Response to anonymous referee #3

We thank the reviewer for his/her detailed and constructive comments and suggestions, which helped us to improve our manuscript. We have addressed the questions as follows:

General comments:

The manuscript by Seo et al. presents an interesting statistical research work using long-term satellite-based BrO column measurements. The analysis process is comprehensive. The findings, especially the wind-direction based analysis, in this work are important for the atmospheric bromine research community. The only major concern I have is why the author did not use tropospheric BrO column products. I am sure with such valuable 10-yrs observations, the author can provide more important and meaningful results to the research community, if both total and tropospheric BrO columns are used. Otherwise, the manuscript is well written and should be published after addressing the following comments.

1) P5 L158: I think the author wants to say all BrO DSCDs (or from which ones?) are fitted by a Gaussian function, and the mode of the function is used in the correction. Anyway, the sentence is not very clear. Please revise it.

As suggested, we have revised sentences (blue text) in P5 L153-160 as follows:

When using a Pacific background spectrum, the retrieved differential slant columns (DSCD) need to be corrected by adding the BrO slant column over that region. Here we follow earlier studies (Richter et al., 2002; Sihler et al., 2012; Seo et al., 2019) and assume a BrO vertical column of $V_{norm,ref}$ = 3.5x10^{13} molec cm^{-2} over the Pacific reference sector. The corresponding BrO SCD is computed by multiplying the $V_{norm,ref}$ with the geometric air mass factor A_{geo}. A_{geo} is defined as:

$$A_{geo} = \frac{1}{\cos(SZA)} + \frac{1}{\cos(VZA)} \quad \text{(SZA: solar zenith angle, VZA: viewing zenith angle)} \quad (1)$$

As the differential BrO slant columns (DSCD) over the Pacific are not exactly 0, the mode μ of a Gaussian fitted to their distribution is taken into account for the normalization correction:

$$\mathrm{SCD} = \mathrm{DSCD} + A_{geo} \cdot V_{norm,ref} - \mu \quad (2)$$

2) P8 L236-237: No information about cloud filtering are provided. BrO enhancement/hotspots induced by large scale low-pressure systems (e.g., the case in

Blechschmidt et al., 2016) may accompany with large cloud covers and even precipitations (e.g., Zhao et al., 2017). How these cloudy pixels were treated? What are their impacts (to sensitivities of stratospheric and tropospheric BrO)? I understand some cloudy pixels should be kept for the purpose of this study. But, can you provide statistical analysis with/without cloudy pixels (e.g., with any threshold like cloud fraction < 0.3 or any reasonable one)?

No cloud filtering was applied in this study on the enhancement of BrO in polar regions. The reasons for this decision and potential errors related to this exclusion of cloud filtering have been added to the revised manuscript as follows (blue text):

In section 4.1 (P8 L237):

In this study, a reference grid with 200×200 km resolution was used. The enhanced BrO occurrence frequency f_{EBrO} was calculated by dividing the number of pixels classified as enhanced BrO column in a given reference grid cell by the total number of satellite pixels within the reference grid cell. "One thing to note is that cloud filtering was not applied in this study. Clouds can affect the BrO column retrieval generally in three ways: (1) the albedo effect related to the increase of the reflectivity and sensitivity for cloudy scenes, (2) the enhancement of optical light path due to multiple scattering inside clouds, and (3) the shielding effect that hides trace gases below clouds. The first two effects could increase the absorption of trace gases and lead to values greater than the actual total BrO column, while the third effect leads to an underestimation of the total BrO column (Antón and Loyola, 2011). Therefore, as clouds affect the BrO retrieval, it is necessary to consider the presence and characteristics of clouds for accurate BrO analysis. However, obtaining long-term reliable cloud products such as cloud fraction and cloud top height over the polar sea ice regions is difficult since detecting clouds and retrieving their properties over a bright snow/sea ice surface from satellite measurements are difficult (Heidinger and Stephens, 2000). Inaccurate cloud data may cause errors in statistical analysis using long-term data. Also, the difference between cloud free and cloudy conditions in polar sea ice regions is relatively small due to the bright surface (Figure 1 in Blechschmidt et al., 2016). Based on these considerations, this study did not attempt to correct the effects of clouds on the enhancement of BrO columns."

Antón, M. and Loyola, D.: Influence of cloud properties on satellite total ozone observations, J. Geophys. Res., 116, D03208, doi:10.1029/2010JD014780, 2011.

Heidinger, A. K. and Stephens, G. L.: Molecular Line Absorption in a Scattering Atmosphere. Part II: Application to Remote Sensing in the O2 A band, J. Atmos. Sci., 57, 1615–1634, doi:10.1175/1520-0469(2000)057<1615:MLAIAS>2.0.CO;2, 2000

3) P8 L240-242. It is a very interesting and important figure (Fig. 2). It shows the Canadian archipelagoes are the BrO swamp. But, I am not sure it is misleading or not. I think the author only used the pixels over the sea with sea ice fraction > 5 % (Section 3.1). So, is this selection make any impact over Canadian archipelagoes (i.e., where the land-sea ratio was determined by what?)? Anyway, from Fig. 2, I think this is the region that has larger land to sea ratio, compare to all other studied regions. Please provide more comments and explanations for this important result.

Fig.A2(a)

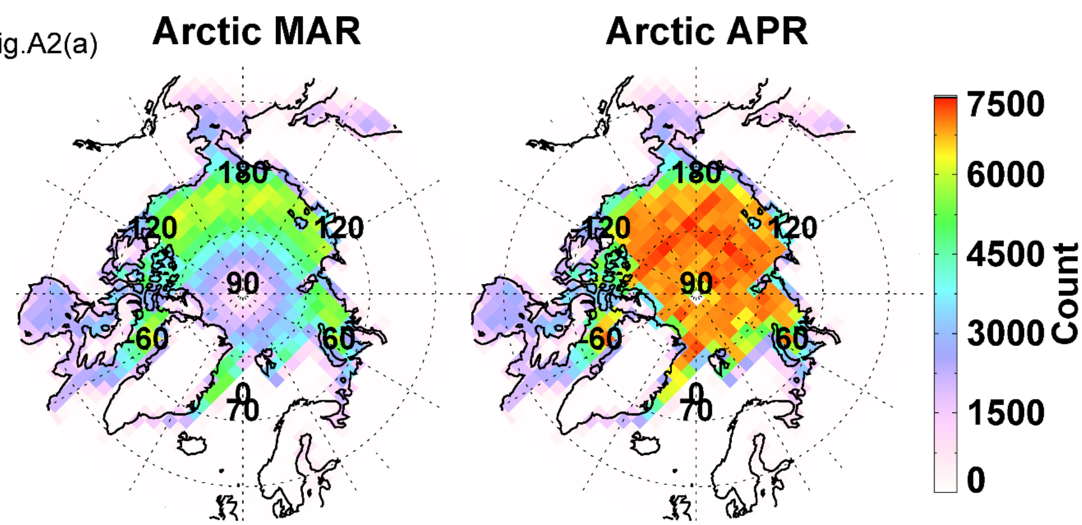


Fig.A2(b)

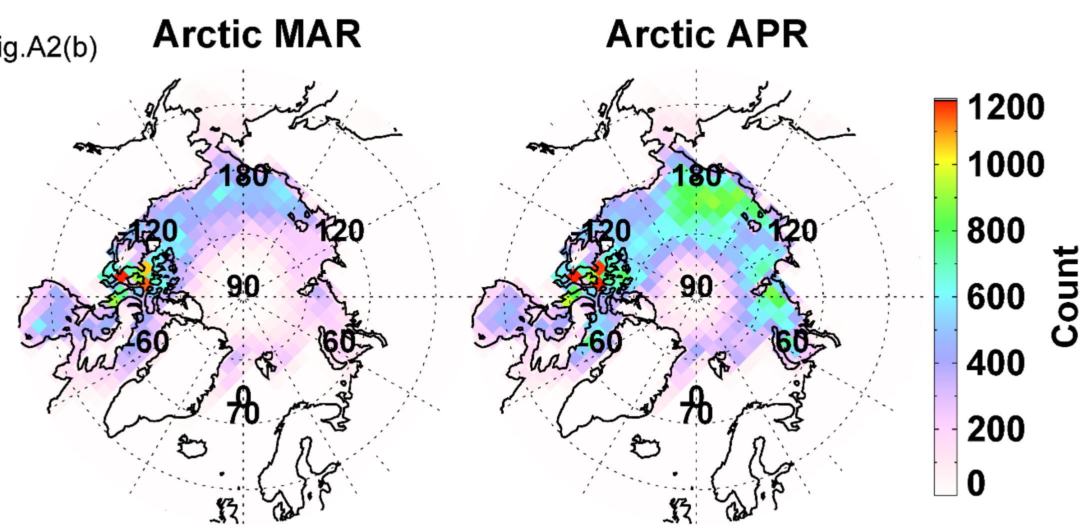


Figure A2. Monthly spatial distribution of the number of (a) all data collected (sea ice concentration > 5%) and (b) selected data for enhanced BrO cases over the Arctic during the study period.

The reviewer is right that the limitation to measurements over sea-ice impacts on the statistics in the Canadian archipelago. As shown in Figure A2, due to the large land-sea ratio in the Canadian archipelago, the number of data points collected for the analysis is low compared to other regions. However, since enhanced BrO cases are observed more frequently than in other regions, the relative occurrence frequency of enhanced total BrO column is high in this region. Since a relatively small number of data points was used in the statistical analysis compared to other regions, the monthly histograms of the total BrO VCD (Fig. 1), the frequency distribution of meteorological factors for the mean field and enhanced BrO cases (i.e. Fig. 3, 6, 9, and 17) as well as Spearman rank correlation analysis (Table 3) will not change significantly if the Canadian archipelago is included or excluded from the study domain.

We have added comments in Section 4.1 (P8 L241) as follows:

In the Arctic, enhanced total BrO columns are frequently observed over the north of the Canadian coast with a frequency of ~0.25 (25 %). Also, over the Hudson Bay, fEBrO is higher than ~0.18 in both March and April. "Due to the large land-sea ratio in the Canadian archipelago, the number of data collected for the analysis is low compared to other regions. However, since enhanced BrO cases are observed more frequently than in other regions, the relative occurrence frequency of enhanced total BrO column is high in this region." The spatial distribution patterns of f_{EBrO} are mostly similar in March and April, but relatively high values of ~0.15 are observed over the Chukchi Sea and the East Siberian Sea in April.

4) P10 L301-306: The positive surface temperature anomalies coincident within the regions that have low-pressure anomalies. I don't think it is a surprise, but a good indication that these analyses are strongly correlated (warmer surface temperature in the low-pressure system). The factors analyzed in this work (e.g., temperature, wind speed, and tropopause) are not truly independent in contributing to the enhanced total column BrO. Without separation of the source of bromine enhancement, i.e., enhancement due to dynamic process (low tropopause, more stratospheric bromine) or chemical process (surface bromine explosion) or both, the results presented here are a bit vague and complex. The mechanism of enhanced BrO columns discussed in this and the previous section (Sects. 4.2.1 and 4.2.2) are mostly for surface bromine enhancement (except low tropopause). So, why not performing all the above analyses with satellite tropospheric BrO data? To me, this will provides more insights from this valuable 10-yrs satellite observations.

We agree with your comment that the factors analyzed in this study are not truly independent. In this regard, additional analysis was performed on the cross correlation between meteorological parameters during the enhancement of total BrO columns and added in section 4.3 (P16 L514) of the revised manuscript as follows:

“The relationship between individual meteorological parameters and the total BrO vertical column investigated above illustrates how each meteorological parameter is linked to BrO variations in terms of temporal and spatial distribution. However, since meteorological parameters are not independent of each other and vary systematically in general, cross-relationships between meteorological parameters affecting directly or indirectly BrO variations should also be considered. For example, Yang et al. (2019) showed that the sea salt aerosol (SSA) production affecting the enhancement of BrO at the tropospheric level is proportional to the sublimation flux of blowing snow which is affected by various meteorological parameters including surface wind speed, temperature and relative humidity. Also, Zhao et al. (2015) and Blechschmidt et al. (2016) showed that large-scale enhanced BrO plumes over the Beaufort Sea are associated with weather systems which change the various relevant meteorological parameters together. They also demonstrated that the size and lifetime of BrO plumes depend on the development stage of the weather system. Therefore, cross-correlations between meteorological parameters for those data having enhanced total BrO columns were investigated (see Table 4). During the occurrence of enhanced total BrO, sea level pressure has a negative correlation with surface level temperature and wind speed, while it has a positive correlation with tropopause height. For example, the development of a low pressure system during the enhancement of BrO columns may correlate with a decrease in tropopause height as well as an increases in surface level air temperature and wind speed. Although the correlation coefficients found are not large, results show that sea level pressure is linked with both surface level meteorological conditions and the tropopause height which can account for stratospheric dynamics. Indeed, pressure systems which usually evolve due to interactions of temperature differences in the atmosphere derive directly the airflow motion within the troposphere and also may affect the tropopause height in relation to the convergence or divergence of air masses. It is also interesting to note from Table 4 that the tropopause height has insignificant correlations with surface level meteorological parameters during the BrO enhancements, except for the air temperature in the Arctic, which is predictable since the tropopause height is a factor more closely related to stratospheric dynamics compared to the surface level weather system.

Table 4. Cross-correlations of meteorological parameters for the enhanced total BrO cases in the Arctic and Antarctic sea ice region.

	Arctic				**Antarctic**			
	Sea level pressure	Temperature	Wind speed	Tropopause height	Sea level pressure	Temperature	Wind speed	Tropopause height
Sea level pressure	1	-0.186	-0.228	0.186	1	-0.163	-0.195	0.173
Temperature		1	0.183	0.249		1	0.158	-0.009
Wind speed			1	-0.013			1	-0.05
Tropopause height				1				1

Also, as the reviewer points out, tropopause height is related to the stratospheric contribution, while surface air temperature and wind are related to the tropospheric contribution on the BrO column.

We agree that in principle, it is more desirable to perform the analysis on tropospheric BrO vertical columns to more clearly distinguish the effect of meteorological factors on the stratospheric and tropospheric BrO columns. However, there are two main reasons for using total BrO vertical column instead of tropospheric BrO vertical column in this study.

First, meteorological systems contribute to both the troposphere and stratosphere as changes in atmospheric pressure, tropopause height, temperature, wind speed and direction interact with each other. For example, high or low pressure systems evolve due to atmospheric temperature differences and the pressure systems may affect the tropopause height and surface level winds. Therefore, this study aims to investigate how the meteorological systems generally affect the total BrO column, rather than attempting to separate the effects on the enhancement of BrO in the troposphere and stratosphere.

The second reason is that the accuracy of tropospheric BrO retrieved by applying a stratospheric correction and tropospheric AMF to satellite observation data over a long period of 10 years is difficult to assess. One of the most used methods for stratospheric correction is the climatological approach developed by Theys et al. (2009), a method using stratospheric BrO profiles based on a parametrization using 3D chemistry transport model BASCOE data. The advantage of this stratospheric correction method is the reflection of both dynamical and chemical effects on the stratosphere using the intermediate input data of total O_3 and stratospheric NO_2 columns from satellite measurements which are rather easily accessible compared to other model data. However, the BASCOE model climatology look-up-table (LUT) developed in Theys et al. (2009) is a result using three years of data (from April 2003 to March 2006) of a low resolution (3.75° x 5°) model run. Since this study is based on the analysis of long-term data for 2008-2018, correction factors for the long-term trend would have to be considered. Also, dynamical effects are not necessarily well reflected in the climatology because of the low spatial resolution of the model run, resulting in large uncertainties of tropospheric columns in situations with large tropopause changes. We therefore decided to use total columns for this study. Once well validated separation methods are available, the analysis should be repeated on tropospheric columns.

The reasons for using total BrO columns to investigate the enhancement of BrO and its relation to meteorological factors have been added to the revised manuscript.

- In section 1 (P4 L126):

In particular, the relationship between total BrO vertical columns retrieved from GOME-2A/2B and meteorological fields including sea level pressure, surface level wind speed and direction, surface air temperature, and tropopause height were investigated. "The reason for using total BrO columns instead of tropospheric and stratospheric columns separately to examine the relationship with the meteorological fields is that existing separation methods for satellite BrO data are difficult to apply to a long-term dataset in both hemispheres. They also have large uncertainties in connection with low pressure systems and large tropopause height changes which affect both stratospheric and tropospheric columns. This study aims to investigate how the meteorological system generally affects the total BrO column, rather than separate the effects on the enhancement of BrO in each atmospheric layer." Differences in meteorological conditions and their regional characteristics between high BrO situations and the mean field were investigated in order to better understand meteorological effects on processes involved in BrO enhancements. Finally, based on Spearman rank correlation analysis, the degree of influence of different meteorological parameters on total BrO columns was evaluated and the most important meteorological parameters, influencing BrO, and their regional patterns were identified.

5) P10 L294-299: Comparing to the frequency distribution of pressure (i.e., Fig. 3), the results (Fig. 6) here show a significant difference between Arctic and Antarctic. Can the author provide some comments on why we observed such differences? Is this indicate some major differences in the driven factors in total BrO at these two regions? Anyway, similar to my previous comments, the Canadian archipelagos have unique conditions in these analyses (i.e., larger land-sea ratio, thus colder than pure sea ice region in general). With/without this region may affect the frequency distributions.

The pattern in the frequency distribution of sea level pressure between the enhanced BrO cases and the mean field is similar in both the Arctic and Antarctic, whereas the difference in the frequency distribution of the surface air temperature is large between the Arctic and Antarctic. The reason why the difference in the frequency distribution of the surface air temperature is more apparent in the Antarctic than the Arctic can be identified in the Fig. 7 and 8. The spatial distribution of surface air temperature anomalies between the enhanced BrO and the mean field shows a slight air temperature increase over the central Arctic. The detection of enhanced BrO in the central Arctic (80-90 ^{o}N) may be related to the transport of plumes with high BrO occurring at relatively lower latitudes (70-80 ^{o}N). The Canadian archipelago region with a larger land-sea ratio is one of the coldest regions in the Arctic as much as the central Arctic, but the temperature anomalies map shows that the temperature is lower when BrO enhancements occur (see Fig. 7). Thus, it is expected that the pattern will not change largely if the Canadian archipelago is not included in the statistical analysis since the main cause of the small difference of the frequency distributions of air temperature between the enhanced BrO cases and the mean field in the Arctic is attributed to the temperature rise in the central Arctic.

Unlike the Arctic, the difference in the range of air temperature frequency distribution between the enhanced BrO cases and the mean field in the Antarctic is large. In the Antarctic, it can be seen that in most regions except Antarctic coastal regions, the surface air temperature decreases strongly when total BrO enhancements occur, especially in the sea ice margin (55-60 ^{o}S). This is related to the contrast between relatively warm air coming from the open ocean region and cold air from the continent / sea ice region which is the result of the very different sea-land distribution in the two hemispheres.

6) P10 L317: Well, I thought the community already found the base assumptions supporting frost flower as the direct-source of bromine explosion is over (Abbatt et al., 2012). The surface area of the frost flower is not as large as expected (e.g., Obbard et al., 2009; Roscoe et al., 2011). There are still some hypotheses that frost flower could play some indirect roles in bromine explosion, but please do not say frost flower is a "primary source of bromine explosion events". Otherwise, this will be misleading, and an overlook of all previous research works.

We agree that the sentence was misleading and revised it as following:

"Frost flowers which are water ice, coated with brine can act as a ~~primary~~ source of bromine explosion events."

7) P11 L334-335: I cannot agree with this. The wind speed anomalies in the Canadian archipelagoes are weaker than the other regions mentioned by the author (e.g., the eastern coast of Greenland). In fact, the wind speed in the Canadian archipelagoes is lower compare to most of other regions. This is topography determined. The conclusion here is not valid (enhancement of BrO columns related to positive wind anomalies), unless one excludes the Canadian archipelagoes in the frequency analysis (which I would suggest to).

Also, even for the high wind regions (the eastern coast of Greenland or centre Arctic sea), I did not see the high frequency of BrO enhancement in Fig. 2. The cause of this might be the high surface wind (10 m wind) is only one of the driven factors for blowing snow induced surface BrO enhancement. But, the author had a discussion of total column frequency (not tropospheric column), which has other major driven factors should be considered. Anyway, perfect separation of all these strongly correlated factors is not possible. But, at least, one can separate the stratospheric signal.

As suggested, we have added descriptions (blue text) for the Canadian archipelago which has different characteristics from most other Arctic regions with respect to the relationship between the surface wind speed and the total BrO column enhancement in the revised manuscript.

- In section 4.2.3 (P11 L326-335):

"Next, surface level wind speed is investigated to evaluate how this may affect the occurrence of total BrO column enhancements. Figure 9 shows the frequency distribution of wind speed at 10 m for the average field and for enhanced BrO cases of the 10 years of measurements in the Arctic and Antarctic sea ice region. The distribution is shifted towards high wind speeds in both polar regions for enhanced total BrO vertical columns, the increase in wind speed being more pronounced in the Antarctic region. The difference in wind speeds is also confirmed by the spatial distribution maps (Fig. 10 and 11). Higher wind speeds are observed in most Arctic and Antarctic regions for situations with enhanced total BrO columns compared to the mean field. In particular, differences in wind speed of more than 5 m·s-1 and high wind speeds of over 10 $m \cdot s^{-1}$ are found at specific regions of the Arctic such as the eastern coast of Greenland, the Bering Strait and the central Arctic. However, the Canadian archipelago has weaker wind speed anomalies with a low wind range of 3-5 $m \cdot s^{-1}$ in both the mean field and enhanced BrO situations due to the effect of topography. In the Antarctic region, wind speeds greater than 12 $m \cdot s^{-1}$ are predominantly observed over the sea ice margins and some of the Antarctic coastline. In the Antarctic region, wind speeds greater than 12 $m \cdot s^{-1}$ are predominantly observed over the sea ice margins and some of the Antarctic coastline. Our results show that enhancements of BrO columns are mainly related to positive wind speed anomalies except for some areas such as the Canadian archipelago. The enhanced BrO columns in the Canadian archipelago, an area where total BrO hotspots are frequently detected with low surface wind speeds, may be attributed to local production/recycling of reactive bromine under a stable boundary layer or an increase in stratospheric BrO."

We partly agree with the statement that separating troposphere and stratosphere would be simplifying the interpretation of the results. However, as discussed above (Question #4), we feel that the accuracy of current separation methods would introduce additional uncertainty. Our results of the relationship between total BrO vertical columns and surface wind speeds show large positive wind speed anomalies (Fig. 10) and high values of the relative frequency of strong surface winds during the occurrence of enhanced total BrO (Fig. 12) along the eastern coast of Greenland and the central Arctic. From these results, we can suppose that although the occurrences of enhanced total BrO columns in these regions are not as high as in other regions, the supply of reactive bromine sources from blowing snow events caused by high surface wind speeds and the tropospheric bromine explosion mechanism contribute to the increase in total BrO columns.

8) P11-12 L355-363: Fig. 12 is the high wind speeds frequency, which shows that we have more high wind conditions at locations such as Greenland or centre Arctic sea. I agree

with this. But, how this can prove high wind speed frequency is consistent with a high frequency of BrO enhancement? I am very confused about this paragraph. For example, if we compare Figs. 2 and 12, we can easily find the eastern coast of Greenland has a low frequency in BrO enhancement but a high frequency in high wind speed. Same for the Canadian archipelagoes, where the high wind is less common but has a very high chance of enhanced BrO columns. I am not challenging the blowing snow scheme, but one should be clear that the transported bromine explosion events may have a different spatial distribution pattern compare to stable shallow boundary layer events. In other words, shallow ones are confined at local, which one might find easy correlation as "low-wind and high BrO" in one place. But, the transported events may be originated or triggered in this 12 m/s wind speed conditions, but transported in relative mild condition (e.g., < 6 m/s). Anyway, the analysis done in the next paragraphs is decent and important (L364-416). Wind speed analysis should be done together with wind direction.

We agree with the reviewer that local BrO enhancements and transported BrO events need to be treated separately, and that transported events are more difficult to link to the driving mechanisms. We also would like to point out that Figure 12 shows regions, where high wind speeds are found frequently during enhanced BrO events, which we take as indication that the high wind speed could be related to the formation of BrO. This is in line with Figures 10 and 11 showing regions where the probability for high wind speeds increases in the presence of BrO.

To clarify the conclusions that can be inferred from the occurrence frequency map of enhanced total BrO column (Fig. 2) and the relative frequency map of high wind speeds during enhanced total BrO occurrences (Fig. 12), the following blue text has been added and revised in section 4.2.3:

- In section 4.2.3 (P12 L363):

The spatial distribution map of surface wind speed anomalies derived in this study shows that during the enhancement of total BrO vertical columns, wind speeds are generally enhanced. However, the average wind speed field during the high BrO cases shows values of 6-8 m·s-1 in most areas. For the tropospheric bromine explosion events created by strong winds, previous studies indicate that wind speeds above ~12 m·s^{-1} are required. The regions that satisfy this wind speed threshold consistently are confined to the Bering Strait, the central Arctic, and the east coast of Greenland in the Arctic and the Antarctic sea ice margins and some coastal locations. This behaviour is clearly identified in the spatial distribution maps of the relative frequency of high wind speeds for the occurrence of enhanced total BrO columns (see Fig. 12) which show where strong surface winds contribute to the enhancement of BrO columns. In Fig. 12, high frequencies above 30 % are found over the central Arctic and eastern coast of Greenland in the Arctic, whereas in the Antarctic, they are most frequently detected around the marginal ice zone of the Weddell and Ross Sea. ~~In short, the results shown in Fig. 10-12 suggest that the occurrence of enhanced BrO columns in the corresponding regions where wind speeds~~

~~are high and positive wind speed anomalies appear may be significantly associated with a tropospheric bromine source generated by high wind speeds.~~ "In particular, although the central Arctic and eastern coast of Greenland are regions where enhanced total BrO columns are not frequently detected in the Arctic as shown in Fig. 2, it is clear that the occurrence of enhanced total BrO columns in the corresponding regions is often associated with higher wind speeds (Fig. 10 and 12). This could indicate that tropospheric bromine sources from blowing snow events generated by high wind speeds are important in these areas."

- In section 4.2.3 (P11 L335):

"Our results show that enhancements of BrO columns are mainly related to positive wind speed anomalies except for some areas such as the Canadian archipelago. The enhanced BrO columns in the Canadian archipelago, an area where total BrO hotspots are frequently detected with low surface wind speeds, may be attributed to local production/recycling of reactive bromine under a stable boundary layer or an increase in stratospheric BrO."

10) P16 L503-504: As the author already found out, use only wind speed is not sufficient (need to include wind-direction at least). Do you have correlation analysis for different wind directions too? Do we have a better (higher) correlation when we have preferred wind-directions?

The reason why the correlation analysis between the surface wind direction and total BrO vertical column was not performed in Section 4.3 is that wind direction is a categorical variable (8 wind direction groups) unlike other meteorological parameters such as sea level pressure, air temperature, wind speed and tropopause height. Instead of the correlation analysis between the wind direction (categorical variable) and total BrO VCD (numerical variable), to investigate the dominant wind direction related to the enhancement of total BrO columns, we examined the spatial distribution of relative frequency for each wind direction during the occurrence of enhanced total BrO columns (Fig. 13-16 in Section 4.2.3). Although the statistical analysis whether preferred wind directions have higher correlation coefficients with total BrO columns has not been performed, it can be assumed by spatial distribution maps of relative frequency anomalies of wind direction between enhanced total BrO cases and the mean field (Fig. 14 and 16). Positive frequency anomalies mean that the corresponding wind direction has a higher correlation with total BrO column than other wind directions in the study area.

11) P18 L562-566: These are significant factors that should be addressed before the analysis. I fully understand the limits and difficulties in performing this large scale study

(both time and spatial). The paper is well written and meaningful. But, I would suggest the author provide these limits before the beginning of the analysis. The author can inform the reader why the stratospheric correction is not applied (i.e., why not using BrO tropospheric columns).

As suggested, we have added limitations and potential weaknesses of this study in the revised manuscript as follows:

- In section 1 (P4 L126):

In particular, the relationship between total BrO vertical columns retrieved from GOME-2A/2B and meteorological fields including sea level pressure, surface level wind speed and direction, surface air temperature, and tropopause height were investigated. "The reason for using total BrO columns instead of tropospheric and stratospheric columns separately to examine the relationship with the meteorological fields is that existing separation methods for satellite BrO data are difficult to apply to a long-term dataset in both hemispheres. They also have large uncertainties in connection with low pressure systems and large tropopause height changes which affect both stratospheric and tropospheric columns. This study aims to investigate how the meteorological system generally affects the total BrO column, rather than separate the effects on the enhancement of BrO in each atmospheric layer."

- In section 4.1 (P8 L237):

In this study, a reference grid with 200×200 km resolution was used. The enhanced BrO occurrence frequency f_{EBrO} was calculated by dividing the number of pixels classified as enhanced BrO column in a given reference grid cell by the total number of satellite pixels within the reference grid cell. "One thing to note is that cloud filtering was not applied in this study. Clouds can affect the BrO column retrieval generally in three ways: (1) the albedo effect related to the increase of the reflectivity and sensitivity for cloudy scenes, (2) the enhancement of optical light path due to multiple scattering inside clouds, and (3) the shielding effect that hides trace gases below clouds. The first two effects could increase the absorption of trace gases and lead to values greater than the actual total BrO column, while the third effect leads to an underestimation of the total BrO column (Antón and Loyola, 2011). Therefore, as clouds affect the BrO retrieval, it is necessary to consider the presence and characteristics of clouds for accurate BrO analysis. However, obtaining long-term reliable cloud products such as cloud fraction and cloud top height over the polar sea ice regions is difficult since detecting clouds and retrieving their properties over a bright snow/sea ice surface from satellite measurements are difficult (Heidinger and Stephens, 2000). Inaccurate cloud data may cause errors in statistical analysis using long-term data. Also, the difference between cloud free and cloudy conditions in polar sea ice regions is relatively small due to the bright surface (Figure 1 in Blechschmidt et al., 2016).

Based on these considerations, this study did not attempt to correct the effects of clouds on the enhancement of BrO columns."

Technical corrections:

P5 L139: Use proper multiple signs in here and thereafter, not letter "x".

This has been corrected in the revised manuscript.

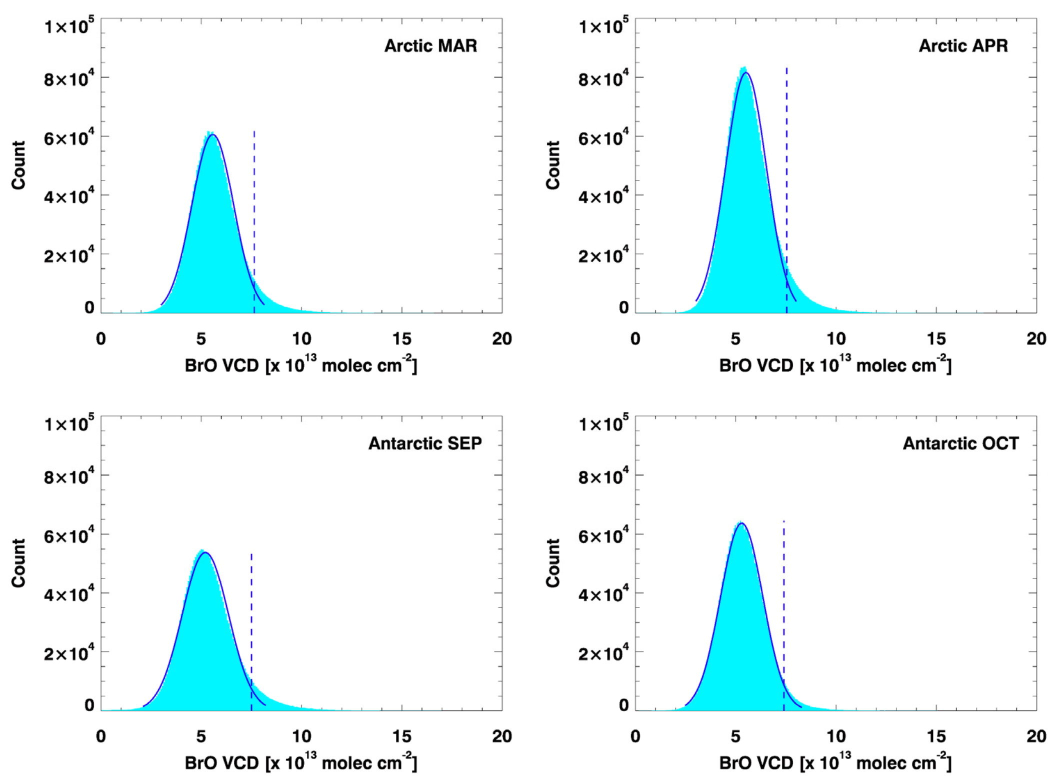
P5 L160: Define DSCD.

As suggested, we have defined the sentence as follows (blue text):

When using a Pacific background spectrum, the retrieved differential slant columns (DSCD) need to be corrected by adding the BrO slant column over that region.

P28. Fig 1: Use consistent y limits for all four panels (e.g., 1e5). The current selections for each panel are a bit arbitrary.

As suggested, changes have been applied to Fig.1.



Figs. 2 and 4: The 0-degree Longitude sign and the 70-degree Latitude sign are jammed.

As suggested, changes have been applied to maps (Fig. 2, 4, 5, 7, 8, 10-16, 18-20) in the revised manuscript. Here, we have attached Fig.2 and 4.

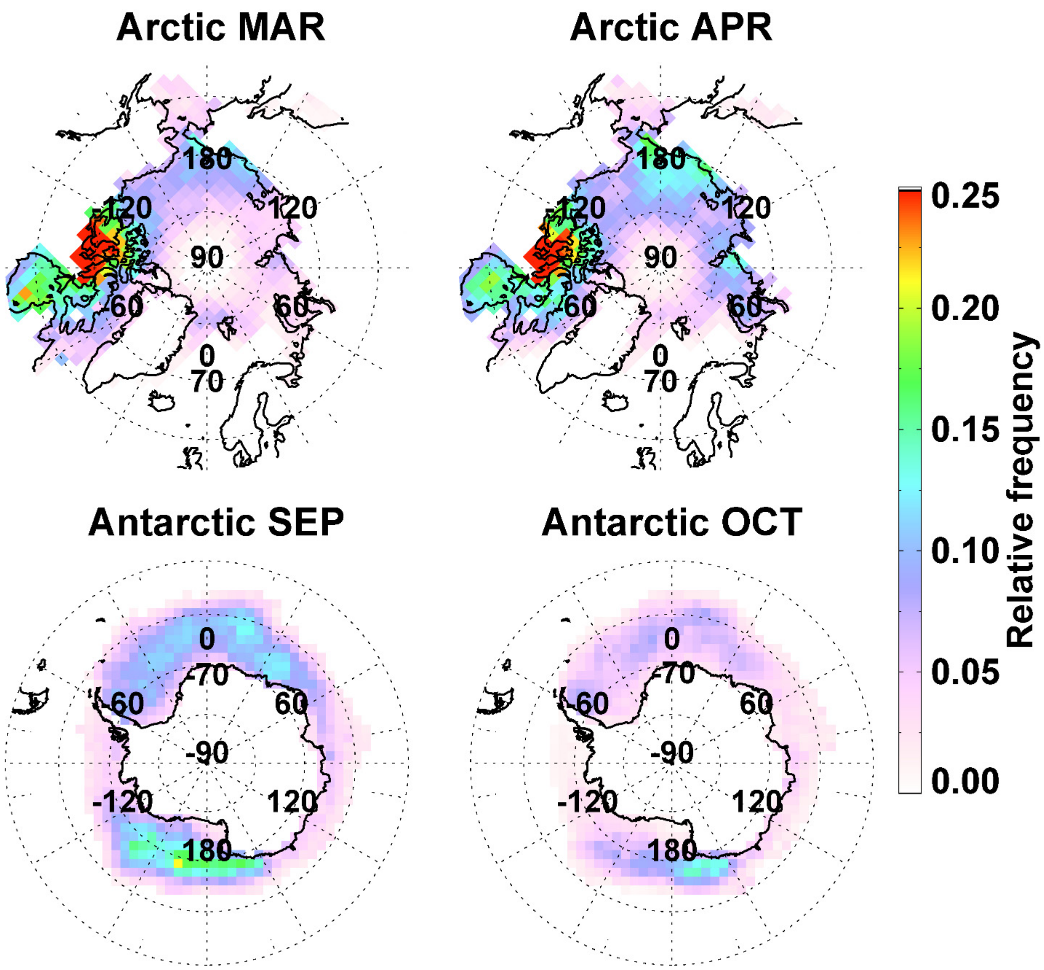


Figure 2. Monthly spatial distribution of the occurrence frequency of enhanced total BrO columns over the Arctic (top left: March, top right: April) and Antarctic sea ice region (bottom left: September, bottom right: October) during the study period of 2008-2018.

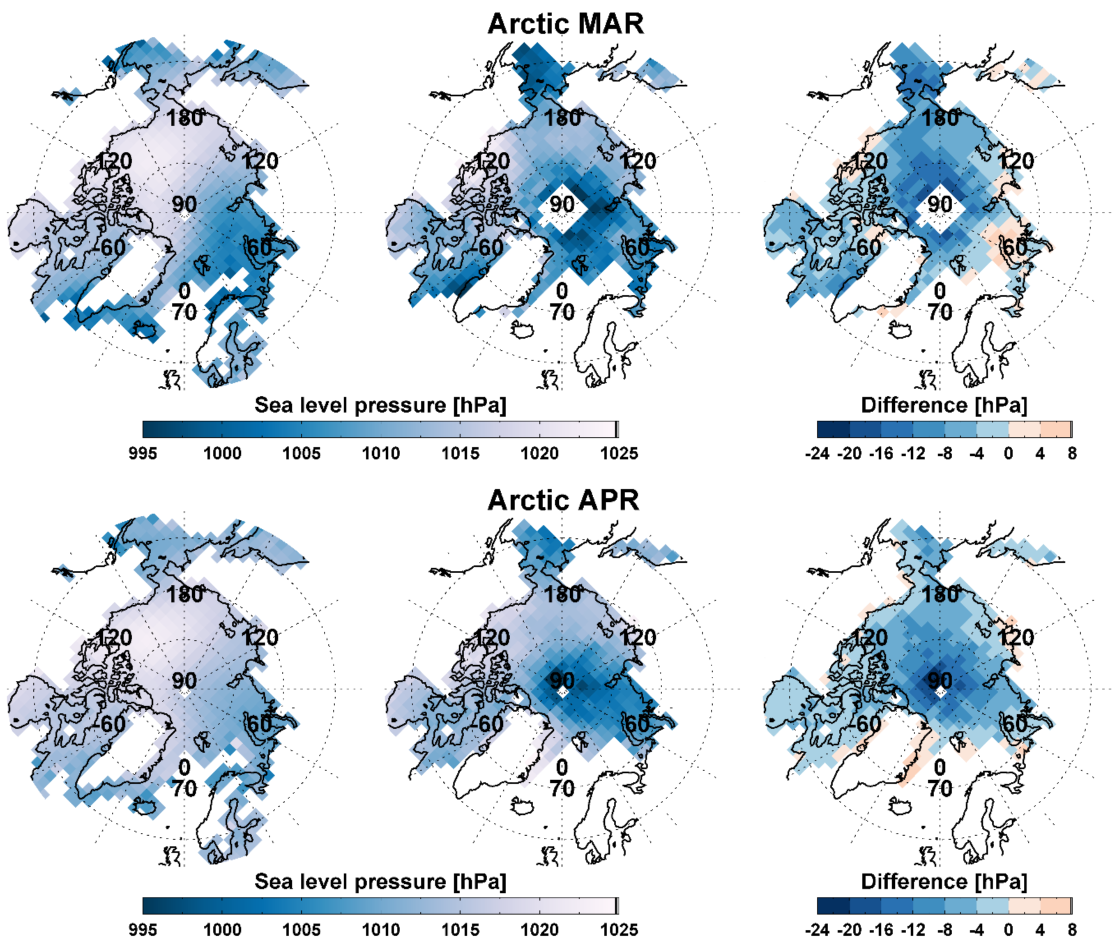


Figure 4. Monthly sea level pressure for the mean field (left), the enhanced BrO case (middle), and sea level pressure anomalies (difference of sea level pressure between the enhanced BrO case and the mean field) (right) over the Arctic in March (upper panel) and April (lower panel).

P13 L421: Please provide the definition of DU (Dobson unit).

As suggested, we have revised the sentence as follows:

Salawitch et al. (2010) found that enhanced total BrO columns over the Hudson Bay observed by OMI are coincident with a low tropopause of ~5 km and high total O_3 column of ~450 DU (Dobson unit).

P20 L627: Capitalize each word; change "Geophysical research letters" to "Geophysical Research Letters."

This has been corrected in the revised manuscript.

P23 L736: Remove “n/a-n/a”.

This has been corrected in the revised manuscript.