Response to Reviewer 1’s Comments

I would like to thank the reviewer for their comprehensive review of the paper. They have highlighted some interesting issues which I have attempted to answer both within the paper and in the response below. The reviewer’s comments are shown in italics and my response to their comments is shown in plain text.

My main comment is related to the period over which the simulations are performed. As explained in L. 153, all the simulation are initialised during a single winter season (2018-2019), but I miss an explanation to why these months were selected for this study and how this choice could potentially influence the results. For example, if persistent weather conditions were present during these four months, this could strongly bias the resulting skill of the ensemble. Also, weather conditions during summer can be very different, therefore I wonder if the statistics would change as well if one were to redo the same experiments for a different period of the year or equally for another winter season. The authors do indicate this potential limitation (L.426-433) and I appreciate that it would require a large amount of extra work to include more months in the study, but I think the paper would benefit from a longer discussion of the potential impact of the selected study period on the robustness of the conclusions.

The reviewers make a very good point. They are also correct that to extend the study would require many months of work and the data volumes generated are prohibitive. We have, therefore added additional discussion of the limitations of the study both in the methodology (section 2) and the conclusions (section 4) as follows:

In section 2: “To explore a range of meteorological conditions both scenarios were repeated every 12 hours over a period of around 4 months (03/11/2018-28/02/2019 for the radiological scenario and 01/12/2018-31/03/2019 for the volcanic eruption scenario) with each simulation being run on single NWP forecast.” has been replaced with “To explore a range of meteorological conditions both scenarios were repeated every 12 hours. Computational constraints restricted the period over which runs could be carried out to 4 months between late autumn 2018 and early spring 2019 so runs were carried out for the period 03/11/2018-28/02/2019 for the radiological scenario and 01/12/2018-31/03/2019 for the volcanic eruption scenario with each simulation being run on single NWP forecast.”

In section 4: “Due to computational constraints this study was only able to examine skill scores over a 4-month period from the end of the northern hemisphere Autumn to the beginning of Spring. This was partially mitigated against for the radiological scenario by using a range of release locations. However, further work would need to be carried out to demonstrate that the results hold for the northern hemisphere summer.”

In this study two very different scenarios (near-surface radiological release versus tropospheric/stratospheric volcanic ash eruptions) are explored to examine if the ensemble meteorology produce more skilful dispersion model predictions. Reading through the manuscript, I did miss some discussion that compared the two scenarios in terms of their relative improvements when using the ensemble forecast (i.e. is it more important to consider the ensemble forecasts for boundary layer releases or volcanic eruptions or do they both benefit equally from the ensemble forecast?). In the final paragraph of the paper (L.438-440), the authors mention that on average the ensemble meteorology outperforms the deterministic model. I think the paper would benefit from a short discussion on whether the impact of using the ensemble meteorology is more significant for one of the two scenarios.

We have added the following paragraph to the conclusions comparing the two scenarios: "Two very different scenarios have been considered, the 48-hour integrated concentrations resulting from a boundary layer release and the time-varying concentrations resulting from a vertical column release over depths of 12 and 25 km. Average Brier skill scores were greater than zero for both scenarios and for all outputs considered suggesting that using ensemble meteorology provides value for a wide range of dispersion scenarios. Brier skill scores tend to be slightly greater for the boundary layer scenario, but further work would be needed to determine whether this was due to the height of the release, the averaging period or the threshold values."

Finally, I also noticed is that throughout the manuscript (text, legends and figure captions), many of the units are not written in the format as outlined in the ACP submission guidelines (e.g. mg/m3 instead of mg m-3). I have annotated most of them in the technical comments below, but please check carefully throughout the manuscript.

I've been through the manuscript and corrected the unit formatting.

Technical corrections/suggestions:
The reviewer's comments are in a different format.

L12: '… at those later time steps for deposition than for air concentration.' Based on figure 6 and 7, I am not sure that the differences in BSS between deposition and air concentration at the later timesteps are significant enough to support this statement. Would it be possible to give an estimate of the uncertainty in the average BSS reported in these figures (e.g. standard deviation)?

We have clarified this statement to indicate that the increase in average BSS over the 24-hour period is greater for deposition than air concentration, since as the reviewers point out this is due to lower average BSS for deposition in earlier time periods rather than higher average BSS for deposition in later time periods.

L47: comminicate -> communicate
Done

L65: need a space between 45 %.
Done

L78: The acronym SNAP needs to be spelled out.
Done

L84: In the following paragraphs several of these case studies are discussed, but no citation/discussion is presented for the ensemble studies of Eyjafjallajökull and Grimsvötn. I think this should be included.

Ensembles studies of Grimsvotn are limited but we have included a citation for this case study. We have also included a discussion of the case studies of Eyjafjallajokull.

L105: used the wrong quotation mark 'dimension'
Done

L109: '…use analysis data…' From the text it is not directly clear what analysis model data / meteorology is. I think a short description would be useful, as it is a key part of the analysis presented in this paper. Or alternatively, the authors could refer to L.186.

The following sentence has been added to clarify the difference between analysis and forecast meteorology: "Here we use analysis meteorology to describe the model meteorological data constructed using a large number of observations to produce a representation of the current state of the atmosphere and forecast meteorology where this atmospheric state is propagated forwards in time."

L119: '…that NWP ensembles including ensembles may…'. I do not understand this sentence, do you mean: '…that NWP ensembles may…'?

I have removed "including ensembles" as this is a typographical error and makes the sentence unreadable.

L130: space needed between 50 m
Done

L131: 1 µm should be in roman font.

Done

Figure 1: What does the green box represent in panel a? Also, a colour scale for both figures (I assume the colours represent topography) is missing.

The green box has been removed and a colorbar added.

L135: '…full 48 hours were output.' Is there a reason to select the 48 hours? In most cases, contaminants will be airborne for longer than the 48 hours. Do we get a different result if we take the output for longer/shorter integration times? I feel some additional argumentation for selecting the 48-hour accumulation period is needed here.

Contaminants can remain airborne for longer than 48 hours but the time period was limited to 48 hours because this is the time period considered by the UK in the initial response to a radiological accident and also to keep model run times manageable.

L136: "10km" space between value and unit
Done

L138: "12km" and "25km" need space between value and unit
Done

L142: "g/hr" should be replaced by g hr-1
Done

L143: kg/m3 should be replaced by kg m-3
Done

L144: "ash was modelled for 24 hours." Related to the comment for L135, is there a reason why the simulations length is chosen to be 24 hours for the volcanic simulations?

The simulations were limited to 24 hours, first, because this is the duration of the forecasts VAAC's are required to produce and, second, to keep run times manageable. A note to this effect has been added to the manuscript.

L.151: "20km" space between value and unit
Done

L.153: The period selected for the simulations is one winter season (NDJFM 2018-2019). The aim of the study is to capture a range of meteorological conditions and I am worried that the current selection only captures a limited number of the possible conditions. If a certain weather pattern was dominant during these months (e.g. for the 2018-2019 winter season the NAO was mostly negative), this might have a large impact on the skill of the dispersion model. Furthermore, mass is removed from the model atmosphere by wet and dry deposition, which I assume can be very different in summer especially for the boundary layer releases. All of this will influence the Brier skill score (BSS). I think some discussion regarding this point should be included.

See response to main comments above.

L155: remove "the"
Done

L161: repetition of definition 'Volcanic Ash Advisory Centre' (L139), so can be omitted here.
Done

L176: "20km" space between value and unit
Done

L177: "30km" space between value and unit
Done

L185: "focus is on the two forecasts at 00 and 12 UTC." I am slightly confused by this sentence, as in the next sentence also the 06 and 18 UTC forecasts are used. Do the authors mean that both for the ensemble and deterministic configurations only the 00 and 12 UTC forecasts are used, but for the analysis meteorology all forecasts are included?

I've relocated this sentence to the end of the section and expanded to read: In this study dispersion forecasts are initiated only on the forecasts (ensemble and deterministic) at 00 and 12 UTC because the data for NAME is only retrieved for the first 6 hours of the 69-hour update forecasts in order to update the analysis meteorology.

L206: "…thresholds for the radiological scenario were chosen to reflect typical distances…" There are no references to any literature to indicate that the found values in figure 2 are indeed typical distances for 48 hrs after the occurrence of a radiological dispersion events. I think some information supporting the typical values should be included.

The reviewers raise a very valid point. This work was carried out following the Horizon2020 CONFIDENCE project (https://portal.iket.kit.edu/CONFIDENCE/index.php?action=confidence&title=objectives) so the setup of the radiological scenario reflects choices made within that project. However, re-reading the CONFIDENCE reports we realised that the distances were based on typical distances at which deposition thresholds were exceeded rather than air concentration thresholds. The text has been modified to reflect that and to link to the final CONFIDENCE paper.

L212: exceed -> exceeded
Done

L213: "100km" space between value and unit
Done

Figure 2: exceeeded -> exceeded. Also need to change the units in the legend to Bsq m-3
Done

L214: "650km and 1000km" space between value and unit
Done

L215: "700km and 1300km" space between value and unit
Done

L222-223: mg/m3 -> mg m-3
Done

L225: mg m-3
Done

L226: "1 km" space between value and unit and remove italics
Done

Figure 3: exceeeded -> exceeded. Also need to change the units in the legend to g m-3
Done

L231: "250km" space between value and unit
Done

L232: "1600km to 2400km" space between value and unit
Done

L238: What could be the impact of the coarser resolution of the ensemble meteorology on the actual dispersion simulated? Would it be possible to downscale the deterministic and analysis meteorology to the same resolution of the ensemble meteorology and run the dispersion simulations with the reduced resolution for one of the cases to test the impact on the results?

It is possible that the different resolutions of the ensemble meteorology and the deterministic and analysis meteorology has an impact on the results, but we don't believe it is a dominant impact. Most meteorological centres sacrifice resolution for ensemble size, so most ensemble meteorological data are at a lower resolution than their deterministic counterparts. In the event of a real atmospheric dispersion incident, we would use the ensemble and/or deterministic meteorology at their native resolutions and therefore we wished to assess their performance at their native resolutions in this study. We have added a note explaining this below line 239 (original submission).

Figure 4: units in the legend should be Bqs m-3 instead of Bqs/m3
Done

Figure 5: 50kBqs/m3 -> 50 kBqs m-3 and 5kBq/m2 -> 5 kBq m-2. Also, many of the crosses in are overlapping making it hard to understand the density of the crosses. I think a box plot would show the same information more clearly.

Figure 5 has been replaced with box plots and units changed

L270: "10 and 30 percent" Are these values for the data shown in figure 5 or is this related to all the different thresholds? Based on figure 4, I would think that the fraction of negative Brier skill scores can be much higher when considering the highest thresholds?

These are the values for the data shown in figure 5 and we have clarified this at the beginning of line 270.

Figure 6: Should this be "Averaged Brier skill score…"? The second comment is related to a possible bias in calculating the average Brier skill score (BSS). As mentioned by the authors, the BSS can range from -infinity to 1 (L266), which is why the adjusted BSS was introduced in equation (3). However, in figure 7, several panels show at least one simulation member for the adjusted BSS to be approximately -1. This indicates that the actual BSS was <<-1. If very low BSS occurred for several individual simulations, you could end up with a negative average BSS, even though the rest of the simulations could be near perfect with a score of approximately 1. Therefore, I think it would be useful to report the range of the actual BSS values (or just the minimum) to understand if this could have impacted the average BSS score presented in the paper.

The reviewer makes and excellent point. The Brier skill score can range from minus infinity to 1 so average Brier skill scores are computed by first computing the average Brier scores for the ensemble and the deterministic meteorology and then using (2) to compute the average Brier skill score. Text to clarify this has been added to the methodology section.

L281: 'Brier skill scores increase with forecast time,…' How much does the increased number of grid points where we have a plume influence the sensitivity of the Brier skill score? During the initial stages of the simulations, only a small number of points have concentrations above any threshold in all three (ensemble, deterministic and analysis meteorology) simulations, while after e.g. 24 hours the plume has spread over a much larger region (as shown in figure 10). If you misrepresent one grid point of the analysis in the earlier stages for the deterministic and/or the ensemble simulation, will this not have a larger impact on the Brier skill score calculated by equation (2) than the same single grid point error after 24 hours? Is it possible that part of the increase in the Brier skill score with time we see in figure 6 and the reduced range in values in figure 7 for later timesteps is caused by the increased plume size?

Investigating the impact of the grid size was out of the scope of this project. However, I have plotted the Brier skill score against area of the plume (below). This shows that the spread of Brier skill scores is greater when the area exceeding the threshold is smaller but there is no bias towards negative or positive skill scores for large or small areas.

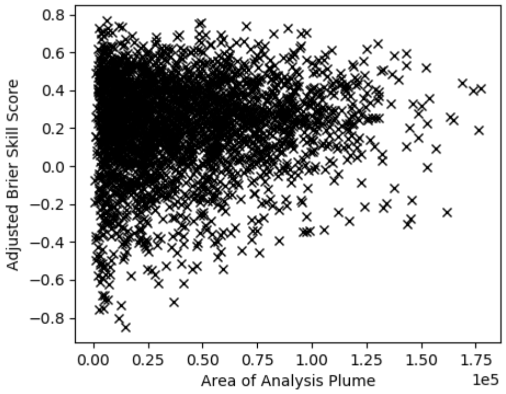

Figure 1: Brier skill score plotted against area of forecast exceeding the threshold for total integrated air activity of Cs-137 above 50kBqs/m3. The area exceeding the threshold is determined from the analysis plume.

In the text, to help clarify this point we have replaced:

“There are fewer negative scoring runs at later forecast time steps implying that the ensemble is more likely to perform better than the deterministic at later time steps. This is possibly due to the increase in ensemble spread at later time steps.”

with “At later forecast time steps there are fewer negative scoring runs and the range of Brier skill scores is narrower. The reduction in negative scoring runs implies that the ensemble is more likely to perform better than the deterministic at later time steps. This is possibly due to the increase in ensemble spread at later time steps. The reduction in the range of the Brier skill scores is likely to be due to the increase in area exceeding the threshold. At early time steps when the plume is narrow the Brier skill score is dominated by a few grid cells and the ensemble tends to be less spread resulting in either a high Brier skill score or a very low Brier skill score. At later time steps the plume is more spread out and the ensemble is more spread so there is a greater range of Brier scores for the different grid cells and the Brier skill score tends to be closer to zero.”

L284: “12km” space between value and unit.

Done

Figure 7: Similar to figure 5, I think a box plot would show the same information more clearly. There also seems to be a single simulation in the dataset that seems to perform much better than all the other simulations and shows up on all the panels in this figure. Is this the same simulation for all panels and is there something special about this Simulation?

Figure 7 has been replaced by a box plot. The single simulation that performed better was erroneous. It was the simulation from the day that there were technical issues with the met data, and it should have been excluded. We have now excluded it from this plot.

L303: I think this should be ‘This resulted in an average Brier skill score of 0.76.’

As this is a Brier score for a single scenario it is not an average score.

Figure 8: Please use a different colour for the green or red contour, as it is hard to see the difference. Also replace ‘kBqs/m3’ -> ‘kBqs m-3’~~.~~

The green contour has been replaced by a red dashed contour and the caption amended to reflect this. Units changed

L305: ‘200kBqs/m3’ -> ‘200 kBqs m-3’
Done

Figure 9: What does the blue triangle in panel a represent? What is the altitude for these wind speed and directions? Are these altitudes at which the contaminants are released in the model?

The blue triangle represents the release location – a note has been added to caption. The wind speeds and directions are at 10m which is a standard height for meteorological observations and close to the release height of 50m – a note about the height has been added to the caption.

L315: ‘2kBq/m2’ -> ‘2 kBq m-2’
Done

L334: Why are you using the Brier skill score for the volcanic simulations and not the adjusted Brier skill score like it was done for the radiological scenarios?

This is a typographical error. I am using the adjusted skill score for the volcanic scenarios and I have modified the text to reflect this.

L339: 2mg/m3 -> 2 mg m-3
Done

Figure 10: Please use a different colour for the green or red contour, as it is hard to see the difference. Also replace 2mg/m3 -> 2 mg m-3.

The green contour has been replaced by a red dashed contour and the caption amended to reflect this. Changed units

Figure 12: Please use a different colour for the green or red contour. Also please change 5mg/m3 -> 5 mg m-3.

The green contour has been replaced by a red dashed contour and the caption amended to reflect this. Changed units

L365: increase -> increases
Done

L433: small -> smaller
Done