Author Response to RC3 for ACP manuscript EGUSPHERE-2024-2159 (Moore et al.)

Our responses to each comment are provided in blue text, with the reviewer comments in black. Line and figure numbers refer to the line numbers in the original submission, for consistency with the Reviewer comments. Quotations in red were added to the revised manuscript.

Review of "Wind-driven Emission of Marine Ice Nucleating Particles in the Scripps Ocean-Atmosphere Research Simulator (SOARS)" by Moore et al.

This work addresses the transfer of INPs from water to air via wind induced wave breaking processes.

The authors present an impressive new facility, the Scripps Ocean-Atmosphere Research Simulator (SOARS) wind-wave channel and describe results from a mesocosm campaign named CHAOS (CHaracterizing Atmosphere-Ocean parameters in SOARS). The authors have studied the effect of windspeed on emission of sea spray aerosol and properties of ice nucleating particles from seawater. A wide range of advanced instrumentation was applied to analyze sea spray aerosol and INPs.

Overall, the manuscript presents an amazing new facility and a large body of data, information and thoughts which can serve as inspiration for other studies.

I have some suggestions for improving the manuscript. After consideration of the comments/suggestions below, I recommend publication and look forward to following future findings from the new SOARS facility.

Response: We thank the reviewer for their detailed reading of the manuscript and for helpful suggestions that have improved it.

Main comments

As I understand, the results presented in the manuscript are based on two fillings of the channel with seawater each lasting several days. I miss one or more overview figures showing how the experiments evolved with time and showing how basic parameters such as temperature of water and air, as well as windspeed varied with time from start to end in each of the two experiments. It could also be marked when sampling of different types were performed. Such figures could be provided as supporting material. This will help the reader get a better basis for the discussion.

Response: We have added an overview figure to Appendix A (Fig. A2 in the revised manuscript) which shows details of the two water fills described in this manuscript. Parameters such as wind speed, seawater chlorophyll *a* and total organic carbon (TOC), air and water temperature, water salinity, and selected seawater nutrient concentrations are shown. In addition, the timing of IS filter collections for INPs and details on lighting and water fill timing are indicated in this new figure. It is copied below:

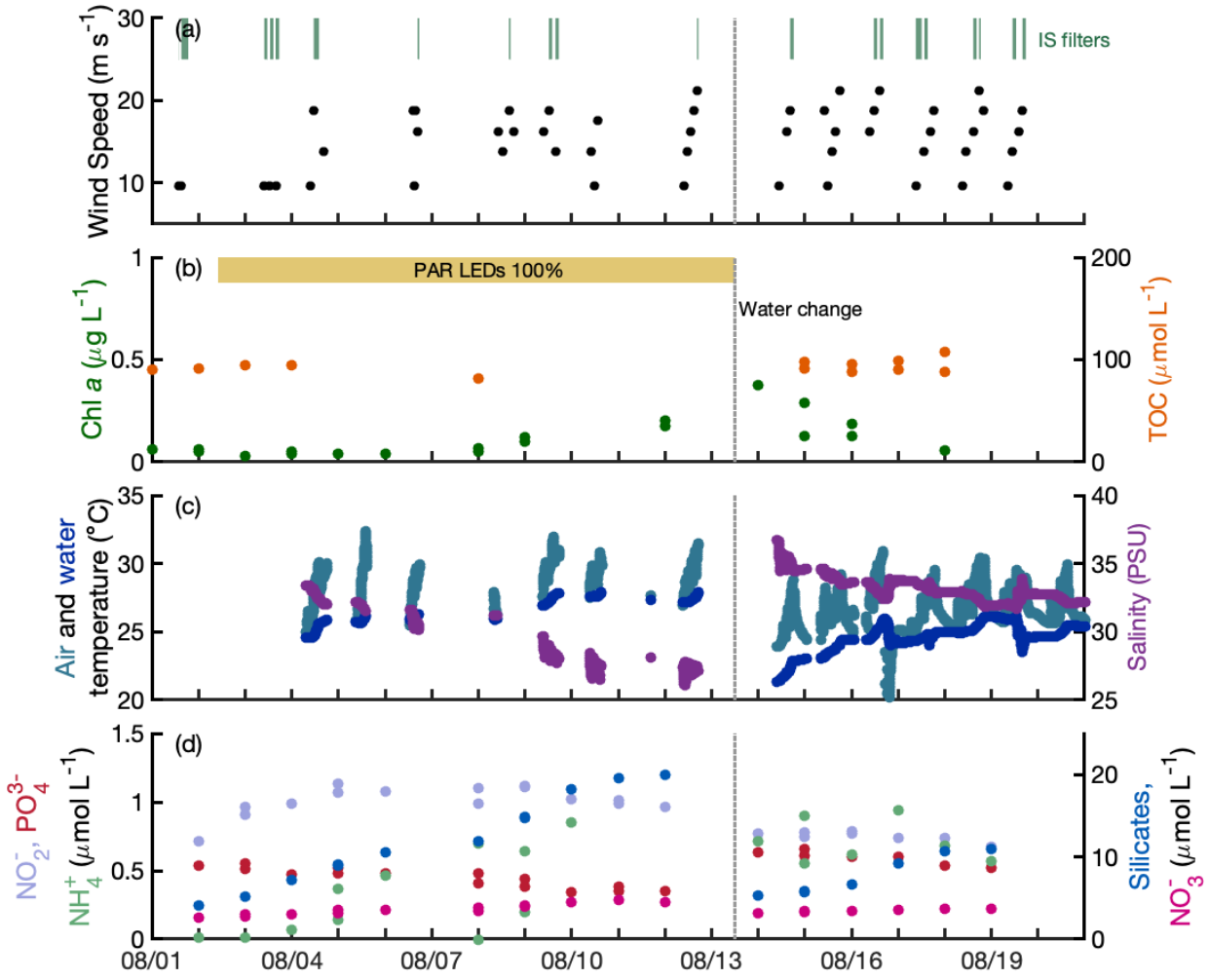

Figure A2. Overview of SOARS parameters during CHAOS, including (a) wind speed and IS INP filter sampling times, (b) chlorophyll *a* and total organic carbon (TOC) concentrations, (c) air and water temperature and seawater salinity, and (d) select seawater nutrient concentrations. Nutrient concentrations shown in (d) are: nitrite (NO_2^-), phosphate (PO_4^{3-}), ammonium (NH_4^+), silicates, and nitrate (NO_3^-). The switch between the third (August 1-12) and fourth (August 14-26) fills of the SOARS channel is indicated in all panels by the dashed gray line. The period when the PAR LEDs were utilized in addition to the solar tubes for lighting is indicated by the yellow bar at the top of panel (b).

Abstract:

Regarding the sentence: “unlike recent measurements from the SOurther Ocean, real-time and offline INP observations during CHAOS exhibited opposite relationships with wind speed which may be related to sampling inlet differences”

I think the abstract would be more informative if the authors explained the relationship from this study explicitly and then say it is opposite to previous field work.

Response: The sentence quoted here was intended to indicate that the online (CFDC) and offline (IS filter) measurements from CHAOS exhibited opposite relationships with wind speed compared to each other. The CFDC results from CHAOS agree with recent field measurements. We have clarified this by rewording this sentence as follows: "In agreement with recent Southern Ocean measurements, online INP concentrations during CHAOS showed an increasing relationship with wind speed, whereas offline CHAOS INP concentrations did not, which may be related to sampling inlet differences."

Methods:

The level of detail given varies, but I assume it is to focus on what is important for the current data-set – for example, it is stated that wind turbine setpoints are calibrated using a TSI Inc. model 9545-A air velocity meter while no details are given on the camera used to infer whitecap coverage. If this manuscript will serve as a reference for future studies in the facility it might be useful if such details are provided. I also realize that wind speed is in focus in this work and that other details may be given in future publications which the authors already mention are in progress or planning, and so perhaps that is why they are omitted?

Response: A detailed overview paper describing the capabilities of the SOARS channel is in progress and will be submitted soon. Because that paper is not yet available to reference, this manuscript provides a broad overview of the facility and more detailed information about the CHAOS campaign and the most relevant components of the SOARS facility, but does not describe every component or capability in great detail.

Were the solar simulators turned on during the current study? What were the brand and wavelength spectrum of the solar simulators and the PAR LEDs?

Response: The solar simulators were on throughout August 2022, and the PAR LEDs were on during August 2-12. The solar simulators are manufactured by SolaTube and match the wavelength spectrum of ambient light, since they simply redirect ambient light into the SOARS channel. The PAR LEDs (ONCE AgriShift MLS) produce broad spectrum white light (400-700 nm). These details have been added to the methods section 2.1.

What were the temperatures of the seawater and the ambient air during the two periods, did they vary?

Response: As mentioned in Section 2.1, water and air temperature were not controlled during CHAOS and were allowed to vary according to the ambient temperature. The new Figure A2 includes a time series of both seawater and air temperatures.

This is a huge facility and water volume, how is the channel cleaned?

Response: Between different wind speed measurements, the air ducts are rinsed with freshwater and then high wind speeds (21 m s^{-1}) are used to remove particle build up from the channel and duct walls. Finally, air is recycled through the HEPA and Carbon MERV filters until particle concentrations have reached baseline levels prior to ramping the wind speed up to the new value.

Between water fills, the water in the channel is drained, and the entire SOARS channel is pressure washed with freshwater and then manually scrubbed. Following another freshwater rinse, the channel is ready to be refilled. These details have been added to the methods section 2.1.

Iine 160: It is a bit unclear what/when the sampling periods took place and how long they were. Sampling periods for different types of sampling (e.g. aerosol filters, INP) could be indicated in overview figures as suggested above.

Response: Sampling periods varied in both time and length each day depending on a variety of factors, including technical difficulties with the new paddle assembly, but were generally several hours per wind speed, with multiple sampling periods per day. Wind speeds and INP filter collections are now indicated in the new summary Fig. A2.

Line 275: why is a density of 2 assumed?. I think there is a typo in the unit: should be g cm-3 not g cm-1?

Response: The density is based on Zieger et al. (2017), and a citation has been added to the text. Thank you for catching that typo, the unit is indeed g cm^{-3}, and this has been corrected.

Figure A3: how should a transmission efficiency larger than one be understood? I suggest to also show the corresponding figure using the corrected values of density etc.

Response: A transmission efficiency larger than one indicates particles of that size are more concentrated in the air stream than their ambient concentration (in the SOARS channel). This enhancement is due to the relative air speeds in the channel and inlet, as well as the inlet orientation and geometry. Sorry for the confusion, but Fig. A3 (now Fig. A4) does in fact show the calculated transmission efficiencies after adjusting for expected particle density, water uptake, and shape factor. We have replaced "later" with "then" in the figure caption and text to hopefully clarify this.

Figure A4: The description of normalization and figure A4 would benefit from further explanation. Under which conditions are the data taken – is the slope the correction factor? What are the uncertainties? Is n300 nm sometimes used for normalization – this is difficult to understand from the text.

Response: Correction factors for the CFDC OPC were derived because its lower size bound is ~300 nm, so it misses smaller particles. Particle concentrations > 300 nm were never used for normalization, on the contrary, they were corrected to better represent the ambient aerosol concentrations in the SOARS channel. Methods section 2.3 has been reworded to clarify this, and that the correction factors were derived from simultaneous SEMS + APS and CFDC OPC measurements (at the same wind speed). The caption for Fig. A4 (now Fig. A5) has been updated to clarify that the slopes shown in the figure are the correction factors applied to the CFDC OPC data. An additional supplementary table (Table C2) has been added, which lists the correction factors and uncertainties for each aerosol parameter. Table C2 is copied below:

Table C2. Correction factors (and 95% confidence bounds) for total particle number, number >500 nm diameter (n500), surface area, and volume concentrations measured by the CFDC OPC, which were derived by comparison with simultaneous (same wind speed) SEMS + APS measurements.

Aerosol Parameter	Correction Factor	R^2
Number (cm^{-3})	18.93 ± 0.74	0.88
n500 (cm^{-3})	0.55 ± 0.04	0.63
Surface Area ($\mu m^2\ cm^{-3}$)	1.93 ± 0.07	0.87
Volume ($\mu m^3\ cm^{-3}$)	1.09 ± 0.05	0.83

In lines 150-153 white cap fraction during CHAOS is discussed, but no data or values are given, is it possible to give such numbers?

Response: White cap fraction in the SOARS channel will be discussed in detail in the SOARS methods paper, which is about to be submitted. Since the actual white cap fraction data is not a focus of this paper, we have added the estimated white cap fraction for 18.5 m s^{-1} and 1.3 amplitude scaling (6.44 ± 1.53%) to the text, but will leave a comparison with open-ocean measurements and other wind speeds and amplitudes to the SOARS methods paper.

As I understand the wind speeds shown in all figures are the values extrapolated to 10 m height (U10) from the measured windspeed at 0.6 m in SOARS – is this correct? The extrapolation is based on Hsu et al. 1994 – I suggest providing the value of p used, also, I was wondering, is it necessary/justified to give the extrapolated U10 windspeed with two decimals (m/s) on basis of Hsu et al?

Response: This is exactly correct. We have added the value of *P* used (0.11) from Hsu et al. (1994) and also clarified that near-neutral stability was assumed. We agree that two decimals are probably not justified and have reduced wind speeds to one decimal in all text and figures.

Results and discussion

Figure 2A –To avoid misunderstandings, I suggest that the equations for activated fraction, surface site density and volume site density are provided. Is surface and volume densities also normalized only to particles larger than 500 nm? (perhaps it does not matter so much as the larger particles dominate these distributions?)

Response: The equations for INP activated fraction and surface and volume site density are now given in Appendix B and referenced in Sec. 3.1. Surface and volume site density are calculated from total particle surface area or volume; only N_{n500} is limited to particles >500 nm.

I suggest showing the surface and volume distributions for the size distributions in Figure A5 in and additional figure.

Response: Since surface area and volume distributions are not discussed anywhere in the manuscript, we are not clear what value this would add for the reader. A study focused on SSA fluxes in SOARS is in progress, which will include the suggested distributions.

Regarding the INE measurements: it is concluded: "The INE stability across multiple fills of the SOARS channel and over time with the same water indicates the observed INP-wind speed relationships were driven by wind-wave interactions rather than biological activity" and in the abstract it says that sea water ice nucleating entity concentrations during CHAOS were stable over time and therefore changes in INPs were driven by windspeed and wavebreaking mechanisms and not seawater chemistry or biology. Were any data on seawater chemical composition or biology available to further support this interesting conclusion? This could be interesting to look further into in future studies.

Response: Yes, measurements of chlorophyll *a*, total organic carbon (TOC), microbial cell counts, and nutrient concentrations were made throughout CHAOS. A selection of these data are now shown in the new summary Fig. A2. Future studies in CHAOS will focus more on the relationship between seawater biology and chemistry and subsequent SSA and gas production.

Minor comments

What is the material of the paddle?

Response: The paddle is made of a fiberglass and foam core with an epoxy coating. It is strengthened with titanium rails, and the edges that contact the ceramic bearing pads on the walls and floor of the channel are covered in teflon slides. These details have been added to the methods Sec. 2.1.

The sentence about SMA (line 25) is in between two sentences about SSA – since SMA is not SSA this is a bit confusing. I suggest moving the SMA sentence to the end of the paragraph.

Response: We have rearranged the paragraph as suggested.

Figure A1: it would be nice with indication of length scales on the figure.

Response: Fig. A1 has been updated with larger labels and a length scale.

Line 116: The function of the MERV 8 and potassium permanganate filters should be explained.

Response: All the air filters installed in SOARS are intended to prevent ambient particle and VOC contamination from impacting measurements inside the SOARS headspace. This has been additionally clarified in Sec. 2.1.

Line 198: I find something is strange in the formulation of this sentence - how can filters be collected without airflow?

Response: Blank filters are “collected” without applying airflow to the filter in order to estimate the process blank of all steps included in INP filter collection. This includes installation of the filters in the filter housing, transport to the SOARS channel, and connection to the sampling tubing. Airflow is not applied because they are intended to estimate INP background contamination and not sample concentrations. As described later in Sec. 2.2.2, the blank filters were used to correct the sample filter INP concentrations to remove background INP concentrations.

Something is wrong with the URL to the Hsu paper in the reference list.

Response: Thank you, this has been corrected.