

## Response to Referee #1

We thank the reviewer for their comments, and respond to each below.

**Reviewer Comment (RC):** This paper presents a standard stratosphere-troposphere separation algorithm for the observations of NO<sub>2</sub> from the TEMPO (Tropospheric Emissions: Monitoring of Pollution) satellite instrument. TEMPO, which will be launched between 2019-2021, will provide space-based measurements in geostationary orbit with a field of regard over North America from southern Canada to Mexico City and the Bahamas. Algorithm developments include the use of independent satellite observations (OMI and GOME-2) for identifying likely locations of tropospheric enhancements and for spatial context, the consideration of diurnally varying partial fields of regard, and a filter based on stratospheric to tropospheric air mass factor ratios. This algorithm is tested with Low Earth Orbit (LEO) from the OMI and GOME-2 satellite instruments. The potential information penalty associated with the limited TEMPO field of regard compared to an identical global algorithm is also examined.

This study fits well with the scope of AMT and the manuscript is well written and clearly structured. Figures are also of very good quality. I recommend publishing the paper in AMT after addressing the following comments.

**Author Response (AR):** We thank the reviewer very much for their positive and constructive remarks.

**RC:** In the absence of daily independent satellite observations for the near-real-time processing, the back-up solution will be to use a climatology built on satellite observations or model data. Then, what will be the level of homogeneity/consistency of the retrieved TEMPO NO<sub>2</sub> column time-series since they will consist in a combination of retrievals performed using different sources of ancillary data? Do you foresee an offline reprocessing based on a unique source of ancillary data? Or this is something which is not needed since this effect will be within the typical stratospheric error due to stratosphere-troposphere separation methods?

**AR:** We thank the reviewer for the opportunity to clarify our strategy. Although we expect any effect near the field of regard edges to be small (as the reviewer points out), we do recommend an offline (or even night time) re-processing of the data using a unique source of ancillary data for outside the field of regard to avoid any inconsistencies in the retrieval over time. Meanwhile, as we demonstrate in the manuscript, a retrieval using the 30-day climatology will produce satisfactory results for near-real-time products.

In response to this reviewer comment, we have added the following text to our manuscript:

Page 18, Line 9:

*“Given these results, our recommendation for TEMPO is to use a climatological estimate (e.g. a 30-day mean) of stratospheric NO<sub>2</sub> for context outside of the TEMPO field of regard during near-real-time retrieval if LEO observations are unavailable. This climatological estimate can be constructed based on satellite-derived observations in LEO from the preceding year and corrected for the time of day based on model results or other independent observations. We would then propose a subsequent re-processing of the data that incorporates the daily LEO observations when available from the correct observation day.”*

**RC:** The validation of the separation algorithm is not discussed at all in the paper. I think that at a later stage, it will be useful to compare the stratospheric NO<sub>2</sub> column estimates with independent reference measurements, e.g. from ground-based DOAS UV-visible spectrometers. As first verification, maybe it would be interesting to compare within the anticipated TEMPO field of regard the estimates of the stratospheric NO<sub>2</sub> vertical column with those included in the OMI and GOME-2 data products used in this study.

**AR:** We agree with the reviewer that validation of the algorithm with independent reference measurements, including ground-based DOAS UV-vis spectrometers, will be useful to pursue. As the reviewer suggests, an initial option for now would be to compare the TEMPO stratospheric estimate with the stratospheric NO<sub>2</sub> estimates already calculated by OMI and GOME-2 algorithms.

In response to this reviewer comment, we have performed this initial evaluation, and added the following text to the manuscript:

Page 10, Line 18:

*“In an effort to evaluate our new TEMPO algorithm with an independent estimate, we compare our stratospheric vertical column with the stratospheric vertical column included in the OMI SPv3 retrieval. Despite using different prior tropospheric estimates, incorporating observations from GOME-2 outside the field of regard during interpolation, and employing different box-car filtering steps, our algorithm is highly consistent with the results from the global NASA standard OMI product over the TEMPO field of regard ( $r = 0.972$ ,  $m = 0.986$ ). Overall, we calculate a mean bias in our new TEMPO algorithm compared to the NASA standard product of only  $-0.05 \times 10^{15}$  molecules  $\text{cm}^{-2}$  (a normalized mean bias of  $-1.5\%$ ).”*

Page 19, Line 19:

*“Our TEMPO algorithm also demonstrates good performance when evaluated against the stratospheric NO<sub>2</sub> columns provided with the NASA SPv3 standard product, but further independent evaluation using ground-based spectrometer network observations will be beneficial.”*

**RC:** Page 6, line 5: a short justification is needed about the fact that data are restricted to SZA smaller than 80°.

**AR:** In response to the reviewer’s comment, we have added the following text to the manuscript:

Page 6, Line 5:

*“We restrict all data to solar zenith angles smaller than 80° to avoid exceedingly long path lengths.”*

**RC:** Page 7, line 1-4: Monthly mean of GOME-2 tropospheric NO<sub>2</sub> columns is used as initial a-priori tropospheric NO<sub>2</sub> estimate. How is it done in practice? Are the GOME-2 data first gridded on the same 0.1°x0.1° regular grid as OMI? A clarification would be helpful here or at the end of the description of the GOME-2 data in Section 2. Also, since the tropospheric NO<sub>2</sub> column can show strong diurnal changes, is the GOME-2 tropospheric column a good estimate of the column at the OMI overpass time?

**AR:** We have clarified agree with the reviewer that tropospheric NO<sub>2</sub> can show strong diurnal changes. However, diurnal variability tends to be highest over NO<sub>x</sub> source regions, and smaller over non-source

regions. For example, Boersma et al. (2008) demonstrate in their comparison of SCIAMACHY and OMI pixels (roughly the same time differences as we would expect from GOME-2 and OMI in our case) that the global probability distribution of tropospheric NO<sub>2</sub> over the Pacific Ocean at the two overpass times show only a small offset, and they attribute this to a negative bias from the OMI retrieval. The high diurnal variability over source regions is inconsequential – these regions should be masked out during our algorithm and should therefore introduce less impact. However, we agree with the reviewer that ideally independent observations from the appropriate time of day would be used.

In response to the reviewer's comment we have added the following text to our manuscript:

Page 7, Line 7:

*"The GOME-2 observations were filtered using recommended quality flags and retaining pixels with cloud radiance fraction less than 0.2, then gridded to the same resolution as our OMI grid."*

*"Ideally, an independent LEO tropospheric estimate for as close to the TEMPO observation time would be used. Nonetheless, diurnal variability in tropospheric NO<sub>2</sub> columns outside of source regions tends to be small (Boersma et al. 2008), and in our case source regions are masked out in a later step."*

**RC:** Page 3, line 6: 'Richter et al., 2005' instead of 'Richter et al. 2005'. Similar corrections should be done on the same page at lines 7, 13, 14; on page 3, line 3; on page 4, line 20; on page 6, line 2.

**AR:** We have made these corrections.

**RC:** Page 4, line 19: 'available' instead of 'avialable'

**AR:** We have made this correction.

**RC:** Page 7, line 30: one bracket should be removed after '2013'.

**AR:** We have made this correction.