Ms. No.: ACP-2021-274

A meteorological overview of the ORACLES (ObseRvations of Aerosols above CLouds and their intEractionS) campaign over the southeast Atlantic during 2016-2018

Ju-Mee Ryoo *et al.*

Major changes in the revised manuscript:

- ***Following the suggestion of Reviewer #2***, we have separated the paper into two parts to deliver key messages more effectively: Part1 (climatology) and Part2 (individual deployments). We focus on the first part (Part 1-Climatology) for this revision. Accordingly, the title is also changed into "A meteorological overview of the ORACLES (ObseRvations of Aerosols above CLouds and their intEractionS) campaign over the southeast Atlantic during 2016-2018: Part 1 - Climatology".
- ***Following the suggestion of Reviewer #1***, we have also investigated the possible reasons for the weaker AEJ-S in August 2017 compared to the climatological mean. How the aerosol from ECMWF CAMS reanalysis behaves along with the meteorological variables during the deployment months has been discussed.

We have taken the reviewers' comments and performed additional analyses based on reviewers' comments. We hope we have addressed all the key comments and suggestions from the reviewers and incorporated them in the revised manuscript. Enclosed is a point-by-point response to each reviewer's comments.

Response to reviewer #1

In this response letter, we repeat the reviewer's questions and answer them one by one. Our response is marked in blue letters.

Review of the paper "A meteorological overview of the ORACLES (ObseRvations of Aerosols above CLouds and their intEractionS) campaign over the southeast Atlantic during 2016-2018" by Ryoo et al. 2021, submitted to Atmospheric Chemistry and Physics Discussions.

General Comments

The paper describes the atmospheric conditions during three field campaigns over southeast Atlantic in 2016-2018. The manuscript is well written and clear, figures quality is good and captions are informative. The authors provide a comprehensive picture of the climatological conditions, seasonal anomalies and synoptic evolution during the deployments, and physical mechanisms are correctly described and widely detailed. The paper appears to be specifically addressed to the community studying the physics of the atmosphere in the southeast Atlantic and provides a valuable contribution to all the teams involved in field campaigns during 2016-2018 for putting their observations into a synoptic context.

However, in my opinion the paper remains almost exclusively descriptive and does not respond to any relevant scientific question. In the main text, several interesting scientific questions are highlighted, but the authors do not investigate any of them, only speculating on possible (always plausible) explanations and requiring further investigation in future papers. For instance, I found very interesting the anomaly (almost disappearance and/or lifting) of the AEJ-S in August 2017, which would be worth to be investigated, in terms of both local and remote drivers.

This is my main and only concern. Despite the overall good quality of the paper itself, I am not sure it fits with the scope of ACP and/or the special issue. I list below a few general and specific suggestions on what I believe could be improved.

=> Thank you for your valuable comments.

Following your suggestions, we trimmed lots of text and kept the key figures. Furthermore, since 1) both reviewers pointed out the length of the manuscripts and 2) the other reviewer suggested that we separate the paper into two parts (***Part 1***: climatology at monthly time scales; ***Part 2***: deployment month at daily to synoptic time scales), we decided to separate the paper into two parts. In this revision, we focus on Part 1 - Climatology.

This is a meteorological overview paper, so our main focus was to describe the overall meteorological conditions during the 2016-2018 ORACLES campaigns. While investigating the underlying mechanism with more depth was important, this was not our focus in this overview paper. However, we examined further the possible environmental factors to cause the anomalous AEJ-S in August 2017, following your suggestion. We found a few distinctive characteristics during August 2017, but among them, we think upper-level disturbances play a significant role in modulating the large-scale environment and thereby the AEJ-S. In order words, the position (phase) of the upper-level disturbance induces an anomalous circulation, thereby changing the cross-latitude temperature gradient over the land, ultimately reducing AEJ-S. We described this more in detail with figures in the response letter below as well as in Part 1 of the revised manuscript.

We have also further investigated a possible remote driver for weakening AEJ-S. As a remote driver, the Madden Julian Oscillation convection (MJO; Madden and Julian, 1994; Wheeler and Hendon, 2004), an intraseasonal convective variability in the equatorial troposphere with a periodicity of about 30-90 days, may contribute to the weakening of AEJ-S in August 2017, because this is weakened over Africa during this period (shown in Fig. 10S in the supplementary material). The MJO can affect the timing and intensity of convectively coupled Kelvin waves and convective activity over Africa (Guo et al., 2014), which can affect AEJ-S activity (Ventrice and Thorncroft, 2013; Zaitchik, 2017). However, this remote driver has been investigated for the AEJ-N, and the MJO's influence on the AEJ-S is less understood and remains unclear.

The paper is very long, with many (25!) multi-panel figures. Figures are often the repetition of similar analysis, it is not easy for the reader to stay focused on the narrative of the paper. The authors could try select non-key information in text and figures and move it to the Supplement.

=> Both reviewers pointed this out, and we worked on this part. We trimmed the texts and tried to keep the main key messages. We also separated the paper into two parts following the second reviewer's suggestion.

In the Summary and Discussion, the authors speculate on the effect of meteorological conditions on the aerosol transport but no evidence of the actual effect is provided (while the cloud-circulation relationship is well described in the paper). I believe this is a key aspect which could provide added value to the paper. ECMWF CAMS reanalysis could be used to frame the aerosol patterns at the regional scale.

=> Thank you for the comments. Following the reviewer's suggestion, we also looked at the ECMWF CAMS reanalysis data. Since we focused on climatology in this paper, we observed the features from the monthly mean data.

The black carbon mixing ratios (BC) and Carbon Monoxide mixing ratios (CO) have similar features as in August 2017; particularly the BC is "lower" in August 2017 than the climatological mean, especially off the coast and over the ocean, shown in Fig. R1. We think this is reasonable because a weaker AEJ-S leads to weaker advection of these burning trace constituents out over the SE Atlantic. BC in September 2016 is slightly higher than the climatological mean, especially at the jet entrance region over land following the ascent (See Fig. R2).

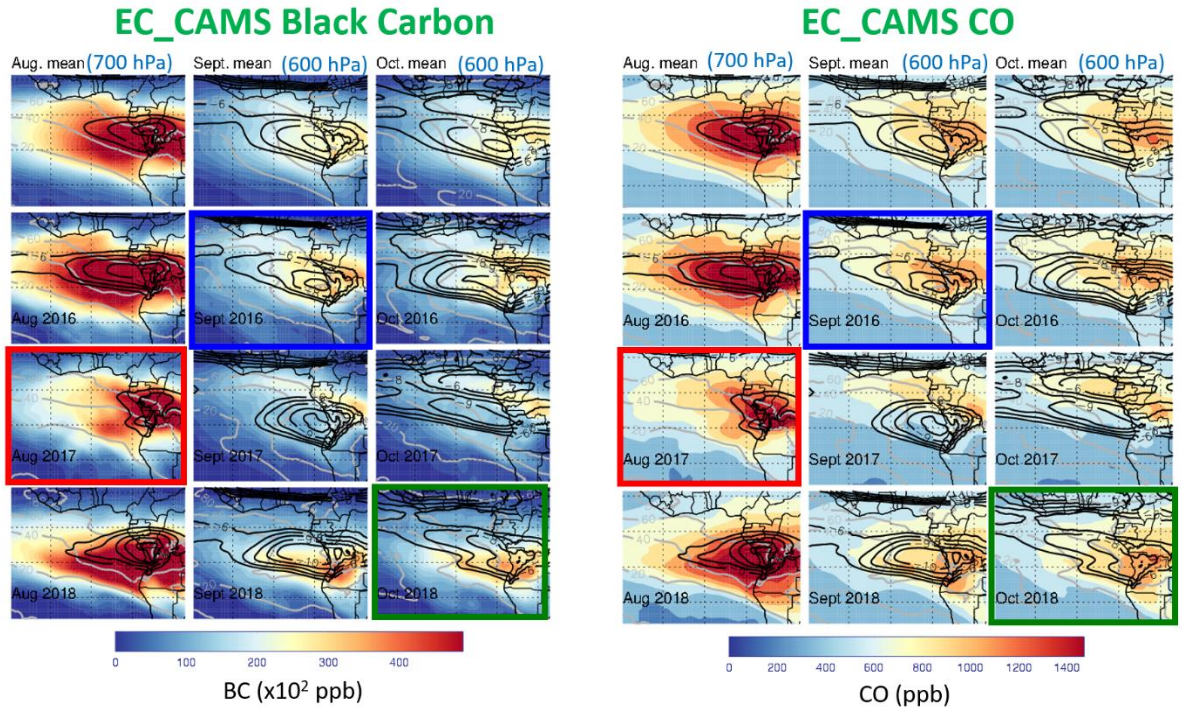

Figure R1. Map of monthly mean (left panel) black carbon mixing ratios (BC, shading, 100 x ppb) and (right panel) Carbon Monoxide mixing ratios (CO, shading, ppb) overlaid by AEJ-S (zonal wind isotach, black contour, m s^{-1}) and RH (gray contour, %) at 700 hPa for August and at 600 hPa for September and October for the (1st row) climatological mean and (2nd – 4th row) the deployment month. The climatology for AEJ-S and RH is based on 2000-2018 from ERA5, and BC/CO is based on 2003-2020 from ECMWF CAMS. The color boxes (red, blue, and green) indicate the month of ORACLES deployment.

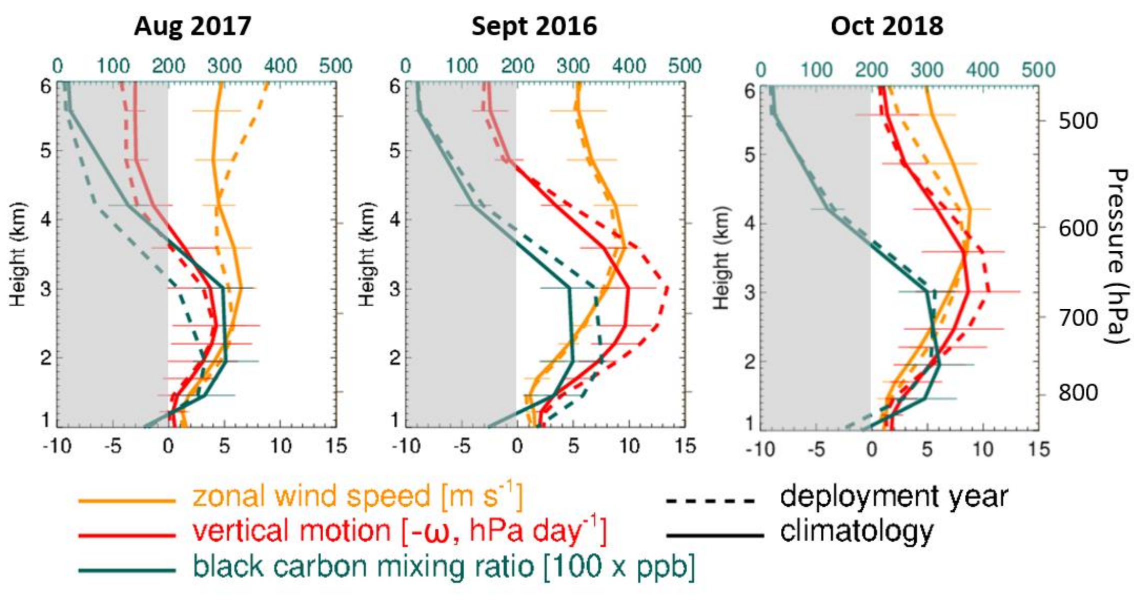

Figure R2. The vertical profiles of BC (green; averaged over the region (4-10° E, 5-10° S), 100 x ppb), vertical velocity (red, omega multiplied by -1 to represent the positive (negative) value as the ascent (descent); averaged over 12-18° E, 12-17° S, hPa day^{-1}), and zonal wind speed (orange; averaged over the region (4-10° E, 5-10° S), m s^{-1}) for August 2017, September 2016, and October 2018. The thin horizontal line at each height level in (b) represents the 1.5 +/- standard deviation of the climatological mean. The gray shading refers to the descent regions. The green (red) box in the middle of (a) refers to the regions for the averaged zonal wind speed and the BC (vertical velocity) values used in (b), respectively.

One interesting feature is that the peak mixing ratio occurs around 2-3 km, shown in Fig. R2 (green lines). The CAMS BC seems somewhat to follow the ascent motion (e.g. BC is higher when ascent is stronger in September 2016 than the climatological mean), but the overall pattern of them does not vary much during August - October. The vertical location of maximum values of BC does not change much. The original expectation was the BC/CO maximum would occur 3.5~4 km especially in September and October, around the level of AEJ-S. Shinozuka et al. (2020) and Doherty et al. (2021) both documented that the aerosols in models tend to have more of their mass located "lower" down than in the ORACLES observations, although their comparisons did not include CAMS data. While more analysis needs to be done, this indicates the assimilation schemes in models still have room for improvement, in how they vertically allocate aerosol. We included these plots along with further discussion in section 3.3 of Part 1 of the revised manuscript.

Specific Comments

Abstract: In the introduction, the authors state that "The goal of this study is to describe the meteorological factors that directly impact aerosols and low clouds, particularly stratocumulus decks during the ORACLES campaign". Therefore I believe that also the anomalies in the aerosol/cloud patterns originating different atmospheric conditions should be mentioned in the abstract.

=> Thank you for the suggestion. We agree with the reviewer. We included the anomalous features of the low-cloud and aerosol compared to the climatology in the abstract of Part 1 of the revised manuscript.

Figures: anomalies should be presented along with assessment of statistical significance, qualitative assessment is not enough.

=> Thank you for pointing this out. We described the statistical assessment along with the plots as well in Part 1 of the revised manuscript.

L64: does the moisture gradient also play a role in the AEJ-S dynamics?

=> AEJ-S is a basically thermally driven circulation. A large meridional (cross-latitudinal) temperature gradient between hot, dry Namibian dryland and cool, moist Congo basin is attributed to the development and maintenance of AEJ-S.

However, the correlation between AEJ-S and inland q is small, indicating that inland moisture itself may be less likely to affect the formation and maintenance of the AEJ-S. This can be understood in the same context as Jackson et al. (2009), in which the AEJ-S may enhance convection through enhancing the vertical ascent at the jet entrance region, with the additional advected moisture acting to reduce the thermal contrast. However, the additional advected moisture north of 10° S does not reduce the thermal contrast much (at most 10%, based on Adebiyi and Zuidema, 2016). Nonetheless, whether the AEJ itself may result from convection still remains unclear, because some studies claimed that latent heat release is a factor in the development of the AEJ-N (Thorncroft and Blackburn, 1999). "

L72: in Lamb and Peppler 1992 I cannot find an explicit reference to SST in the Benguela region as related to Sahel rainfall variability, they rather describe a basin-wide influence of North and South Atlantic. This sentence should be modified or removed.

=> The first author apologizes for the misinterpretation of the Lamb and Peppler (1992) paper. Although there is no mention of SST in the Benguela region in the paper, the figures in the paper cover this region, and the region also seems to be included in the tropical Atlantic regions and associated with sub-Saharan rainy season variability. However, considering that this paper focuses on sub-Saharan West Africa, it is less relevant to the regions we are interested in, this reference is removed as suggested by reviewers.

L162: any reference for the choice of the threshold at 230K?

=> The 230K threshold was chosen because this threshold shows a good estimate of convective rainfall. For example, Zuidema (2003) used a 235K threshold because of a documented fit between area- and time-averaged rainfall and brightness temperature (Arkin, 1979), which perform well for most regions. Ohsawa et al. (2001) also obtained 230K as a good estimate of rainfall when performing regression analysis of rainfall gauge data and satellite data.

However, we did not use the brightness temperature data for the climatological overview, we removed this description from Part 1 of the revised manuscript.

L178-179: how D values are determined?

=> D is the height that the maximum planetary boundary layer over both land and ocean. During the deployment period based on the reanalysis data and model data, the decoupled boundary layer is not higher than 3km over the ocean and 6km over the land (typically, D is not higher than the cloud top heights). Furthermore, the aerosol plume height and the airmass trajectory over the south Atlantic region that we are interested in is well under about 6 km. This is why we set D as 6 km over the land and 3km over the ocean.

In addition, D values were introduced for detecting the cloud-topped BLH including decoupled stratocumulus layer using 6 hourly data for detailed investigation during the deployment month. However, we used the ERA5 monthly mean BLH data (which is calculated based on the bulk Richardson number) in Part 1 of the revised manuscript. Thus, the methodology of the cloud-topped BLH detection is removed in Part 1 of the revised manuscript.

Figure 2: what do histograms in a-c exactly display? Why is pressure altitude reported in km on the y-axes?

=> The (a-c) represents the distributions of aerosol top height (red), cloud top height (blue), and the separation between clouds and overlying aerosols (yellow) as a function of longitude, between 10-22.5S using CALIOP version 3 aerosol profile product from 2006 and 2012. These figures are reproduced from Redemann et al. (2021). “Pressure altitude” is meant to refer to the height converted from the pressure level since variables in reanalysis data are reported in isobaric surfaces (pressure levels). That is why we named it pressure altitude. We changed it into “Height (km)” in Part 1 of the revised manuscript.

L223: the AEJ-S anomaly in August 2017 looks like a vertical shift of the jet. This is rather unusual, why not to explore possible local/remote mechanisms explaining this feature?

=> Thank you for your comments. This was certainly an interesting feature. While we perceived its unique features and found that very interesting, we wanted to focus on the meteorological and climatological overview in this paper. However, following your suggestion, we decided to pursue for investigating more possible local and remote drivers in the August 2017 AEJ-S feature. As we described earlier, the mid-latitude upper-level disturbances play a large role in modulating the large-scale environment and thereby the AEJ-S (Kuete et al., 2020). In order words, the position of upper-level disturbance induces an anomalous circulation, thereby changing the cross-latitude temperature gradient over the land, ultimately reducing AEJ-S in August 2017. This disturbance also intensifies the anticyclonic circulation on the right side of low PV, assisting in the development of anomalously high large-scale subsidence. This can also affect AEJ-S because the AEJ-S weakens when subsidence is strong, because the lower-level updraft is blocked by the subsidence (Adebiyi and Zuidema, 2016). These features are also consistent with Kuete et al. (2020). More detailed discussion is provided with the figure in the response letter below (Fig. R4) as well as in section 3.4 of Part 1 of the revised manuscript.

Figures 2 and 3: plotting individual year anomalies (with significance) would be also helpful.

=> We plotted the anomaly of horizontal wind speed and RH at 700hPa for August and 600 hPa for September and October. We also included the other anomaly fields both in the main manuscript and in the supplementary materials.

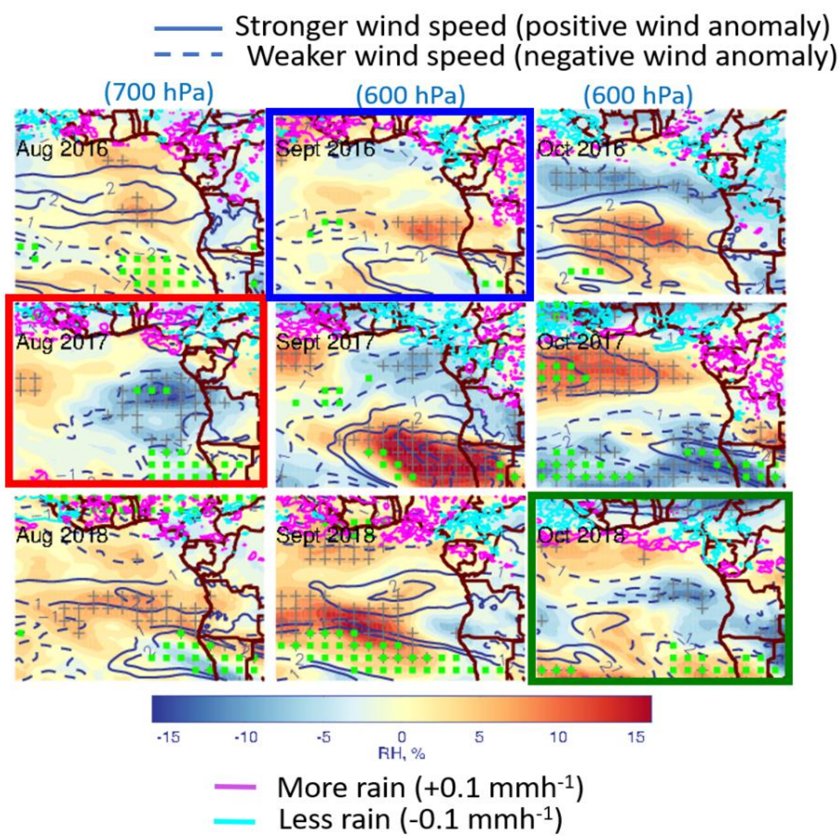

Figure R3. Maps of the anomalies of horizontal wind speed, RH, and precipitation (contour, -0.2,-0.1,0.1,0.2 mm hr-1) at 700 hPa for August and at 600 hPa for September and October. The anomalies are computed by subtracting the monthly mean value from the climatological mean (2000–2018). The magenta (cyan) lines show more (less) than the climatological mean precipitation. The green square (gray cross) indicates the wind anomaly (RH anomaly) data is significant at the 85% confidence level. The color boxes (red, blue, and green) indicate the month of ORACLES deployment.

L251: how did you estimate the strength of recirculation?

=> We estimated the strength of recirculation by looking at the radius from the mid-level anticyclone driven by AEJ-S. The stronger the AEJ-S is, the larger the radius of the anticyclone is.

L254: the AEJ-S almost disappears in Aug 2017, the mechanism leading to this particular feature is worth to be further investigated.

=> As mentioned earlier, our primary focus in this paper is to provide the meteorological overview during the ORACLES deployment year. Thus, investigating the mechanism leading to the feature is NOT the primary focus. However, we agree that August 2017 has an interesting feature, and is worthwhile to investigate it further. Thus, following your suggestion, we decided to investigate some possible local and remote drivers leading to the weak AEJ-S in August 2017. This is discussed on page 1 of this response, with more detail provided below.

Previous studies have shown that the upper-level mid-latitude disturbance can modulate the temperature gradient over SE Atlantic (Adebiyi and Zuidema, 2018; Kuete et al., 2020), and the different phases of upper-level waves play an important role in modulating the strength of the AEJ-S over the SE Atlantic as well (Kuete et al., 2020). Motivated by these studies, we examine whether the upper-level disturbances can contribute to the weakening of AEJ-S in August 2017 and how they modulated the AEJ-S.

To examine how the circulation associated with the upper-level disturbance can influence the AEJ-S further, we computed the thickness (heat low over the continent) anomaly with the upper-level PV anomaly at 250 hPa. Indeed, the upper-level disturbance is closely linked to the change in thickness, which is proportional to the layer mean temperature, shown in Fig. R4a. For example, in August 2017, the negative PV anomaly is linked to positive thickness anomaly (warm air), and the anticyclones associated with this advect the cool air from the mid-latitude ocean, reducing the heat low over the land (Fig. R4a).

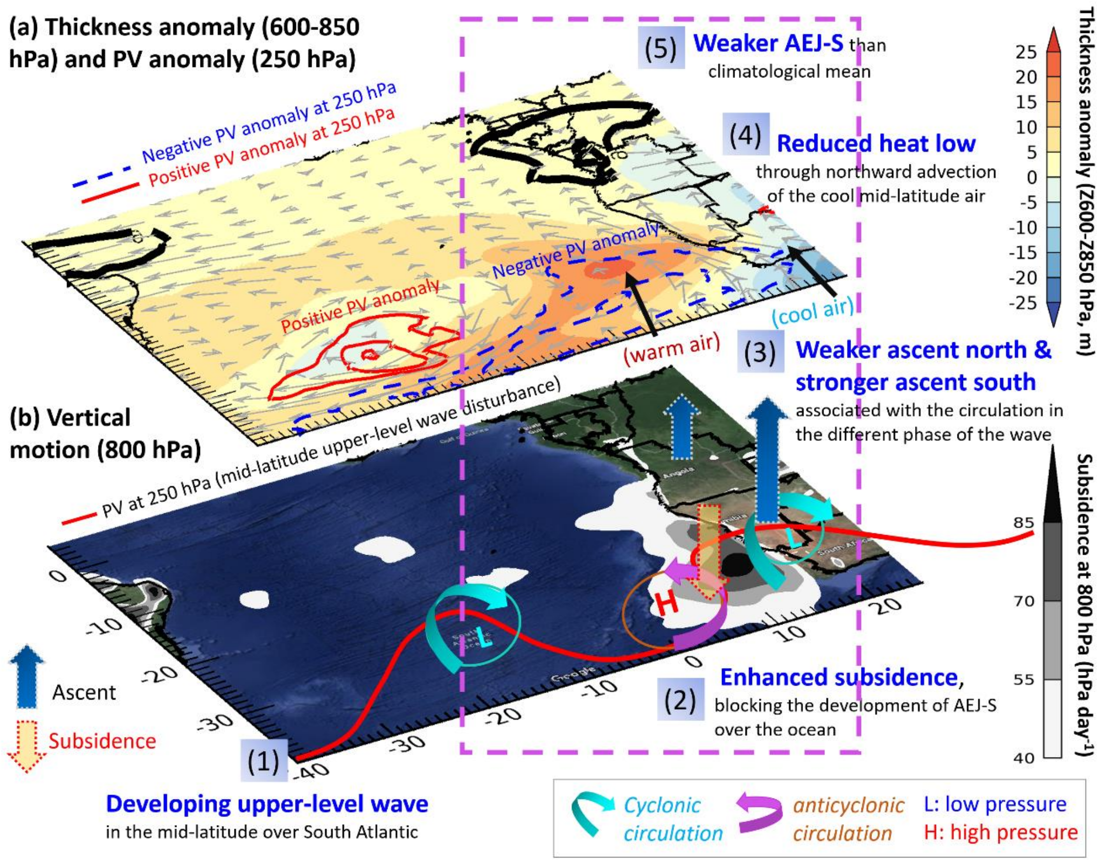

Figure R4. *Schematics of the upper-level disturbance and associated circulations, leading to the change in a vertical motion, reduction of the heat low through northward advection of the cool mid-latitude air, resulting in the weaker AEJ-S in August 2017 over the land at the north of 10° S. The enhanced subsidence also contributes to preventing the development of AEJ-S over the ocean:* **(a) Map of 250 hPa PV anomaly (dashed contour, PVU; the blue dashed (red solid) line represents the negative (positive) PV anomaly), thickness anomaly (Z600hPa – Z850hPa, shading, m), and 250 hPa horizontal wind anomaly (gray arrow, m s^{-1}) overlaid by AEJ-S (zonal wind isotach at 700 hPa, m s^{-1}). (b) Subsidence (positive values from omega at 800 hPa, hPa day^{-1}) plotted on the Google™ Earth.**

The negative (positive) PV anomaly corresponds to high (low) thickness anomaly and warm air (cool air). The cyclonic (anticyclonic) circulation represents the winds turning clockwise (anticlockwise) in SH associated with the phase of the upper-level wave. The dashed magenta box represents the features that occurred in the August 2017 deployment.

Figure R4 shows the schematics of the anomalous 250 hPa circulation associate with the developing mid-latitude upper-level wave (or disturbance). An anomalous ascent is found downstream of the troughs, and anomalous subsidence is found upstream of the trough. This subsidence and ascent drive an anomalous anticyclone and cyclone in the 900-600 hPa depth region up to the upper-tropospheric region (~ 250 hPa), leading to northward motion over Namibia. This advects air from higher mid-latitude latitudes (i.e. cooler air) to the Angolan highlands, reducing the meridional temperature contrast between the Angolan highlands and the Congo Basin, leading to weaker AEJ-S over the land at the north of 10° S. Together with this, the subsidence over the ocean is much stronger in August 2017 especially off the Benguela coast up to around 3° S, preventing the AEJ-S from transporting to the ocean (Adebiyi and Zuidema, 2016), which is also closely tied to the phase of the upper-level disturbances (Kuete et al., 2020).

These upper-level waves and associated circulations also explain the variability and strength of the heat low and AEJ-S during the other deployment months as well. (Fig. 9S in the supplementary materials).

We also found distinctive features in August 2017 based on the monthly mean data, such as 1) The large-scale subsidence is large compared to the climatological mean. 2) The temperature and moisture advection off the coast of 5-10° S and 0-10° E is weaker compared to the climatological mean, consistent with a weaker-than-average AEJ-S.

As a remote driver, the Madden Julian Oscillation convection (MJO; Madden and Julian, 1994; Wheeler and Hendon, 2004), an intraseasonal convective variability in the equatorial troposphere with a periodicity of about 30-90 days, may contribute to the weakening of AEJ-S in August 2017, because this is weakened over Africa during this period (shown in Fig. 10S in the supplementary material). The MJO can affect the timing and intensity of convectively coupled Kelvin waves and convective activity over Africa (Guo et al., 2014), which can affect AEJ-S activity (Ventrice and Thorncroft, 2013; Zaitchik, 2017). However, this remote driver has been investigated for the AEJ-N, and the MJO's influence on the AEJ-S is less understood and remains unclear.

This discussion is included as section 3.4 in Part 1 of the revised manuscript.

L278-300: in discussing Fig. 4, please specify when you discuss Aug 2017, Sep 2016 and Oct 2018.

=> We apologize that we do not clearly specify which month when we discuss the individual month. We specified them in Part 1 of the revised manuscript.

L360-361: "correlation" word should not be used if correlation is not computed (Fig. 6 does not show correlations).

=> Sorry for the incorrect use of the wording. We did perform correlation analysis using 6 hourly data in the deployment month, which will be Part 2 of the manuscript, so the wording might come from that. We carefully reworded the paragraph related to Fig. 6.

L437: no "robust correlation" is shown in Fig. 8, see comment above.

=> This is a good point. Yes, we performed the correlation analysis, but we got a high correlation for some deployment and a very low correlation for some deployment, so we could not find a clear correlation during the deployment months.

L568: in Fig. 13, I cannot see the midlatitude weather system on 8 Sep 2016.

=> The mid-latitude (around 30 S) cyclone seems to be developed around September 24, 2016. And the large-scale anticyclone is dominant on 8 September 2016. We corrected that. However, since we focus on the climatological part in this revision, Fig. 13 is not included in Part 1 of the revised manuscript.

L753: Meridional wind is not displayed in Fig. 19, so how can we see "southeasterly winds"?

=> Thanks for catching this. The statement was based on both Fig 19d and Fig. 20(e, f). We corrected that. However, since we focus on the climatological part in this revision, Fig. 19 is not included in Part 1 of the revised manuscript.

Figure 24: is the seasonal cycle removed before computing daily correlations?

=> The monthly climatological mean value is removed from the data before computing daily correlations. However, Fig. 24 is not included in Part 1 of the revised manuscript.

Technical corrections

L81: West African monsoon.

=> We corrected it.

L161: typo, brightness.

=> We corrected it.

L240: magenta dashed box region is not displayed in Fig. 3.

=> Sorry for the missing box region. However, since we do not include the precipitation histogram in the revised manuscript, the magenta dashed box is not displayed anymore. We carefully worked on the figure caption appropriately in Part 1 of the revised manuscript.

L535: check punctuation.

=> Thanks. We checked it thoroughly in the revised manuscript.

Reference

Adebiyi, A. A., and Zuidema, P.: The role of the southern African easterly jet in modifying the southeast Atlantic aerosol and cloud environments. Q. J. R. Meteorol. Soc. 142: 1574–1589, doi:10.1002/qj.2765., 2016.

Arkin, P.: The relationship between fractional coverage of high cloud and rainfall accumulations during GATE over the B-scale array. Mon. Wea. Rev., 107 , 1382–1387, 1979.

Doherty, S. J., Saide, P. E., Zuidema, P., Shinozuka, Y., Ferrada, G. A., Gordon, H., Mallet, M., Meyer, K., Painemal, D., Howell, S. G., Freitag, S., Dobracki, A., Podolske, J. R., Burton, S. P., Ferrare, R. A., Howes, C., Nabat, P., Carmichael, G. R., da Silva, A., Pistone, K., Chang, I., Gao, L., Wood, R., and Redemann, J.: Modeled and observed properties related to the direct aerosol radiative effect of biomass burning aerosol over the Southeast Atlantic, Atmos. Chem. Phys. Discuss. [preprint], https://doi.org/10.5194/acp-2021-333, in review, 2021.

Guo, Y., and Jiang, X. and Waliser, D. E.: Modulation of the Convectively Coupled Kelvin Waves over South America and the Tropical Atlantic Ocean in Association with the Madden–Julian Oscillation, J. Atmos. Sci., 71, 1371-1388, 2014.

Madden, R. A. and Julian, P. R.: Observations of the 40–50-Day Tropical Oscillation–A Review, Mon. Weather Rev., 122, 814–837, 1994.

Ohsawa, T., Ueda, H., Hayashi, T., Watanabe, A., and Matsumoto, J.: Diurnal variations of convective activity and rainfall in tropical Asia. J. Meteor. Soc. Japan, 79 , 333-352, https://doi.org/10.2151/jmsj.79.333, 2001.

Shinozuka, Y., Saide, P. E., Ferrada, G. A., Burton, S. P., Rerrare, R., Doherty, S. J., Gordon, H., Longo, K., Mallet, M., Feng, Y., Wang, Q., Cheng, Y., Dobracki, A., Freitag, S., Howell, S. G., LeBlanc, S., Flynn, C., Segal-Rosenhaimer, M., Pistons, K., Podolske, J. R., Stith, E. J., Bennett, J. R., Carmichael, G. R., Da Silva, A., Govindaraju, R., Leung, R., Zhang, Y., Pfister, L., Ryoo, J.-M., Redemann, J., Wood, R., and Zuidema, P.: Modeling the smoky troposphere of the southeast Atlantic: a comparison to ORACLES airborne observations from September of 2016, Atmospheric Chemistry and Physics, https://doi.org/10.5194/acp-2019-678, 2020.

Thorncroft, C. D., and Blackburn, M.: Maintenance of the African easterly jet. Q. J. R. Meteor, 125 , 763–786, 1999.

Ventrice, M. J., Thorncroft, C. D.: The Role of Convectively Coupled Atmospheric Kelvin Waves on African Easterly Wave Activity, Mon. Wea. Rev., 141, 1910-1924, DOI: 10.1175/MWR-D-12-00147.1, 2013.

Wheeler, M. C., and Hendon, H. H.: An all-season real-time multivariate MJO index: development of an index for monitoring and prediction, Mon. Wea. Rev. 132, 1917-1932, 2004.

Zaitchik, B., F.: Madden-Julian Oscillation Impacts on Tropical African Precipitation, Atmos. Res. 184, 88-102, 10.1016/j.atmosres.2016.10.002, 2017.

Zuidema, P.: Convective Clouds over the Bay of Bengal, Mon. Wea. Rev. 131, 780-798, https://doi.org/10.1175/1520-0493(2003)131<0780:CCOTBO>2.0.CO;2, 2003.

Response to reviewer 2

In this response letter, we repeat the reviewer's questions and answer them one by one. Our response is marked in blue letters.

This paper is important and presents original work on a feature that has not received much attention. I was originally going to rate this as "minor revision". However, I realized that the length and complexity is such that very few would read it. I am extremely interested in this topic, but would dread, as a researcher, having to go through this article. The word count must be close to 15,000, roughly twice that accepted by most journals. It indicates 26 figures, yet most have numerous panels. In most cases those panels are quite independent of each other, so that 40 figures is a more realistic number. I am indicating major revision because I feel it is imperative that the authors break this into two articles. That is actually not that difficult or time-consuming to do. It will guarantee that the work receives more attention.

Based on this comment, I have stopped the review around Figure 5.

=> Thank you for your valuable comments. We appreciated your comments. Following your suggestion, we now separate the paper into two parts. Part 1 of the revised manuscript is focused on the climatology part.

I do hope the authors will consider what is suggested above, as it is important work and should eventually be published. Also, the authors might want to look at the extensive work on the fogs and stratus done by Cermac and colleagues and cite some of that literature.

=> Thank you for your suggestion. We cited Cermak et al. paper like "Like Cermak et al. (2009), an extensive analysis to separate the low clouds into the detailed cloud types such as stratocumulus, stratus, and fog, will be desirable. However, considering that the fraction of annual low cloud cover due to stratocumulus over the SE Atlantic Ocean is larger than 70% with a peak of 90% (Wood, 2012), we assume that the low clouds represent stratocumulus clouds in this study. "in section 2 (line 154-157 in page 6).

INDIVIDUAL COMMENTS

The abstract is too long and includes too many details that really belong in the text. This is particularly the case in describing the anomalous characteristics for the three months considered.

=>. We reduced the abstract for the revised manuscript. Reviewer 1 however requests more information be included on the cloud and aerosol anomalies within the abstract, so we do expect to keep information pertaining to the anomalies in the abstract.

Good overview of the background literature. Variables considered and data sets to derive them are clearly described.

=> Thank you for your comments.

A major concern is their use of ERA-5 because its representation of the AEJ-S is questionable. The core tends to be over the ocean in the various diagrams, with little extension over the land in most cases. The only paper that focuses directly on the AEJ-S is Kuete et al. (2020) in Climate Dynamics (see also Jackson et al. 2009). Of the three reanalyses Kuete et al. examined, only ERA-Interim shows a pattern similar to that in this paper. The others show a core further land-ward and extensive development over the land.

The greater development over land is consistent with the idea that the temperature gradient between the rain forest to the north and the dry season in the savanna to the south is the cause of the jet. I would suggest that the authors start by showing the jet in at least two additional reanalyses, in order to recognize that there are differences. MERRA and JRA 55 would be good choices. They should also speculate on how the use of ERA-5, with the core over the ocean, would affect their results.

=> Thank you for pointing this out. To comply with the reviewer's comments, we investigated the location of AEJ-S in the other reanalysis data such as MERRA2, JRA 55, and NCEP/NCAR for climatology and deployment month, using monthly mean data. The climatology is based on 2000-2018 for all reanalyses data. They have different spatial resolutions: ERA-5 has 0.25 deg x 0.25 deg, MERRA 2 has 0.625 deg x 0.5 deg, and JRA55 and NCEP/NCAR reanalysis has 2.5 deg x 2.5 deg resolution, respectively.

All three reanalyses, ERA5, MERRA2, and JRA55 data, show similar features in terms of location and strength of AEJ-S, with the weakest magnitude shown within the most coarsely resolved reanalysis, namely the JRA55 (see Fig. R1). However, the local enhancement of the upper-level wind is evident within all three reanalyses mentioned above.

One small difference in ERA5 and other reanalyses is that the core of AEJ-S is slightly displaced to the coast in the higher resolution data such as ERA5 and MERRA2 in September and October, as the reviewer mentioned. We investigated this a bit more and found that this might be related to the variability of the AEJ-S core altitude at the jet entrance region and exit region represented in the monthly mean data in ERA5. The preliminary analysis showed that the core of AEJ-S using the monthly mean data in ERA5 tends to occur around 3.5 km (slightly lower than 600 hPa) at the jet entrance region over land, while it gets up to about 4 km (about the same as 600 hPa) at the jet exit region over the ocean, more apparently in October.

We also checked the zonal wind isotach at 650 hPa level and found that the core is located over land, especially in the climatological mean. When we looked at the 6-hourly wind data at 600 hPa, AEJ-S is certainly originated from the land in ERA 5 (not shown). Therefore, while the actual position in the monthly mean data may need to be interpreted with caution in different resolutions of data and different reanalysis products, we think the position of the AEJ-S in ERA5, MERRA2, and JRA55 is still reasonable.

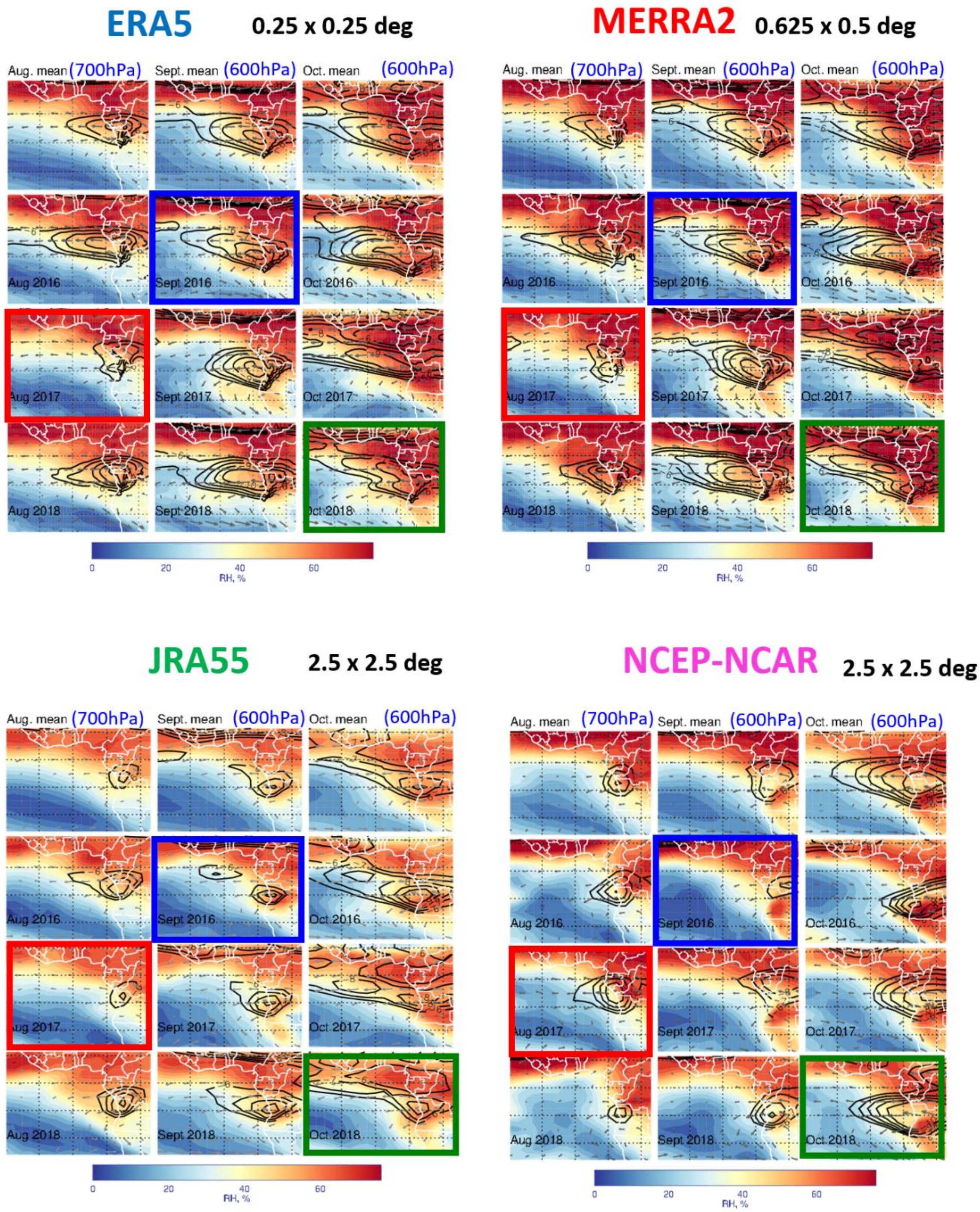

Figure R1. Map of zonal wind (black contours, from -10 m s^{-1} to -6 m s^{-1} with 1 m s^{-1} interval), RH (shading, %), and horizontal wind vector at 700 hPa for August and at 600 hPa for September and October for (1st row) the climatological mean (2000–2018) and (2nd – 4th rows) the August, September, and October in 2016-2018. The plots are made using ERA5, MERRA2, JRA55, and NCEP/NCAR (from top left to bottom right) reanalyses data, respectively. The color boxes (red, blue, and green) indicate the month of ORACLES deployment.

To examine the effect of the coarse resolution, we also compared NCEP/NCAR data with JRA55 because both data have 2.5 deg x 2.5 deg resolution, shown in Figs. R1 and R2. Interestingly, although NCEP/NCAR data also shows some AEJ-S features in the climatological mean, the NCEP/NCAR shows the greatest differences compared to the other three reanalyses data in many aspects during August-October. There is neither strong subsidence over 12-18° E, 10-25° S nor enhanced upper-level wind over 5-10° S in NCEP/NCAR but, rather, these features are displaced much further to the north (0-5S) for many months in 2016-2018. One large difference between NCEP-NCAR and the other three reanalyses is that the subsidence is very weak in August 2017. Related to this, AEJ-S in August 2017 from NCEP is slightly stronger than the climatological mean. Kuete et al. (2020) also showed that the location and magnitude of AEJ-S in NCEP2 differ from ERA-Interim, MERRA2.

Not only the magnitude of AEJ-S but also the position of AEJ-S, especially its vertical location, is different in NCEP/NCAR. This may be another reason (besides subsidence) why August 2017 has a slightly stronger AEJ-S in NCEP-NCAR compared to the other reanalyses. Furthermore, a very strong updraft around 0-5° N over land is also found for NCEP-NCAR in general compared to the other three reanalysis data, which are not observed in the other reanalyses such as ERA-interim, ERA-5, MERRA2, and JRA-55.

In short, the weaker AEJ-S in August 2017 is most profoundly shown in ERA5, MERRA2, and weakly in JRA55 as well, but not shown in NCEP/NCAR. Other large-scale subsidence features and local upper-level wind enhancements over the 5-10° S region are all shown in all ERA5, MERRA2, and JRA-55. This finding was included in the discussion of Fig. 4 in Part 1 of the revised manuscript.

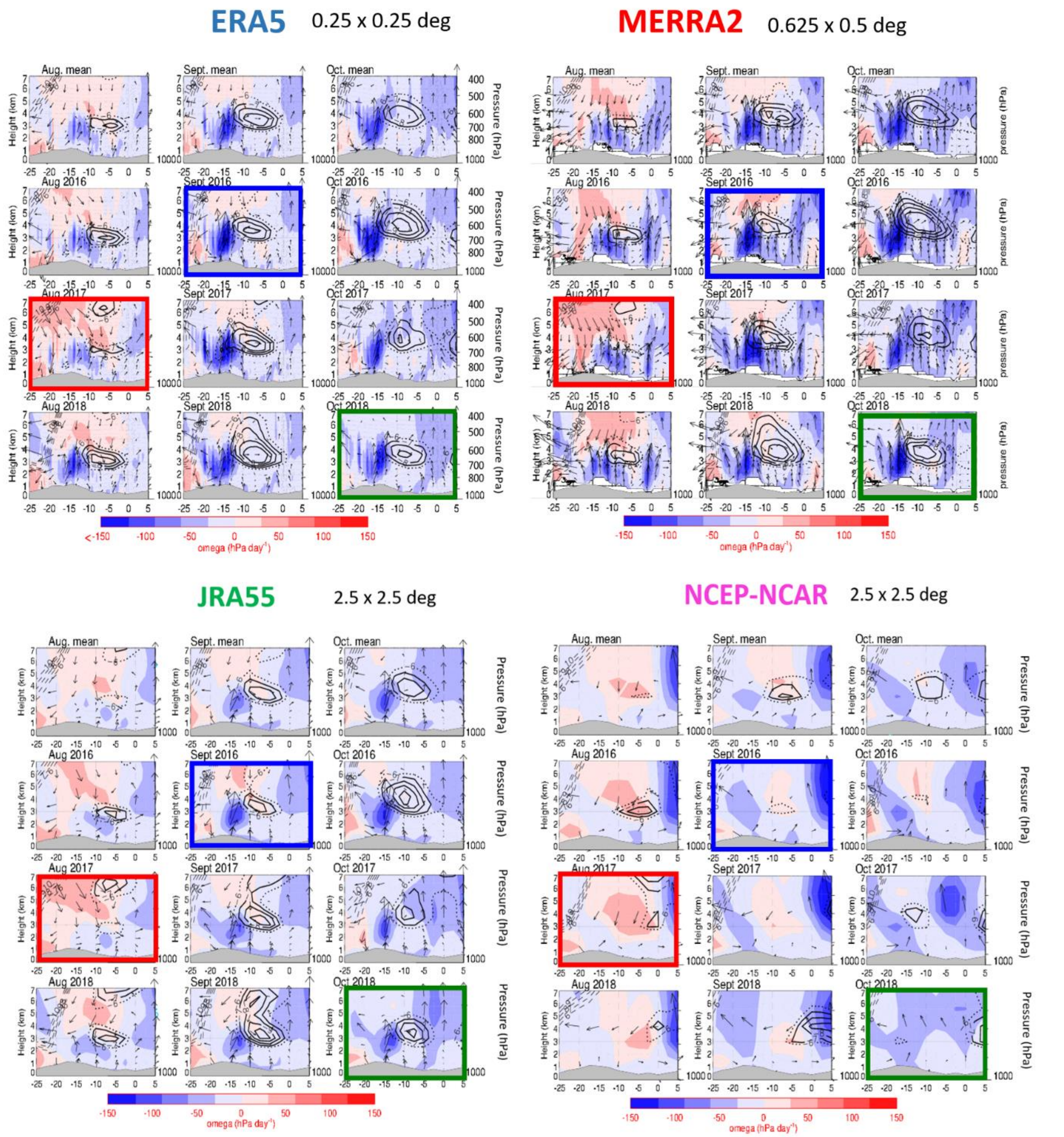

Figure R2. Latitudinal cross-sections of vertical velocity (omega (ω), shading, hPa day^{-1}) averaged over the jet entrance region (12–18° E) overlaid by wind vector (meridional wind vs vertical wind; the vertical wind (ω, hPa day^{-1}) is multiplied by -1 to represent the ascent as a positive value). Zonal wind (black contour, m s^{-1}) is overlaid for the (1st row) climatological mean and (2nd – 4th rows) August-October in 2016-2018. The gray-filled area represents the inland topography. The plots are made using ERA5, MERRA2, JRA55, and NCEP/NCAR (from top left to bottom right), respectively. The color boxes (red, blue, and green) indicate the month of ORACLES deployment.

A general issue: the authors discuss altitude both in terms of pressure level and height. However, their figures only give height, but call it pressure altitude (not a commonly used term). Putting the associated pressure level somewhere (e.g., once at the far right of the figure) would really help the reader.

=> We followed your suggestion in the revised manuscript.

More specific points:

Line72 and 73 I looked at both papers cited and do not see the links suggested here. This statement should be removed. Lamb and Peppler do not even consider the same season evaluated in this article.

=> "SSTs along the Benguela coast are strongly linked to rainfall variability in the Sahel (Lamb and Peppler, 1992) and western equatorial Africa (Balas et al., 2007)."

The first author apologizes for the misinterpretation of the Lamb and Peppler (1992) paper. Although there is no mention of SST in the Benguela region in the paper, the figures in the paper cover this region, and the region also seems to be included in the tropical Atlantic regions and associated with sub-Saharan rainy season variability. However, it is less clearly stated, and this paper focuses on sub-Saharan West Africa, it is less relevant to the regions we are interested in. In addition, there is no reason to believe the two forms of variation are linked other than through a different, unmentioned, common driver. Thus, this reference was removed as is the Balas et al. (2007) reference.

Figs. 1 b and c are too busy, so hard to interpret.

=> The Figure 1b and 1c in the previous manuscript presents the multiple fields of the climatological mean values, such as RH, zonal wind, thickness (layer mean temperature). Our intention for this figure is just to provide the overall climatological characteristics in the SE Atlantic. We made it simple in the revised manuscript.

Lines 220-225 That feature cannot possibly be part of the Tropical Easterly Jet because it is clearly a relatively local feature. The TEJ commences over the central Indian Ocean and then extends over Africa. Also, the Wu et al. (2009) reference is not appropriate here. That paper concerns the AEJ-North only. The TEJ is well known and several papers describe is directly, starting with papers in the 1960s or 1970s. A more recent paper on the TEJ is Nicholson and Klotter (2021), which I think appeared in the International Journal of Climatology.

Also in that section, I wonder if the pattern described could instead be a

"moist tongue" near the level of the AEJ-S. Sometimes cross-circulations are associated with jet streams. This could be determined by looking at the meridional wind.

=> Thank you for your suggestion. We found upper-level wind development in August 2017 interesting and tried to find clues within previous studies that examined similar features. We now realize we misinterpreted a connection between the TEJ and AEJ-N, thus we removed this discussion on TEJ in the revised manuscript.

Fig. 3. The caption indicates a box is shown at the top left of (a) giving the area over which precipitation is averaged. I cannot see this box. However, the coordinates are given, so the box is not really necessary, but the caption must be changed.

=> Sorry for the missing box region. We do not include the precipitation histogram in Part 1 of the revised manuscript, so the magenta dashed box is not displayed.

Please note that in determining the impact on rainfall, this was not the best region to choose. The jet appears to be characterized by a "jet streak" circulation, with rainfall enhanced in the right entrance quadrant and left exit quadrant (Jackson et al. 2009). By averaging more or less over the entire region of the jet, the impact on rainfall is probably lower than if the right entrance quadrant were used. I am not suggesting that the authors change anything. This comment is only for their own reference. But they might examine this and see if results are enhanced.

=> Thank you for the valuable comment. As you pointed out, most of the precipitation occurs over land and the right entrance quadrant. With this suggestion in mind, the precipitation histogram in the previous version was deleted to prevent the misinterpretation.

Fig. 5. What is -1*omega?

=> The omega is the vertical pressure velocity (unit in hPa day^{-1}). The negative omega represents the ascent motion, and the positive omega represents the descent motion. The vertical velocity in isentropic coordinate (omega, ω) is associated with vertical velocity in isobaric coordinate (w) by $\omega = -\rho g w$, where ρ is a density, and g is gravity. To make the visual support, we multiply -1 by omega (since ρ is invariant in the low-troposphere and g is constant) so that we can simply refer to upward-pointing arrows as the "ascent" and downward pointing arrows as the "descent". Thus, -1*omega means the "multiplying -1 by omega". -1*a negative omega implies descent, -1*a positive omega implies ascent.

Reference

Jackson, B., Nicholson, S. E., Klotter, D.: Mesoscale Convective Systems over Western Equatorial Africa and Their Relationship to Large-Scale Circulation, Mon. Wea. Rev, 137, 1272-1294, doi: 10.1175/2008MWR2525.1, 2009.

Kuete, G., Mba, W. P., and Washington, R.: African Easterly Jet South: Control, maintenance mechanisms and link with Southern subtropical waves, Climate Dynamics, 54, 1539-1552, doi: 10.1007/s00382-019-05072-w, 2020.