REVIEW REPLY: "Sensitivity to deliberate sea salt seeding of marine clouds – observations and model simulations"

Reply to anonymous referee #2

The authors are thankful to anonymous referee # 2 for comments that have helped clarify several aspects of the manuscript. We have carefully considered the comments as noted below.

1) We agree that the meaning of "collection five" may be unknown to some readers and have included a sentence to clarify:

"(…) **and are from the Collection 5 processing stream. The collection number indicates what algorithms are used to process the satellite observations (http://modis-atmos.gsfc.nasa.gov/).**"

2) We agree that the performance of the NorESM model in the AeroCom project allows the reader to set our forcing estimates into context. The paragraph is rewritten:

"**In the latest published quantification, the atmospheric component of NorESM (CAM-Oslo) has an indirect effect of - 1.9 Wm^{-2} compared to an AeroCom mean of -1.6 Wm^{-2} (*Quaas et al.,* 2009). Since then the model has been modified and the value is now around -1 Wm^{-2} (A. Kirkevåg, personal communication), as discussed in an upcoming paper.**"

3) The CMIP5 aerosol emissions are used. The text is changed to make this clear.

4) We agree that this part of the documentation may not be relevant for this study and have removed it.

5) Thank you for pointing out that the value of N_{min} is not important in this study. The paragraph is rewritten:

"**The N_{min} chosen in equations (4) and (5) is of crucial importance for the absolute magnitude of the cloud-weighted susceptibility. However, in this study the purpose is to find what areas over ocean are more sensitive than others, and then the value of N_{min} is not important.**"

6) Thank you for pointing out that the use of equation 7 was not properly explained. It is used to calculate optical thickness from model output. The paragraph is rewritten:

"(…) and for model results the optical thickness was calculated based on cloud droplet effective radius (r_e), cloud liquid water path (*LWP*) and the density of liquid water (ρ_L) following e. g. *Liou* (2002):"

7) Thank you for pointing out that there was a mistake in the data description of the CDNC data set. Data are available over land, but are considered to be less reliable there. We have rewritten the paragraph to make this clear:

"Data on CDNC are taken from the *Quaas et al.* (2006) data set and are retrieved from the joint histogram of MODIS COD and MODIS CDR for liquid water clouds, and diagnosed assuming adiabatic clouds. The uncertainty in CDNC is largely tied to the uncertainty in retrievals of CDR (*Quaas et al.,* 2006) and to the correctness of the assumption on adiabaticity. The product is more reliable for homogeneous, single-layer clouds than for more complex clouds, and the uncertainty is expected to be lower over ocean than over land surfaces."

8) The cloud droplet effective radii referred to here are obtained from the MODIS retrievals. This is now mentioned in section 2.1: Satellite Data.

9) The other referee on this manuscript does not agree on the unimportance of the cloud fraction. We have rewritten the text in this paragraph to clarify that the cloud fraction dominates *where the solar zenith angle is low,* not everywhere:

"**Comparing the cloud-weighted susceptibility to Figures 1(a) and 2(a) indicates that at low and mid latitudes the function (eq. 5) is dominated by the cloud fraction rather than by the susceptibility. One exception is the area of high cloud-weighted susceptibility over the Indian Ocean, which is influenced by a high susceptibility (Fig. 1(a)). Overall, the most susceptible areas (Fig. 1(a)), corresponding to regions of low CDNC, have small cloud fractions (Fig. 2(a)).**"

10)

i) We have rewritten the sentence in order not to include a plot of anthropogenic AOD:
"Overall, the most susceptible areas (Fig. 1(a)), corresponding to regions of low CDNC, have small cloud fractions."

ii) It is the susceptibility (Fig. 1(a)), not the cloud-weighted susceptibility (Fig. 2(b)) that is discussed here. We included a reference to figure 1(a) to make this clearer.

11) The absolute magnitude of the signal off the west coast of Canada is reproduced, but not the strength of this signal compared to other regions. Notice that the color bars in Figures 2(b) and 2(d) differ. We now mention that the discussion concerns the relative strength of the signals:

"The model does not reproduce the relative strength of the signals found off the west coasts of Canada and India from MODIS retrievals."

12) Thank you for pointing out that an additional figure would strengthen our argument on this point. We have now included a figure that shows the percent time with a decrease in column integrated CDNC resulting from sea salt seeding (Fig. 6(d)). This figure shows that the ocean regions of positive or small negative forcing in Fig. 4(a) are co-located with the regions that experience a decrease in CDNC most frequently:

"Figure 6(d) shows the percent time with a decrease in column integrated CDNC. Ocean regions where this number is high are co-located with regions of small negative or positive forcing estimates in Fig. 4(a), indicating that the positive forcing occurs when the added sea salt leads to the opposite effect of that desired. The decrease in column CDNC over land surfaces has little influence on the radiative budget both because of the large surface albedo and because these clouds generally have high CDNC and their albedo is less sensitive to changes in this quantity (Eq. 2)."

We rewrote section 2.3 to give an equation number to what is now equation 2:

"The change in albedo with CDNC, defined as cloud susceptibility, is given by (*Twomey*, 1991):

$$\frac{dA}{dN} \approx \frac{A(1-A)}{3N} \qquad \textbf{(2)}$$

and it is clear that this quantity is largest for intermediate A (0.5) and small N (N_{min})."

13) We agree. Figure removed.

Technical correction 1) We have reformatted the reference.

Technical correction 2) Thank you for pointing out that the color of the "not a number" values were part of the color bar for the plotted data. We have corrected this in Fig. 1, Fig. 2 and Fig. 3.

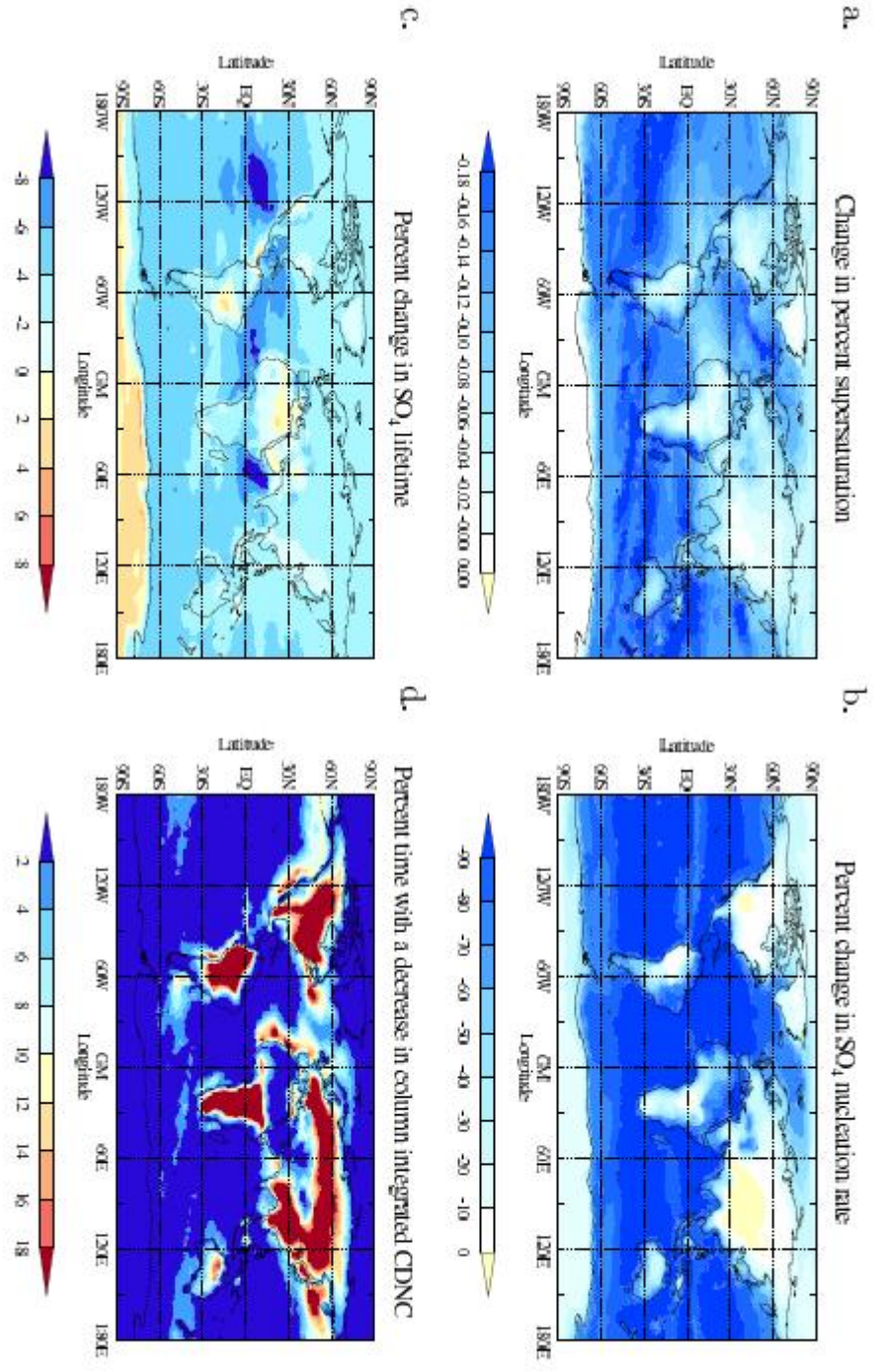

Fig. 6. NorESM: (a) Change in percent cloud supersaturation with respect to water at ~930 hPa, (b) percent change in SO_4 nucleation rate at ~930 hPa, (c) percent change in SO_4 lifetime, and (d) percent time with a decrease in column integrated CDNC. Annual averages.