Reply to the comments of the manuscript entitled "The effectiveness of solar radiation management for marine cloud brightening geoengineering by fine sea spray in worldwide different climatic regions" by Zhe Song et al.

We truly appreciate the reviewer for all the constructive comments and suggestions. We have adopted all of the suggestions in our revised manuscript. The followings are our point-to-point responses to the reviewer's comments. The responses are shown in **brown and bold fonts,** and the added/rewritten parts for the revision are presented in **blue and bold fonts**.

Reply to Reviewer #1:

The authors completed a substantial revision of their first draft to address the comments made by the reviewers. The manuscript is much improved. I have a few comments that can be considered major and several minor comments. I am recommending a major revision so that the authors have time to complete the revisions.

Response:

We thank the reviewer for your careful review.

Major Concerns:

1. The WP region has large cloud cover in northern part of the region. Did you consider shifting this region northward to capture this cloud cover? Also, why wasn't this area of cloud cover used for the "sensitive" region as it shows the largest change in radiative forcing (Fig 11d)? Related to this, why doesn't 1b for the WP region show similar results as 11d – because for the rest of the regions, figure 1b and 11 show similar results?

Response:

We thank the reviewer for the valuable suggestion. We have already noted that the northern boundary of the WP region is indeed cloudier, as demonstrated in the experiments in which aerosol injection is performed over the whole region. In the Methods section, we describe the criteria for the selection of the sensitive region: in order to better capture the transport effects of aerosols, the sensitive region needs to be far away from the boundary. If the WP region is shifted northward, we expect that the results may be similar to those in the NP, SP and SA regions.

This study focuses on the results of implementing marine cloud brightening (MCB) in five open ocean regions and aims to explore the commonalities and characteristics of MCB in different regions rather than focusing on specific regions. Therefore, we focus on the overall performance of the whole region rather than the cloud amount distributions at a specific location. In addition, since the cloud distribution changes with seasonal and atmospheric conditions, the optimal effects of MCB in a specific region can be explored more deeply in future studies by adjusting the regional extent, resolution, and simulation time.

Figure 1b shows the result of injecting sea salt aerosols in a sensitive area, while Figure 11 shows the result of injecting the whole area, so the two are themselves different experimental results and are not comparable. The figure corresponding to Fig. 1b should be

Fig. S27 in the original manuscript (Fig. S19 in the new revised manuscript). Figure S19 in the revision here is similar to the results of WP in Fig. 1b.

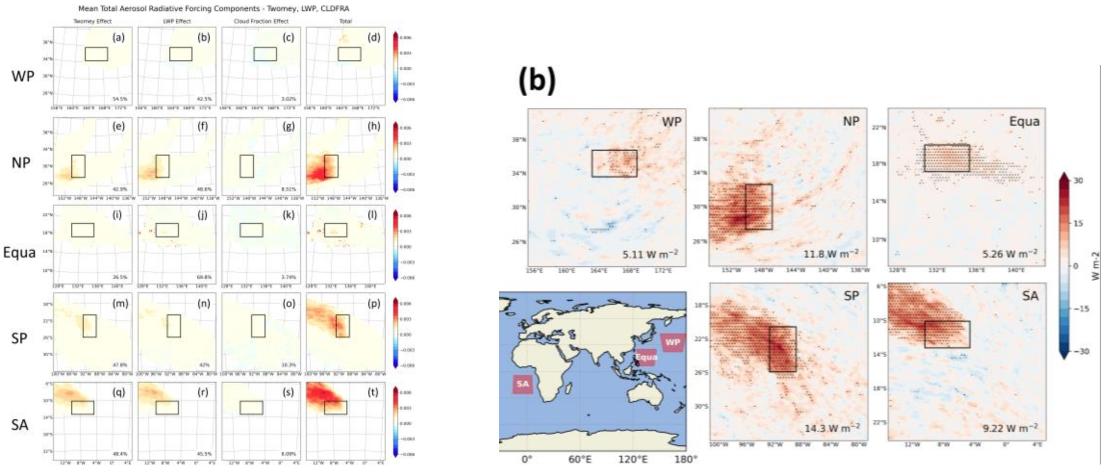


Figure S19. Spatial distribution of cloud property changes in response to SW_CLD radiation after uniform injection of sea-salt aerosols only in the sensitive area. The first column is the Twomey effect, the second column is the LWP effect, the third column is the cloud fraction effect, and the fourth column is the cloud susceptibility ($\frac{\Delta\alpha}{\Delta \ln \mathrm{AOD}}$) to aerosol injection for the sum of the three effects. The percentage contribution of each to the total SW_CLD response over the entire region is labeled in the lower right corner.

2. Need to better conceptualize that regions like the Eq are dominated by SW_AER because cloud cover is minimal. Some parts of the manuscript read like the Eq region does not brighten clouds, where the dominant reason SW_CLD is low in the Eq region is because there are few clouds. Please clarify this feature for the reader throughout the manuscript.

Response:

Thanks to the reviewer for pointing out this problem. In the original manuscript, it was mentioned that: "In the Equa, the responses of SW_TOT are entirely caused by SW_AER." We have emphasized this description in the revised manuscript.

Added/rewritten in Section 3.2:

In the Equa, the responses of SW_TOT are entirely caused by SW_AER. This is due to the low cloud cover in Equa (Fig. 2i), so the SW_CLD caused by aerosol injection is small here.

3. Need to define saturation. The lines in Figure 7 do not show saturation (at least by my definition), saturation would mean no slope, but SW_CLD for SA, NP, and SP still show an upwards slope from 1 to 2 10-9 kg m-2 s-1. You would need to include injections up to 3, 4, 5, x 10 -9 kg m-2 s-1 to truly show where saturation is met.

Response:

Thanks a lot for your suggestion. The results of WP and Equa in Figure 7 have already shown saturation, while the slopes of SW_CLD of NP, SP and SA have decreased. We understand the rigor of the reviewer and we have added more experiments for five regions by injecting 3×10^{-9} kg m^{-2} s^{-1} of sea-salt aerosols. The results show that the slope of SW_CLD in NP, SP and SA regions is already very small (Figure 7). After the injection amount increases from 2×10^{-9} kg m^{-2} s^{-1} to 3×10^{-9} kg m^{-2} s^{-1}, the changes of SW_CLD in NP, SP and SA are 15.9 →16.7 W m^{-2}, 13.1→13.5 W m^{-2} and 13.5→14.8 W m^{-2}, respectively. We believe that this has reached saturation.

Added/rewritten in Figure 7:

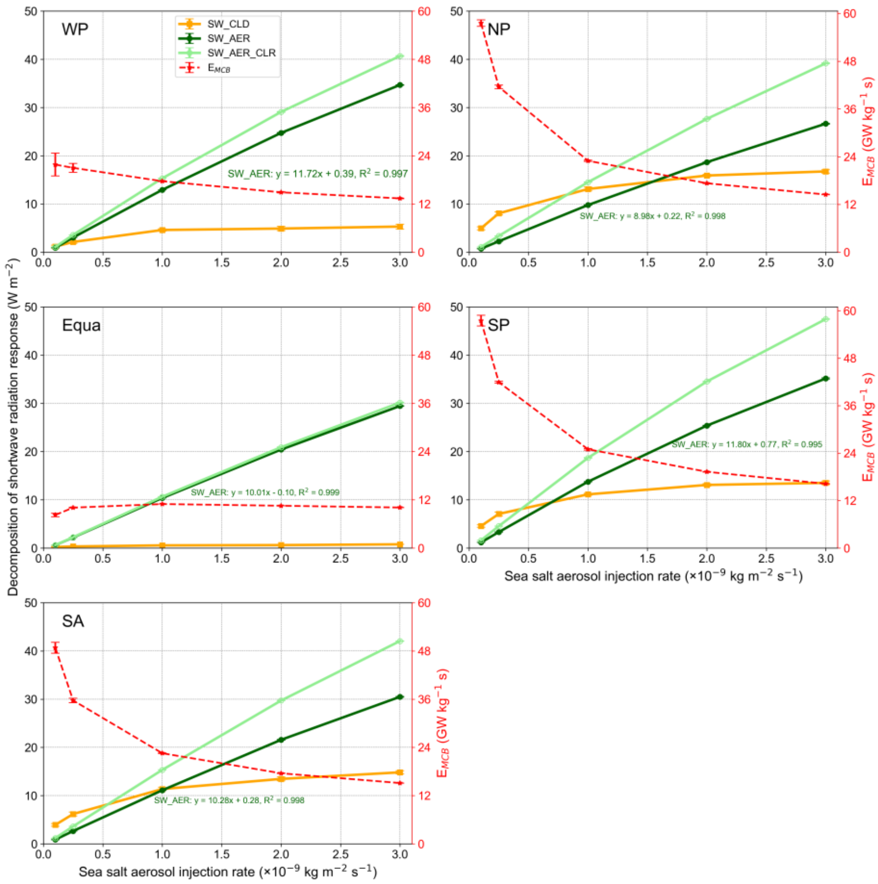


Figure 7. Changes in SW_CLD, SW_AER, and SW_AER_CLR radiative responses due to sea-salt aerosols uniform injected in varying amounts in five ocean regions, and corresponding changes in E_{MCB}. SW_AER and SW_AER_CLR are labeled with the results of the corresponding linear regression analysis. Error bars reflecting ensemble spread.

Minor Concerns:

1. The title is a little confusing, consider "The effectiveness of solar radiation management using fine sea spray across multiple climatic regions"

Response:

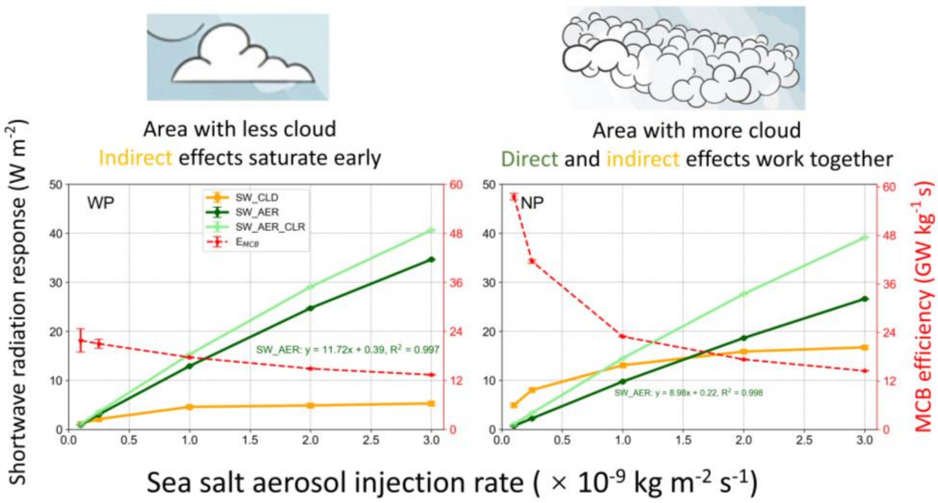
We thank the reviewer for the suggestions on the title. We have changed it to "The effectiveness of solar radiation management using fine sea spray across multiple climatic regions" in the revision.

2. Graphic Abstract – I suggest removing the figure panel with ship and the large blue arrow above it.

Response:

Thanks a lot for your suggestion. We have removed the graphic panel with ship and the large blue arrow above it in the revised manuscript.

Added/rewritten in Graphic Abstract:



3. Line 29 – I don't think "controversy" is the right term here. I suggest something like: "The relative contributions of direct and indirect effects in MCB implementations remain uncertain. Here, we quantify both effects by designing model simulations to simulated MCB for five open ocean regions around the globe."

Response:

Thanks a lot for your suggestion. We have revised this sentence in the abstract.

Added/rewritten in Abstract:

The relative contributions of direct and indirect effects in MCB implementations remain uncertain. Here, we quantify both effects by designing model simulations to simulated MCB for five open ocean regions around the globe.

4. Line 40 – "… amounts and selecting areas sensitive to the injection"

Response:

Thanks a lot for your suggestion. We have revised this sentence in the abstract.

Added/rewritten in Abstract:

This study provides quantifiable radiation and cloud variability data for multiple regional MCB implementations and suggests that injection strategies can be optimized by adjusting injection amounts and selecting areas sensitive to the injection.

5. Line 52 – remove "more innovative"
6. Line 53 – replace "by attempting" with "that"

Response for comments #5 and 6:

Thanks a lot for your suggestions. We have modified this sentence in the introduction.

Added/rewritten in Introduction:

Against this backdrop, scientists are turning their attention to geoengineering methods to reduce or offset the impacts of climate change through artificial interventions in the climate.

7. Line 58 – remove "certain"

Response:

Thanks a lot for your suggestion. We have removed the word in revision.

Added/rewritten in Introduction:

Among these, marine cloud brightening (MCB) has a realistic basis and is considered the most likely SRM method for regional applications.

8. Line 69–71 – consider whether this sentence is necessary to your study

Response:

Thanks a lot for your suggestion. We have deleted this sentence that is not necessary to the study.

9. Line 77 – Should Latham et al. 2008 be Latham et al. 2014?

Response:

Thanks for your careful review. The correct reference should be Latham et al. 2014.

Added/rewritten in Introduction:

For example, the sprayed aerosols have lower environmental risks and can be applied locally to change the regional climate (Latham et al., 2014).

10. Line 80 – Needs a citation at the end of this sentence

Response:

Thanks a lot for your suggestion. We have added the corresponding references.

Added/rewritten in Introduction:

However, despite these potential advantages, the long-term effects and potential risks of MCB are not fully understood, and there are significant uncertainties as well as ethical, political, and environmental risks (Carlisle et al., 2020; Feingold et al., 2024).

Carlisle, D. P., Feetham, P. M., Wright, M. J., and Teagle, D. A. H.: The public remain uninformed and wary of climate engineering, Climatic Change, 160, 303–322, https://doi.org/10.1007/s10584-020-02706-5, 2020.

Feingold, G., Ghate, V. P., Russell, L. M., Blossey, P., Cantrell, W., Christensen, M. W., Diamond, M. S., Gettelman, A., Glassmeier, F., Gryspeerdt, E., Haywood, J., Hoffmann, F., Kaul, C. M., Lebsock, M., McComiskey, A. C., McCoy, D. T., Ming, Y., Mülmenstädt, J., Possner, A., Prabhakaran, P., Quinn, P. K., Schmidt, K. S., Shaw, R. A., Singer, C. E., Sorooshian, A., Toll, V., Wan, J. S., Wood, R., Yang, F., Zhang, J., and Zheng, X.: Physical science research needed to evaluate the viability and risks of marine cloud brightening, Science Advances, 10, eadi8594, https://doi.org/10.1126/sciadv.adi8594, 2024.

11. Line 81 – Literatures -> Literature

Response:

Thanks a lot for your suggestion. We have revised the word in the revision.

Added/rewritten in Introduction:

Therefore, most of the current literature examine the environmental and climate impacts of MCB implementation through modeling.

12. Line 89 – Consider starting a new paragraph with "The implementation region …"

Response:

Thanks a lot for your suggestion. We started a new paragraph in the revised manuscript.

13. Line 96 – controversial -> uncertain & it would be good to cite some of these papers that calculate the direct and indirect effects

Response:

Thanks a lot for your suggestion, we have added the appropriate references in the revision.

Added/rewritten in Introduction:

The contributions of direct and indirect effects of aerosols during the implementation of MCB are still uncertain and quantitative assessment of both is lacking (Haywood et al., 2023;

Partanen et al., 2012).

14. Line 100 – oceans worldwide -> ocean regions

Response:

Thanks for your suggestions. We have revised this sentence in the revision.

Added/rewritten in Introduction:

…, to implement MCB in five open ocean regions.

15. Line 124 – Consider starting a new paragraph with "Sea salt emissions …"

Response:

Thanks a lot for your suggestion. We started a new paragraph in the revision.

16. Line 147 – included the globe … -> include globally, the tropics (30S-30N), and regions ..
17. Line 148 – remove ", and so on"

Response for comments #16 and #17:

Thanks for your suggestions. We have revised this sentence in the revision.

Added/rewritten in Method:

As summarized in Table S1, the MCB geoengineering implementation areas include globally, the equator (30°S–30°N) and regions with extensive coverages of marine stratocumulus clouds.

18. Line 156 – remove "numbers"

Response:

Thanks a lot for your suggestion. We have deleted this word in the revision.

Added/rewritten in Section 2.2:

The grid of WRF and CMAQ are 190×190 and 173×173, respectively, …

19. Line 165 – Related to my major comment above, the WP arguably has the densest cloud cover of any region, it's just located in the northern part of the region (Figure 2). Be careful how you explain the results for the WP region, as it is a heterogenous domain with respect to cloud cover.

Response:

Thanks a lot for your suggestion. We specifically point this out in the Discussion section (original manuscript L503-506): "In the WP, the injection of sea-salt aerosols into the sensitive area does not fully reflect its susceptibility because we choose to calculate the sensitive areas away from the boundary, and the greatest susceptibilities in the WP region happens to be in the northern part of the region near the boundary."

Again, we emphasized this point when describing the SW_CLD result for WP.

Added/rewritten in Section 3.2:

In contrast, the SW_CLD response is smaller in the WP and Equa regions. This is because of the low cloud cover in the Equa, and it is also worth noting that the cloud in the WP is centrally distributed in the northern part of the region, and its SW_CLD response is larger in the north.

20. Line 192 – Also related to my major comment above, why wasn't the northern part of the WP region found as the sensitive area?

Response:

Thanks a lot for your suggestion. We responded to this question in Major Comments. We selected the sensitive areas with aerosol transport in mind and therefore avoided areas close to the boundary. The northern part of the WP is more cloudy, and moving the area northward may have similar results as NP, SP, and SA. The effect of implementing MCB in specific regions can be further explored in subsequent studies by adjusting the regional settings and simulation conditions.

21. Line 204 – "preset" do you mean used as a boundary or initial condition?

Response:

Thanks a lot for your question. The "preset" here means that the sea surface temperature (SST) is provided by NCEP-FNL data and used as the boundary condition of the model, not the initial condition. This means that the SST remains fixed during the simulation and does not evolve over time.

22. Line 207 – "radiation" -> "radiative"

Response:

Thanks a lot for your suggestion. We have revised the word in the revision.

Added/rewritten in Section 2.3:

The responses of SW_TOT to the injections of sea-salt aerosols could be divided into the cloud radiative effects (SW_CLD, excluding the direct effect of the aerosols) and direct scattering effects when clouds are present (SW_AER).

23. Line 215 – existed -> exists
24. Line 216 – is -> are

Response for comments #23 and #24:

Thanks a lot for your suggestion. We have revised the words in the revision.

Added/rewritten in Section 2.3:

At this time, only the direct scattering effect of aerosols exists, which are considered to be the maximum MSB potential generated by injecting sea-salt aerosols when there is no cloud.

25. Line 217 – Consider rearranging the sentence to read "… injected by the four different sea-salt aerosol injection strategies, we propose …"

Response:

Thanks a lot for your suggestion. We have revised this sentence in the revision.

Added/rewritten in Section 2.3:

Due to the different amounts of sea-salt aerosols injected by the four different injection strategies, we propose the concept of MCB efficiency (E_{MCB}) to measure the relationships between the amount of sea-salt aerosol injections and the resulting radiation flux responses (Table S2).

26. Line 223 – include "the" between "much SW_TOT"

Response:

Thanks a lot for your suggestion. We have revised this sentence in the revision.

Added/rewritten in Section 2.3:

…, that is, how much the SW_TOT responses are expected to …

27. Line 224 – remove "in the current study area"

Response:

Thanks a lot for your suggestion. We have revised this sentence in the revision.

Added/rewritten in Section 2.3:

E_{MCB} = 1 means that injecting 1 kg of sea-salt aerosols per unit time is expected to produce a 1 GW (10^9 W) SW_TOT response.

28. Line 241 – means -> mean

Response:

Thanks a lot for your suggestion. We have revised this word in the revision.

Added/rewritten in Section 2.3:

The horizontal bars on α_c and f are defined as the monthly mean of the Base, …

29. Line 242 – There are 23 supplemental figures! – Consider if you need all of these. A reader will not be inclined to look at any of the supplemental material if it's overwhelming

Response:

Thanks a lot for your suggestion. We understand that too much supplementary material will make our paper difficult to read, so we deleted 8 figures in the supplementary material as you suggest. We have deleted Figures S8-S13, Figure S24, and Figure S26 of the original manuscript in the revision.

30. Line 254 – consider rearranging to "Three ensemble members were generated for each experiment in each region."
31. After line 254 – can you detail here how you created your ensemble?
32. After line 255 – Can you detail here what statistical test you used to determine significance?

Response for comments #30, 31 and 32:

Thanks a lot for your suggestion. We created the experimental ensembles using a stochastic kinetic-energy backscatter scheme to add stochastically perturbations (Berner 2011). We used a two-tailed t-test to determine whether the difference between the control simulation and the experiment was significant at a 95% confidence level. Incorporating the comments of another reviewer, we have revised this sentence in the revision.

Added/rewritten in Section 2.3:

Additional statistics are obtained by generating three ensemble members for each experiment in each region using a stochastic kinetic-energy backscatter scheme to add stochastical perturbations (Berner et al., 2011). A two-tailed t-test was applied to assess whether the difference between the Base simulation and the experiment was statistically significant at the 95% confidence level.

Berner, J., Ha, S.-Y., Hacker, J. P., Fournier, A., and Snyder, C.: Model Uncertainty in a Mesoscale Ensemble Prediction System: Stochastic versus Multiphysics Representations, Monthly Weather Review, https://doi.org/10.1175/2010MWR3595.1, 2011.

33. Line 263-265 – Make sure to state throughout your results that a change in a variable is being compared to BASE and note whether these changes are statistically significant.

Response:

Thanks a lot for your suggestion. We have clarified the variable changes for comparison.

Added/rewritten in Section 3.1:

… increase the SW_TOT at the TOA by 0.07–25 W m^{-2} in the five ocean regions compared with the Base experiment (Fig. 3a).

34. Line 268 – Uniformly -> Uniform

Response:

Thanks a lot for your suggestion. We have revised this word in the revision.

Added/rewritten in Section 3.1:

Uniform injections of sea-salt aerosols …

35. Line 269 – can remove “continental west coast”

Response:

Thanks a lot for your suggestion. We have revised this sentence in the revision.

Added/rewritten in Section 3.1:

The three stratocumulus regions of NP, SP, and SA have the most significant SW_TOT responses, …

36. Line 292-306 – This paragraph was unclear to me. But, I do feel it’s important to justify the wind dependent experiments. Can you revise this paragraph for clarity?

Response:

Thanks a lot for your suggestions. We have revised this paragraph to more clearly convey the background, strategy comparison, and research significance of the wind speed-related experiments. The revised paragraph is developed according to the following logic:

Background introduction: Point out the relationship between sea-salt aerosol and wind speed, and explain the rationality of the injection strategy based on wind speed.

Strategy comparison: Analyze the differences and characteristics of the two strategies based on wind speed and uniform injection.

Conclusion and suggestions: Explain the applicability of different strategies and the basis for selecting strategies that need to be considered.

Added/rewritten in Section 3.1:

The productions of sea-salt aerosols in nature are strongly correlated with wind speed, and most models associated sea-salt aerosol emissions with wind speed (Ahlm et al., 2017; Grythe et al., 2014). Injection strategies depending on wind speed make the distributions of added sea-salt aerosols closer to the natural distributions. In natural environments, sea-salt aerosol emissions in strong-wind areas (e.g., storm or typhoon areas) and surf zones are usually much larger than in weak-wind areas. Therefore, injection strategies depending on wind speed concentrate the added sea-salt aerosols in strong-wind areas and surf zones, while the weak-wind regions increase relatively little sea-salt aerosols (Fig. S4). Injecting uniformly at a fixed rate in the model will result in a large increase of sea-salt aerosols in places with originally low aerosol concentrations (e.g., weak-wind regions). This strategy may not truly reflect the distribution characteristics in the natural environment. However, the uniform increase injection strategy also has its advantages: it can not only avoid the situation of a smaller increase in sea-salt emissions in regions with lower wind speeds, but can also identify the geographical areas most sensitive to the increased sea-salt aerosols and producing the largest TOA radiation perturbations (Alterskjær et al., 2012). Therefore, when using models to simulate the injections of sea-salt aerosols by increasing the emission rate, it is necessary to fully consider the impact of different injection strategies on the distribution of sea salt emissions and to choose a suitable strategy with the purpose of the study.

37. Line 308 – “injection rate” do you mean “injection amount”?

Response:

Thanks a lot for your suggestions. We have revised this word in the revision.

Added/rewritten in Section 3.1:

… the injection amount is about 1/20 of the full domain injection.

38. Line 314 – remove although
39. Line 314 – remove only; ~5 W m 2 is still large

Response for comments #39 and #39:

Thanks a lot for your suggestion. We have revised this sentence in the revision.

Added/rewritten in Section 3.1:

In the WP and Equa regions, the increases in SW_TOT are 5.11 and 5.26 W m^{-2}, respectively.

40. Line 328 – Pertaining to my major comment, Eq response of SW_TOT is dominated by SW_AER because there are few clouds in this region. This should be explicitly stated for the reader.

Response:

Thanks a lot for your suggestion. Yes, we have responded to your question and highlighted this point in the major concern.

Added/rewritten in Section 3.2:

In the Equa, the responses of SW_TOT are entirely caused by SW_AER. This is due to the low cloud cover in Equa (Fig. 2i), so the SW_CLD caused by aerosol injection is small here.

41. Line 333 – responses -> response

Response:

Thanks a lot for your suggestion. We have revised this word in the revision.

Added/rewritten in Section 3.2:

… and the NP, SP, and SA regions provide more SW_CLD response, …

42. Line 345 – grids -> locations

Response:

Thanks a lot for your suggestion. We have revised this word in the revision.

Added/rewritten in Section 3.2:

… and in some locations they even led to a reduction, …

43. Line 360-361 – Should be moved to Discussion

Response:

Thanks a lot for your suggestion. We have moved this sentence to the Discussion section.

44. Line 365 – radiation -> radiative

Response:

Thanks a lot for your suggestion. We have revised this word in the revision.

Added/rewritten in Section 3.2:

… indicating that the changes in SW_TOT are mainly driven by the cloud radiative response (Fig. 5).

45. Line 365-366 – Again, note cloud cover's role in SW_CLD for Eq and WP

Response:

Thanks a lot for your suggestion. We have already emphasized this point in the revision.

Added/rewritten in Section 3.2:

In contrast, the SW_CLD response is smaller in the WP and Equa regions. This is because of the low cloud cover in the Equa, and it is also worth noting that the cloud in the WP is centrally distributed in the northern part of the region, and its SW_CLD response is larger in the north.

46. Line 371-372 – Isn't this just because the region is much larger than the sensitive area. You could find the mean SW_TOT in W m-2 for the sensitive region and the full region without the sensitive region included
47. Line 379-381 – same comment as above

Response for comments #46 and #47:

Thanks a lot for your suggestion. Yes, what we want to express here is that aerosols can affect a larger area outside the sensitive area through transports. In fact, we initially calculated the mean SW_TOT inside the sensitive area and the mean SW_TOT outside the sensitive area, but we found that this calculation method would lead to a very low average value outside, because it depends on the size of the outside area. If the outside area is expanded, then the average value of the entire area will be very low. Calculating the total amount can avoid this problem.

48. Line 385-389 – What is meant by saturation – because these results aren't true, SW_CLD is still increasing for NP, SP, and SA. See major comment above and revise

Response:

Thanks a lot for your suggestion. Please refer to our response to your major concerns. We have added more experiments with higher injection amounts, and although the SW_CLD of NP, SP, and SA still increased, the slopes are very small, and we believe that this has reached saturation.

49. Figure 7 Caption – should be error bars reflecting ensemble spread

Response:

Thanks a lot for your suggestion. We have added description of the error bars in the revision.

Added/rewritten in Figure 7:

Figure 7. Changes in SW_CLD, …. Error bars reflecting ensemble spread.

50. Line 394 – was -> is

Response:

Thanks a lot for your suggestion. We have revised this word in the revision.

Added/rewritten in Section 3.2:

This implies that the SW_TOT at Equa is almost exclusively…

51. Line 399 – again, I don't think your results show saturation.

Response:

Thanks a lot for your suggestion. Please refer to our response to the major concerns. The new results can already demonstrate the saturation of SW_CLD.

52. Line 430 – aerosol -> aerosols

Response:

Thanks a lot for your suggestion. We have revised this word in the revision.

Added/rewritten in Section 3.2:

When injecting sea-salt aerosols in sensitive areas, …

53. Line 435-436 – is this a regional mean?

Response:

Thanks a lot for your question. Yes, it's a regional mean.

54. Line 439-447 – consider removing or moving to sup material

Response:

Thanks a lot for your suggestion. We have deleted these sentences to streamline the paper.

55. Line 448 – higher -> greater?

Response:

Thanks a lot for your suggestion. We have revised this word in the revision.

Added/rewritten in Section 3.4:

In the regions with more cloud cover, such as …

56. Line 450 – Need space at end of sentence

Response:

We thank the reviewer for the careful review and we have added a space at the end of the sentence.

57. Line 456 -459 – Are these regional means? Please clarify such instances for the full manuscript

Response:

Thanks a lot for your question. Yes, we emphasized this description in the Methods: "Unless otherwise specified, all results in this study are shown as overall regional monthly averages of the ensemble."

58. Line 459-469 – Are these necessary results for your main points? I think you can remove these lines

Response:

Thanks a lot for your question. Yes, here we show changes in cloud properties due to aerosol injection, which is important for the MCB study and part of the later discussion of comparisons with other studies. Therefore, we chose to keep these results.

59. Line 477 – This is the first use of the word "significant" – significance should be determined by a statistical test not just if one number is larger than another.

Response:

Thanks a lot for your suggestion. We have revised this word in the revision.

Added/rewritten in Section 3.5:

…, CRF'_{param} is primarily driven by perturbations in cloud albedo (Fig. S25, first column), and it surpasses the changes in cloud fractions and their interactions.

60. Line 500 – are the clouds more susceptible in these regions, or are there just more clouds?

Response:

Thanks a lot for your question. Clouds in these regions are more susceptible because the spatial distribution of susceptibility and cloud cover is not consistent.

61. Line 517 – another example of saturates when nothing shows saturation
62. Line 517 – Yes, the cloud brightening rate does slow (the clouds are difficult to brighten further). See major comment

Response for comments #61 and #62:

Thanks a lot for your suggestion. Please refer to our response to the major concerns. The new results can already demonstrate the saturation of SW_CLD.

63. Line 522 – modification -> cloud brightening

Response:

Thanks a lot for your suggestion. We have revised this word in the revision.

Added/rewritten in Section 3.5:

Regions initially susceptible to cloud brightening gradually became less susceptible, …

64. Line 523 – remove use

Response:

Thanks a lot for your suggestion. We have deleted this word in the revision.

Added/rewritten in Section 3.5:

Other General Circulation Model (GCM) studies also found similar results.

65. Line 525 – New paragraph beginning with "This study highlights…"

Response:

Thanks a lot for your suggestion. We started a new paragraph in the revised draft.

66. Line 536-573 – A really long paragraph that needs to be condensed or split. Also, the paragraphs needs to better clarity how this study compares with others – I'm unsure what you main point(s) are. A table may help with the comparisons.

Response:

Thanks a lot for your suggestion. We agree that the original paragraph was too long and could be written more clearly. To address this, we have split it into three paragraphs. These paragraphs now clearly describe the background, our results, the comparison with previous studies, and the discussions of the reasons for the differences.

Added/rewritten in Section 4:

In the early stages of Earth-System modeling studies, the MCB processes were often simulated by presetting CDNC = 375 or 1000 cm^{-3} in the lower regions of the ocean (Jones et al., 2009; Latham et al., 2008; Rasch et al., 2009). However, many follow-up studies have suggested that injections of sea-salt aerosols have difficulty to produce a uniform CDNC field due to aerosol dilutions, depositions, and the dependences of the spray rate on wind speed. The CDNC is highly variable spatially, and studies have even reported reductions in CCN and CDNC caused by the injections of sea-salt aerosols (Alterskjær et al., 2012; Korhonen et al., 2010; Pringle et al., 2012).

In this study, after injecting accumulation mode sea-salt aerosols at a rate of 10^{-9} kg m^{-2} s^{-1}, the average CDNC concentrations for five ocean regions range from 60.2 to 100 cm^{-3}, and the spatial distributions are uneven (Fig. 10 and Figs. S14–S17). Figure 9b indicates that the CCNs in the five regions increase linearly (R^2 = 1) with increasing sea-salt aerosol injections, but not all of the CCNs are converted to cloud droplets. After doubling the injection amounts, the regional average CDNC is 84.8–130 cm^{-3}, with only some grid points exceeding 200 cm^{-3} within the regions. When the injection amounts are increased to 3×10^{-9} kg m^{-2} s^{-1}, the regional average CDNC is 98.8 - 140 cm^{-3}. This implies that injecting more sea-salt aerosols at this point does not result in more cloud droplets, and the conversion of CCN into cloud droplets is less efficient, which slows the CDNC growths and tends to saturation (Fig. 9c).

Our findings align with Alterskjær et al. (2012), who injected sea-salt aerosols at the same rate (10^{-9} kg m^{-2} s^{-1}) and observed the average CDNC below 375 cm^{-3} due to competitive effects and reduced aerosol activation. Notably, however, Wood (2021) found that decreased activation due to competition may be overestimated in the Abdul-Razzak and Ghan activation parameterization used in many GCMs relative to a parcel model. Partanen et al. (2012) used wind-adjusted injections and reported CDNC values of 596–784 cm^{-3}, with even higher values (>1000 cm^{-3}) for smaller-sized aerosols, attributing this to overestimations of particle solubility and size. Hill and Ming (2012) increased sea-salt aerosol concentrations by a factor of five, raising CDNC from 68 to 148 cm^{-3} at 850–925 hPa. It is noteworthy that Hill and Ming (2012) increased all modes of sea-salt aerosols. Many studies have reported that selecting the appropriate injection particle size is crucial for MCB (Andrejczuk et al., 2014; Hoffmann and Feingold, 2021; Partanen et al., 2012), and injecting Aitken and coarse modes may even lead to a positive forcing with CDNC decreasing (Alterskjær and Kristjánsson, 2013). However, Wood (2021) argued that particles with a geometric mean dry diameter of 30–60 nm were most effective in brightening cloud layers, and Goddard et al. (2022) similarly found that injecting Aitken mode sea-salt aerosols generated larger radiative flux changes compared to accumulation mode. There are still considerable discussions about choosing the appropriate aerosol particle sizes during the implementation of MCB, with different models and parameterization schemes providing different recommendations. The sensitivity of MCB to particle size is not considered in this paper and was left for future research.

67. Line 575 – with a "local" maximum

Response:

Thanks a lot for your suggestion. We have revised this sentence in the revision.

Added/rewritten in Section 4:

… increases cloud albedo in the five ocean regions by 0.13–0.20, with a local maximum of more than 0.3.

68. Line 576 – could reach -> reaches

Response:

Thanks a lot for your suggestion. We have revised this sentence in the revision.

Added/rewritten in Section 4:

…, the regional average cloud albedo reaches 0.45–0.55, …

69. Line 577 – What is the targeted change in cloud albedo?

Response:

Thanks a lot for your question. This sentence may be confusing here, so we moved it to the back. Many studies have proposed cloud albedo targets that MCB wants to achieve, such as "Bower et al. (2006) suggested that to compensate for the warming associated with doubling atmospheric CO_2 concentrations, a cloud albedo change of 0.16 was needed in three stratocumulus cloud regions (off the west coast of Africa and North and South America, representing 3% of global cloud cover)"

70. Line 582-583 – citation(s) needed

Response:

Thanks a lot for your suggestion. We have added the corresponding references.

Added/rewritten in Section 4:

It was also suggested that injecting sea-salt aerosols in a clean, undisturbed state would produce more brightening (Wood, 2021).

71. Line 613 – the regional oceans -> five ocean regions

Response:

Thanks a lot for your suggestion. We have revised this sentence in the revision.

Added/rewritten in Section 4:

This study provides quantifiable data on cloud and radiation changes for the implementation of MCB over five ocean regions, and …

Reply to the comments of the manuscript entitled "The effectiveness of solar radiation management for marine cloud brightening geoengineering by fine sea spray in worldwide different climatic regions" by Zhe Song et al.

We thank you for all the constructive comments and suggestions. We have adopted all of the suggestions in our revised manuscript. The followings are our point-to-point responses to the reviewer's comments. The responses are shown in **brown and bold fonts,** and the added/rewritten parts for the revision are presented in **blue and bold fonts**.

Reply to Reviewer #2:

Thank you very much for the response and revised manuscript. I believe the paper is in good condition and is ready for publication with minor revisions. I have a few general comments:

Response:

We thank the reviewer for your acknowledgement and careful review.

Major Concerns:

1. Line 527-528: Since the clouds, convection, and aerosols are still parameterized in WRF like the global models (and you are only simulating over oceans, so topography resolution does not play a role) the reasons why higher resolutions are better for aerosol-cloud interactions are not obvious in my opinion. I think adding a sentence on Ma et al., 2015 would provide crucial insight here: they find that CAM5 (which shares some parameterizations to WRF) achieves higher droplet nucleation rates at higher resolution due to increasing subgrid vertical velocity and higher aerosol concentrations.

Response:

Thanks a lot for your professional suggestion. We have revised this sentence and added corresponding descriptions and references.

Added/rewritten in Section 4:

This study provides more detailed cloud composition changes due to sea-salt aerosols injection. The model achieves higher droplet nucleation rates at higher resolution due to increased subgrid vertical velocity and higher aerosol concentrations (Ma et al., 2015).

2、Figure S3: I believe the computation in Fig. S3c are incorrect. By eye, SP uniform emissions gives a number flux of ~0.22x10^9/m2/s and fixed-wind-adjusted gives ~0.12x10^9/m2/s. Considering the forcing is 25Wm-2 for the former and 17Wm-2 for the latter, the E_MCB_number = 104 W m-2 / (m-2 s-1) for uniform emissions and E_MCB_number = 142 W m-2 / (m-2 s-1) for the fixed-wind-adjusted. Similarly, the SP Natural x 5 should be larger as well (SW_TOT = 1.7 W m-2; num flux = 0.01 m-2 s-1, so E_MCB_number = 170). This aligns the results with the direction of the cloud forcing non-linearity (as smaller number fluxes have higher efficiency) and more clearly explains the difference between the uniform and fixed-wind-adjusted cases.

Response:

Thanks a lot for your careful review. This is indeed an error in our calculation. We corrected the error and re-drawn the figure, and the result is indeed as the reviewer said.

Added/rewritten in Section 3.1:

The results showed higher MCB number efficiency with less aerosol number flux injected (Fig. S3c). In the same quality injected, the aerosol number varied greatly (Fig. S3d) and the MCB number efficiency is higher for Fixed-wind-adjusted than for uniform injection (Fig. S3c).

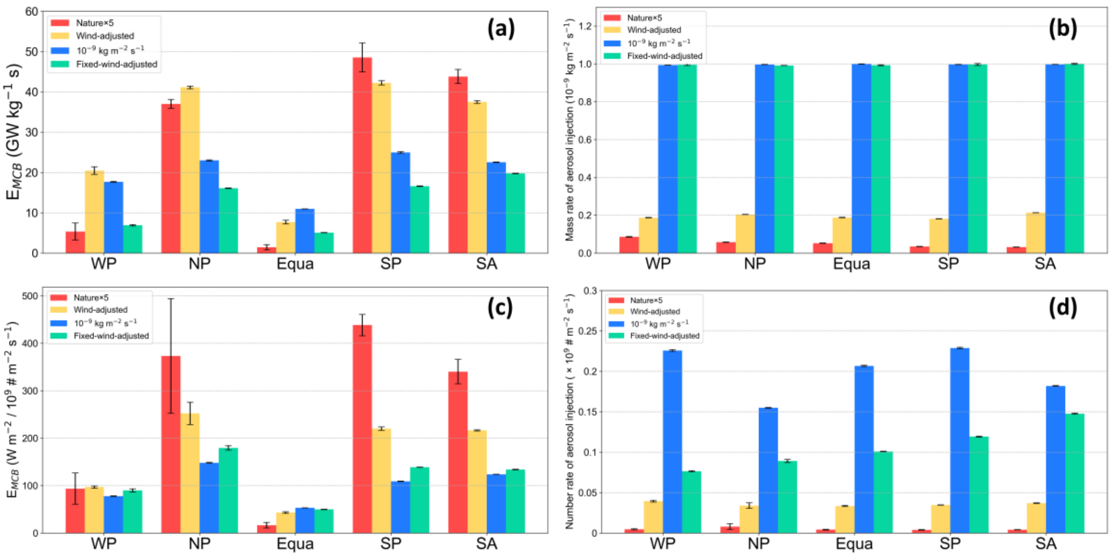


Figure S3. The MCB efficiency (a) and injection rates (b) in terms of aerosol mass, and MCB efficiency (c) and injection rates (d) in terms of aerosol number across different strategies in five ocean regions.

Minor Concerns:

1. Abstract Line 34-35: Clarify wording to "the sea salt aerosol effect on shortwave radiation is dominated by the indirect effect via brightening clouds"

Response:

Thanks a lot for your suggestions. We have revised this sentence in the abstract.

Added/rewritten in Abstract:

When the injection amounts are low, the sea-salt aerosol effect on shortwave radiation is dominated by the indirect effect via brightening clouds, showing obvious spatial heterogeneity.

2. Line 214-215: "At this time, only the direct scattering effect of aerosols existed" -> "For this flux, only the direct scattering effect of aerosols exist as clouds are ignored, "

Response:

Thanks a lot for your suggestions. We have revised this sentence in the revision.

Added/rewritten in Introduction:

For this flux, only the direct scattering effect of aerosols exist as clouds are ignored, which are considered to be …

3. Line 254-255: "The perturbations by generating three ensemble members for each experiment in each region were added" -> "Additional statistics are obtained by generating three ensemble members for each experiment in each region." (I'm assuming these are initial condition ensembles)

Response:

Thanks a lot for your suggestions. Incorporating the comments of another reviewer, we have revised this sentence in the revision.

Added/rewritten in Introduction:

Additional statistics are obtained by generating three ensemble members for each experiment in each region using a stochastic kinetic-energy backscatter scheme to add stochastical perturbations.

4. Line 268: "Uniformly injections" -> "Uniform injections"

Response:

Thanks a lot for your suggestion. We have revised this word in the revision.

Added/rewritten in Section 3.1:

Uniform injections of sea-salt aerosols …

5. Line 337-340: I would argue this is mainly because the fixed rate uniform results in more number flux (see comment 2 above)

Response:

Thanks a lot for your suggestion. Yes, we agree with the reviewer's point. We cited it as the main reason and revised this sentence in the revision.

Added/rewritten in Section 3.2:

This is mainly because the fixed-rate uniform injection leads to a larger aerosol number flux (Fig.s3d). In addition, the injection strategy relying on wind speed distributed most of the increased sea-salt aerosols to areas with already high emissions, such as strong-wind areas and surf zones, where the excess marine aerosols have already saturated the cloud responses, resulting in minor changes in SW_CLD.

6. Line 347: "exhibit noticeable discontinuity" -> "exhibit noticeable differences"

Response:

Thanks a lot for your suggestion. We have revised this word in the revision.

Added/rewritten in Section 3.2:

The spatial distributions of the SW_CLD responses exhibit noticeable differences, …

7. Line 374: "by the prevailing winds" -> "due to the prevailing winds"

Response:

Thanks a lot for your suggestion. We have revised this sentence in the revision.

Added/rewritten in Section 3.2:

The SW_CLD responses in NP, SP, and SA extend to the west and northwest of the injection due to the prevailing winds, …

8. Line 381-382: "There are consistencies in the spatial distributions of SW_AER and SW_CLD responses." -> "SW_AER and SW_CLD have similar spatial distributions due to the transport of the aerosols."

Response:

Thanks a lot for your suggestion. We have revised this sentence in the revision.

Added/rewritten in Section 3.2:

The SW_AER and SW_CLD responses have similar spatial distributions due to the transport of the aerosols.

9. Line 399: "saturated" -> "saturate"

Response:

Thanks a lot for your suggestion. We have revised this word in the revision.

Added/rewritten in Section 3.3:

This implies that at higher injection levels, the contributions of SW_CLD to total radiation change saturate, and cloud properties no longer significantly change.

10. Line 403: "function" -> "cool"

Response:

Thanks a lot for your suggestions. We have revised this word in the revision.

Added/rewritten in Section 3.3:

In some cloud-free regions or weather conditions, injected sea-salt aerosols are still able to cool through direct scattering.

11. Line 411: "Therefore, wind-dependent..." -> "The lower E_MCB of the fixed-wind-adjusted injection relative to the fixed uniform injection therefore indicates wind-dependent..."

Response:

Thanks a lot for your suggestions. We have revised this sentence in the revision.

Added/rewritten in Section 3.3:

The lower E_{MCB} of the Fixed-wind-adjusted injection relative to the fixed uniform injection therefore indicates that wind-dependent injection strategies led to …

12. Line 428: "It is reflected that in regions with strong cloud radiation effects"-> "This is reflected in the fact that in regions with higher cloud fractions"

Response:

Thanks a lot for your suggestion. We have revised this sentence in the revision.

Added/rewritten in Section 3.3:

This is reflected in the fact that in regions with higher cloud fractions, such as the NP, SP, and SA regions, the differences between the SW_AER and SW_AER_CLR responses are also larger.

13. Line 446-447: ", causing solar radiation to be reflected back into space and tend to scatter more uniformly or backward rather than forward." -> "and tend to scatter more uniformly or backward rather than forward, causing solar radiation to be reflected back into space."

Response:

Thanks a lot for your suggestions. In conjunction with another reviewer's comments and with a view to streamlining the paper, we have removed this sentence in the revision.

14. Line 459-461: Isn't the difference in efficacy between the whole-region and sensitive-area injections mainly due to the much lower total mass emission rate (area-sum) in the sensitive-area simulations?

Response:

We apologize for the misunderstanding of our description. When aerosols are injected uniformly within the sensitive area alone, and when aerosols are injected uniformly over the entire area, they are injected in the same amount for the inside of the sensitive area, but the radiation and cloud response are different. This is mainly due to the fact that when injecting over the whole area, the aerosols outside the sensitive area are transported inside the sensitive area and produces more impacts. To avoid misunderstanding, we have revised the sentence to make this point more clearly.

Added/rewritten in Section 3.4:

The injection of sea-salt aerosols uniformly within the sensitive areas results in smaller

effects on cloud microphysical properties compared to uniform injections across the entire region, even though the total injection amount within the sensitive areas is the same in both scenarios.

15. Line 501: "cloud that" -> "cloud responses that"

Response:

Thanks a lot for your suggestions. We have revised this sentence in the revision.

Added/rewritten in Section 3.4:

Injecting sea-salt aerosols in sensitive areas mostly results in cloud responses that are located outside the sensitive areas.

16. Line 539: "were difficult" -> "have difficulty"

Response:

Thanks a lot for your suggestions. We have made this correction in the revision.

Added/rewritten in Section 4:

However, many follow-up studies have suggested that injections of sea-salt aerosols have difficulty to produce a uniform CDNC field …

17. Line 770-772: Rasch et al., 2024 has been published in GMD: https://gmd.copernicus.org/articles/17/7963/2024/.

Response:

Thanks a lot for your suggestion. We have updated this citation.

Rasch, P. J., Hirasawa, H., Wu, M., Doherty, S. J., Wood, R., Wang, H., Jones, A., Haywood, J., and Singh, H.: A protocol for model intercomparison of impacts of marine cloud brightening climate intervention, Geoscientific Model Development, 17, 7963–7994, https://doi.org/10.5194/gmd-17-7963-2024, 2024.