RC2

General comments:

"The Antarctic stratospheric Nitrogen Hole: Southern Hemisphere and Antarctic springtime total nitrogen dioxide and total ozone variability in Sentinel-5p TROPOMI data" provides a scientifically useful analysis of a TROPOMI measurements of nitrogen dioxide during the Antarctic ozone hole. The study demonstrates that co-located TROPOMI NO_2 and O_3 observations can be used to clearly identify the evolution of chemical differences between inner and outer polar vortex air masses throughout the springtime. While demonstrating the viability of a new dataset for the analysis of the Antarctic ozone hole is scientifically important, improvements to the presentation of the data and details about the design of the analysis are needed.

Response: we thank the referee for the review efforts and the comments that have helped improve the paper. Below follows a detailed response to the comments including for each comment a description of the modifications that have been made.

Specific comments:

1. The introduction could be improved by focusing on the advances offered by the TROPOMI dataset and the authors' analysis, specifically:
    a. What improvements or unique capabilities does this satellite dataset offer?
    b. What problem or scientific question does the dataset answer?
    c. The background on prior satellite studies could be condensed.

Response

1a. The TROPOMI satellite instrument builds on the legacy of hyperspectral UV/VIS satellite instruments like GOME, SCIAMACHY, OMI, and GOME-2. TROPOMI provides satellite observations with unprecedented spatial resolution, accuracy and precision compared to its predecessors. Although designed for improved monitoring tropospheric pollution, it nevertheless also equally improves stratospheric NO2 and/or total NO2 column observations.

Action: we add the following to the introduction:

"The TROPOspheric Monitoring Instrument (TROPOMI) is the first of the next generation of hyperspectral UV/VIS satellite instruments. Designed and developed based on experience with satellite instruments like GOME, SCIAMACHY, GOME and GOME-2 it provides satellite observations of unprecedented spatial resolution and accuracy."

1b. Apart from providing measurements of a trace gas relevant for stratospheric ozone and catalytic ozone depletion at an unprecedented scale and with unprecedented accuracy (as explained in **1a**), a key aspect is that these measurements add some new stratospheric monitoring capacity that otherwise currently is suffering from aging satellites and steady decline in the number of such satellites. The scientific community has a commitment towards continued monitoring of the stratosphere and the ozone layer as part of the Montreal Protocol "for the protection of the ozone layer". Satellite measurements have been crucial for this commitment. Fewer satellite and deteriorating satellites are making meeting this commitment more difficult. Developing new satellite data applications is therefore very much welcomed. Especially is they are based on satellite instruments that are expected and planned to be operational for many decades ahead in time.

Action. We added the following paragraph to the introduction:

"Furthermore, the current suite of satellites that can be used for stratospheric monitoring is aging and the number of such satellites is dwindling. This is a significant concern for the scientific community and their commitment towards monitoring the ozone layer as part of the Montreal Protocol for "Protection of the Ozone Layer". Recovery due to the phase out of emissions of ozone depleting substances is a slow process and full recovery is only expected in the second half of the 21st century. However, unusual stratospheric events can strongly affect the ozone layer thickness from year to year. Whether such year-to-year changes in stratospheric ozone are anomalous or the result of natural variability is crucial for confident statements whether recovery is progressing as expected (or not). Satellite instruments measuring the stratospheric chemical composition other than ozone have been essential for understanding this year-to-year variability and thus meeting the commitment of the scientific community towards monitoring the ozone layer support of the Montreal Protocol. Given the aging suite of stratospheric monitoring satellites and their dwindling numbers, identifying new stratospheric monitoring applications is more than welcome for continued stratospheric monitoring. Especially if these applications are based on satellite instruments that are planned to remain available for many decades into the future."

1c. Because the topic and application introduced in this paper in essence is new – with the exception of the two exploratory research papers based on the earliest generation of hyperspectral UV/VIS satellite instruments in the mid-2000s – our thinking was to provide an as complete as possible earth observation context of stratospheric NO2 observations - taking limitations in publication length into account.

Hence the lengthy "background on prior satellite studies". We are pretty confident that knowledgeable people in the field will ask – just like we did – as to why this has not been published before and how this related to the extensive research done on stratospheric chemistry.

Furthermore, given that this paper could be the start of a series of new publications an overview with a "background on prior satellite studies" would provide a good starting point for anyone building on our paper.

Hence out preference to keep the section on the "background on prior satellite studies". We could do otherwise but would prefer for the editor to make a decision on this.

Action: we leave it up to the editor to decide if the "background on prior satellite studies" should be shortened or not.

2. Additional details in the methods describing the range of latitudes used in each analysis are needed.

Response. See comment (2) by referee #1 for a similar question and our response that comment.

Action: the following was added to the discussion section 4.

"In addition, although the diurnal cycle in SNO2 is relatively small compared to its seasonal cycle it nevertheless can affect satellite retrievals and validation results. Dube et al. [2021] reported order of magnitude 10-20% effects for SAGE III/ISS solar occultation limb retrievals with larger effects for higher latitudes. Although their results are not one-on-one applicable to the results presented here they clearly indicate the need for properly assessing diurnal cycle effects on TROPOMI SNO2 measurements and validation."

We also added the following to the end of section 2.1.

"A qu_value > 0.5 excludes any TROPOMI observation with a solar zenith angle > 81.2°. During the Antarctic summer this leads to some observations from the descending TROPOMI orbit over Antarctic to be include in the daily average (TROPOMI orbits the sunlit part of the earth from south to north)."

3. In the analysis of NO_2/O_3 correlations, how are the mask boundaries determined? What effects are there, if any, on the conclusions of the analysis if the boundaries are varied?

Response: the boundaries between the three different masks are the result of a manual iterative process. We came to these boundary after some experimenting and testing. The main reason for them is that these three masks consistently separate the inner-edge-outer vortex regions, regardless of the time period start, the time period end and the timp period duration. In that sense these boundaries are robust, although they are purely empirical. We have entertained the thought to distinguish between two distributions in vortex edge region (see answer to next question) but decided against it to keep it simple.

Action:

4. Can the "mixing lines" be geographically and temporally isolated into discrete eddies/filaments?

Response: this continues/builds on the answer to comment (4) above.

In short: good question, in all honesty we don't really know, it surely looks like it could be the case but that requires much more research.

There is at least an easy separation possible for the MASK-3 region – as is also obvious from the phase diagrams. There is almost always a vortex edge section with reduced NO2 and reduced O3. This is likely explained by total ozone over Antarctic during Antarctic springtime generally following a wave-1 pattern (maximum-minimum-maximum along a full longitude circle). The location of the minimum and maximum rotates throughout spring in a clockwise fashion and with a time scale of two weeks or so (if I recall correctly). We believe that these locations might be areas of something one could call "vortex leakage", areas where cross-vortex edge mixing takes place

Given the multiple TROPOMI overpasses per day – including ascending and descending orbits – could be the reason that during daytime there appear multiple "mixing lines" in the phase diagram (Figure 5). Simply a case of the vortex edge regions having spatially moved during the 12 hours between the previous and next overpass during late Antarctic spring. For the phase diagrams covering longer periods it becomes more and more difficult to distinguish these mixing lines, as evidence by many figures in the paper. Rather they developing into a continuous distribution: the vortex edge continuously changing locations and thereby NO2-O3 ratios due to different dynamics and advection and different altitudes.

However, to fully understand and explore vortex edge dynamics requires much more extensive research, something we felt more suitable for a follow-up paper and/or research proposal. That includes the question whether mixing lines could be "geographically and temporally isolated into discrete eddies/filaments". Like stated above, yes, a possibility, looks like it, but for now we don't know. Furthermore, we have done much more analysis and made many more plots than ever would be possible to show in a paper (see as an example the animation in the supplement) so we already had to condense a lot of material for this paper.

Action: no action

a. Can the simple phase analysis of "mixing lines" recreate a similar structure on a 2-d plot? Figure 9 is not convincing on its own. Consider including actual seasonal trends.

Response: see also previous answer. We are not sure what the referee means here: the aim of this conceptual figure is to highlight that shifts in (spatial) phasing in even simple distributions with different locations spatially of minimum and maximum values lead to variations in a phase-diagram that is not dissimilar from what is observed.

We constructed Figure 8 based on an extensive series of TROPOMI SNO2-TCO3 phase diagrams along a range of latitudes and for a range of dates that show more or less similar albeit more complex patterns that nevertheless in essence come down to the same point: phase differences in collocated data with different locations of their minimum and maximum.

But as in previous answers: space limitations in a research paper do not allow us to present most of the analyses and figures we made.

Hence why we prefer to keep Figure 9 as it is.

Note that obviously latitude is not the best coordinate here – equivalent latitude would be preferred but that is also something for a future project.

Action: no action

Technical comments:

1. Subscripts for the common notation of SNO_2 and TCO_3

Action: changed through the document

2. Improve the figure labels, especially dates

Action: figures have been updated also in accordance with a number of comments from referee #1

3. Figure 4 is redundant

Response: without further explanation it is not clear why figure 4 is redundant. We would argue Figure 4 provides necessary spatiotemporal global (zonal mean) information on the seasonal cycle in SNO2. No other figures contain similar information. Also, as this paper are in part is inspired by Wespes et al. (2022) who present a similar figure for IASI HNO3 this allowing a visual direct comparison with their results (the TCO3-SNO2 phase-diagrams are something new and not available for other trace gas combinations).

Hence we have a strong preference to keep Figure 4.