

Referee # 1

We thank Referee #1 for the helpful comments. Please find our responses below.

General comments

1) The oxidation of DMS by OH happens by two pathways: H-abstraction from the methyl group and OH-addition onto the sulphur atom. The H-abstraction pathway leads predominantly to SO₂. The OH-addition pathway leads predominantly to DMSO (Barnes et al. 2006). The DMSO is then further oxidised into MSIA and subsequently into MSA or SO₂ (see von Glasow and Crutzen, 2004; Zhu et al., 2006; Barnes et al. 2006; Hoffmann et al., 2016). A direct conversion of DMS into SO₂ is unlikely and only convenient if the OH-addition pathway is parameterised. As the present study aims at the investigation on how the formation of DMSO and subsequent multiphase chemistry affects the SO₂ yield, I do not understand why the authors produce DMSO only in a yield of 0.4 and the residual yield is SO₂. The addition pathway has to be revised according to the literature to consider the DMSO formation more adequately including higher yields. $\text{DMS} + \text{OH} \rightarrow \text{DMSO} + \text{HO}_2$ (Schultz et al., 2018)

Response: As shown in Barnes et al. (2006), the (CH₃)₂S-OH adduct is formed via the OH-addition pathway. The (CH₃)₂S-OH adduct reacts with O₂ to produce mainly DMSO under NO_x-free conditions (Arsene et al., 1999; Barnes et al., 2006). However, both Turnipseed et al. (1996) and Hynes et al. (1993) found the yield of DMSO from the (CH₃)₂S-OH + O₂ + NO reaction to be about 0.5 when NO is present in their experiments. It is difficult to extrapolate the yield of DMSO under atmospheric NO_x conditions and DMSO₂ could be formed under low NO_x and low temperature conditions in the remote marine atmosphere (Barnes et al., 2006). The most recent JPL report (Burkholder et al., 2015) also quoted a yield of DMSO from (CH₃)₂S-OH + O₂ + NO reaction to be 0.5 from Turnipseed et al. (1996) and Hynes et al. (1993).

Pham et al. (1995) uses a yield of 0.6 for SO₂ and a yield of 0.4 for DMSO for the addition channel of the DMS+OH reaction in a global three-dimensional chemical transport model, based on laboratory results of Barnes et al. (1988). These yields were also used in other global model studies (Cosme et al., 2002; Spracklen et al., 2005; Breider et al., 2010).

Thus, the OH-addition pathway leads predominantly to DMSO, as argued by the reviewer, only occurs under NO_x-free conditions. The reason why Schultz et al. (2018) used a unity yield of DMSO for the additional channel of DMS+OH reaction was not explained in that paper. It seems more common in the modeling community that the yield of DMSO from the addition channel of DMS+OH reaction is not unity. Since the consequence of the addition channel of DMS+OH reaction is still not well understood, we think it is more reasonable to use the same product yields of SO₂ (0.6) and DMSO (0.4) as previous modeling studies (Pham et al., 1995; Cosme et al., 2002; Spracklen et al., 2005; Breider et al., 2010). To investigate the importance of this assumption, we perform an additional sensitivity run by using a unity yield of DMSO for the addition channel of the DMS+OH reaction. The global DMSO, MSIA and MSA burden increase

by 33%, 50% and 74%, respectively. The global SO₂ and sulfate burden both decrease by 2%.

Changes in the manuscript:

- Add R_{add} to Table 3 as a sensitivity run.
- Add MSA/nssSO₄²⁻ ratio for R_{add} run to Fig. 10.
- At Page 5, Line 11: add “Product yields of 0.6 for SO₂ and 0.4 for DMSO have been commonly used in global models (Pham et al., 1995; Cosme et al., 2002; Spracklen et al., 2005; Breider et al., 2010) based on experiments described in Turnipseed et al. (1996) and Hynes et al. (1993).”.
- At Page 13, Line 19: add “The model run with a unity yield of DMSO from the additional channel of DMS oxidation by OH (R_{add}) largely overestimates MSA/nssSO₄²⁻ observations, with $N_{\text{MB}}=281\%$.”.

2) MSIA and MSA are acids. The dissociation of these acids will increase the effective uptake coefficient. In the present study, no dissociation is implemented. Especially, MSA is a strong acid (pKa = -1.92) and should reside predominantly in its dissociated form in aerosol particles and cloud droplets. Hence, as dissociated MSA will not undergo phase transfer, a much higher amount partitions in the aqueous phase as it is calculated by the modelling approach. However, if the pH of aerosols and cloud droplets would be fixed in the model, the effective Henry's Law coefficient can easily be calculated. Then, the implementation of the effective Henry's Law coefficient can be an appropriate way to restrict the numerical costs. Still, in the present model study the pH value is predicted. Thus, the effective Henry's Law coefficient cannot be used. Therefore, the dissociation has to be treated in the model to enable a realistic partitioning and chemistry of MSIA and MSA.

Response: The acid dissociation of MSIA and MSA was considered in the model, although it was not specifically described. We used the same rate constant for the oxidation of MSA_(aq) and MS⁻ by OH_(aq), for the oxidation of MSIA_(aq) and MSI⁻ by OH_(aq), and for the oxidation of MSIA_(aq) and MSI⁻ by O_{3(aq)}. Now we have used different rate constant for each of these reactions in the updated manuscript (Table 1). The updated MSI⁻+O_{3(aq)} reaction rate constant is about an order of magnitude lower than before, which results in more dissolved MSIA oxidized by OH_(aq) than by O_{3(aq)}. The updated MS⁻+OH_(aq) reaction rate constant is 4.7 times lower than before, which results in a large increase in the global MSA burden (from about 10 to 20 Gg).

Changes to the manuscript:

- In Table 2, add pKa for MSIA and MSA: pKa(MSIA)=2.28 and pKa(MSA)=-1.86 (Hoffmann et al., 2016).
- In Table 1, add “MSI⁻+OH_(aq)→MSA_(aq)”, “MSI⁻+O_{3(aq)}→MSA_(aq)” and “MS⁻+OH_(aq)→SO₄²⁻” and corresponding rate constants.
- At Page 9, Line 21: modified as “Globally, multiphase oxidation in cloud droplets and aerosols by OH_(aq) (53%) and O_{3(aq)} (24%) is the biggest sink of MSIA, followed by gas-phase oxidation by OH (19%).”

- At Page 9, Line30: add “By considering cloud droplets only, Hoffmann (2016) suggested $\text{OH}_{(\text{aq})}$ is more important (1.5 times faster) than $\text{O}_{3(\text{aq})}$ for MSIA oxidation, which is consistent with our results. Since information such as $\text{OH}_{(\text{aq})}$ concentrations in aerosols, aerosol water content and cloud liquid water content were not provided in Hoffmann et al. (2016), we do not further compare our MSIA oxidation by $\text{O}_{3(\text{aq})}$ and $\text{OH}_{(\text{aq})}$ to Hoffmann et al. (2016).”
- At Page 10, Line 12: change “In R_{all} , the global MSA burden is 10 Gg S.” into “In R_{all} , the global MSA burden is 20 Gg S.”
- At Page 10, Line 26: modified as “MSA+ $\text{OH}_{(\text{aq})}$ accounts for 12% of MSA removal in R_{all} , and the rest of MSA is removed via dry (12%) and wet (76%) deposition.”
- At Page 12, Line 29: change “Figures 10 and 11 show that modeled MSA/nss SO_4^{2-} ratios are in good agreement with MSA/nss SO_4^{2-} observations” into “Figures 10 and 11 show that modeled MSA/nss SO_4^{2-} ratios calculated from R_{all} can generally reproduce the spatial variability of MSA/nss SO_4^{2-} observations, especially the latitudinal trend of increasing ratios towards the south where anthropogenic sources of nss SO_4^{2-} are less important. However, modeled MSA/nss SO_4^{2-} ratios overestimate observations by a factor of 2 on average”
- More changes in the MSIA and MSA budgets are shown in Section 3.3, 3.4 and 3.6.2 in the updated manuscript.

3) The implemented kinetic reaction rate constant for MSA with the OH radical is nearly five times higher than the two other ones given in Barnes et al. (2006). Given the comments on the high rate constant in Barnes et al. (2006), I think the lower ones has to be preferred. This will significantly affect also the oxidation of MSA.

Response: In the updated manuscript, the lower rate constant for MSA oxidation has been used (Table 1) ($1.29 \times 10^7 \text{ M}^{-1} \text{ s}^{-1}$ at 298 K instead of $6.10 \times 10^7 \text{ M}^{-1} \text{ s}^{-1}$). The global MSA burden increases from 10 Gg to 20 Gg. The modeled MSA/nss SO_4^{2-} ratio for the run with all new reactions added overestimates the observations by a factor of 2 on average, which suggests more MSA oxidation is needed. The high rate constant for MSA oxidation (4.7 times higher) is now used in the sensitivity run $R_{\text{moreMSA+OH}}$.

Changes to the manuscript:

- In Table 1, update rate constant for MSA oxidation.
- At Page 10, Line 12: change “In R_{all} , the global MSA burden is 10 Gg S.” into “In R_{all} , the global MSA burden is 20 Gg S.”
- At Page 10, Line 26: modified as “MSA+ $\text{OH}_{(\text{aq})}$ accounts for 12% of MSA removal in R_{all} , and the rest of MSA is removed via dry (12%) and wet (76%) deposition.”
- At Page 12, Line 29: change “Figures 10 and 11 show that modeled MSA/nss SO_4^{2-} ratios are in good agreement with MSA/nss SO_4^{2-} observations” into “Figures 10 and 11 show that modeled MSA/nss SO_4^{2-} ratios calculated from R_{all} can generally reproduce the spatial variability of MSA/nss SO_4^{2-} observations, especially the latitudinal trend of increasing ratios towards the south where anthropogenic sources of nss SO_4^{2-} are less important. However, modeled MSA/nss SO_4^{2-} ratios overestimate observations by a factor of 2 on average”
- At Page 13, Line 15: add “Due to the small chemical loss of MSA in our model,

MSA/nssSO₄²⁻ in model run without MSA + OH_(aq) ($R_{\text{noMSA+OH(aq)}}$) is similar to that in R_{all} . The model run with a larger reaction rate coefficient of MSA + OH_(aq) ($R_{\text{moreMSA+OH(aq)}}$) results in a decrease in modeled MSA/nssSO₄²⁻ (24% on average) compared to R_{all} .”

4) The oxidation of DMSO in the gas phase yields only 0.95 MSA. The residual 0.05 should be dimethyl sulfoxide (DMSO₂), which will be predominantly being further, but slowly, oxidised into SO₂. Thus, to close the mass balance, a 0.05 yield of SO₂ should be implemented.

Response: In the updated manuscript, we have applied a 0.05 yield of SO₂ to the oxidation of DMSO in the gas phase. This results in negligible changes in the SO₂ budget, as it is a very small source of SO₂ (Fig. 1).

Changes to the manuscript:

- Update “DMSO+OH→0.95MSIA+0.05SO₂^(new)” in Table 1.
- Add a pathway “DMSO→SO₂” with 98 Gg S yr⁻¹ in Fig. 1.

5) The oxidation of DMS can also affect new particle formation. As the authors have stated the formation of MSA by aqueous-phase chemistry will not result in new particle formation. I am missing a discussion how the newly implemented multiphase DMS chemistry scheme affects new particle formation. Have the authors investigated how new particle formation is changed between R_{all} and R_{std} ? Please address this issue in the discussion of the model results.

Response: We did not investigate how new particle formation is changed between R_{all} and R_{std} . This will be an important investigation in the future using an aerosol microphysics model simulation.

Changes to the manuscript:

- At Page 14, Line 16: add “Quantifying the impacts of our updated sulfur oxidation scheme on new particle formation is out of the scope of this study and should be addressed in the future.”.

Minor comments

1) The term ‘multiphase’ means connection of oxidation in gas and aqueous phase. Therefore, the usage of multiphase mechanism or multiphase oxidation addressing oxidation in the aqueous phase is wrong. It has to be stated aqueous-phase mechanism or aqueous-phase oxidation.

Response: In the updated manuscript, we use multiphase oxidation for the process involving gas and aqueous phase, and we use aqueous-phase oxidation for the process happening in the liquid.

Changes to the manuscript:

- In Table 1 and Table 4, change all multiphase reactions into aqueous-phase reactions with corresponding rate coefficients.

2) The conversion yield of DMS into SO₂ and MSA with the new approach is 78% and 13%, respectively. The addition of these numbers does not reach 100%. What are the residual 9%? Are this DMSO and MSIA? These also needs to be stated.

Response: The conversion yield of DMS into SO₂ and MSA in the new approach should not be 100% due to loss of the intermediates DMSO and MSIA via dry and wet deposition.

Changes to the manuscript:

- At Page 14, Line1: modified as “Compared to the standard GEOS-Chem model run, the updated sulfur scheme in this study decreases the conversion yield of DMS to SO₂ ($Y_{\text{DMS} \rightarrow \text{SO}_2}$) from 91% to 75% and increases the conversion yield of DMS to MSA ($Y_{\text{DMS} \rightarrow \text{MSA}}$) from 9% to 15%. The remaining 10% of DMS is lost via wet and dry deposition of DMSO and MSIA.”

- In the abstract, add “The remaining 10% of DMS is lost via deposition of intermediates DMSO and MSIA.”

3) Can the authors please provide how much dry and wet deposition contribute to the lifetime of DMSO, MSIA and MSA?

Response: The dry deposition loss contributes 16%, 2% and 12% to the lifetime of DMSO, MSIA and MSA, respectively. The wet deposition loss contributes 11%, 2% and 76% to the lifetime of DMSO, MSIA and MSA, respectively. Chemical oxidation is responsible for the rest of the losses.

Changes to the manuscript:

- At Page 9, Line 1: modified as “DMSO is removed from the atmosphere via gas-phase oxidation by OH (33%), multiphase oxidation by OH in cloud droplets (37%) and aerosols (3%), and dry (16%) and wet deposition (11%). The lifetime of DMSO is about 11 hours.”

- At Page 9, Line 20: modified as “MSIA is mainly removed in the troposphere via both gas-phase and multiphase oxidation by OH, with a lifetime of 4 hours. Dry (2%) and wet (2%) deposition of MSIA accounts for 4% of MSIA removal in the troposphere. Globally, multiphase oxidation in cloud droplets and aerosols by OH_(aq) (53%) and O_{3(aq)} (24%) is the biggest sink of MSIA, followed by gas-phase oxidation by OH (19%).”

- At Page 10, Line 19: modified as “MSA+OH_(aq) accounts for 12% of MSA removal in R_{all} , and the rest of MSA is removed via dry (12%) and wet (76%) deposition. The lifetime of MSA is 2.2 days globally”.

4) Page 2, Line 25: ‘DMS + BrO’ and ‘DMS + OH(g)’ spaces are missing

Response: We have updated the manuscript accordingly.

Changes to the manuscript:

- Add spaces.

5) Page 3, Line 21-22.: Recently, cooking was mentioned as an anthropogenic source for MSA by Dall’Osto et al. (2015)

Response: We have updated the manuscript accordingly.

Changes to the manuscript:

- At Page 3, Line 23: change “MSA has only a natural source” into “MSA is generally considered to have a predominant natural origin”.

6) Page 5, Line 8-11: The authors have mentioned that no Cl is produced from the heterogenous reaction ‘HOBr + Cl⁻ + H⁺’ in the model system. This reaction will lead to BrCl formation. Box model studies show that the photolysis of BrCl is an important source for both Cl and Br radicals in the atmosphere (Bräuer et al., 2013), because it recycles HOBr effectively back to Br. As the authors did not include this production pathway for Cl radicals, I wonder if it is implemented for Br radicals? Please clarify this.

Response: In our model, we used monthly mean Cl mixing ratios from Sherwen et al. (2016). The reason why we used their Cl mixing ratio outputs in our model is that they have a more detailed chlorine chemistry scheme (considering Cl-Br-I coupling) than ours. They considered “HOBr+Cl⁻+H⁺→BrCl” in cloud droplets and sulfate aerosols in their model, but did not include this reaction on sea salt aerosols as this led to unrealistically high bromine abundances over the ocean.

Our model is based on Chen et al. (2017), which includes “HOBr+Cl⁻/Br⁻+H⁺ → BrCl + Br₂” reaction in both cloud droplets, sulfate aerosols and sea salt aerosols. We consider inclusion of sea salt debromination to be a better parameterization of bromine budget in the marine boundary layer. Thus, the BrO mixing ratios in our model are the BrO mixing ratios in Chen et al. (2017) that included “HOBr+Cl⁻+H⁺→BrCl”. In sum, in our model Cl mixing ratios are from Sherwen et al. (2016) and BrO mixing ratios are from Chen et al. (2017).

Changes to the manuscript:

- At Page 5, Line 13: Delete “from the HOBr+Cl⁻+H⁺” reaction” from the sentence “We used monthly mean Cl mixing ratios from Sherwen et al. (2016), which considered Cl-Br-I coupling but did not include chlorine production from the HOBr+Cl⁻+H⁺” reaction on sea salt aerosols that was suggested to be the largest tropospheric chlorine source in Schmidt et al. (2016).”

7) Page 4, Line 13-14: Can you please provide the resolution of the vertical levels?

Response: The matrix below shows the altitude of the upper bound of each layer in km. For example, the first layer is from 0 to 0.123 km; the second layer is from 0.123 km to 0.254 km; the 47th is from 68.392 km to 80.581 km.

[0.123 0.254 0.387 0.521 0.657 0.795 0.934 1.075 1.218 1.363 1.510 1.659
1.860 2.118 2.382 2.654 2.932 3.219 3.665 4.132 4.623 5.142 5.692 6.277
6.905 7.582 8.320 9.409 10.504 11.578 12.633 13.674 14.706 15.731 16.753 17.773
19.855 22.004 24.24 26.596 31.716 37.574 44.286 51.788 59.924 68.392 80.581]

Changes to the manuscript:

- At Page 4, Line 14: Add “The vertical layer thickness ranges from 120-150 m for the first 12 layers to 200-800 m for the 13th-27th layers and >1000 m for the rest (http://acmg.seas.harvard.edu/geos/doc/archive/man.v9-01-02/appendix_3.html#A3.5.2).” .

8) Page 5, Line 15: ‘DMS + O₃(aq)’, ‘DMSO + OH(aq)’, ‘MSIA + OH(aq)’, ‘MSIA + O₃(aq)’, ‘MSA + OH(aq)’ spaces are missing

Response: We have updated the manuscript accordingly.

Changes to the manuscript: Add spaces.

9) Page 5, Line 29-30: Model simulations show that the concentration of OH in the aqueous phase of marine cloud droplets and aerosols can differ up to two orders of magnitude (see Herrmann et al., 2010 or Brüer et al., 2013). This cannot be derived from the approach of Jacob (2005). Have the authors tried to implement these differences in OH concentration between the bulk of aerosol particles and cloud droplets into the modelling framework?

Response: We did not implement different OH concentrations between the bulk aerosol particles and cloud droplets in the model. Instead, we did one sensitivity run by reducing OH concentrations in both cloud droplets and aerosols by two orders of magnitude ($R_{\text{lowOH(aq)}}$). Following the reviewer’s suggestion, we run a sensitivity run by reducing the aerosol OH concentration by a factor of 20, following the maritime condition in Herrmann et al. (2010). As expected, the global DMSO and MSIA burden increase by 1% and MSA burden decreases by 2%. The small changes are due to the fact that the aqueous-phase oxidation by OH_(aq) occurs mainly in clouds instead of aerosols in our model and less oxidation by OH_(aq) in aerosols is compensated by more oxidation in other forms (e.g. oxidation in clouds).

Changes to the manuscript:

- At Page 6, Line 11: add “We conduct another sensitivity simulation by reducing the [OH_(aq)] in aerosols only by a factor of 20 (Herrmann et al., 2010) and found negligible

changes (<2%) in the global sulfur burden.”.

10) Page 6, Line 7: Usually, these rate constants are measured at 298K not 273K.

Response: In the updated manuscript, we do not have this temperature limitation. More aqueous-phase oxidation can occur at low temperature, which affects especially the MSIA burden as aqueous-phase oxidation is the main sink of MSIA (Fig. 1). We agree this is a more reasonable parameterization.

Changes to the manuscript:

- At Page 6, Line 16: delete “Multiphase sulfur reactions added in the model are only activated when the air temperature is above 273 K, to be consistent with the temperature at which their rate constants were obtained (Table 1).”.

11) Page 7, Line 16-17: Measured concentrations of Cl radicals are often in the range of 104 molecules cm⁻³ (Saiz-Lopez and von Glasow, 2012). Have the authors performed a sensitivity study with higher concentrations (e.g. 5x10³ molecules cm⁻³)? How is the contribution then affected?

Response: In the updated manuscript, we have conducted a sensitivity run by increasing the Cl mixing ratio by an order of magnitude. The fraction of DMS oxidized by Cl increases from 4% to 28%. This results in changes in the global DMS (-29%), DMSO (-2%), MSIA (-12%), MSA (10%), SO₂ (-2%) and sulfate (-3%) burden.

Changes to the manuscript:

- At Page 7, Line 17: add “ $f_{[Cl]DMS+Cl}$ increases to 28% in a sensitivity run increasing Cl mixing ratios by an order of magnitude.”.

- At Page 8, Line 2: add “However, a recent study suggests that this is an overestimate of tropospheric Cl abundance (Gromov et al., 2018).”

12) Page 9 Line 1: Once MSIA is formed, it is quickly, nearly instantaneous, further oxidised in the atmosphere. If 66% of the precursor DMOS stay below 2 km altitude, which processes trigger the 17% smaller contribution of MSIA?

Response: The reason why a larger fraction of DMSO stays below 2 km than MSIA is that MSIA is oxidized faster than DMSO in the marine boundary layer. As shown in Table 1, the reaction rate constant for $DMSO_{(aq)}+OH_{(aq)}$ reaction is $6.63 \times 10^9 M^{-1} s^{-1}$ at 298 K while the reaction rate constant for $MSI^{-}+OH_{(aq)}$ reaction is $1.2 \times 10^{10} M^{-1} s^{-1}$ in the model. In addition, MSIA can also be oxidized by $O_{3(aq)}$, which results in even shorter lifetime of MSIA in the marine boundary layer (below 2 km). The MSIA produced via gas-phase oxidation by OH in the upper troposphere has a longer lifetime compared to MSIA in the marine boundary layer due to smaller amount of clouds and aerosols for the MSIA oxidation in the aqueous phase in the upper troposphere. Thus, a larger amount of

MSIA stays in the upper troposphere (above 2 km).

Changes to the manuscript:

- At Page 9, Line 4: add “The smaller fraction of MSIA below 2 km compared to DMSO is due to faster oxidation of MSIA by OH_(aq) and O_{3(aq)} in clouds and aerosols (Table 1).”

13) Page 9, Line 8-10: The addition of all percent leads to 99%, please revise to give 100%.

Response: We have updated this accordingly.

Changes to the manuscript:

- At Page 9, Line 10, modified as “MSIA is mainly removed in the troposphere via both gas-phase and multiphase oxidation by OH, with a lifetime of 4 hours. Dry (2%) and wet (2%) deposition of MSIA accounts for 4% of MSIA removal in the troposphere. Globally, multiphase oxidation in cloud droplets and aerosols by OH_(aq) (53%) and O_{3(aq)} (24%) is the biggest sink of MSIA, followed by gas-phase oxidation by OH (19%).”

14) Page 9 Line 17: ‘Hoffmann’ not ‘Hoffman’

Response: Thank you, this has been fixed.

Changes to the manuscript: Change “Hoffman” into “Hoffmann”.

15) Page 10, Line 13-14: Which OH concentrations are used in these studies? Are these comparable to the present study?

Response: None of those studies (Pham et al, 1995; Chin et al., 1996; 2000; Cosme et al., 2002; Hezel et al., 2011) reported global OH concentrations. In addition, none of those studies included oxidation of MSA by OH_(aq) in clouds and aerosols, as mentioned in the manuscript. The OH concentration in our model has a global annual mean of 1.3×10^6 molecule cm⁻³.

Changes to the manuscript:

- At Page 10, Line 22: add “Information about the global distribution of MSA concentrations and deposition from these previous modelling studies are needed for comparison.”

16) Page 11, Line 9-10: Are there no data of DMS available for 2007? What is with the Cape Verde Observatory at which DMS is permanent measured since 2006 (Carpenter et al., 2010)? Why are these data not used?

Response: We are not able to find reported DMS data for 2007. We would like to

compare our model results with other DMS observations once provided.

Changes to the manuscript: No changes.

17) Page 26, Fig. 4: Over Central Asia, the oxidation of DMS by BrO shows the highest source for DMSO. Why is this reaction so strong in this region? Please provide proper reasons. Furthermore, the authors should consider to discuss the modeled concentration patterns of key oxidants.

Response: The oxidation of DMS by BrO shows the highest source for DMSO over central Asia is because high BrO abundance predicted in the model due to less reactive bromine deposition there (Schmidt et al., 2016). It should be noted that both DMS and DMSO are at very low concentration over central Asia as DMS is emitted from the ocean. This study focus on sulfur oxidation over the ocean. In the updated manuscript, we have added a global distribution of BrO, Cl, OH and O₃ in Figure 12. This study focus on sulfur oxidation and we refer to previous literatures for reasons causing the global distribution of these oxidants.

Changes to the manuscript:

- Add Fig. 12.

- At Page 5, Line 15: add “The global distributions of tropospheric annual-mean concentrations of BrO, Cl, OH and O₃ are shown in Fig. 12. The high BrO abundances over subtropics and polar regions are due to low deposition fluxes of reactive bromine (Schmidt et al., 2016) and the high BrO abundance over Southern Ocean is due to its source from sea salt debromination (Chen et al., 2017). The high Cl abundance over coastal regions in the Northern Hemisphere is due to heterogeneous uptake of N₂O₅ on sea salt aerosols to produce reactive chlorine (Sherwen et al., 2017).”

(18) Comments on the formatting of the references

- 1) Page 15, Line 19: Formatting error of the DOI number.
- 2) Page 15, Line 27: Please provide the DOI number.
- 3) Page 16, Line 3: Formatting error of the DOI number.
- 4) Page 16, Line 6: Formatting error of the DOI number.
- 5) Page 16, Line 8: Please provide the DOI number.
- 6) Page 16, Line 11: Please provide the DOI number.
- 7) Page 16, Line 26: Please provide the DOI number.
- 8) Page 17, Line 11: Formatting error of the DOI number.
- 9) Page 17, Line 30: Formatting error of the DOI number.
- 10) Page 17, Line 32: Please provide the DOI number.
- 11) Page 18, Line 2: Please provide the DOI number.
- 12) Page 18, Line 7: Formatting error of the DOI number.
- 13) Page 18, Line 9: Please provide the DOI number.
- 14) Page 18, Line 18: Please provide the DOI number.
- 15) Page 19, Line 3: Formatting error of the DOI number.

- 16) Page 19, Line 21: Please provide the DOI number.
- 17) Page 19, Line 24: Please provide the DOI number.
- 18) Page 20, Line 29: Formatting error of the DOI number.
- 19) Page 21, Line 8: Formatting error of the DOI number.
- 20) Page 21, Line 10: Please provide the DOI number.
- 21) Page 21, Line 19: Please provide the DOI number.
- 22) Page 21, Line 25: Formatting error of the DOI number.
- 23) Page 21, Line 34: Formatting error of the DOI number.
- 24) Page 22, Line 2: Please provide the DOI number.
- 25) Page 22, Line 5: Formatting error of the DOI number.
- 26) Page 22, Line 8: Formatting error of the DOI number.
- 27) Page 22, Line 12: Formatting error of the DOI number.
- 28) Page 22, Line 14: Formatting error of the DOI number.
- 29) Page 22, Line 19: Please provide the DOI number.
- 30) Page 22, Line 24: Please provide the DOI number.

Response: Thanks for the comments. We have updated the manuscript accordingly.

Changes to the manuscript:

- Format the references accordingly.