the super-zoom mode is approximately a factor of $\sqrt{8}$ worse, which is expected for a system with 8 fewer measurements and dominated by random noise (Fig. 2b).

Responses to Reviewer #1 detailed comments

We have made changes as suggested by the reviewers for all of the detailed comments. We note below the ones that require a response.

P1992 L9-16: Please specify how far your DOAS retrieval is different from the operational retrieval.

and

P1992 L11: The observed reflectance spectra are fit”: rather, the cross-sections are fitted to the measured spectra.

Response:

We modified the paragraph describing our DOAS retrieval as follows:

Text: We have attempted to emulate the operational retrievals (Boersma et al., 2007;Bucsela et al., 2006). We retrieve slant column NO₂ by performing a DOAS linear least squares fit (Platt and Stutz, 2008;Wenig et al., 2005) of an NO₂ cross section (Vandaele et al., 2002), an O₃ cross section (Bogumil et al., 2001), a Ring spectrum (Chance and Spurr, 1997;Chance and Kurucz, 2010), a water vapor cross section (Harder and Brault, 1997), and a third-order polynomial to the logarithm of the observed reflectance. We perform the fit over the 405-465 nm spectral window.

P1992 L9-16: The reviewer asks us to define SNR in the methods section.

Response: We no longer use SNR to assess the quality of the dataset (See major comments).

P1993 L10-12 and 18-22: The lengthy list of dates and places disturbs the readability of the text and should be put in respective tables.

Response: We added a table that details the location and dates of orbits used (Table 1)

P1993 L16: “six operational-scale overpasses from successive years”: are these data taken from the operational DOAS retrieval?

Response: Added “retrieved in the same manner” to indicate that NO₂ was retrieved in the same manner as it was for super-zoom mode data (p1993 L16).

P1994 L5-6: “non-overlapping”: what does that mean?

Response: Deleted the word “non-overlapping” from P1994 L5-6 as a descriptor of the six-orbit average. The wording was originally intended to clarify that the orbital track shifts a few km each orbital-repeat period (16 days), providing observations the surface

and thus enhancing the spatial detail of a long-term average (see Russell et. al 2010 for more info).

P1994 L6: “observations, as listed in table xyz”

Response: We deleted several reported values from the text but maintained a few key values. We feel that the number of reported values that remain is small enough that moving the numbers to a table would diminish the readability of the manuscript.

P1995 L2: define the “fitting error”

Response: Despite using precision of slant NO₂ retrieved over the remote ocean to assess uncertainty (see Major Issue 1), we still discuss fitting error for sake of interest. We computed the NO₂ fit error from the residuals.

Text: The NO₂ fit error computed from DOAS residuals does not increase by a factor of $\sqrt{8}$ for super-zoom observations (not shown) indicating that there are systematic residuals not reduced by averaging. While the origin of these systematic residuals is unknown, we speculate that there is slight spectral misalignment in the DOAS fitting procedure. One possible explanation for this misalignment is the lack of a shift and squeeze adjustment to improve the spectral calibration of individual spectra. However, the magnitude of any uncertainty that remains is negligible in comparison to the signal observed over sources of interest (Fig. 3)

P1995 L11: “detection threshold deduced previously”: How is the detection threshold defined? How far does it depend on the assumed “background”?

Response: Originally, a detection limit of 1.5×10^{16} molecules cm⁻² was determined by taking three-times the fitting error (2.5×10^{15}) plus the background average (7.5×10^{15}) of slant NO₂ retrieved off the coast on the same orbit. We now discuss the observed enhancements in terms of the precision and background retrieved over the ocean.

Text: Super-zoom observations capture a maximum in slant column NO₂ directly to the south of the Satpura Power Plant in Sarni, India (Fig. 3j; 2.2×10^{16} molecules cm⁻²), a value that is seven times larger than the variability and average observed over the remote ocean on the same overpass.

P1995 L11: “SNR<5 are unreliable”: If the NO2 column in the stratosphere would be 10 times higher, the SNR would be much better, but the value of the tropospheric pattern would be still the same! Determine the precision of SCDs instead (or in addition)!

Response: We accept the comment and discuss uncertainty in terms of observational precision over a remote region instead of a SNR or fitting error issue (See major comments).

P1996 L21: “non-negligible”: How long is it?

Response: For a point source the conversion to NO₂ depends on entrainment of O₃-rich background air with the NO-rich plume. The timescale of this process depends on the spatial extent of the source region and the local meteorology, and is thus uncertain without this information. Heue et al. (2008) show that this entrainment process was still occurring 1 km downwind of a point source in similar wind conditions ($\sim 3 \text{ m s}^{-1}$) indicating that it may also be non-negligible over Dubai. However, we removed discussion of the NO to NO₂ conversion time-scale because we believe meteorological and sampling effects are more important.

Text: The enhancement directly over JAFTZ (**A**) is not as large as the enhancement downwind (**B**) because the source is near the leeward edge of the 13 km OMI pixel, which dilutes the signal with that of the clean marine background. In addition, the winds were stagnant between 10 AM and noon, during which NO₂ presumably accumulated over the source (**A**) and was transported downwind (**B**) when the winds shifted inland at midday (3 m s^{-1} , 11 km hr^{-1}).

P1996 L24:- please cite also other studies that estimated the NO_x lifetime from the downwind evolution:

Response: We have removed discussion of lifetime.