Response to Referee #1

This paper applies Self-Organizing Maps to sea level pressure fields to identify 20 circulation patterns in the Arctic spring, and then analyzes the observed distributions of pollutants associated with these patterns. The analysis aims to demonstrate how the transport and distribution of pollutants in the Arctic varies depending on the circulation pattern and to provide an observation-based test of chemistry transport models. This is an original and interesting idea, and the Self-Organizing Map method is state-of-the-art. However, more discussion of uncertainties and sampling of the satellite data in the Arctic is needed. In addition, the inclusion of 20 different circulation patterns makes the results complicated to interpret. I list general and specific comments below.

We thank the referee for the encouraging words and constructive suggestions. Please find below point by point reply to your comments.

General comments:

1. The presence of snow and ice, as well as cloud cover, can pose challenges for satellite retrievals or affect how much data is available, potentially leading to sampling biases. Please include more discussion of the sampling and any uncertainties for each satellite product in the Arctic environment. If ground or aircraft-based observations are available to validate the findings, that would also strengthen the paper.

We agree completely with the referee that the surface conditions and cloud cover play an important role in the data sampling. We have, in fact, examined these issues in detail in the beginning when the experimental setup was designed, based on the experience of using these OMI, AIRS and CALIPSO datasets in the high latitude regions.

Different considerations are required for different satellite sensors and the trace gas in question.

For example, please find below the results from a sensitivity study, which shows the comparison of NO2 anomalies during the first four circulation types in two scenarios, namely a) when the all-sky OMI NO2 retrievals are analysed (top row) and b) when the stricter cloud clearing criteria is used in that the retrievals are considered only when the total cloud cover is less than 30% (bottom row). There are undoubtedly some small regional differences in the anomalies in both cases, but the overall signal is very robust. We clearly see the transport of NO2 in the Arctic in both cases.
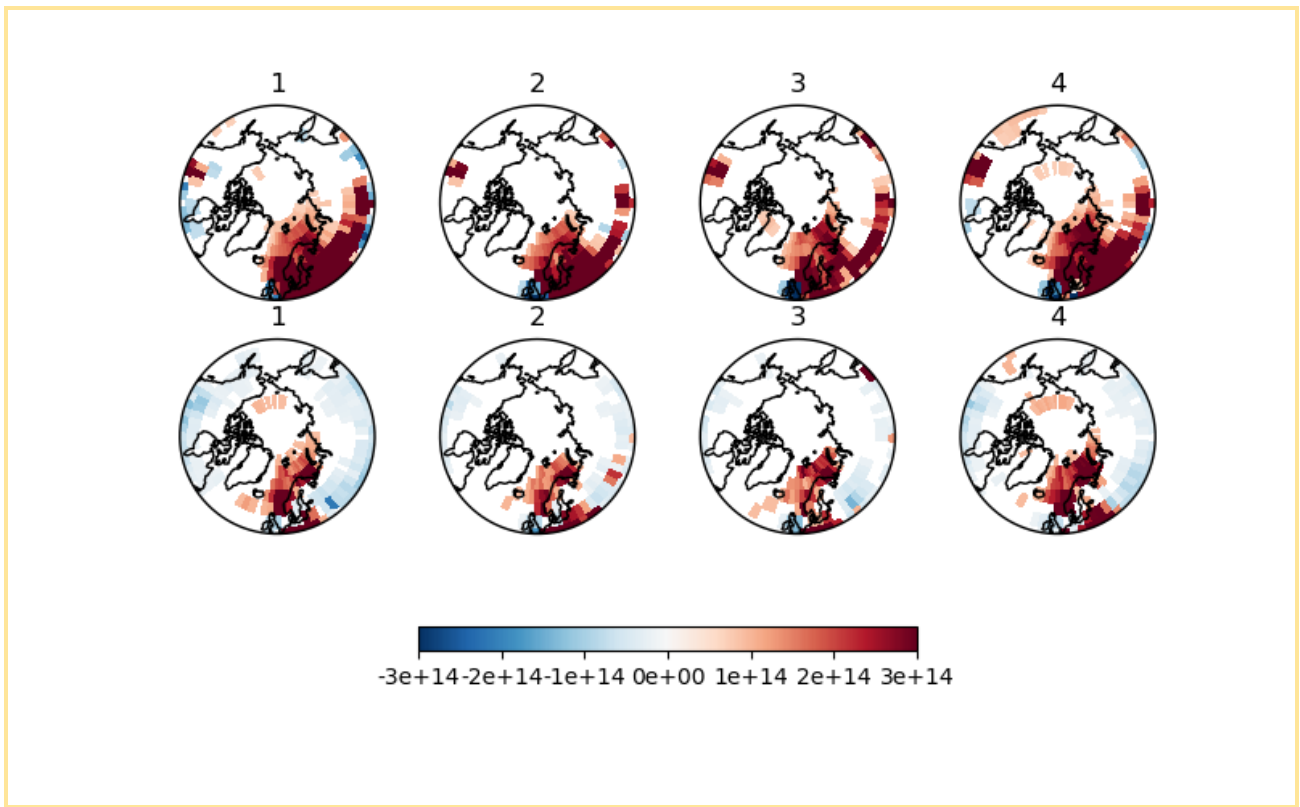
In the case of carbon monoxide from AIRS, we have allowed retrievals when the cloud cover is up to 70%. This is mainly because the hyperspectral capability of AIRS allows relatively accurate retrievals even under the presence of partial cloudiness. Moreover, the high latitude regions are often characterized by the presence of either low level boundary layer clouds or the high thin cirrus clouds, both of which do not significantly affect the AIRS retrievals in the free troposphere at 500 hPa. Below we show the results from another sensitivity study wherein CO anomalies for the first circulation type are shown when the AIRS cloud fraction is constrained to 30%, 50% and 70%. Here as well, we can see that there are some small regional differences, but the main signal remains robust.
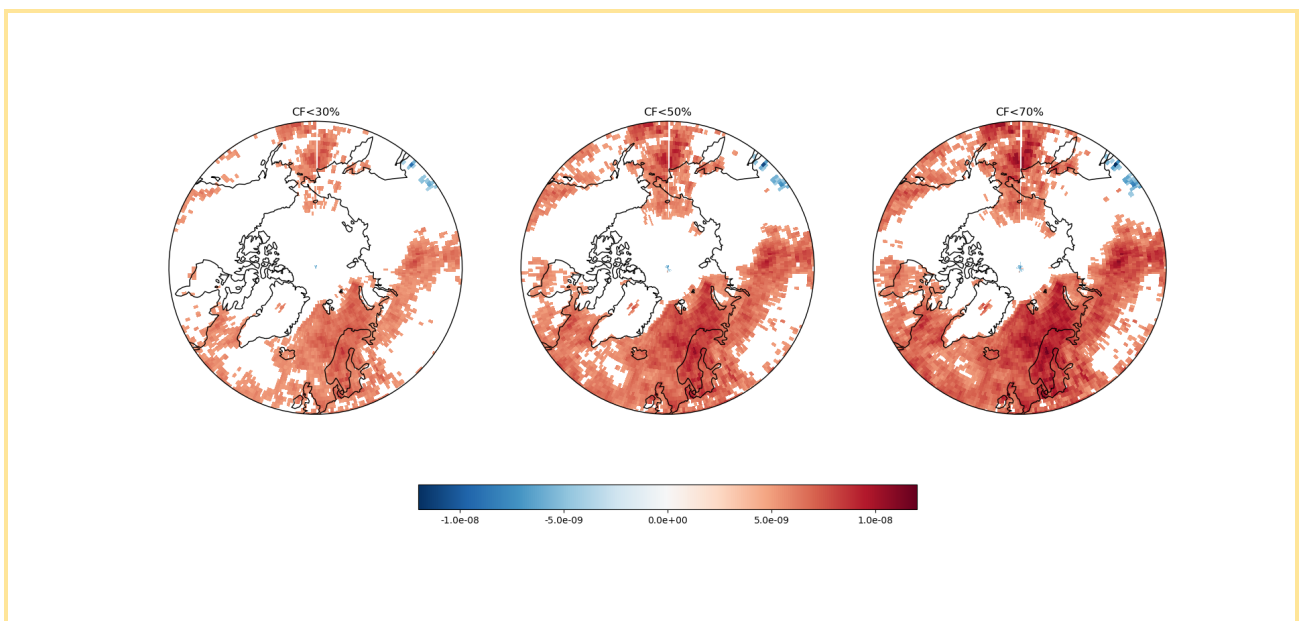
The aerosol retrievals from CALIOP-CALIPSO are surface blind and CALIOP is probably the best sensor to date to delineate aerosols from clouds. We have used CALIOP retrievals only when the

Cloud-Aerosol Discrimination (CAD) Score is between (and equal to) -100 and -20, thereby ensuring that the selected features are indeed aerosols. We have furthermore used retrievals only when the CALIOP extinction quality flag is 0, 1 or 2, ensuring the successful retrievals.
It is also worth pointing out that previous studies have shown that the circulation patterns that favour pollution transport into the Arctic are also associated with the transport of heat and moisture into the Arctic, which in turn leads to increased cloudiness (Devasthale et al., 2020; Thomas et al., 2019; Johansson et al., 2017). Therefore, we decided to relax the cloud clearing thresholds in order to capture these most realistic scenarios (while ensuring that the broader signal is not affected by such relaxation). By imposing a strict threshold on cloud cover (for example, analysing only clear-sky conditions to ensure the best quality retrievals) would introduce unrealistic clear-sky biases in the anomalies shown in the manuscript.

We have added a discussion regarding this point in the revised manuscript.

2. Section 2 mentions that ozone at 925 hPa from CAMS is used in the analysis because of the lack of reliable lower tropospheric ozone observations. Does this mean that the CAMS ozone at this level is primarily model-based? Has it been validated for the Arctic? This should be discussed since it is relevant to whether this method provides an observation-based test of chemical transport models.

The following sentences have been added to the manuscript "The validation of the ozone CAMS reanalysis product is carried out extensively using ground based measurements (TOAR database for surface ozone (Schulz et al., 2017a; 2017b) and ozonesondes globally (Inness., et al., 2019; Huijnen, et al., 2020). CAMS assimilation system makes use of data from SCIAMACHY, MIPAS, OMI, MLS, GOME-2, and SBUV/2 for ozone. Even though the surface ozone is primarily model based, upgrades in the CAMS chemical data assimilation system, assimilated measurements etc have improved the near surface estimates.".

3. What is the reason for allocating 20 circulation types? Could this number be reduced? The discussion often refers to multiple types together. For example, line 183 mentions 4 types under the influence of a strong anticyclone. Are these 4 still completely different patterns? It is also difficult to intuitively visualize the distinction between the 20 different maps presented in the plots, as the same main features seem to be present in multiple maps. If the number of maps were reduced, or perhaps the presentation of the plots organized to focus on a smaller number of clearly-distinguishable ones, the discussion would be easier to follow.

We originally wanted to capture as many different circulation types as possible. Having 20 circulation types means that some of them may be similar over certain regions or may not show a strong signal. We nonetheless decided to include them all to avoid doing some sort of "cherry picking". We do however agree that it is possible to reduce them and achieve a balance. The Referee #2 also raised a similar issue.

In the revised manuscript, we have therefore included only 8 circulation types. The selection was based on a) the strength of the signal observed in the trace gases 2) the frequency of occurrence of the circulation types and 3) the diversity and strength of the circulation pattern. The results for all 20 circulation types will be kept as the Supplementary Material.

4. One suggestion for presenting the main results more clearly is to include a figure that shows all of the pollutant anomalies (CO, NO2, O3, AOD) side by side for a couple of the main circulation patterns, so that the reader can easily see how anomalies in different pollutants relate to each other for a given circulation pattern.

As mentioned above, we are planning to reduce the number of circulation types. Showing the pollutant anomalies for each species and AOD side by side with each circulation type would increase the number of plots. We would prefer to explain briefly towards the end of the section how the different species relate with one another.

Specific Comments:

Line 141: Please define TqJ

- Clarified in the revised text. TqJ signifies the joint temperature and humidity retrievals. These are recommended to be used for the process and climate studies.

Line 167: Why is the weighting needed? To ensure each month of spring receives equal weight?
- Yes. Since the number of events in each month are different and also depend on the circulation type, the weighting ensures that the climatology also reflects this event distribution.

Line 171: It is stated here that only statistically significant anomalies are shown, but some figures (like Fig. 3) appear to show anomalies everywhere. How is significance or non-significance indicated?
- We chose not to mask the anomalies of meteorological variables (in Figs. 2, 3 and 4) based on the statistical significance. This is to facilitate the interpretation of the selected circulation types and the better understanding of the transport patterns. However, we decided to show only the statistically significant anomalies when presenting the anomalies of the chemical pollutants (NO2, CO and O3) and AOD.

Line 206: What does "those circulation types" refer to?
- The term refers to the 20 circulation types considered in the manuscript. In the revised manuscript, the number of circulation types will be reduced to 8, see comment above (General comment #3).

Lines 268-295: I find it difficult to relate this discussion to the large number of alternating positive and negative anomalies that appear in Fig. 7. Perhaps the analysis would be more convincing if multiple circulation types were grouped together to improve sample size and data coverage.
- See answer to one of the General Comments above.

Fig. 1: A discrete colorbar might be easier to interpret.
- A discrete colorbar is used and the figure is revised.

Fig. 2: Streamlines might be a nice addition to help visualize the direction of transport
- Streamlines are added in Fig. 2.

References:

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