Response to ’Comment on acp-2022-233’ by Referee #2

We thank the Referee for his/her time and his/her constructive comments. We have complied with most of the proposed changes. In the following, the comments made by the Referee appear in black, while our replies are in blue.

This study uses a meso-scale model at convection-permitting scales to analyze the impact of aerosol-radiation interactions on simulated large-scale motions with a focus on African Easterly Jet-South (AEJ-S). The authors also use the same simulations to estimate the direct and semi-direct effects of aerosols over the southern African biomass burning and outflow region. Even though there is no lack of motivation for such a study and its usefulness for the modeling community in improving (or finding consensus) in estimating the impact of biomass burning aerosols (BBA) on radiation budget, clouds, and circulation/transport over this region. Especially since the vertical distribution of aerosols after long-range transport have been found to be lacking in many global models for this region.
We thank the Referee for recognizing the interest of our study and its focus on the Southern African Easterly Jet. Because of his/her interest in the vertical distribution of aerosols, we added a new figure (Fig. 10 with the new numbering) to discuss the radiative effects of BBA on their vertical distribution.

However, there are serious concerns regarding the modeling approach and the use of over-simplistic assumptions regarding aerosol properties in the model, as mentioned below under my major comments. There is a need for some substantial modeling work to be redone/added before one can infer anything meaningful from the results and analysis presented in their Section 4 and beyond. I do not recommend the publication of the manuscript in its current form but can be reconsidered for review once additional modeling work is performed and analysis is redone.
We agree with the Referee that we have used a somewhat simplified representation of BBA aerosol properties in order to perform high-resolution cloud-resolving simulations. However, our assumptions about aerosol properties are quite realistic, as shown by many comparisons with observations. It is common to use simplistic parameterizations of, for example, convection or aerosol chemistry in chemistry-climate models when studying aerosol radiative effects. We have performed additional analysis to address the Referee’s concerns, and we hope that our responses below will convince the Referee of the robustness of our results and of the significance of the radiative effect of BBA in accelerating the S-AEJ and changing the regional circulation over southern Africa and the southeast Atlantic.

Major comments:
When performing forecast runs or free-running simulations, it becomes necessary to perform ensemble runs (with larger number of ensemble members for shorter forecast periods) to understand the sensitivity of the model to the initial conditions in simulating/predicting the thermodynamic, wind and other meteorological fields. It is imperative to judge that how significant are the changes in wind speeds, temperature, cloud cover etc. (using a t-test for example) that the authors report between the two simulations versus the model internal variability.
We agree that the significance of any change can be estimated using ensemble averages. Therefore, we performed sensitivity simulations to initial conditions following the methodology of Das et al. (2020) and included the associated results (Figs. 4 and 10 with the new numbering and two other figures in Appendix A) in the revised paper. This allows us to test the significance of changes due to BBA radiative effects, as requested.

Is the model assumption of SSA=0.85 at 532 nm? It would be worth demonstrating the assumed SSA curve for rest of the solar spectrum (or at least 400-1000 nm, where absorption due to biomass burning and dust are most relevant). The model assumed SSA value is representative of strongly absorbing aerosols, possibly for the more aged smoke that was observed over the Ascension or during ORACLES. However, there is quite some variability of SSA over the continent (which is also part of the modeling domain), see Figure 11 of Piston et al. (2019). Therefore, I wonder if this strong heating (with SSA=0.85 everywhere) over the continent is exaggerating the changes in large-scale motions. The sensitivity of the model results to different SSA assumptions becomes critical here and should be discussed.
The SSA value of 0.85 assumed by the model is indeed representative of strongly absorbing aerosols. In Sec. 2.1

(lines 82–84), we wrote ”This value, which corresponds to strongly absorbing aerosols, is close to the vertical average estimated at Ascension Island (Wu et al. 2020) and over the southeastern Atlantic (Pistone et al. 2019, Cochrane et al. 2022).” Following your suggestion regarding ”Section 3.1, Figure 2”, we revised Fig. 2 (see below) by including the AERONET and BBRAD SSAs. We added ”The SSA is also shown for AERONET and BBRAD with dotted lines. In order to produce a column SSA value for comparison with AERONET, the BBRAD simulated SSA is averaged after weighting its value according to the aerosol optical depth at each vertical level.” Figure 2 shows that the SSA varies with station and the BBRAD simulation captures the observed variation of SSA with station well.

Specific comments:

Lines 27-33: There are several noteworthy references for modeling semi-direct effect over SE Atlantic in recent years, especially for the similar modeling scales authors are looking at. For example, Lu et al. (2018), Gordon et al. (2018) and Das et al. (2020). These are worth citing in this section along with their major findings in relation to direct and semi-direct effect and how that compares to current study.

We thank the Referee for the references. We added three new references (Das et al. 2020; Tummon et al. 2010; Key and Haywood 2003). The studies of Lu et al. (2018) and Gordon et al. (2018) address the aerosol-cloud interaction that we do not consider (line 54).

Section 3.1, Figure 2: Why is the spin-up time for aerosols considered within the 16d forecast period? A better or more common approach is to spin-up the aerosols for at least a 7–10-day period before the forecast, while the meteorology can be reinitialized using the ECMWF forecast from the starting point of forecast. This way the complete 16-day period can be used for analysis, which is what would make more sense to be able to make anything of the direct and semi-direct effect estimates presented later.

The spin-up time for aerosols varies with location, as shown by comparison with AERONET AOD (Fig. 2). It is only 1 d for stations over or near fire source areas (e.g., Sakeji and Lubango) and 7 d for remote stations (e.g., Ascension Island and St. Helena). This 7 d spin-up time explains why we show fields averaged between 8 and 16 September. This also allows the BBAs to have a full radiative impact on the atmospheric circulation. Starting the numerical experiments with the same meteorological conditions, but with a different BBA loading, would reduce the overall effect on atmospheric conditions. Instead, the approach used here maintains consistency between the BBAs and the meteorological fields, which is essential as the BBAs feedback on the circulation.

In Sec. 2.1, we added ”The 7 first day is used to spin the model up and the results are shown for averages between 8 and 16 September. It corresponds to the time required for the BBAs to reach the westernmost islands in the Atlantic, as shown below. It also allows the BBAs to have a full radiative impact on the atmospheric circulation while keeping them consistent with temperature and the winds.”

Further, not only AOD, but it would also be worth comparing the model SSA with retrievals from AERONET over these sites, including Mongu and Namibe sites. One would have assumed to include the two sites at the first place since they are the long-term sites over this region, with Mongu being a prime BB source example and Namibe has some considerable dust influence, which would be good to see provided the model includes dust as well. The resulting SSA (of the aerosol mixture, BBA + Dust) is important to constrain here since not only loading, but absorption/scattering will control the aerosol radiative impact and its feedback on the circulation.

Following your suggestion, Fig. 2 was revised (see below). First, the selection of AERONET sites includes Namibe and Mongu (at the expense of Bamenda and Henties Bays). Second, the SSA is shown in addition to AOD. Over Mongu, the BBRAD value (0.87) is greater than that of AERONET (0.85). Over Namibe, no dust is simulated and the SSA value is observed and simulated around 0.86: this shows the absence of a ”considerable dust influence” for the period considered in our study. Overall, BBRAD reproduces the AERONET AOD and SSA values for most stations. This makes us confident about the optical properties of BBA that we use.

Fig 3. Difference plots here would be useful for each row. Also, quantitative difference in windspeeds would be useful to demonstrate rather than qualitative description since the focus is on changes in AEJ-S based on the manuscript title/objectives.

We added four new figures (Figs. 4 and 10 with the new numbering and two other figures in Appendix A) showing the differences and their significance.

Section 4.1. How do the DRE and radiative heating compare to other studies in literature? Authors just mention comparison to Mallet et al. currently. Also, 3-4 times higher values of DRE and radiative heating could also be because of higher model AOD magnitudes compared to MODIS and strongly absorbing SSA assumption. The seasonal mean versus September mean reasoning alone cannot explain such large differences.
We now refer to Sakaeda et al. (2011), in addition to Mallet et al. (2020), for the seasonally averaged DRE values of $-30\,\mathrm{W\,m^{-2}}$. Note that we incorrectly calculated the ratio of the September value of $-100\,\mathrm{W\,m^{-2}}$ to the seasonal value of $-30\,\mathrm{W\,m^{-2}}$. This ratio is 2–3 times, and not 3–4 times. We agree that the high values of AOD can explain the large values of DRE. Lines 243–244, we wrote ”The larger magnitude is explained by both the greater insolation and AOD in mid-September compared to seasonal values.” Also note that the AOD comparison with AERONET does not show any high model BBA values, nor does the newly added SSA comparison with AERONET. We added ”In terms of radiative forcing efficiency, i.e. DRE divided by AOD, it is between -10 and $-20\,\mathrm{W\,m^{-2}}\,\tau^{-1}$, a value consistent with the estimate of Sakaeda et al. (2011)”

Fig. 8: This figure is trying to present too much information in single panel (especially, c-d and e-f). Also, why meridional cross-sections are shown for this analysis when the AEJ-S flow is zonal? It would make more sense to show contours/cross-sections in the direction of plume transport (i.e., along longitude), starting from land and extending up to the ocean rather than meridional cross-sections over two narrow strips.
Figure 8 is intended to show the key, albeit numerous, variables explaining the main changes between the two simulations. It is a meridional cross-section because it allows for discussion of the S-AEJ, a zonal thermal wind. When introducing Fig. 8, we added ”The latitude-height cross-section is used to show the S-AEJ thermal wind for which the zonal wind varies with the meridional temperature gradient.” The directions of the plume transport are shown in Fig. 11 using trajectories. Some are effectively westward, others turn southward.

Line 375 and 382: The use of words like “first semi-direct effect” and “another radiative semi-direct effect” is misleading or inaccurate in these sentences. There is a whole lot of literature and history on how direct, semi-direct and indirect effect of aerosols have been defined. These effects have traditionally been defined with respect to the impact of aerosols on clouds and radiation balance. Unless authors are redefining what encompasses “semi-direct effect”, they should refrain from using “semi-direct effect” arbitrarily or when implying the aerosol heating feedback on circulation rather.
The wording ”semi-direct effect” was changed to ”BBA impact on circulation”.

Overall, it is hard to make anything of the changes discussed in 4.3 and beyond unless it is comparison between model ensemble-means. It would benefit to show difference plots between your BBRAD and NORAD set of simulations for most of your variables (cloud fractions, wind speeds, temperature etc.) with significant changes depicted with hatching/shading. For example, change in surface temperature by 3K and average heating rates by 1K day-1 (line 371) are too large and one would wonder if it’s because of coarse representation of BBA in the model or due to the very short period of analysis with a single member run during which most fields have not stabilized in the model.
We disagree that the daily heating rate is too high. As written line 255, ”Overall, the heating rates due to BBA are within the range of daily values around $1\,\mathrm{K\,day^{-1}}$ reported by Mallet et al. (2020).” (This is the value that is repeated line 371 in the conclusion). This value was also obtained by Tummon et al 2010 (see their figure 7). We added this reference in the text as well the reference to Keil and Haywood (2003), who found an even larger heating rate of $1.77\,\mathrm{K\,day^{-1}}$.
We disagree that the surface temperature is too high. As written line 294, ”the cooling effect of -3 K has been reported in the literature (Mallet et al. 2020).”
The BBAs are indeed represented in a coarse way using a mass tracer. However, their optical properties are correct in the BBRAD ensemble, as shown by the comparison with AERONET, and their vertical distributions are correct, as shown by the comparison with lidar observations.
The dynamics and thermodynamics fields are ”stable” as much as a chaotic atmosphere can be. There is no indication of ”not stabilized fields” in the average fields of either. Following your suggestion, we calculated ensemble-means. As intuitively expected, the changes are significant where the differences in temperature, wind, etc. are large. This is shown for some additional figures. Note that the period is in September, when the S-AEJ maximum coincides with the AOD maximum over southern Africa (line 37). This largely explains why the circulation shows a strong response to the radiative effects of the BBA.

Comment on Data availability: The modeling results, at least the ones used for demonstrating the analysis presented within the paper should be uploaded and published using an appropriate data repository. The sentence stating, "The Meso-NH-derived fields and back trajectories data can be obtained upon request to the corresponding author of the paper" does not suffice based on current ACP guidelines on data policy.
This sentence echoes that recently published in the ACP paper by Flamant et al. (2022). It is planned to upload a subset of the simulations to the AERIS data center which hosts the AEROCLO-sA database. A data paper is currently being written.

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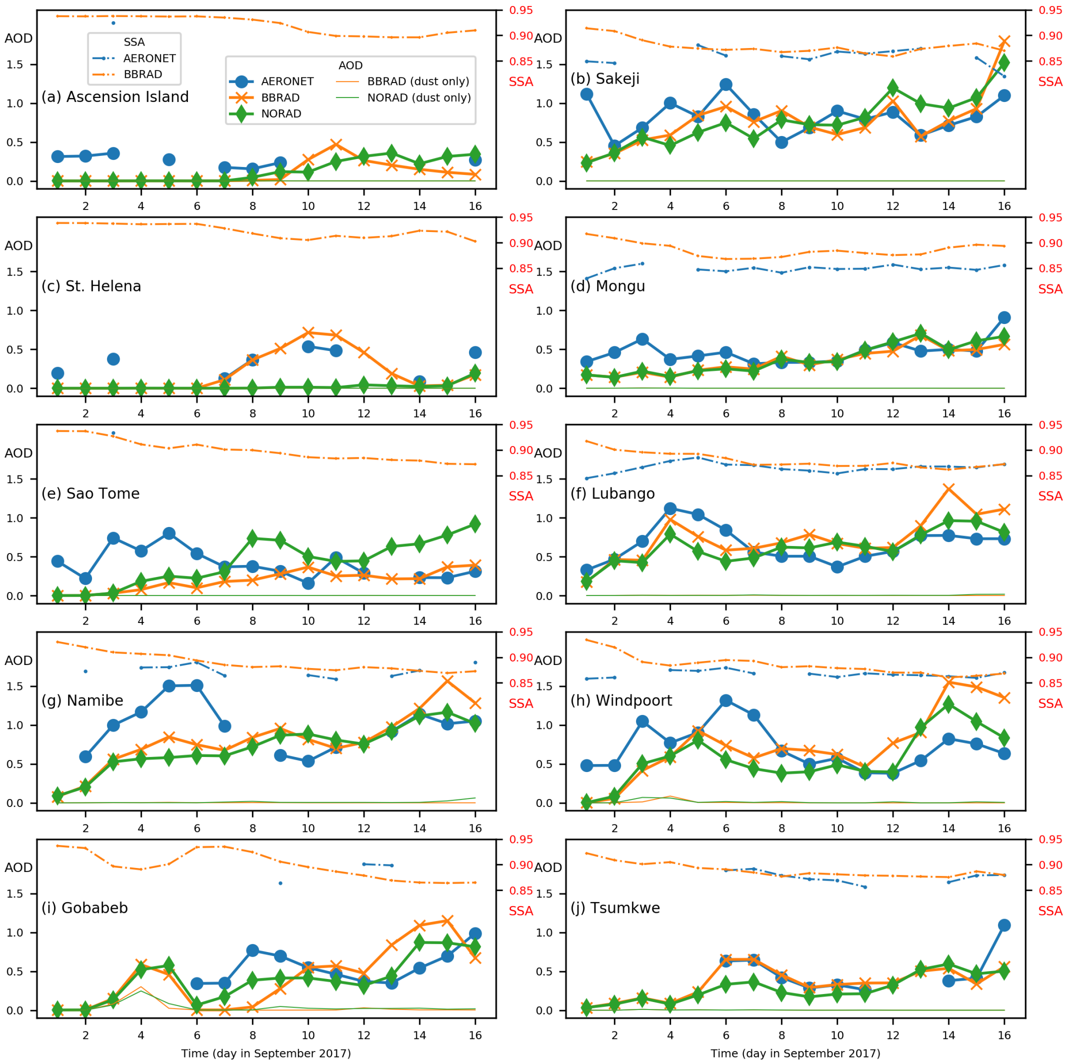

Figure 2 (revised): Time evolution of daily mean AOD at 532 nm between 1 and 16 September 2017 from AERONET (blue), BBRAD (orange) and NORAD (green) at **(a)** Ascension Island, **(b)** Sakeji, **(c)** St. Helena, **(d)** Mongu, **(e)** São Tomé, **(f)** Lubango, **(g)** Namibe, **(h)** Windpoort, **(i)** Gobabeb and **(j)** Tsumkwe. The orange and green thin lines show the AOD due to dust for BBRAD and NORAD, respectively. The blue and orange dotted lines show the SSA at 440 nm for AERONET and BBRAD, respectively. Results are shown for the BBRAD and NORAD members starting at 00:00 UTC 01 September 2017.