Response to reviewer #2

We thank the reviewer for their helpful comments and the suggested changes / clarifications. We address each comment in turn below. Reviewer comments are in bold, and changes made to the manuscript in italics.

Page 4, line 74: Plural "extend of cloud-aerosol gaps"

The manuscript has been amended to read "*extent of cloud-aerosol gaps*".

Page 5, Model setup: Maybe add a sentence to the lateral boundary conditions. In assume they are periodic?

The reviewer is correct; the lateral boundary conditions are periodic. This has been included in the model setup section.

Page 6 and 7, Setup of elevated-aerosol experiments: Unfortunately, the CALIOP measurements are not that reliable, which makes this paragraph less significant. For cloud measurements it is often a trade-off between accuracy and representativeness of different datasets. Aren't there other data available, like aircraft measurements that could complement the used data?

We have complemented the CALIOP (532 nm channel) analysis with the Cloud-Aerosol Transport System (CATS) 1064-nm lidar dataset on-board the International Space Station (CATS-ISS_L2O_D-M7.2-V3-00_05kmLay). The CATS lidar retrieves feature altitudes using the 1064 nm wavelength channel, which is better able to retrieve the lower extent of the aerosol layer than the 532 nm channel used by CALIOP as it is not fully attenuated (Rajapakshe et al., 2017). The CATS dataset is only available for 3 years, compared to the 10 years of CALIOP data used for the current climatology, hence we present both datasets. Figure R1 below shows that the aerosol layer is closer to the cloud top in the CATS dataset than in the CALIOP dataset. Both datasets display considerably variability in the cloud-aerosol gap but provide evidence that the gap is most likely less than 1000 m. Therefore our experimental design remains appropriate. The corresponding figure in the manuscript (Figure 1) has been updated with Figure R1 and the text has been updated to reflect these changes.

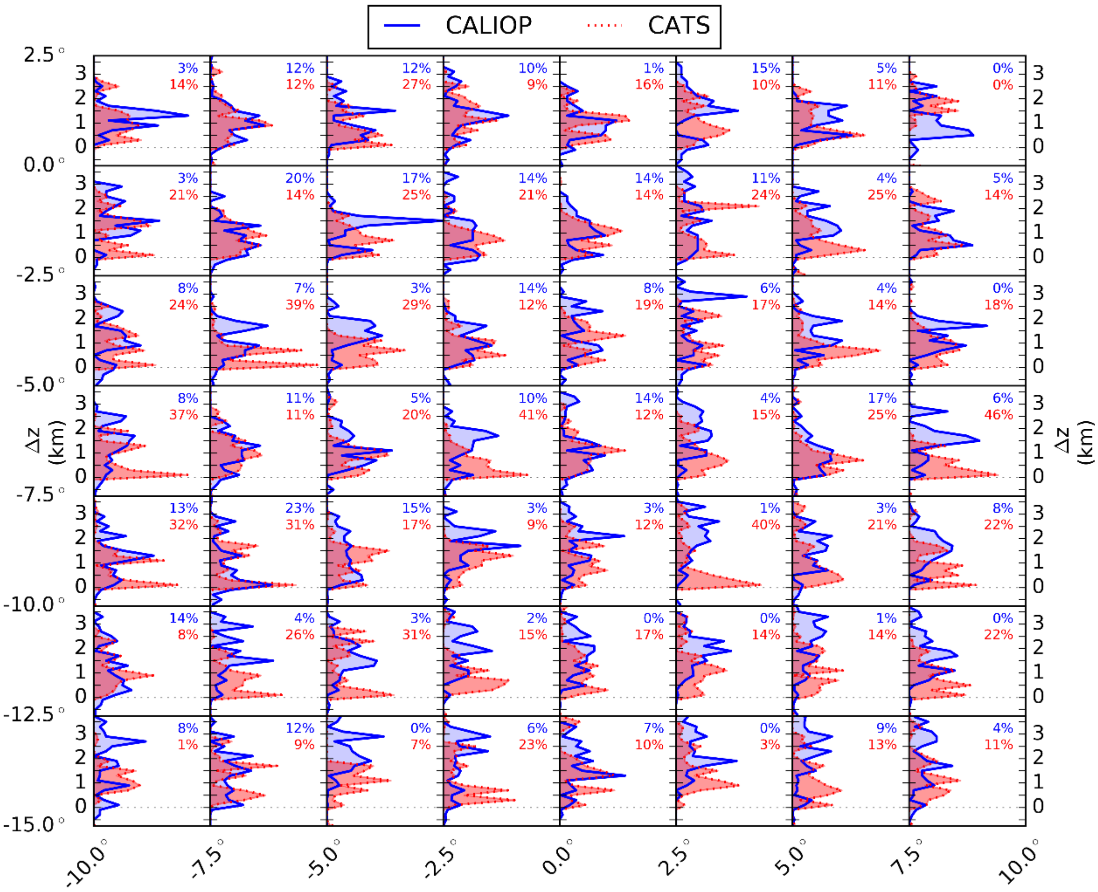

Figure R1. Normalised frequency of occurrence of gap distance between cloud layer top and aerosol base heights from CALIOP (blue solid line) and CATS (red dotted line) for single layer coincidences of aerosol and cloud in the months of July, August, and September (2007–2016 for CALIOP; 2015-2017 for CATS) over the southeast Atlantic (15°S to 2.5°N, 10°W to 10°E). Gaps are binned from -1.5 to 5.5 km in 200 m increments and data in each grid has been normalised to the maximum frequency across the whole study area. The percentage of scenes where the aerosol layer base is less than 360 m above the cloud top height is shown in the top right of each subplot, in blue for CALIOP and red for CATS.

Page 7, line 195: I refer to "This type of experiment is analogous to a satellite retrieval that estimates the AOD and aerosol layer top but does not detect the lower extend of the aerosol layer." How can this be analogous, if you cannot infer the geometric thickness? Do you assume an extinction profile?

Our explanation was confusing and has been clarified. The situation we are describing is when column-integrated total AOD, as retrieved for example by MODIS, is combined with partial knowledge of the layer geometric thickness, as retrieved for example by CALIOP. This combination occurs for example in the CCCM product. We have rewritten the paragraph to clarify the point we are making as follows:

"*This type of experiment aims to understand the importance of correctly retrieving the full extent of the aerosol layer from a satellite retrieval when only the AOD is known. Those variables are for example provided in the combined CCCM satellite product (Kato et al., 2010; 2011).*"

Page 7, end of line 185: “absorbing aerosol” instead of “layer”.

This has been amended as suggested.

Page 8, Eq.1: The ordering of the flux terms in the formula is wrong. It must be:

$$SDE = F_{TOA,aerosol} - F_{TOA,no-aerosol} - DRE$$

Agreed. We have corrected the formula in the manuscript.

Page 14, Fig. 5: Is below-cloud RH the vertical mean for the distance from ocean surface to the cloud base? Otherwise, at which height is the value taken?

The below-cloud RH is the vertical mean from above the ocean surface to the cloud base. We have clarified this in the manuscript and updated Figure 5 and Figure 6. While amending the figures, a mistake in plotting RH at the surface layer has been detected. This has been fixed and the mistake does not affect any of the text as the same response is observed in all figures.

Page 15, line 340: Based on Fig. 6e the total water path (TWP) (units kgm-2), and not the total water content (TWC) (kgm-3) is compared. The reduction in total water path is in-line with the reduced BL height (which also decreases by about 15

We have amended the manuscript to read ‘*total water path*’ and have changed the variable ‘Total BL qt’ to ‘*TWP of BL*’ throughout the manuscript. The reviewer’s comment seems to have been truncated, so we cannot respond to the missing part.

Page 17, Eq. 3: This equation is confusing. The following formulation should be equivalent:

$$Z_{lower} = Z_{max} \cdot (1 - 0.025)$$
$$Z_{upper} = Z_{max} \cdot (1 + 0.25)$$

If not, please rewrite it in a more understandable way.

Agreed. The suggested equation is more understandable. We have rewritten the equation as suggested.

Page 17, line 374: The explanation provided is not very convincing. Isn't the initial peak of positive SDE occurring before or around midday? Anyway, at the time it occurs, the clout top height and entrainment rate seem not to be significantly affected by the aerosol layer (look at Fig. 5 or Fig. 7 red line of the 500m-gap experiment). How much does the elevated aerosol layer affect radiative cooling of the cloud tops at night? Does the initial positive spike in SDE could be related to this?

Page 19, lines 415 - 417: See comment above

As the reviewer rightly suggests, the positive SDE occurs before midday rather than after midday as we erroneously wrote. This has been corrected.

The reviewer is not convinced by our explanation and suggests the positive SDE may be influenced by changes to the cloud-top longwave cooling. We have addressed this comment by including a new figure (Figure R2 in this document, Figure S1 in the revised manuscript) in the supporting information and improving our explanation in the manuscript. The new figure focuses on the cloud response in the first day (from 0230 to 1600) and includes the changes to cloud properties, buoyancy flux, advected total water content tendency, cloud-top longwave cooling, and LW fluxes for three of the experiments with a variable cloud-aerosol gap (with AOD=0.2 and layer geometric thickness of 250m).

The new figure shows that the positive SDE is driven by the decrease in LWP (Figure R2b) that is most evident at 0830 and 1000 for the experiments with gaps of 0 and 100 m. This response is caused by an increase in cloud base height (Figure R2a) without a corresponding change in cloud top height, which thins the cloud and reduces the LWP. Cloud base height increases because of weaker mixing within the boundary layer which reduces the transport of moisture within and beneath the cloud (Figure R2d). That reduced transport occurs because at 0830 the buoyancy flux throughout the profile weakens (Figure R2c), at the time at which entrainment starts to sharply decrease (Figure 5b). Note that below-cloud RH (Figure 5d) does not increase until after midday which indeed suggests that the increasing cloud base height is driven by in-cloud changes or the flux of moisture to the cloud base. As the day progresses the continued reduction in entrainment rate results in a moister boundary layer and an increase in RH below the cloud, which allows the cloud base to decrease and LWP to increase. This explains why stronger perturbations to the entrainment rate on the first day (such as when the layer is close to the cloud) results in a quicker recovery of the LWP (see Figure 7). This improved explanation has been included in Section 3.3.1.

With regards to the cloud-top LW cooling, we would expect the cooling rate to be weakened by the presence of the elevated aerosol layer and any additional heating of the layer, both of which would increase downwelling LW. Figure R2e shows that there are instantaneous differences in LW cooling up to a magnitude of 20 K day^{-1}, however the sign changes throughout the day. The response of the net LW flux shown in Figure R2f confirms that there is little impact to the fluxes above cloud before sunrise. The buoyancy flux profiles in Figure R2c do show a limited response to the aerosol layer before sunrise (at 0400 hours) in all experiments but there is little simultaneous LWP response. The dominant cloud response appears to occur after sunrise, which suggests the decrease in LWP is driven by an enhanced inversion strength rather than weakened cloud-top LW cooling. We have included a brief discussion of this additional effect in Section 3.2.1.

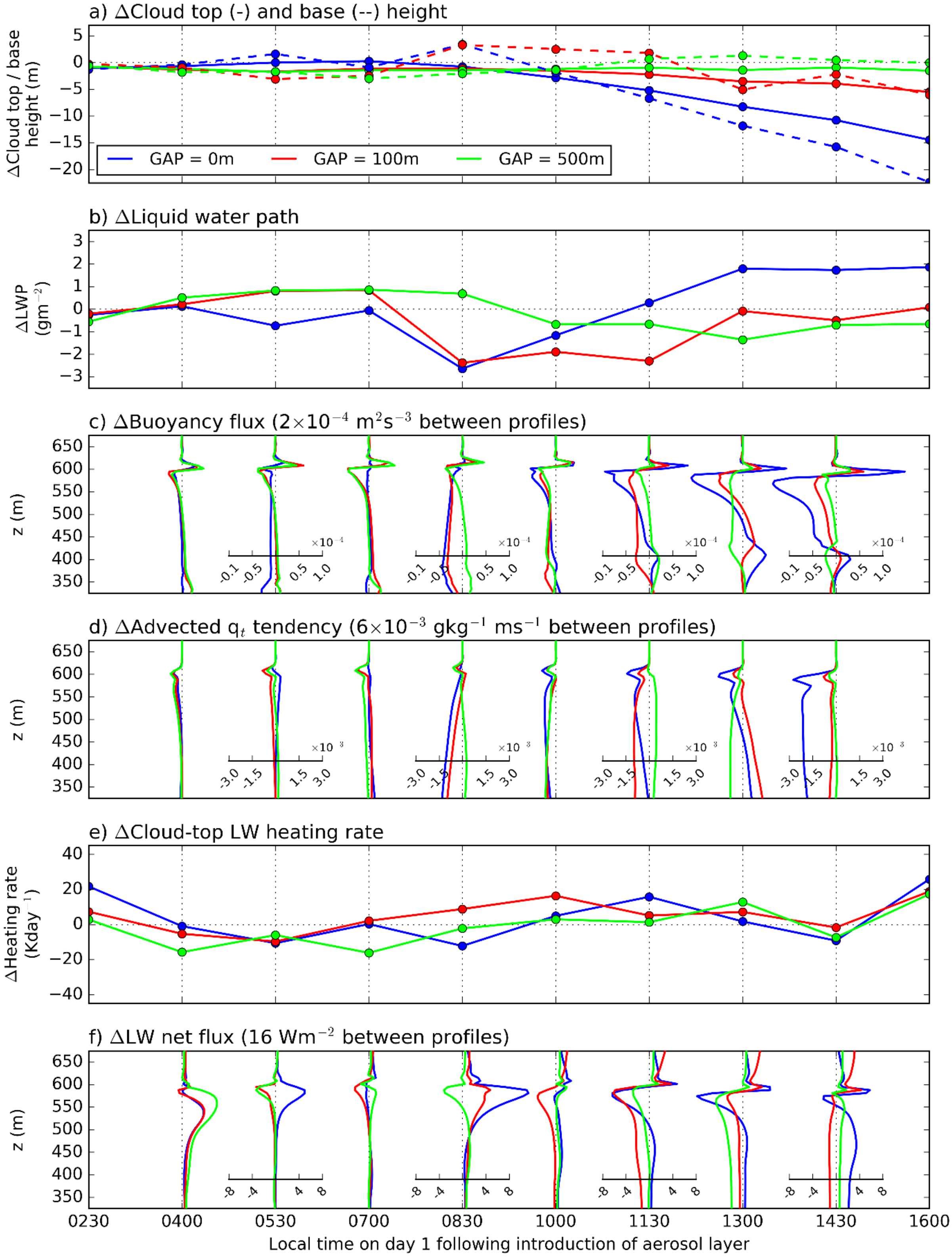

Figure R2. Response to the presence of an aerosol layer above the cloud (gap of 0 m in blue, 100 m in red, and 500 m in green) of a) the cloud top (solid line) and cloud base (dashed line) heights, b) the cloud liquid water path (LWP), c) profiles of the mean buoyancy flux, d) profiles of the mean advected total water content tendency, e) cloud-top longwave cooling, and f) profiles of mean longwave net flux (positive values indicate increased downward flux). The geometric thickness of the aerosol layer is 250 m and its optical depth is 0.2. Data is shown for the first day following the introduction of the aerosol layer. Mean instantaneous profiles (shown in panels c, d, and f) for each time are centred on a value of zero, depicted by the vertical dotted lines. Each profile is separated on the x-axis by a constant magnitude shown above each corresponding plot.

Page 27, Fig. 10 e,k,q: Please specify “BL mean” and “BL total”. I assume the dotted line is “BL total”? If “BL total” refers to TWP and “BL mean” to TWC you can see how the moisture content of air increases within the BL, despite an overall decrease in TWP due to the shrinking of the BL

We have amended the figure and text as suggested to provide clarity.

Page 29, line 633: This can only hold true if it is reasonable to neglect emission of longwave radiation of the aerosol layer and ergo its insulating effect

This relates to the comment about cloud-top LW cooling addressed above with Figure R2. Figure R2f shows the response of the net LW flux profiles. Before sunrise the net fluxes above cloud are < 1.5 % greater when the aerosol layer is present, suggesting a weak insulating effect. During the day this increases up to a maximum of ~ 5 % as the temperature of the aerosol layer increases, but still indicates a weak insulating effect.

Section 3.2.1 already contains a discussion of the changes to LW fluxes and cloud-top cooling following the comment above, and we have added the following sentence to the discussion and conclusions section:

“*The insulating effect of the aerosol layer only weakly influences the net longwave fluxes and divergence above the cloud.*”

Page 29, line 638: “, the magnitude of SDE is increased. . .”, or “, SDE is amplified. . .”is less ambiguous, as the sign of SDE is negative.

Agreed. The manuscript has been amended to read “*SDE is amplified*”.

Page 31, line 719: missing “explain”

The manuscript has been amended as suggested.

References

Kato, S., S. Sun-Mack, W. F. Miller, F. G. Rose, Y. Chen, P. Minnis, and B. A. Wielicki, 2010: Relationships among cloud occurrence frequency, overlap and effective thickness derived from CALIPSO and CloudSat merged vertical profiles. J. Geophys. Res., 115, D00H28, https://doi.org/10.1029/2009JD012277

Kato, S., and Coauthors, 2011: Improvements of top-of-atmosphere and surface irradiance computations with CALIPSO-, CloudSat-, and MODIS-derived cloud and aerosol properties. J. Geophys. Res., 116, D19209, https://doi.org/10.1029/2011JD016050

Rajapakshe, C., Zhang, Z., Yorks, J. E., Yu, H., Tan, Q., Meyer, K., Platnick, S. and Winker, D. M. 2017: Seasonally transported aerosol layers over southeast Atlantic are closer to underlying clouds than previously reported, Geophys. Res. Lett., 44(11), 5818–5825, doi:10.1002/2017GL073559