

Author Response to Referees: Revised Submission

acp-2020-1213

Summer aerosol measurements over the East Antarctic seasonal ice zone

Jack Simmons et al.

a) Anonymous Referee #1

The authors wish to thank referee #1 for their time in reviewing the revised manuscript. The authors are grateful that referee #1 finds our changes to the initial manuscript satisfactory. Comments on the revised submission are addressed below. The referee is quoted in italics, and author responses in standard font. Edited text from the manuscript is included in quotations. A document showing tracked changes since review is also included in the revised resubmission.

I believe the authors have made satisfactory corrections to the manuscript and responses to the reviewers. The only minor issue I found was an incomplete sentence and repeated sentences in the Figure 1 caption.

Thank you for this feedback. The caption for Figure 1 now reads:

“Figure 1: Voyage tracks of the SIPEX-II and PCAN voyages. Voyage tracks of the SIPEX-II (spring 2012, grey) and periods of the PCAN voyage (summer 2017, orange) for which measurements were analysed. Measurements from the southward PCAN transit are excluded due to instrument malfunction. Grey shading represents the sea ice area observed at the mid-point of the SIPEXII voyage as detected by the Nimbus-7 satellite (National Snow and Ice Data Centre, 2021). No sea ice was present in the plotted region at the midpoint of the PCAN voyage. An interactive map of RV Investigator voyage tracks can be found [here: https://www.cmar.csiro.au/data/underway/?survey=in2017_v01](https://www.cmar.csiro.au/data/underway/?survey=in2017_v01).”

In the future, it would help the reviewer if the authors included the changes made to the text and figures in the reviewer responses when practical.

Thank you for this feedback- this is understood and this information will be included from now on.

a) Anonymous Referee #3

The authors wish to especially thank referee #3 for reviewing this manuscript as this stage of proceedings. Their comments have proved useful and the authors believe these points serve to clarify the message of the manuscript. As for referee #1's comments, responses to comments on the revised submission are addressed below. The referee is quoted in italics, and author responses in standard font. Edited text from the manuscript is included in quotations. A document showing tracked changes since review is also included in the revised resubmission.

Main comments:

The structure of the discussion must be revised. The description of categorization by wind direction and absolute humidity should be part of the Methods section. Another option is to start the Results and Discussion section with this description. Lines 223-292 should be moved further down, after the description of the categorization method. Figure 2 does not make any sense when referred to and discussed before this description. My recommendation is to start with the description of this method, and then, to present and discuss aerosol results.

Thank you for this feedback. As suggested, the text in this section has been re-arranged. The following text has been inserted to the start of the results and discussion:

“In the following sections, categorisation of air masses has been performed using both wind direction and absolute humidity. Following a definition of the borders of the categories, the overall aerosol properties observed during the voyage are presented. Differences in aerosol properties within categories defined by wind direction and absolute humidity are then considered and the implications of the findings discussed.”

Consideration of the overall aerosol properties observed during the campaign (previously lines 223-292) has been shifted after the description of the categorisations. This now exists in the manuscript as:

“ 3.3 General properties of observed aerosol populations”

All sections in the Results and Discussion have been re-numbered to account for the addition of this new section (i.e. what was previously Section 3.3 is now 3.4 etc.). Also, Figure 2 has been shifted below Figure 4, and figure numbers (2-4) adjusted accordingly. In-text figure references have also been edited.

SIPEX-II / PCAN comparison:

1. while the authors highlight the difference in sea-ice extent in Figure 1, this is not mentioned later in the discussion. Could the different environmental conditions explain part of the differences during the two campaigns?

This is a very useful revision- thank you for the suggestion. The following text has been added in Section 3.8 (Explaining observed seasonality).

“Spring measurements taken during SIPEXII voyage were taken while significant concentrations of sea ice surrounded the measurement platform, as indicated in the shading in Fig. 1. Very limited sea ice was present in these latitudes during the PCAN voyage. It is important therefore to consider the implications of ice-melt related algal bloom when comparing spring and summer measurements in the seasonal ice zone.”

2. In addition, the authors do not fully address the point made by reviewer #2 about the description of the inlet system. The description of the sampling inlet and associated inlet losses on the Investigator are a welcome addition to the manuscript. However, it does not explicitly tell how the two systems compared. The authors mentioned in their response that the inlet system used on Aurora Australis was characterized separately. A few lines about that in the Methods section and later in the discussion would be appreciated.

Thank you for this feedback, we have added some detail in comparing the inlet systems. The following text has been added to the methods section, Section 2.2.:

“ The present work includes comparison to aerosol concentrations reported by Humphries et al. (2016) taken on board a different research vessel, the Aurora Australis. It is prudent at this stage to note the differing inlet efficiencies for this separate inlet system. An overall inlet transmission efficiency of 0.89 has been reported, generated from a combination of theoretical and experimental characterisation (Humphries et al., 2015).”

The following has also been added to the Results and discussion, Section 3.7.

“It is important to note that these measurements were taken from different platforms, and therefore different particle inlet transmission efficiencies must be considered. However, the difference in the magnitude of enhancement observed in the Polar cell, which does not depend on inlet transmission efficiency in both voyages demonstrates that there is a robust difference in aerosol populations observed between voyages.”

3. Lines 549-551: Did Humphries et al. 2016 use the same method to categorize measurements? It is unclear to me if that's the case and thus how concentrations in Polar cells during the two campaigns can be directly compared.

It is noted that different techniques were used to classify Polar cell measurements between voyages – SIPEXII used changes in aerosol populations backed up by trajectory analysis. Insufficient immediate change in aerosol population was observed in the PCAN measurements for the same technique to be used. Therefore meteorological variables were used in this study to define the cells. It is recognised that these techniques differ. However, the Polar cell/Ferrel cell division is climatological and therefore it can be expected that dominant wind directions associated with measurements in each cell are persistent across seasons. Also, back trajectory analysis for the PCAN measurements divided by wind direction shows a favourable comparison with those from SIPEXII (free tropospheric influence, air masses travelling from above the Antarctic continental interior before descending near the Polar front for Polar cell measurements compared to transport in the marine boundary layer for Ferrel cell air masses.). Text has been added at this point (Section 3.7) to clarify this:

“Humphries et al. (2016) defined Polar cell measurements using a clear change in observed aerosol population along with detailed back trajectory analysis. This method is different to that used here. However the persistent nature of dominant surface winds associated with Polar and Ferrel cells, coupled with back trajectories (plotted in supplementary Fig.S2 and Fig S3) aligning with those modelled for SIPEXII measurements allows comparison between Polar cell measurements to be made between the voyages.”

In the abstract, and later in the discussion, the authors mention “seasonal differences in atmospheric circulation including potentially more significant katabatic outflow in summer”. How robust is this assumption? According to Parish and Cassano (2003), “summertime winds cannot be expected to contain a significant katabatic component, owing to enhanced solar heating of the ice slopes”.

Thank you for this comment- you highlight a flaw in our reporting. This should be explained better: we propose increased influence of katabatic flow on observed aerosol population, driven by weaker and less frequent synoptic low-pressure systems (compared to spring). This has been clarified in the abstract:

“However, the smaller changes observed in the present analyses suggest seasonal differences in atmospheric circulation including lesser impact of synoptic low-pressure systems in summer.”

The relevant text in the discussion has also been changed (Section 3.8), and now reads:

“Instead, **increased influence of the katabatic outflow** on measurements in the Polar cell documented by Chambers et al. (2018) is observed and strengthens the relationship between CN3 concentration and AH. It is recognised that katabatic outflow has an annual minimum in summer (Parish and Cassano, 2003). However, during periods of limited insolation, downslope drainage driven by latent cooling still occurs during the summer months, especially in the high-wind East Antarctic (e.g. Yu et al., 2020, Chambers et al., 2018).”

Finally, the wording of the conclusion has also been edited, and now reads:

“Instead, katabatic outflow from the Antarctic continent more strongly influences particle number concentration enhancement.”

The authors mention that “southern measurements are separated from the Polar/Ferrel classification in an attempt to isolate the known influence of katabatic outflow on near-coast measurements”. While I fully support this initiative, Table S2 shows that there’s more measurements with low AH in the polar vs. southerly category. I’m concerned this method is not entirely successful here.

It is recognised that using wind direction is not a perfect way to identify katabatic outflow. Using, for example, diurnal cycles in Rn^{222} as done by Chambers et al. (2018) is a more robust method.

However given the context of classifying measurements by wind direction, this method was selected for consistency in this manuscript. Humphries et al. (2016) proposed an atmospheric transport pathway of air mass descent from the free troposphere transport pathway in the polar cell in this region. This transport pathway was also observed in 'continental Antarctic airmasses' by Alroe et al. (2019). It would be expected that this air, having spent significant time in the free troposphere, would be associated with low levels of absolute humidity. Figure S2 provides evidence for this, with many of the airmasses classed as 'Polar' showing recent evidence of free tropospheric residence.

Also, given that katabatic flow is not dominant all of the time (as suggested earlier) during the Antarctic summer, the frequency of katabatic flow is expected to be relatively small.

From section 3.6:

“It should be noted that the Low AH category includes a greater percentage of the measurements (45%) compared to the Type 3 and 4 days reported by Chambers et al. (2018) (~27%) so likely includes measurements not influenced by katabatic drainage.”

Therefore it is expected that significant overlap exists between the Polar and Southerly categories. The follow sentence has been added:

“... southern measurements are separated from the Polar/Ferrel classification in an attempt to isolate the known influence of katabatic outflow on near-coast measurements. It is recognised that identifying katabatic flow by wind direction is not ideal. However, given the context of classifying measurements by wind direction, this method has been used in this study for consistency.”

I found a number of typos (see line-by-line comments), a thorough proofreading step would have been appreciated.

The authors appreciate this feedback and will take this into account in future work.

Line-by-line comments:

Line 21: Please indicate where the cruise started, something like: “(...) during a summer 2017 voyage from Hobart, Tasmania, to the East Antarctic seasonal sea ice zone”.

Thank you- this edit has been made as suggested. The text now reads: “...during a summer (January-March) 2017 voyage from Hobart, Australia to the East Antarctic seasonal sea ice zone.”

Figure 1, caption: the sentence “Measurements from the southward transit are excluded due to instrument malfunction” is mentioned twice (line 139-140 and line 140-141). In addition, a portion of the sentence is missing and we don't know what is supposed to indicate the

voyage period for which measurements were analyzed. In addition, could you add ground-based stations on the map, e.g., Casey and Dumont d'Urville, to help the readers orientate themselves?

Thank you- the caption has been adjusted and duplication removed. The caption now reads:

“Figure 2: Voyage tracks of the SIPEX-II and PCAN voyages. Voyage tracks of the SIPEX-II (spring 2012, grey) and periods of the PCAN voyage (summer 2017, orange) for which measurements were analysed. Measurements from the southward PCAN transit are excluded due to instrument malfunction. Grey shading represents the sea ice area observed at the mid-point of the SIPEXII voyage as detected by the Nimbus-7 satellite (National Snow and Ice Data Centre, 2021). No sea ice was present in the plotted region at the midpoint of the PCAN voyage. Nearby Antarctic stations are plotted to assist interpretation. An interactive map of RV Investigator voyage tracks can be found here: https://www.cmar.csiro.au/data/underway/?survey=in2017_v01.”

Figure 1 has also been updated, including the location of the stations mentioned.

Line 228-229: “it has been necessary to limit this analysis has been limited to the time period of the shortest dataset”. Please rephrase.

Edited as suggested, sentence now reads: “...it was necessary to limit this analysis to the time period...”

Line 274-275: “A median size distribution plotted (...) has a bimodal shape”. Are the authors referring to a specific figure here? See main comment above on the structure of the discussion, it is currently quite confusing.

Thank you, understood. The sentence now reads: “A median size distribution plotted from all valid SMPS measurements for the analysis period during PCAN (supplementary Figure S1, black trace) has a bimodal shape...”

Line 276: typo “close to 70 nm..” Thank you- the extra full stop has been removed.

Figure 2: I would replace “No_cat” by “Other”. “No_cat” seems to suggest missing wind data, which is not the case. Also please give more detail in the caption, e.g., explain what the low, mid, and high AH categories refer to (give the thresholds in gH₂O/m³). The caption should be self-explanatory. Finally, can you use different colors for “No_cat” and “southerly”? (I know I’m being picky here).

Thank you for this comment. The name of the ‘No_cat’ classification has been altered to “Other” as suggested in figures and in text. The colour palette has also been slightly adjusted to ensure two distinct categories are not plotted using the same colour. This change in colour palette and category names is also reflected in Fig. 2 and Fig. S1.

The order of figures has now been changed, so the box plots (previously Figure 2) are now included further down the manuscript than the frequency histogram of AH measurements (previously Figure 4). The caption of the frequency histogram of AH measurements details the boundaries, as does the caption of the wind rose figure (previously Figure 3, now Figure 2) for the wind measurements. Hopefully this restructure means readers are able to interpret the boxplots correctly without restating category boundaries in the caption.

Figure 3: same as above, the caption should be self-explanatory. Explain what the 56.6 S latitude threshold is, something like: “Wind rose for wind measurements south of 56.6 S, i.e., excluding homebound transit to Hobart, Tasmania”. In addition, “Frequency histogram of wind measurements plotted in 2b”, should be 3b.

Thank you for this comment. The caption has been edited and now reads:

“Figure 2 (a): Wind rose for the entire analysed PCAN voyage (February 6-March 4, 2017). (b): Wind rose for wind measurements south of 56.5° S (excluding measurements from the homeward transit to Hobart Tasmania, the Transit category), showing selected sectors. There are three areas demonstrating a higher density of wind measurements, from the WNW (Ferrel, sector: 225-298°, width 73°), from the SE (Polar, sector 99-148°, width 49°) and from the S (Southerly, 148-217°, width 69°). These sectors, capturing 76% of available wind measurements, are shaded in blue (Ferrel, 22%), grey (Southerly, 20%) and orange (Polar, 34%) respectively. (c): Frequency histogram of wind measurements plotted in 2b with 1° bin size. Ferrel (blue), Southerly (grey) and Polar (orange) sectors are highlighted.”

Lines 321-323: “The southern edge of the Ferrel cell is expected to display a dominant NW wind, and the northern edge of the Polar cell is expected to be associated with a dominant SE wind”. Can you cite a few papers here to back this up?

I have added some citations- a mix of articles and reference texts.

Line 447: typo. “in the differences in difference”.

Thank you, this sentence now reads “... are evident in the differences in observed particle concentrations...”

Figure 5, Fig S2 and S3: I’d appreciate having the southerly category plotted here as well.

Thank you- we appreciate the usefulness of this suggestion. However, the authors experimented and found that plotting > 3 distributions on a single panel makes it very difficult to interpret the plot. The median size distribution for the southerly category is therefore plotted in Figure S1 instead of in Figure 5 as requested.

The Southerly and ‘Other’ categories have been included in Figure S2 as requested. Text noting this has been added to Section 3.6:

“Interestingly, the trajectories for the Southerly category also show history of descending airmasses.”