Response to Reviewer #1 comments on Manuscript egusphere-2023-956: Microphysics of radiation fog and estimation of fog deposition velocity for atmospheric dispersion applications

This manuscript is a detailed description of studies of fog physics in the Abu Dhabi region in the winter seasons 2021 and 2022. Twelve events were analyzed, while not all instrumentation was operative during all 12 events. Nevertheless, the data sets bear a lot of information. The manuscript is long, providing much information about fog physics and meteorological conditions. Much of the description provided does not seem focused in terms of the scientific goal of the manuscript.

We appreciate the reviewer's feedback on our work, and thank him/her for his/her several comments/suggestions that help to further improve the quality of our study. We have shortened the paper and sharpened our message, placing greater emphasis on the main scientific goals of the study. Below we address each separately, highlighting in the text where changes, if any, were made.

This reviewer has 2 major concern:

(1) How was the ultrasonic anemometer located with respect to the FM120 fog spectrometer? The photographs in Figure 1 suggest that these 2 instruments were not co-located. That would lead to the conclusions that all eddy covariance (EC) data with respect to turbulent LWC and fog droplet fluxes were void. Authors need to either present convincing arguments that the positions of the 2 instruments were close enough to each other (please provide exact details) for EC application, or to delete all information and data from the manuscript that refers to fog EC.

Reply: We appreciate your meticulous observation regarding the co-location of the 3D ultrasonic anemometer and the FM120 fog spectrometer, and acknowledge the potential implications for the eddy covariance (EC) data interpretation. The 3D ultrasonic anemometer is strategically installed at a height of 4 m on a 10-m meteorological tower. The positioning of this anemometer is approximately 6 km upwind from the FM120 fog monitor's location. We concur with your concerns regarding the inherent uncertainties tied to the estimation of the liquid water turbulent flux due to the spatial separation between these two instruments.

The logistical constraint of our study is that the anemometer is situated at a remote location where a power source, essential for operating the fog monitor, is unavailable. However, we would like to highlight that the fog events under investigation exhibited spatial homogeneity. In other words, variations in droplet size, density, and turbulence characteristics are minimal between the two locations. This homogeneity feature is a valid hypothesis in this study, in particular because the area where the two instruments are installed is a hyper-arid environment with flat terrain and homogeneous land cover (bare earth), which most likely will lead to low spatial changes in the fog deposition rate. This is exemplified in the SEVIRI fog Red-Green-Blue images for the three events presented in Figure 8, which we have referenced below (Figure R1). As the reviewer can see, the fog patches encompass almost whole UAE and the two locations (6 km apart from each other’s) are completely under the same fog cloud.

01 UTC, 27 Jan, 2022	01 UTC, 04 Feb, 2022	04 UTC, 24 Feb, 2022

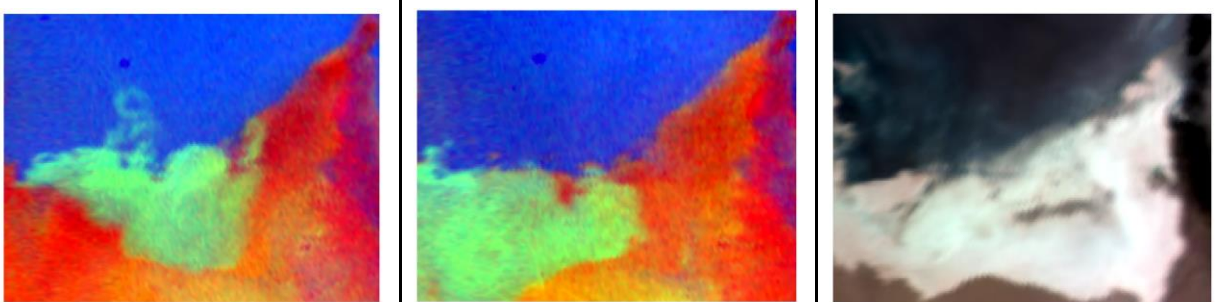


Figure R1. SEVIRI Fog Red-Green-Blue (RGB) plots for the 27 January, 04 and 24 February 2022 events, shown at 01 UTC, 01 UTC and 04 UTC, respectively.

Furthermore, we have compared the meteorological parameters at both sites. The correlation coefficients for air temperature and relative humidity between the two locations for the three fog events in 2022 are 0.98 and 0.96, respectively. This provides further evidence of the similar meteorological conditions at both sites during the fog events.

In light of the reviewer’s feedback, we have re-evaluated our presentation of the EC data in the manuscript, ensuring that we clearly communicate the limitations and provide an adequate justification for our approach (Lines: 188 – 208, section 2.2.4).

(2) Please provide evidence that a data collection rate of 1 Hz (line 145) is sufficient to compute reasonable fog LWC fluxes.

Reply: Thank you for highlighting the need for clarity regarding the data collection rate. We regret the oversight in our initial submission. For precision, our 3D ultrasonic anemometer records measurements at a frequency of 10 Hz, while the fog monitor operates at 1 Hz. We begin by determining the perturbations in the vertical velocity component using the 10 Hz data from the anemometer. It is essential to note that the fog monitor's operational capability is capped at a 1 Hz sampling time. The sampling times for all instruments used in this study have now been added to Table 1. Therefore, for the purpose of calculating fog deposition flux, we average the vertical velocity perturbations over a 1-second interval. These averaged perturbations (w') are subsequently utilized to estimate the fog deposition flux.

Turbulence in the atmosphere is characterized in terms of its energy distribution across different scales. The Kolmogorov spectrum for the inertial subrange describes this turbulent energy distribution across frequency bands. Within this subrange, turbulent energy predominantly transfers from larger to smaller scales without major production or consumption. The energy spectrum can be expressed as $E(f) \propto f^{-\frac{5}{3}}, f$ denoting the frequency (Stull, 1988). Our 10 Hz sampling captures most of the turbulence within this subrange. Averaging these to a 1-second interval acts as a low-pass filter, retaining the larger, more energetic eddies relevant for fog deposition flux. These large eddies are fundamental to the vertical transport in the atmosphere, while higher frequency, smaller eddies contribute less to this transport (Stull, 1988). When monitoring vertical fluxes, the focus is often on the time-averaged fluxes, enabling the use of considerably lower sampling rates. For illustration, (Bosveld and Bouten, 2001) utilized a 1 Hz sampling rate for eddy-covariance measurements made 30 m above an 18 m coniferous forest. Hence, our methodology is aligned with the scales most relevant to fog deposition flux and the principles of atmospheric turbulent spectra. It should be noted that the sampling rate also depends on the complexity of the environment where the eddy-covariance system is operating. In our case, both the anemometer and the fog monitor are deployed in hyper-arid, flat terrain characterized by bare land. These additional clarifications have been included in the revised version of the manuscript (Line: 466 – 488, section 2.6). We trust this provides clarity on our methodology, and we appreciate your attentive feedback.

Further comments:

1. In the abstract, please explain the acronyms MYJ PBL scheme and FLEXPART upon their first mention

   Reply: We apologize for the oversight. In the abstract, "MYJ PBL scheme" stands for the Mellor-Yamada-Janjic Planetary Boundary Layer scheme, while "FLEXPART" denotes the FLEXible PARTicle dispersion model. We have now expanded these acronyms both in the abstract and within the main text (Line: 24-25).

2. line 27: The precision of the number 23.16 is too high.

   Reply: Thank you for pointing that out. We have adjusted the value to a more appropriate precision level in the revised manuscript for better clarity and readability (Line: 28).

3. line 32: The precision of the numbers 2.11 and 7.87 is too high. Please use only 2 significant digits. In this case: 2.1 and 7.9.

   Reply: Thank you for your suggestion. We have adjusted the values of 2.11 and 7.87 to 2.1 and 7.9, respectively, in the revised manuscript (Lines: 33).

4. line 163, Table 1: Replace Luft by Lufft

   Reply: We apologize for the oversight. The reference to "Luft" in text and Table 1 has been corrected to "Lufft" in the revised manuscript (Line: 176). Thank you for bringing this to our attention.

5. Line 214: Re-type forty-five

   Reply: Thank you for pointing it out. We have corrected the text in line xx, replacing the word form "forty-five" with its numeral representation "45" in the revised manuscript (Line: 253). We appreciate your diligence.

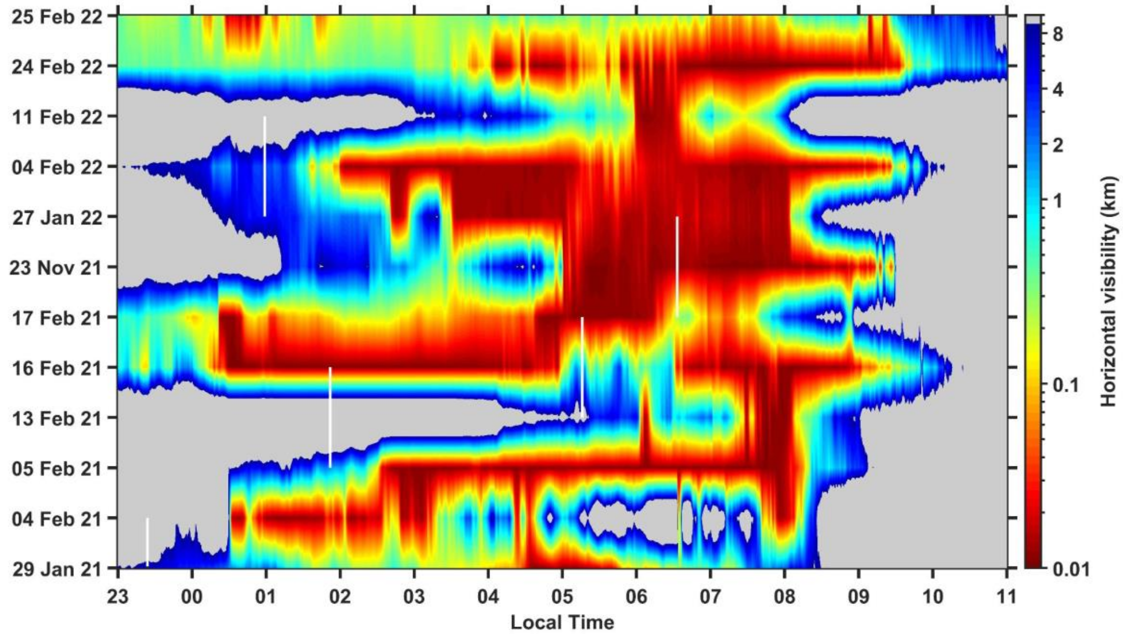
6. Lines 282 – 285: The described procedure lets this reviewer suspect that there might be a circular conclusion. Please provide evidence showing that this is not the case.

   Reply: We appreciate the insightful comment. As stated in the text (lines 322-323), the decision to use the threshold of 0.1 g m^{-3} was not arbitrary, but instead grounded on empirical observations from trial simulations. These simulations were benchmarked against independent LWC observations at the BNPP. We observed a consistent overestimation of the near-surface LWC by the WRF model when compared to these independent measurements. By implementing the stated threshold, our intention was to more closely align the model's outputs with observed data, in other words ensure that the model captures as much as the observed fog clouds as possible. We have now made this clear in the text (lines 328-332). It is important to note that while this threshold did influence certain aspects of our model's results, our conclusions were drawn from a broader analysis that is not solely reliant on this threshold. In other words, the threshold serves as a corrective measure to a known model bias but is not a foundational pillar upon which our conclusions rest.

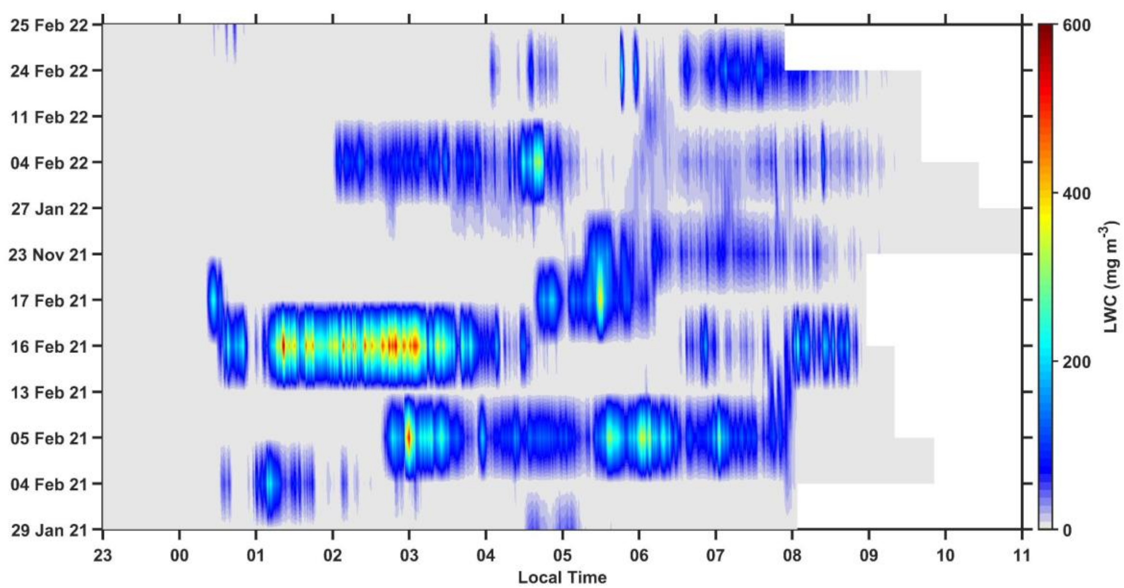
7. Fig. 2: In the graphical representation, data of individual fog events overlap each other. Please separate individual events from each other.

   Reply: Thank you for your valuable feedback regarding the visibility of the lines in Figure 2. In our initial revision, a different reviewer highlighted the value of maintaining the line plots, emphasizing their relevance and utility for conveying specific aspects of our findings. As such, we have opted to retain Figure 2 in its current format to uphold the integrity of these insights. However, we deeply appreciate your concern regarding clarity and, to that end, a contour plot illustrating the diurnal variability in horizontal visibility, liquid water content, number concentration during the 12 fog cases is provided below for enhanced visualization and clarity. We hope this additional figure aids in the understanding of our analyses and we sincerely thank you for your astute observation.

(a) Horizontal visibility



(b) Liquid water content



(c) Number concentration

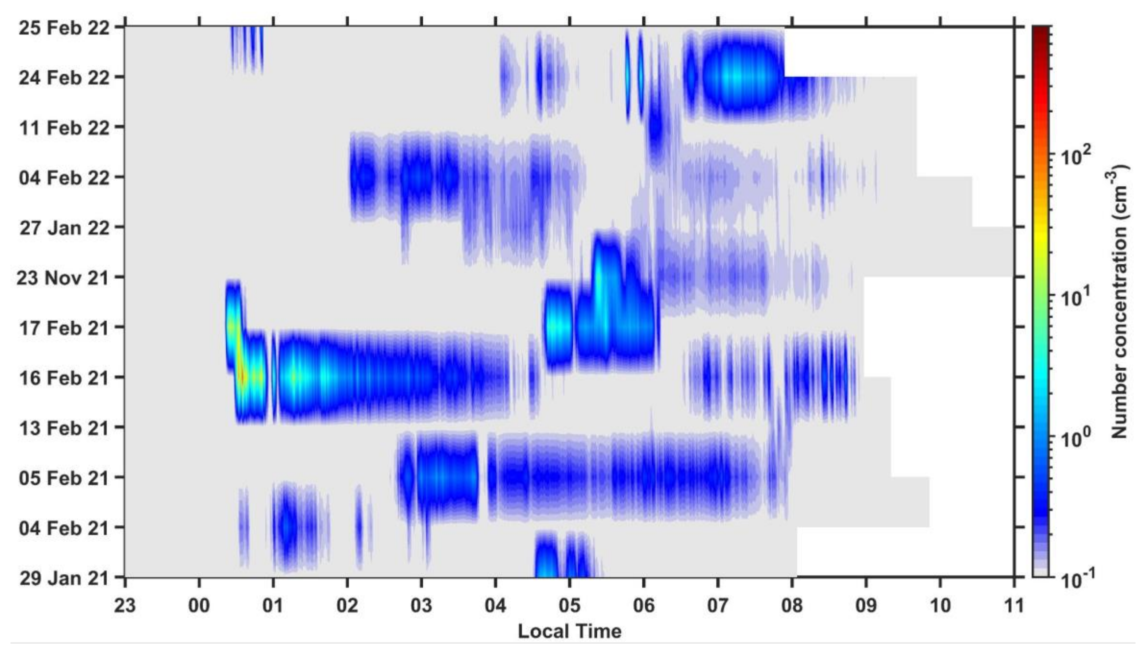


Figure R1. Diurnal variations in (a) horizontal visibility (km), (b) liquid water content (LWC; mg m^{-3}) and (c) number concentration of cloud droplets (cm^{-3}) for 12 fog events at BNPP

8. Fig. 5: Please be more specific on the shading. It is not clear what it exactly means.

   Reply: Thank you for pointing it out. In Fig. 5b, the gray shaded area represents times when the visibility is less than 1 km (i.e. fog is present at the site). We have updated the caption of Fig. 5 in the revised manuscript to reflect this clarification.

9. Line 514 – 516: Agreed in principle. However, the reasoning is still speculative and must be classified as such in the manuscript.

   Reply: We appreciate the reviewer's insight and agree with his/her comment. To address this, we have modified the section to better represent our findings and to reflect a more cautious interpretation in light of the available data (Line: 629:660). We now clarify the specific stage of the fog (peak of the mature stage) in which the observed phenomenon occurs. Also, added Figure 5c, Box plot showcasing the distribution of mass and number density for 12 fog events, both during the onset and mature stages of fog, distributed across four droplet-size ranges: 1-5 µm (black), 5-10 µm (red), 10-20 µm (blue), and 20-50 µm (green). Once again, we are grateful for the reviewer's constructive feedback and will make the necessary adjustments to the manuscript to ensure its clarity and scientific rigour.

10. Fig. 6a: The rH not even reaching 90 % in one of the events (no. 3?) needs explanation. Could it be a measuring artefact? If yes, what would that mean for the data of the other events?

Reply: Thank you for bringing this to our attention. Upon revisiting our data, it appears that the event the reviewer is referring to is event 4. For event 4, and despite its shorter duration of around 30 min (Table 3), the average RH during the fog event was still above 90%. As per reviewer suggestion, we have computed the mean RH and wind speed for all fog events and added them to Table 3. Your feedback is invaluable in ensuring the clarity and robustness of our findings. We are grateful for your meticulous review.

11. Fig. 6a: In view of this reviewer, it is not useful to compute and to show composite data as presented here, because the timing of the individual fog events differs largely.

Reply: Thank you for your feedback regarding the composite data presented in Fig. 6a. We understand your concerns about the differing timings of individual fog events potentially affecting the composite's accuracy and relevance. In light of your comment, we have removed the composite line from Figures 6a-b. We appreciate your input in helping improve the clarity and the rigor of our presentation.

12. Fig. 8: It is not clear what "turbulent vertical velocity" should be. It would be much netter to show the turbulent LWC fluxes or fog droplet number fluxes.

Reply: We apologize for the confusion regarding "turbulent vertical velocity" in Fig. 8. In this context, we used turbulent vertical velocity flux, to quantify the intensity of turbulence. However, upon reflection and in light of your feedback, we acknowledge that it would have been more appropriate to estimate the turbulence kinetic energy (TKE), which is a widely recognized metric for turbulence quantification. Consequently, we now present the TKE in Figure 8b. We would also like to point out that the LWC fluxes are already illustrated in Figures 9(a-c). Thank you for bringing this to our attention.

13. Fig. 9 shows that during a significant portion of the fog duration, the turbulent LWC fluxes are upward. Although this is briefly mentioned in a side comment in lines 620 and 621, and although this phenomenon has been observed by several authors at other locations, this phenomenon and the potential causes should be discussed in much more detail.

Reply: We would like to thank the reviewer for raising this issue. Indeed, several authors have reported upward turbulent LWC fluxes during fog, such as Degefie et al. (2015) for fog events around Paris during November 2012 - March 2013. It can occur in response to condensational growth near the ground surface and a subsequent broadening of the fog droplet size distribution. An inspection of Fig. 9 indicates this may also be the case in the selected fog events. We have stated this in the text (lines 799-803) and would like to thank the reviewer again for his/her comment.

References

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