Interactive comment on "Conceptual model of diurnal cycle of stratiform low-level clouds over southern West Africa"

Response to reviewer 3

Dear reviewer 3,

We thank the reviewer for his/her valuable and constructive suggestions, which led to significant improvements of the quality of our manuscript. Below we detailed how his/her comments are addressed in the revised version of the manuscript. The major corrections made in the manuscript and cited in this document appear in italic.

Major Issues

In Figure 6 you have shown the scatter plot of degree to decoupling (Bretherton and Wyant, 1997; Jones et al. 2011) and the bulk Richardson number. Maybe you can show the same plot colored by the different phases of the boundary layer mentioned in table 1, or color code them with the cloud fraction. This will show if the stratus clouds are coupled to the surface or not and whether the shallow cumulus form due to surface heating or shear (Zhu et al. 2001 JAS). Consistent with previous studies mentioned above, maybe you can calculate the ratio of cloud top cooling and surface heating, and contrast that with decoupling index.

Figure 6 is built with data acquired during the stratus phase; the objective was to analyze the coupling during that phase before the start of the surface thermal convection (the coupling during the convective phases is out of the scope of this paper). During that phase the cloud fraction is 100%. We do agree with the reviewer that this should clearly be indicated in the text and in the legend and those have been modified.

The sentence P12-l18 is now: *"Figure 6, where the bulk Richardson number in the subcloud layer is plotted against the difference between the CBH and the LCL estimated from the radiosondes* ***launched during the stratus phase*** *at Savè and at Kumasi."*

The legend is now: *"Bulk Richardson number (Ri_b) in the subcloud layer against height difference between cloud base height (CBH) and lifting condensation level (LCL)* ***estimated from the radiosondes launched during the stratus phase*** *at Savè and at Kumasi. Colors stand for the different IOPs."*

We do agree with the reviewer that the convective phase and especially the stratus to cumulus transition is also interesting in term of coupling. The convective phase is currently analyzed in details and the results will be submitted soon in an other manuscript. Unfortunately, it is quite difficult to estimate the cloud top cooling with the collected data as suggested by the reviewer, but we do try to give some clue on that point.

Figure 8 and associated text: Please mention some previous studies that have shown any relationship between the "integrated flux" and "LLC breakup time".

As suggested by the reviewer 3, we use now the averaged flux instead of the integrated flux (see response to following comment). The following sentence: "As expected, <Rn>, <LE>, and <H> are negatively correlated with the stratus breakup time with correlation coefficients below -0.64 for Savè and Kumasi (Fig. 8)." is now "*Figure 8 shows a negative correlation between <Rn>, <LE>, and <H> and the stratus breakup time with correlation coefficients below -0.64 for Savè and Kumasi.*"

It is unclear what you mean by integrated flux and how it was calculated. Also, why do you choose to calculate integrated flux rather than the average flux itself like that has been done by numerous studies? This is especially crucial as the measurements are made in a Eulerian setting and there is no way of knowing the “history” of the parcels.
We agree with the reviewer that the averaged flux can be used in this study and all the figures are modified consequently. The way the integrated fluxes was calculated was indicated p14: “...the temporally integrated flux from 0600 UTC to 1600 UTC.”. The unit was Jm^{-2} as indicated in Figures 8 and 9. The averaged flux is the ratio of this integrated flux by the time duration (36 000 sec in our case - from 6 to 16 UTC). Consequently the scatter plot are perfectly similar with integrated or averages flux.

Also, how do you define the LLC breakup time, what is the objective criteria for determining it? Thanks.

The response to this comment is merged with the response to comment about cloud fraction (see below).

Similarly, in Figure 9 you have shown a scatter plot between surface flux and LCL. Under high surface flux conditions due to stronger mixing, the mixed layers are deeper than those under weaker surface flux conditions. Not sure if this is something worth showcasing in a paper.
We fully agree with the reviewer that this figure shows a very common results but we decided to keep this figure for three reasons:
1/ it is the only figure that presents some data from the third site Ile-Ife.
2/ it is part of the following argumentation (see comment below)
3/ very few measurements exit in this part of the world, so it seems important to show them when they exist even if the results are confirming some expected relationship.

However, it is puzzling to see that in Figure 9b that a lower LCL results in a later breakup. Do you have any physical explanation of this? The text only describes the figure without drawing any conclusions. Thanks.
This results is not that surprising considering the figures 8 and 9a. We improved the text to better emphasize this “*Finally, the link between the CBL development and the stratus breakup time is shown, for the Savè and Kumasi sites, in Figure 9b. Latter stratus breakup implies lower net radiation at surface (Fig. 8) and therefore weaker surface flux conditions (Fig. 9a) which lead to a lower vertical development of the CBL. The LCL is half, when LLSC breakup occurs after 1100 UTC, that compared to an LCL associated with early-morning LLSC breakup. The impacts of this on the moist convection during the afternoon need detailed investigations.*”

Line 17 on page 12 says that “the stratus reduces the NLLJ strength because of turbulent mixing in the cloud layer”. It is unclear to me where in the manuscript have you have shown this, or any other manuscripts that have shown this? The Stratus clouds can surely modify the boundary layer turbulence, but the LLJ is a meso-gamma scale phenomenon (∼200 km), much greater than the typical scales of stratocumulus clouds. Please show evidence of this or remove the sentence.

We have no mean to show evidence of this except that the wind is reduced in the stratus layer as soon as this one forms. We tried to compare the vertical profile of the wind speed for cloudy nights and clear nights but the clear nights are rare (1 or 2 in Savè). The conditions very special for these two cases with very weak NLLJ. We think that the turbulence in the cloud is able to induce the decrease of the wind speed because the NLLJ and the LLC do have the same horizontal scale. There are both meso-gamma phenomena. The stratus in southern west Africa extends over more than 800 000 km^2. The NLLJ can be mixed up in the stratus layer from the Guinean coast to Savè. However, we changed the sentence and suggest this as an explanation.

The following paragraph: "*As shown in Figure 3, the stratus and the NLLJ could interact in two ways: (1) the stratus may reduce the NLLJ strength because of the turbulent mixing in the cloudy layer, and (2) the turbulence below the NLLJ core modifies the conditions in the subcloud layer*." is now "*As shown in Figure 3, the stratus and the NLLJ could interact in two ways. First, the stratus could reduces the NLLJ strength because of the turbulent mixing in the cloudy layer. Such an effect of the stratus turbulent mixing on the meso-scale phenomenon that is the NLLJ, is possible because the stratus extend over more than 800 000 km^2 from the Guinean coast up to 10° N latitude. Secondly, the turbulence below the NLLJ core modifies the conditions in the subcloud layer.*"

The moisture advection can bring saturation at the top of the boundary layer causing cooling. Thereby forming clouds and not needing surface moisture. This seems to be the case scenario 2 (Figure 7c and 7e). In other cases, it seems that the clouds are coupled to the surface even at night (Figure 7a). It is unclear to me how you objectively defined the three scenarios.

We do not understand what period or stage the reviewer is discussing in his comment. Concerning the stratus formation, we showed in Figure 4 that the change in relative humidity is due to the cooling and not to the moistening. The three scenarios have been objectively defined looking, case by case:

- the cloud base height relatively to the LCL along the stratus and convective phases; we interpret the departure between both in terms of coupling.
- the standard deviation of the cloud base; this discriminates stratus (low standard deviation) from cumulus clouds (high standard deviation).

All the stratus nights during the campaign at Savè follow one of the three scenarios described in the paper. We agree with the reviewer that we defined all the parameters shown in Figure 7 but they are not explicitly mentioned as criteria for the definition of the scenarios.

The following paragraph : "*The way in which the stratus layer and the surface are coupled (or not), as discussed in the previous section, plays a determining role on the breakup. Three scenarios have been observed at Savè, illustrated in Figure 7.*" is now " *The way in which the stratus layer and the surface are coupled (or not), as discussed in the previous section, plays a determining role on the breakup. Based on CBH evolution relatively to LCL and CBH standard deviation along the stratus and convective phases, three scenarios have been defined at Savè, illustrated in Figure 7.*"

Page 6, Line 14: you calculated the stratus cloud fraction by using the cloud base height values below 600 m, however in schematic shown in Figure 2 it is apparent that stratus clouds can exist with bases above 1 km. Would it be possible to re-do the figure with bases below 1 or 1.5 km? this also contradicts the text on Page 13, line 13 that uses 1 km threshold.

- We thank the reviewer for pointing this inconsistency in the text. The cloud fraction estimate using the cloud base below 600 m was first used by Adler et al, 2019. They used a 600 m height threshold because their focus was the stratus phase and the breakup time. Once the study has been extended to the convective phase and especially to the stratus-cumulus transition, the threshold has been increased to 1000 m because cumulus base can be higher than 600m.

- The stratus breakup time is determine as indicated p13-l8: *"A cloud fraction larger than 95 % is chosen as a criterium to determine the presence of stratus clouds above the supersite."*. We agree with the reviewer that this explanation should be also given p6 when the method for cloud fraction estimate is presented.

- The height in Figures 2 and 3 is normalized by the LLC base when the stratus forms. So these figures do not indicate directly the height of the base. However, we realized that the LLC base when the stratus forms is not quantified in the text.

Then, considering the three points above, several passages in the text have been modified:

P6, l4: *"A ceilometer was deployed at the Savè and Kumasi sites, continuously providing the cloud-base height (CBH). The LLSC fraction (Adler et al., 2019) was deduced from the percentage of CBHs measured below 1000 m. Adler et al., 2019 used a 600 m height threshold for the stratus phase analysis. This threshold is increased up to 1000 m in the present study, consistently with Dione at al. (2019), to allow the stratus to cumulus transition analysis during the convective phase. A cloud fraction larger than 95 % is chosen as a criterium to determine the presence of stratus clouds above the supersite, from which the stratus appearance and breakup times are deduced. An other method for theses two times estimate was use of the infrared cloud camera (Dione et al., 2019)."*

P9, l27: "*Figure 4 shows averaged vertical profiles, over stable and jet phases, of specific humidity and temperature contributions to the total change in RH at the Savè and Kumasi sites. The height is normalized by the cloud base when the stratus form. The median value of the cloud-base at Savè and Kumasi are 227 m a.g.l. and 137 m a.g.l., respectively (Kalthoff et al., 2018). At Savè, the cooling causes at least 80 % of the RH increase.*"

Minor Issues

Abstract, page 1 line 14: Insert "surface" before buoyancy. Thanks. This has been modified.

Page 2 line 1: I would say "form" rather than "appear". This has been modified.

Page 2, line 15: Insert "the" before "daytime". This has been modified.

Figure 1: The thick circle denoting it to be a super-site at Ile-Ife doesn't line up with the other filled circles in both panels.

The filled circle for the permanent synoptic meteorologic station does not line up with the circle for the super site instrumented for the DACCIWA field experiment because the two sites are not exactly at the same location. We used the GPS coordinates.

Page 6 line 25: use "at which" rather than "when".

CBH stands for Cloud Base Height. "...cloud base height at which the low level cloud form..." does not seem correct to me. We wanted to say that, for the normalization, we use the height of the clouds when they form. We think that "CBH when the LLC form" is the good sentence to say this.

Page 7 text: It doesn't have line numbers so difficult to point out, but it needs to be revamped for grammar. Thanks.

We are sorry but we did not find in these 4 lines what needs to be corrected. Some minor changes have been made, suggested by reviewer 2

The UTC time is same as Local time. This needs to be mentioned somewhere in the text. Thanks.

We agree with the reviewer that difference between Local Solar time and UTC must be defined for each site. The following sentence has been added P, l: *"UTC and local solar time are only about 6 min,* *10 min, and 18 min apart at Kumasi (-1.5601° E, 6.6796° N), Savè (2.4275° W, 8.0009°N), and Ile-Ife (4.5574°W, 7.5532°N), respectively. The results are henceforth presented according to UTC."*

Table 1: Would it be possible for you to mention in a column the average and standard deviation of surface fluxes, cloud fraction, cloud top height and cloud base height for each phases? Thanks.
We understand that the reviewer 2 ask these information for stratus and convective phases only and not for the stable and jet phases (since the stratus is not formed yet). All these information are sometimes difficult to provide; others are now included in the text or a reference is added :

- The surface flux are very low during the night (stratus phase) and furthermore very difficult to estimate for different reasons: (1) the sonic anemometer and the Licor hygrometer measurements are not systematic because of high level of relative humidity (~100%) or even some remaining droplets on the sensors, and (2) the hypothesis of homogeneity and stationary are very often not verified. This is why we started the temporal integration of the surface flux at 6 UTC. Concerning the convective phase, the average fluxes are given in Figure 8 and 9.
- There was a cloud radar in Savè, but the cloud summit was very often difficult to estimate from these measurements (Adler et al. , 2019). Furthermore this information was not available in Kumasi.
- As explained in a previous response, we added the median value of the LLC base during stratus phase at the two sites. The temporal evolution of the cloud base is presented in Kalthoff et al., 2018, and this information is now provided in the text. "*Kalthoff et al. (2018) present the temporal evolution of the distribution of the cloud base estimates by the ceilometer along the stratus and convective phases at the Savè and Kumasi sites*."

Page 13, Line 7: Change to "between this level and the bases of cumulus clouds forming in the afternoon". This has been modified.
Page 13 Line 12: Please change "summit" to "cloud top". It is also elsewhere like caption of Figure 7. This has been corrected.
Figure 3: There are no "red numbers" in the figure. This has been corrected.
Figure 4 and 5: Please mention the significance of the dashed line.
The following sentence has been added to the legend of figure 3, 4 and 5: *"The horizontal dashed line (Z*=1) indicates the CBH when the stratus form."*