Review of "Aerosol-cloud interactions in mixed-phase convective clouds. Part 2: Meteorological ensemble" by Miltenberger et al.

The authors perform ensemble simulations of a case of deep convection forming along a sea-breeze convergence line in the southwestern UK. Detailed analysis of the case is first presented in the accompanying paper Part 1. Using an ensemble of simulations, the authors perform concurrent investigations into the variability in simulated cloud properties due to meteorology and the variability due to aerosol scenario. A total ensemble of 30 members is used, comprising 10 meteorological members (produced by downscaling a global ensemble with perturbed initial conditions) and then for each meteorological member employing 3 aerosol scenarios (a standard case close to that observed in accompanying Part 1, and a low and high case with respect to the standard case). When ensemble members are paired according to the meteorological initial and boundary conditions, aerosol-induced changes to the cloud properties are found to be consistent across the ensemble. The authors find statistically significant aerosol-induced changes to the cloud droplet number concentration, cloud fraction, convective cell number and size, outgoing shortwave radiation and precipitation efficiency. The authors conclude that for most cloud properties a large number of ensemble members (order 100 or more) of meteorological conditions is required to detect a robust aerosol effect. Only for impacts on cloud droplet number concentration and shortwave radiation are small sample sizes sufficient.

The manuscript generally presents and explains the results clearly, and I find it to be a very useful scientific contribution to the literature, where case studies rarely employ ensemble methods (especially when high-resolution cloud-resolving models are used). However, there are many typos and language errors scattered throughout the manuscript which must be addressed before publication. Further, I find the figure ordering and the placement of a couple of key figures in the supplementary information to be somewhat detrimental to the reader's comprehension, and I would recommend giving this careful attention before publication.

I have provided detailed comments below. I recommend publication in ACP subject to major revisions.

General comments:

1. The manuscript contains many typos and errors that the team of authors should really have addressed together through proof-reading before submission for review. I have listed these in my specific comments.

2. I believe there are some inconsistencies in the references to ensemble members. I have noted these in my comments on Section 4.2.

3. **Figure ordering:** I found the order of figures somewhat counterintuitive and hard to follow.

I had to lay my printed copy of the figures and the supplementary figures out next to each other in order to follow the arguments made in the text. Whilst I appreciate that there are

already a lot of figures in the paper, I would suggest moving figure S8 to the main paper if possible.

Further, the figure ordering in the main paper is not logical. I appreciate that it is difficult to optimally order figures when investigating concurrent sensitivities, but I would recommend placing the order of current Figures 7,6,5 as such. On P10 L4, the reference to Fig 7a, I had to jump ahead several Figures in order to see this. On P10 L34 I had to jump back again to Fig. 5, which is referenced for the first time after Fig.s 7 and 6 are discussed in detail. Why put Fig 5 in its current location? You would make it much easier for the reader if it appeared after 6 and 7.

Page 11, 1st paragraph: again, you refer to Fig 9 and then immediately after to Fig 11, and Fig 10 is not even mentioned until page 13.

4. General comments on figures:
Many of the figures have lines joining the points representing each ensemble member. This is misleading, as the abscissa on these figures show ensemble members (a discrete dataset) and not continuous data. I recommend removing these lines.

Figure SI 9 – I tried very hard to understand this Figure, but it many things in it don't make sense to me. See notes under my comments referring to individual figures.

5. Section 2:
Stochastic physics – are stochastic physics used in the regional model as well as the global model? Are stochastic physics used in the full set of ensemble runs? (Are you using stochastic physics as well as perturbed initial conditions?) What kind of stochastic physics are used? Which schemes and which parameters? Etc. This needs a little more explanation if you are discussing a study which aims to capture meteorological variability.

6. Section 3.1:
P6 L13 – Was the model microphysics output passed offline through the same radar algorithm as the Radarnet data? If not, could part of the difference be because the online UM dBZ calculation is different from the dBZ calculation in the Radarnet algorithm?

7. Section 4.1:
P9 L5-6: "These members have a higher cloud fraction" – do you know why this is the case for these members?
P9 L17-18: Is this also related to the cloudiness (higher cloud fraction in these members)?

8. Section 4.2:
P10 L11-12: Members 4 and 7 have a particularly large surface sensible heat flux – can you explain why? It doesn't seem like they stand out in terms of cloudiness (Fig. 6).

P10 L22: largest (smallest) values for ensemble members 8(4) – I find it hard to see by eye on this Figure, but doesn't this actually apply to members 9(5) not 8(4)?

P10 L22-23: Really? I find this hard to see (Fig 6d vs Fig SI 7c)

P10 L25-26: ensemble members 1,2,5,8 have a relatively large fraction of deep clouds – I don't see this. What about e.g. member 6 (Fig SI 8a)?

P10 L29: changes in condensate generation, i.e. air mass lifting – have you looked at the dynamical convergence to see if this is the case?

P10 L32:

- "member 8 has a relatively large PE" – I disagree with this. Many others have a greater PE, e.g. 1, ctrl, 6 (Fig. 7)
- "and the largest fraction of clouds with tops above 4.3 km" – I also disagree with this. The largest fraction of clouds with tops above 4.3 km is seen in member 6 (Fig SI 8a).

I think in this sentence perhaps the authors mean to refer to member #6, not member #8? Then I agree with the statements made in the sentence.

P11 L1-4: this final section is not particularly well-explained and no relevance is given. Can you say anything about the processes and impact or importance?

P11 L3-4: Largest (smallest) values occur for ensemble members 2(7) – I only just agree with this. Do you mean member 1 not member 2 for the largest SW radiation values and largest CF?

Specific comments and typos:

P1 L16: "consider" -> "considered"
P2 L3: "climate system"
P2 L4: "The main issues…"
P2 L5: "… on model grid scales several orders of magnitude larger, and the…"
P2 L6: "In the last few decades" / "In recent decades"
P2 L6-7: "the modification of cloud properties has been studied in particular"
P2 L7-8: "… and the relation between particle number concentrations and radiation" – this whole sentence feels quite clumsy.
P2 L13: "necessitated by" -> "necessary because of"
P2 L15: "changes to simulated for individual clouds" – simulated what?
P2 L17: You could also include a reference here to the 2012 paper by Seoung Soo Lee where placing an aerosol perturbation in the mesoscale domain of a simulation led to intensification of convection within an MCS but suppressed precipitation in the larger-scale domain. (Reference provided at the end of this set of comments)
P2 L29: Southern Great Plains
P3 L6: What do the authors mean by "cloud-induced changes to large-scale forcing"? Does this refer to large-scale circulation and / or synoptic forcing, or something else?
P3 L8: "has also" -> "also has"
P3 L10: relay -> rely
P3 L11: rises -> raises
P3 L12: datasets
P3 L12: has recently been demonstrated

P3 L14: Southern Great Plains
P3 L23: in future forecasting systems
P3 L28: 30th
P3 L34: baseline
P4 L2: a precipitation -> precipitation
P4 L4: the observed aerosol
P4 L7: convective invigoration hypothesis needs a description and / or citation
P4 L10: investigate whether the
P4 L17: Section number missing. (should this be Section 5?)
P4 L23-24: The way this sentence is written doesn't quite make sense.
P4 L25: do you mean "9 members are selected from", not "selected for"?
P4 L32: mesoscale
P5 L3-4: repetition of "current study"; you could just say "to our main conclusions".
P5 L6: In addition to (delete comma)
P5 L11: h a grid -> horizontal grid ?
P5 L32: datasets
P6 L3: peninsula (remove capital P)
P6 L16: have also reported
P6 L15: underdispersive over longer
P6 L31: smaller if (delete comma)
P7 L21, 23, 26: dewpoint
P7 L31: ensemble members
P9 L20: similar, with a well-mixed
P9 L25: temperate -> temperature
P10 L3,8: mesoscale
P10 L4: "G is very well correlated" – have you actually correlated this (or can you)?
P10 L4-5: Figures 4a and 7a are difficult to compare as they are on different pages
P10 L14: convergence
P10 L18: areal
P10 L26: an about 20% -> about a 20%
P10 L 10-31: refer to Fig SI 8a
P11 L3: largest (smallest) cloud fraction – please refer to Fig 6c.
P11 L4: distribution of cloud top heights (Fig. 11b) – you also need to refer to the Fig. showing CTH.
P 11 L8: "low", "high": open quotations are the wrong way wrong (LaTeX `` not ")
P 11 L9: "which have a factor of 10 lower and higher aerosol number concentrations, respectively, than the standard profile"
P11 L10: altitudes
P11 L10: The mean and effective radius – mean what? Mean radius and effective radius?
P11 L12: the first section of this study?
P11 L13: ensemble members
P11 L17; Figure 5 should be moved, as discussed in the major comments
P11 L21: "suggest only minor changes in the cloud-base vertical velocity distribution" – can you plot this distribution? Doesn't this contradict the previous statement made about convergence?
P11 L24: "the number of cells decreases with increasing background aerosol concentration, but the cell area increases" – this is interesting! Can you explain why this happens?

P11 L30: cloud top height increases
P12 L2: “ensemble members 1,2,7,8, and 9“ (missing space between “and9”)
P12 L2: “ensemble members 1,2,7,8, and 9“ – this is also true for member 4
P12 L3: “does not increase further (members 1 and 2)” – doesn’t member 2 increase?
P12 L5: higher than 4.3 km shows only
P12 L7: aerosol scenario is likely (remove comma)
P12 L8: “maximum” (open quotation incorrect way round)
P12 L12: “only a small change”
P12 L14: “-4 – 2.5%” - this notation is confusing. Do you mean -4% to -2.5%, or -4% to +2.5%?
P12 L18: I do not understand Figure SI9.
P12 L21: Can you plot delta G and delta L instead of G, L?
P12 L29: “seized” -> “sized”
P 12 L32: simulations in the standard
P12 L34: in Figure 7c in my printed copy, member 7 also looks like it has no change
P12 L34: “The latter have a relatively small decrease of PE and comparatively large delta G” – but member 1 also has a decrease in PE and delta G, but a decrease in precip in standard vs low scenarios, and is outside the shading in Figure 10.
P13 L1: “comparatively large delta G” – this is hard to see from Fig 7a. Can you plot delta G and delta L instead of G and L?
P13 L10: “Exceptions are ensemble members 3,4 and 5…” – you should point out that the behavior in each of these members is different from each other. For the (a) low to standard and (b) standard to high aerosol scenarios, member 3 has an (a) decrease and (b) increase, member 4 has an (a) decrease and (b) decrease, and member 5 has an (a) increase and (b) decrease.
P14 L11: two sections
P14 L20: datasets
P14 L29: realisations
P15 L4: distribution in different cloud top height classes
P 15 L11: Precipitation formation is known…
P1 L21: accordingly displays
P15 L29: very similarly to
P15 L34-35: “the liquid water path (…) shows little sensitivity to the aerosol scenario” – actually, there is a decrease in LWP (Fig 9b) which is not that much weaker than the increase in CWP (Fig 9a) – this indicates even more strongly than you currently state that the FWP must increase!
P16 L9: mesoscale
P17 L2: “perfect” (open quotations incorrect way round)
P17 L3: only slightly different
P18 L4: exact number is
P18 L7: several 100 ensemble members -> several hundreds of ensemble members
P18 L11: Why is low-high so different from low-standard and standard-high?
P18 L13: Accumulated precip stands out here – are you able to explaim why? (It’s the only one that needs fewer observations for an increase of number concentration above the standard scenario).
P18 L14: “the thermodynamic constraints on aerosol-induces changes…” – constraints for this particular case, or general constraints?

P18 L15: allows us to put the aerosol-induced changes / allows the aerosol-induced changes to be put

Comments on individual figures:

Fig 4:

- Don't join these points with lines

Fig. 5:

- Can you comment on why these are so invariant?
- What do the colours represent?
- I think Figure 5 should appear AFTER Figure 6 (given the ordering of discussion in the manuscript)

Fig. 6:

- "cloud fraction is the fraction of the domain for which" (add "the", remove comma)

Fig 7:

- Fig. 7a would be clearer if you plotted delta G and delta L instead of absolute values
- Don't join these points with lines
- "the last column in each panel"
- Caption: "means" – do you mean ensemble mean, or ensemble means?

Fig 10:

- What do the open versus the filled circles represent?
- Legend: should "high processing" be "high aerosol"?
- Caption: "black symbols" – I can't see any black symbols on Fig 10
- Caption: downward / upward triangles: I can't see any of these on Fig. 10

Fig. SI 2:

- "The distributions consider cloudy…"

Fig. SI 3:

- caption L3: "observational data"

Fig. SI 4:

- I find the dark blue lines hard to distinguish in my printed copy

Fig. SI 7:

- 7b: where are the points for ctrl data on the CIN and CAPE Figures?

Fig SI 8:

- How sensitive is this figure to how you choose to define low / medium / deep cloud tops?
- It would be worth placing labels on the Figure with "low", "med", "deep" near the relevant set of points, just to make it clearer for the reader.
- Again, I don't think these points should be joined with lines.

Fig SI 9:

- I found it almost impossible to understand this Figure. Are condensation and deposition shown separately, or combined? What are the symbols? What do IG and IL refer to? Also, as mentioned in the major comments, I don't think that the points

representing the ensemble members should be joined with lines. This is not a continuous dataset. (My printed copy also has different linestyles in the Figure, which are not explained, but I suggest to remove the lines entirely).

- Caption: … and deposition rates

Comments on tables:

Table 1:

- Caption: variable (columns)… aerosol scenarios (rows) – aren't these the other way round? (Don't the rows show the variables and the columns the aerosol scenario?)
- What do the bold numbers in the table mean?

Table 2:

- Why does the low-high scenario need so few samples compared to low-standard or standard-high?

Additional references:

https://journals. Lee, S.S., 2012: Effect of Aerosol on Circulations and Precipitation in Deep Convective Clouds. *J. Atmos. Sci.,* **69**, 1957–1974, https://doi.org/10.1175/JAS-D-11-0111.1
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