We thank the reviewers for their thoughtful and constructive feedback on our submitted manuscript, “Contrasting characteristics of open- and closed-cellular stratocumulus cloud in the Eastern North Atlantic.” We have made some substantive changes to the manuscript to address this feedback, most notably: (a) we have significantly expanded the literature review regarding the mechanisms responsible for the transitions between organizational cloud states, (b) we have quantified differences in additional variables between the open- and closed-cellular cases including the advection and surface fluxes and (c) we have scaled the height coordinate of our radiosonde plots by the observed boundary layer depth and (d) we have re-evaluated the estimates of liquid water path and precipitable water vapor from the microwave radiometer, and have removed measurements that are impacted by instrument wetting during precipitation events. The changes have significantly improved the manuscript, particularly providing an improved context for our results within the existing literature. Below, please find a point-by-point response to each of the reviewer comments including a documentation of the changes made to the manuscript.

Anonymous Referee #1

Specific comments

Line 42-42, and 316-317: **"Despite these important impacts, the atmospheric processes responsible for the formation and maintenance of these organizational states remains poorly understood." A host of literature exists on the processes that are involved in driving and maintaining closed- and open-cell stratocumulus cloud decks, and the processes that convert one into the other. Hence writing that "processes responsible for the formation and maintenance of these organizational states remains poorly understood" is incorrect. Here are a few references. Please add any other works based on a literature search and change the text to reflect the existing understanding of the subject.**

We thank the reviewer for the comment and have taken the opportunity to significantly expand the literature review particularly with respect to the body of work on the observational and modeling study of the mechanisms responsible for the transition between cloud organizational states. We have included all the references that were suggested and more.

Additional references and discussion have been added throughout the manuscript, but particularly in the introduction. For example,

Lines 40-51: “ These differing modes organize the internal diabatic forcings within the MBL, impacting the low-level cloud fraction, shortwave albedo and liquid water path driving the localized contribution to the radiative energy balance and water cycle (e.g., Rossow et al. 2002; Savic-Jovcic and Stevens 2008; Wood et al. 2008; Wood et al., 2016). The key processes responsible for these organizing states have been the subject of much research over the past several decades with the interaction among precipitation and boundary layer dynamics identified as a main driver (e.g. Bretherton et al. 2004; Comstock et al. 2005, 2007; Sharon et al. 2006; Stevens et al. 2005; Savic-Jovcic and Stevens 2008; Wang and Feingold, 2009; Feingold et al. 2010). Aerosols, through their influences on the formation and suppression of drizzle have also been found to have important implications on MBL cloud organization (e.g. van Zanten and Stevens, 2005; Petters et al., 2006; Sharon et al., 2006; Wood et al., 2008; Xue et al., 2008; Wang and Feingold, 2009; Bretherton et al., 2010; Wood et al., 2011). The interplay of these different mechanisms and their relative importance under different regimes remains and area of active research and a needed target for improved understanding and representation in large-scale atmospheric models (Wood et al., 2016; Jensen et al., 2016)."

Line 72-83: "The driving mechanisms for changes in the organization of MBL stratocumulus clouds have also been the target for a number of modelling focused studies over recent decades. Shao and Randall (1996) perform simulations incorporating increasing complexity of the model analysis for closed cellular MBL clouds. They found that cloud-top radiative cooling is a primary driver of the boundary layer dynamics and cloud organization. Feingold et al. (2010) combine satellite observations with numerical simulations to show the role of collisions between precipitation generated cold pools in driving the characteristics of open-cellular cloud organizations and their oscillation between different, weakly stable states. While many studies have noted the importance of drizzle in the transition between organizational cloud states, Yamaguchi and Feingold (2014), through idealized three-dimensional simulations, highlight the importance of the spatial distribution of the precipitation. Feingold et al. (2015) perform a series of idealized cloud-resolving model simulations to investigate the two-way transitions between open- and closed-cellular cloud populations. Their findings reiterate the importance of precipitation in the transition from the closed- to open-cellular states and emphasize that stabilization of the boundary layer due to this precipitation and increased longwave cooling acts as a barrier to cloud formation and recovery to the closed-cellular cloud state."

Line 428-433: "A number of studies over recent decades have identified the importance of aerosols, drizzle and their impacts on boundary layer dynamics in determining the cellular organization of clouds within the MBL. However, the interplay of these different mechanisms and their relative importance under different regimes remains and area of active research and advances in our understanding are necessary for improved representation in large-scale atmospheric models (Wood et al., 2016; Jensen et al., 2016)."

Line 54-56: **" However, Wood et al. (2011) and Terai et al. (2013) found that drizzle rates are not significantly different between open and closed cells, concluding that drizzle, and its associated thermodynamic feedbacks, are not the only factor causing the transition between mesoscale organizations." There is more to be written on this subject - see, e.g., Yamaguchi et al., 2015, "On the relationship between open cellular convective cloud patterns and the spatial distribution of precipitation", and Feingold et al., 2015, "On the reversibility of transitions between closed and open cellular convection".**

In the added discussion of modeling studies of the transitions between cloud mesoscale organizations we have discussed the further importance of the additional importance of the spatial distribution of drizzle (Yamaguchi et al. 2015) and the associated convergence/divergence from precipitation driven cold pools (Feingold et al. 2015).

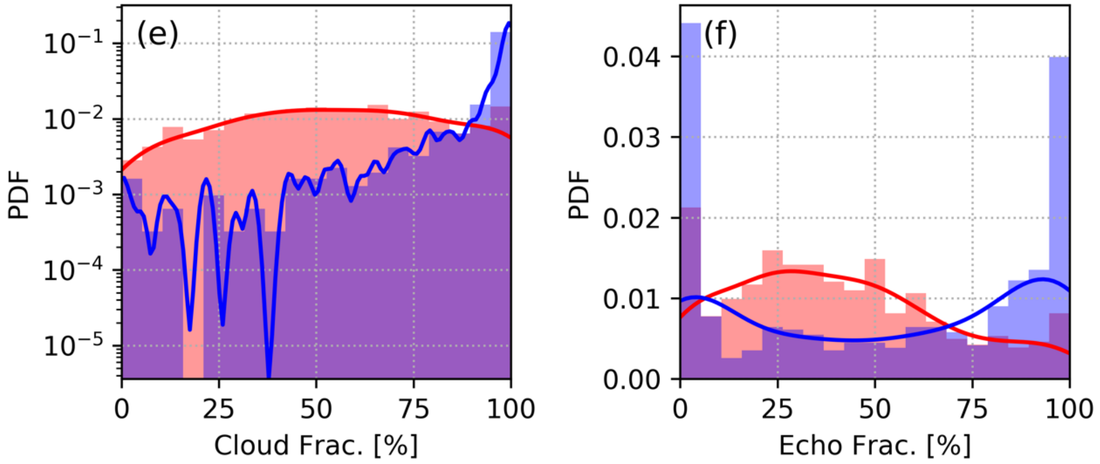
Lines 77-81: “While many studies have noted the importance of drizzle in the transition between organizational cloud states, Yamaguchi and Feingold (2014), through idealized three-dimensional simulations, highlight the importance of the spatial distribution of the precipitation. Feingold et al. (2015) perform a series of idealized cloud-resolving model simulations to investigate the two-way transitions between open- and closed-cellular cloud populations.”

***Line 63-65:* "Hence, most of the open-cellular stratocumulus that are observed over the ENA are fundamentally different than those observed in the other parts of the subtropical oceans under quiescent large-scale forcing conditions" Cold air outbreaks do conceptually differ from the air masses in the eastern subtropical oceans with stratocumulus cloud decks, but do the open cells really differ in these two situations, and how? In other words, it will not do to just state that "open-cellular stratocumulus that are observed over the ENA are fundamentally different than those observed in the other parts of the subtropical oceans under quiescent large-scale forcing conditions" without supporting evidence, literature references, and specifics. Please provide these or remove this passage if it cannot be supported.**

We agree with the reviewer that this statement is likely overstating the differences, is not supported by the analysis, and not definitively evident from the existing literature. We have elected to remove this sentence from the manuscript.

***Figure 8e:* A logarithmic y-axis might perhaps help visualize the data better(?)**

Agreed. We have replaced the linear scale with a logarithmic scale. See new figure here.



Anonymous Referee #3

Major comments:

1. It is not straightforward from Figure 4 to conclude that "cold air advection is stronger for open-cellular cases". It seems the majority of trajectories in open-cell cases align with the SST contours, indicating a weak temperature gradient along the trajectory. Quantification is needed, which is absent in the analysis.

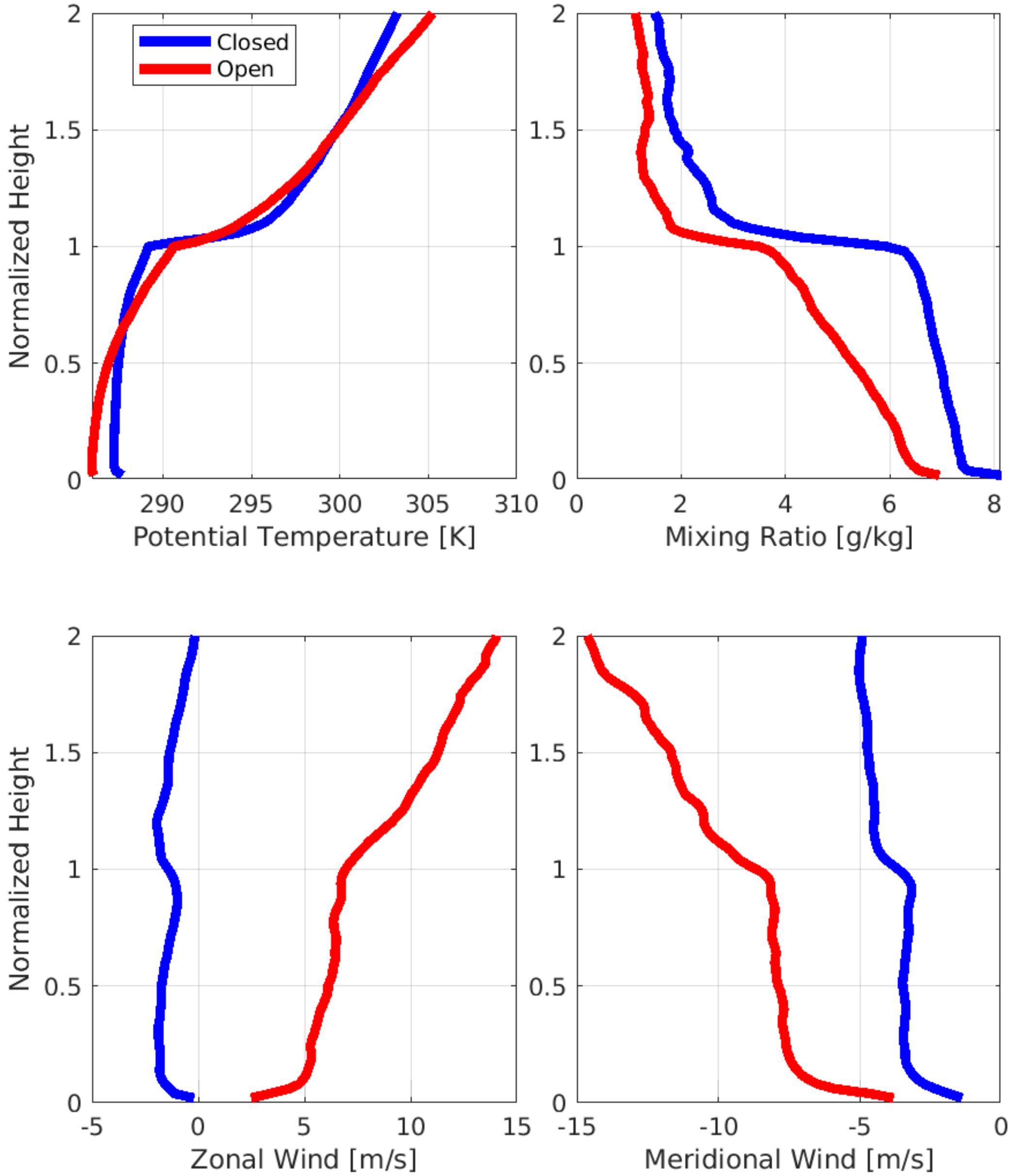
We have calculated the mean and standard deviation of temperature and moisture advection for the pixel north of the ENA site for the open- and closed-cellular cases. We find that both open- and closed cellular organization populations show mean cold- and dry-air advection with the open-cellular cases showing stronger cold-air advection, and the closed-cellular cases showing stronger dry-air advection. We have included the mean values and standard deviations for each population in Table 3.

In the discussion of Figure 4, we have added the qualifier "relatively stronger cold air advection" regarding the open-cellular cases and provided a pointer to Table 3. We have also added the following bullet to the discussion of Table 3, "Both open- and closed-cellular populations show mean cold- and dry-air advection with the open-cellular cases showing stronger cold-air advection, and the closed-cellular cases showing stronger dry-air advection.

2. The analyses of the composite sounding have a couple of problems. First, the height should be scaled (e.g. by the main inversion height) to avoid artificial cancellation. Second, similarly, scaling may be needed for the temperature and humidity because samples are from different seasons (e.g. scaled by the seasonal mean). Given the limited number of cases, the composite absolute values of both variables may be biased toward a specific season with the largest samples.

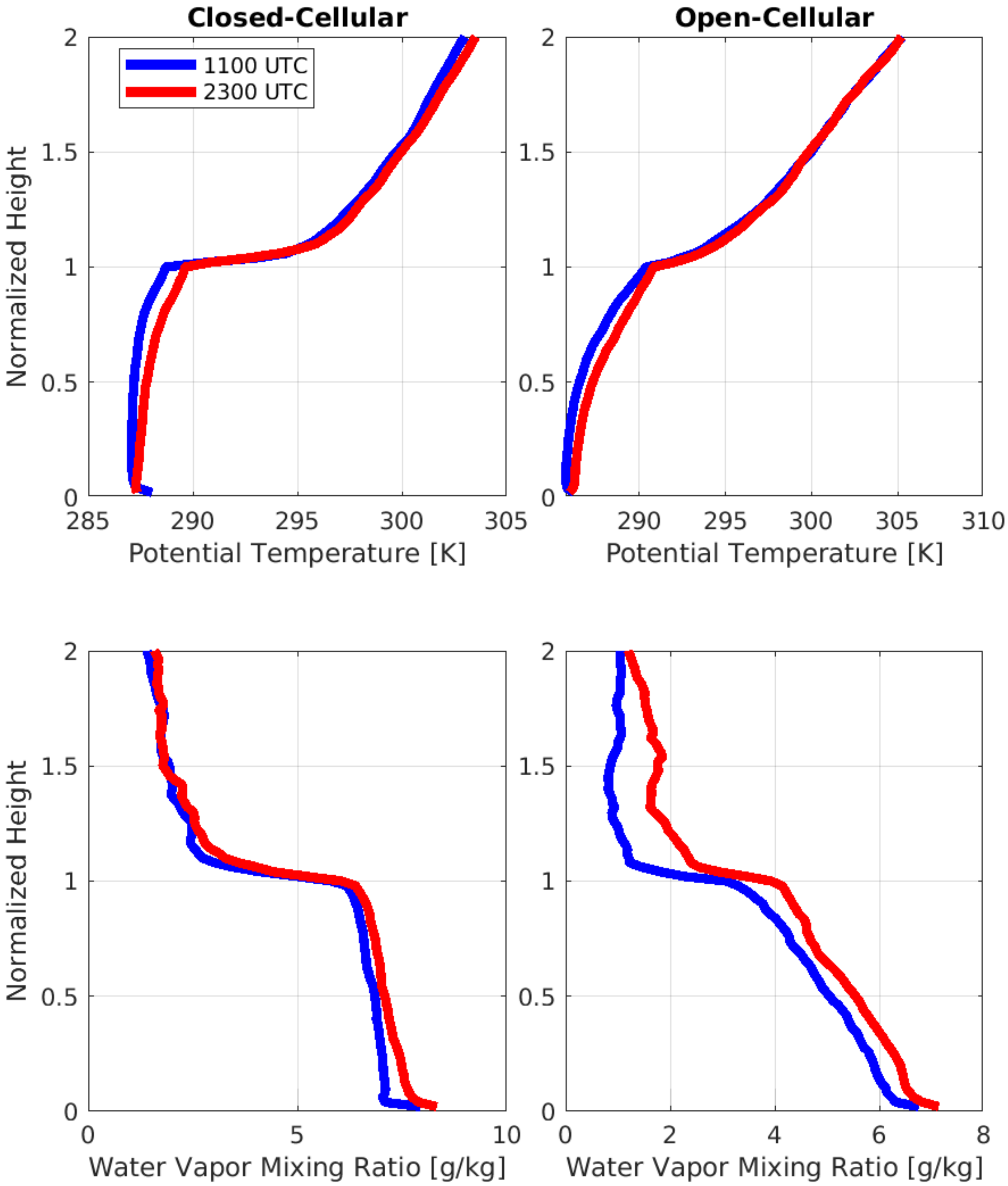
Care must always be taken in the creation and interpretation of composite visualizations. While scaling can help to highlight some features, it also can hide others. Taking the reviewers suggestions, we have scaled the sounding height by the inversion base height and used this for the vertical coordinate in Fig. 5 and Fig. 6. While this does change the shape of the profiles, particularly highlighting the sharpness of the inversion, it does not change the conclusions drawn from the previously presented plots. We have chosen to replace both Fig. 5 and Fig. 6 with these scaled-height composites. Regarding further scaling of temperature and humidity due for soundings in different seasons, since the seasonal distribution of cases is very similar for the two populations (see Table 2), and we are not aiming to distinguish seasonal differences the scaling to temperature and moisture should not be necessary.

We have added the following text, describing the height normalization at lines 234-236, "For these composite profiles, the height coordinate is normalized by the height of the base of the subsidence inversion to avoid smoothing of the boundary layer thermodynamic structure (Augstein et al. 1974; Mahrt, 1976; Albrecht et al., 1995)."



148

149 New Figure 5


Closed-Cellular
Open-Cellular
1100 UTC
2300 UTC
Normalized Height
Potential Temperature [K]
Water Vapor Mixing Ratio [g/kg]
0
0.5
1
1.5
2
285
290
295
300
305
310
0
5
10
2
4
6
8

New Figure 6

3. The discussion about the time evolution of the thermodynamic structure (Fig. 6) lacks physical insights. How do the diurnal cycle and advection influence evolution?

The mean advective tendencies for both open- and closed-cellular organizations suggest cold- and dry-air advection which would manifest in cooling and drying of the boundary layer as a function of time. Figure 6 shows little to small increase in the temperature, and a moistening, of the boundary layer with time. This suggests that the local diurnal cycle plays a significant role in the evolution of the boundary layer thermodynamics, This is supported by the differences in the mean sensible and latent heat fluxes for the cloud organizations which show larger fluxes, and so larger increases in temperature and moisture for the open-cellular cases, consistent with the results shown in Figure 6.

We have added text at lines 252-258 to describe the relative contributions of large-scale advection and local surface fluxes to the evolution of boundary layer thermodynamics, "Given that the mean advective tendencies show cold- and dry-air advection for both cloud organization populations, we would expect advection to drive cooling and drying with time for each cloud organization population. Figure 6 shows small to little increase in the temperature and a moistening of the boundary layer with time for both open- and closed-cellular cases. This suggests that the local diurnal cycle plays the more significant role in the evolution of boundary layer thermodynamics. The difference in the mean sensible and latent heat fluxes between open- and closed-cellular cases is consistent with the changes in thermodynamic structure showing larger fluxes, and so larger increases in temperature and moisture for the open-cellular cases."

4. Line 198. Could you discuss why closed-cell cases are more coupled? Is it due to large-scale factors such as temperature advection or the boundary-layer scale factor such as cloud-top radiative cooling or precipitation?

Our expectation is that closed-cellular cases would occur under more coupled conditions due to shallower boundary layers, stronger cloud-top radiative cooling (e.g. Shao and Randall, 1996) and less precipitation.

We have added the following text at lines 240-242, "This is consistent with our expectations as the organization in closed-cellular cases are driven by relatively stronger cloud-top radiative cooling (e.g., Shao and Randall, 1996) and occur under shallow boundary layer depths with less precipitation."

5. Lines 222-223. Again, why open-cellular cases are associated with stronger subsidence needs more discussion. From the perspective of PBL mass conservation: dzi/dt = ent - wsub, in which zi is the inversion height, ent it entrainment rate, and wsub is subsidence rate. Larger subsidence leads to PBL shallowing whereas open-cellular cases have deeper PBL. Therefore, it must be the stronger entrainment that is responsible for the deeper PBL.

In addition to the subsidence rate and entrainment of air from the free troposphere, the surface fluxes and wind-driven turbulence will also play an important role in the depth of the PBL. As has been noted in previous studies, and is quantified for our cases in table 3, the surface energy fluxes and horizontal winds are significantly stronger in the open cellular cases. The increased surface fluxes have been attributed to heating from greater downwelling radiative fluxes at the surface, a consequence of the lower cloud fractions for the open-cellular cases. Stronger boundary layer winds also result in greater production of mechanically-generated turbulence and a a deeper boundary layer. We suspect that the stronger subsidence, for these cases that are generally occurring during cold-air outbreak conditions, is associated with post-frontal circulations.

We have added the following text at lines 276-280, "This greater subsidence rate is likely the result of post-frontal circulations during cold-air outbreak conditions. The deeper boundary layers for the open-cellular cases must be maintained by a combination of increased turbulence (Ghate et al., 2019, 2020) generated by the stronger wind speeds and surface sensible and latent hear fluxes which are significantly larger during closed-cell cases (Kazil et al., 2014; Wang et al., 2010), a consequence of the smaller cloud fractions and thus greater surface downwelling radiative fluxes."

6. Line 230. Still, why open-cellular cases have slightly higher PWV should be discussed. The key idea of Zhou and Bretherton's series of studies on cellular convection is that PWV *perturbation* **is highly correlated with LWP perturbation. For case-averaged PWV, the story is completely different. The latter is a synoptic-scale problem whereas the former is a mesoscale problem.**

The reviewer is correct that the result from Zhou and Bretherton is not quite appropriate here, and we have thus removed this comparative statement. This comment also led us to scrutinize the LWP/PWV analysis a bit more closely where we found we have not properly accounted for precipitation influences on the microwave radiometer measurements. We have not removed measurements that are flagged as being influenced by precipitation, and in addition, removed PWV values that are more than two standard deviations away from the daily mean value. This results in removing a number of the larger PWV and LWP values in the dataset, particularly in the open-cellular cases where drizzle is prevalent. Removal of these suspect points changes: (1) the size of one of the peaks in the PWV histogram for open-cellular in Fig. 8, and removes some of the tail to larger values, (2) mutes the diurnal cycle in PWV and LWP shown in Fig. 9. and (3) changes the normalized values of LWP and PWV in Figure 11, but does not have any impact on the conclusions. We also find that the mean PWV (Table 3) is now slightly less for open-cellular cases compared to the closed-cellular cases.

The following changes have been made to the text:

Line 121-122, "MWR measurements that are flagged as being influenced by rain or PWV measurements that lie beyond 2 standard deviations of the daily mean are removed"

Line 294-295, “Also, the PWV is identical for the two organizations with slightly more variation for the open-cellular cases.”

Line 345 – 346. “The two cloud populations show very little difference in the PWV (Fig. 8b) with the closed-cellular cloud cases showing a more well-defined peak at the mode values, consistent with the similarity in the bulk properties presented in Table 3.”

Minor comments:

Figure 1: the resolution is a little bit too low.

We have included a much higher resolution version of this image.

Figure 9: use local time or mark the period of day/night times.

The time zone difference from UTC at the ENA site is no greater than 1 hour, so there is little difference between UTC and local time. However, to avoid any confusion, we have changed the time scale to local time.