Response to interactive comments by anonymous referee #2

General comments
This study attempts to answer, given inversion strength, why weaker subsidence promotes thicker stratocumulus cloud layer and larger liquid water path (LWP), which has been suggested both modeling and observational studies. The authors utilize a recently developed LWP-budget analysis method for ASTEX large eddy simulations.
Their LWP budget analysis shows that (1) magnitude of drying due to subsidence is small, (2) weaker subsidence dries less cloud, (3) weaker subsidence reduces radiative cooling for daytime, (4) drying due to entrainment and moistening due to cloud base flux almost cancel each other for any subsidence rate. Thus, subsidence effect stands out even though its magnitude is much smaller than other processes. Overall, I think that the study improves our understanding for the subject, and the manuscript is generally well written. After clarifying some questions below, the manuscript is ready for publication.

We thank the reviewer for his kind words and useful suggestions on the manuscript. Below, we respond to each of the comments individually.

Specific comments / technical corrections
- I think that the authors should add something like "for the same inversion properties (e.g., inversion strength and thickness)" when they introduce past studies that suggest increase of LWP and increase of cloud amount as subsidence is weaken. If the inversion properties are different, weaker subsidence may not result in larger LWP.
Indeed, the statement that weaker subsidence results in a larger LWP is only valid when all other properties, in particular the inversion properties, are kept the same. We changed the text as follows: "LES results and mixed-layer model studies show that for fixed large-scale conditions such as the SST and the horizontal wind speed, a reduction of the large-scale subsidence causes the stratocumulus steady-state liquid water path (LWP) to increase, e.g. Bretherton et al. (2013) and De Roode et al. (2014). "

Bretherton, CS, PN Blossey, and CR Jones (2013), Mechanisms of marine low cloud sensitivity to idealized climate perturbations: A single-LES exploration extending the CGILS cases, J. Adv. Model. Earth Syst., 5, 316–337.

De Roode, S. R., A. P. Siebesma, S. Dal Gesso, H. J. J. Jonker, J. Schalkwijk, and J. Sival, 2014: A mixed-layer study of the stratocumulus response to changes in large-scale conditions. J. Adv. Model. Earth Syst., 6, DOI: 10.1002/2014MS000347.

- Equation (4): Is there a problem if the authors use actual lapse rate of q_l from their LES data?
There is no problem when the actual lapse rate of q_l is diagnosed from the LES data. In fact, this actual lapse rate is very close to the adiabatic lapse rate of q_l as the cloud fraction is very close to unity throughout the cloud layer. When the LWP budget equation was developed, it was attempted to reduce the amount of input parameters for the LWP budget equation to the minimum, hence the lapse rate of q_l (which is a dependent variable) was approximated. To clarify, we added the following text: "Following Van der Dussen et al. (2014) the value of Γ_{ql} is approximated by assuming a moist adiabatic temperature lapse rate. As the stratocumulus cloud layer is typically vertically well-mixed, this is in good agreement with the actual value of Γ_{ql} that can be obtained the vertical profile of q_l."

-How is z_i measured?
The inversion height is defined as the top of the inversion layer, z_i^+. We clarified this:
"We define the inversion height z_i as the top of the inversion layer, z_i^+, since the evaluation of the turbulent fluxes at this height results in the best closure of the LWP budget as discussed in Section

2.2. The inversion layer is usually only several tens of meters thick, so this somewhat unconventional definition of zi has negligible impact on the remaining terms in the budget."

- Equation (5): How is entrainment velocity measured?
The entrainment velocity is measured as the change of the inversion height in time (see our response to the previous question on the detection of z_i) corrected for the influence of subsidence, according to equation 1. We added the following to clarify this:
"The entrainment rate w_e is determined from the diagnosed time evolution of the inversion height and the prescribed subsidence at the inversion height using Eq. (1)."

- Typo at line 16, page 17234: "Eqs. (4)-8)" should be "Eqs. (4)-(8)".
Thank you for noticing.

- What is the authors definition of cloud fraction?
We added the definition used for the cloud fraction right below Eq. (9):
"Here $c_f(z)$ is the fraction of grid cells in a horizontal slab at height z for which $q_c > 0$. Note that this definition excludes the presence of rain water."

- Add more description for DALES in 3.2. Too short.
We agree. We rewrote the section to the following, which is more informative in our opinion:
"The Dutch Atmospheric LES (DALES) model version 4.0 (Heus et al., 2010; Böing et al., 2014) was used to perform the simulations in this study. This model features, among others, an anelastic core, fifth-order hybrid weighted essentially non-oscillatory advection (Jiang and Shu, 1996; Blossey and Durran, 2008), the RRTMG scheme for radiation (Iacono et al., 2008), bulk microphysics (Kogan, 2013) and subgrid-scale turbulence following Deardorff (1980). The model version and settings are identical to those used by Van der Dussen et al. (2015)."

Böing, S. J., 2014: The interaction between deep convective clouds and their environment. Ph.D. thesis, Technical University Delft, Delft, 133 pp (Available from Technical University Delft, Delft, The Netherlands, http://repository.tudelft.nl).

Deardorff JW. 1980. Stratocumulus-capped mixed layers derived from a three-dimensional model. Bound.-Layer Meteor. 18: 495–527.

- "thinning contribution", "thinning tendency", and "cloud thinning": When these are used for LWP tendency, they should be replaced by "drying". Cloud layer thins, but not LWP.
Indeed, in general referring to a decrease of the LWP as a thinning of the cloud might not be correct. However, as we are dealing with a stratocumulus cloud layer that is vertically well-mixed and has a cloud cover of 100%, the LWP and the thickness of the cloud layer are inseparably linked. Hence, our loose use of the word thinning. We have some objections against using "drying" when referring to a LWP tendency, as this could be confused with a tendency of total humidity. Actually, a LWP tendency can also be caused by a change of the temperature. In that case, mentioning a drying of the cloud layer is probably correct, but slightly confusion.
We chose to put a remark explaining our use of the word thinning when referring to the LWP tendency at the beginning of the article:
"Note that in the discussion below we will loosely refer to a negative LWP tendency as a thinning of the stratocumulus layer, as the LWP is closely related to the cloud thickness as long as the cloud cover is unity. Because the stratocumulus cloud decks we are investigating are vertically well mixed, the LWP is approximately proportional to the cloud layer depth squared (Albrecht et al., 1990). Ghonima et al. (2015) actually demonstrated that the LWP budget and the tendency equation for the cloud layer thickness derived by Wood (2007) are analogous."

B. A. Albrecht, C.W. Fairall, D. W.Thomson, and A. B.White, 1990: Surface-based remote sensing of the observed and the Adiabatic liquid water content of stratocumulus clouds, GRL, 17, 89-92.

Mohamed S. Ghonima, Joel R. Norris, Thijs Heus, and Jan Kleissl, 2015: Reconciling and Validating the Cloud Thickness and Liquid Water Path Tendencies Proposed by R. Wood and J. J. van der Dussen et al.. J. Atmos. Sci., 72, 2033–2040.

Wood, R. (2007). Cancellation of aerosol indirect effects in marine stratocumulus through cloud thinning. Journal of the Atmospheric Sciences, 64(7), 2657–2669. doi:10.1175/JAS3942.1

- Fig. 1a: add vertical line to indicate sun rise and sun set.

We chose to make the nighttime grey in Fig 1a and we changed the figure caption accordingly. Thanks for this suggestion.

- The discussion in page 17238 is hard to follow.

We agree and rewrote much of the discussion, to hopefully make it easier to follow:
“After about 8 hours of simulation, the sun rises. The stratocumulus layer absorbs a fraction of the solar radiation, which causes a warming tendency that partly offsets the longwave radiative cooling of the cloud. Therefore, the net cloud thickening effect due to radiation diminishes during the day. This has a pronounced effect on the total LWP tendency, which becomes negative leading to the sharp decrease of the LWP with time as shown in Figure 1a. As the LWP decreases, the stratocumulus layer produces less precipitation, such that the thinning tendency due to precipitation reduces to approximately zero after about 14 hours. This shows that the feedback of the LWP on the generation of precipitation acts as a buffering mechanism that levels out variations of the LWP on timescales of several hours.
The decrease of the net radiative cooling during the day also diminishes the production of turbulence in the cloud layer. This is reflected by a weakening of the Ent and Base terms in Figure 1b that are both turbulence driven. Interestingly, the response of the turbulence intensity to the change of the radiative forcing is delayed by several hours, which is particularly clear for the Base-term. As a result, the minimum LWP in Figure 1a occurs about two to four hours after local noon.”

- "Surprisingly" in line 24, page 17238: Show time series of precipitation. Is large precipitation expected?

Thanks for this remark. We consider the choice of the word “surprisingly” as inappropriate, as the LWP at this stage is low, so little precipitation is expected. Hence we rewrote the sentence.
“At this stage the LWP has become low, resulting in little precipitation and hence a negligible drying tendency due to precipitation.”
We deem it unnecessary to include time series of the precipitation rate, as this is very similar to its LWP tendency (in Fig. 1b) according to Eq. (8).

- What is the authors definition of cloud cover?

To clarify we added the following definition:
“Figure 2a shows the projected cloud cover σ, fraction of LES vertical sub-columns with $q_c > 0$, for the three sensitivity simulations in which the large-scale subsidence velocity is varied.”

- Second paragraph in page 17239: I think that this is very hand wavy argument. Any evidence?

We propose the most likely cause for the difference in the moment of stratocumulus breakup between the original and the idealized simulations as we think that further speculation will distract too much from main message of this article. Hence, we chose to state more clearly that we provide only the most likely explanation about the differences:
“A prominent difference however is the moment of stratocumulus breakup, which occurs approximately 10 hours earlier in the original ASTEX transition. As a possible explanation this is most likely due to the magnitude of the horizontal wind that decreases in the second half of this transition and causes a drastic reduction of the surface humidity flux. In the sensitivity experiments on the other hand, the horizontal wind speed is constant in time possibly leading to a greater moisture supply to the stratocumulus layer, which prolongs its lifetime. The latent heat flux results of our idealized LES sensitivity experiments are consistent with a recent model intercomparison study on

Lagrangian stratocumulus transitions (De Roode et al. 2015), which explains that for a constant wind speed and a linearly increasing SST with time the LHF should increase exponentially with time."

de Roode, S. R., I. Sandu, J. J. van der Dussen, A. S. Ackerman, P. Blossey, D. Jarecka, A. Lock, A. P. Siebesma, and B. Stevens, 2015: Shallow cumulus control on the stratocumulus lifetime: LES results of EUCLIPSE/GASS Lagrangian stratocumulus transitions. Revised version to be submitted to J. Atmos. Sci.

- Line 28 in page 17239 "the entrainment rate is found to increase...": Does the inversion strength become weaker for the weak subsidence case? Provide figure for inversion strength for all cases. Climatologically, subsidence and inversion strength are positively correlated. Is it also true for these simulations?

We added a figure with the inversion jumps of humidity (figure 4a) and liquid water potential temperature (figure 4b) as suggested. We also added some discussing on this point:
"The inversion strength, as measured by $\Delta\theta_l$, is hardly affected by the change of the subsidence rate as is shown in Figure 4b, because the change of θ_l is about as large in the cloud layer as in the free troposphere. The differences in the entrainment rate therefore cannot be explained by changes of the inversion strength. This is somewhat unexpected as large-scale subsidence and lower tropospheric stability are positively correlated at longer time-scales (e.g. Myers and Norris, 2013)."

- Line 2 in page 17240 "...most likely the result of the larger stratocumulus thickness h,...": Show the time series of cloud thickness for all cases.

The time series of the cloud thickness looks virtually identical to the time series of the LWP in Fig. 2b, which is the result of the cloud cover of 100% throughout the entire LES domain for most of the simulation time. Adding a figure showing stratocumulus thickness would hence not be very informative (see remark about ghonima paper above).
We however chose to rewrite this line somewhat, to clarify the reasoning:
"Such an increase was also found by Sandu and Stevens (2011) and it is most likely the result of the larger LWP (see Fig. 2b). This typically causes the cloud layer to be more energetic…"

- Line 18 in page 17241 "...for the lowest subsidence case...": Show the time series of three terms for the entrainment contribution term.

Following your suggestion, we decided to add another figure showing the three terms of Eq. (5) separately to make the discussion easier to follow. We refer to this figure in the text as follows:
"Figures 6a-c individually show the three terms that together constitute the contribution of entrainment to the LWP tendency of Eq. (5). The last of these terms accounts for the deepening of the cloud layer due to entrainment (Figure 6c), which according to Eq. (1) causes the inversion height and consequently the cloud top height to rise with time. It is important to note that the cloud layer thickness h arises in the last term on the rhs of Eq. (5) due to the fact that the maximum cloud liquid water content is present at the cloud top, with its top value being approximately proportional to the cloud layer depth. If the cloud top of a deep cloud increases due to entrainment, this will yield a larger increase in the LWP than if the cloud top of a shallower cloud rises by the same distance. Therefore, this term increases with the cloud thickness h. For the weak subsidence simulation, h is larger than for the reference simulation. This effect opposes the cloud thinning due to entrainment warming and drying, and causes the entrainment contribution to δLWP for the lowest subsidence case to be positive (i.e. with respect to the reference case).
Note furthermore that for weaker subsidence the boundary layer grows deeper, causing the cloud layer to become drier with respect to shallower boundary layers (Park et al., 2004;Wood and Bretherton, 2004). Hence, the magnitude of the inversion jump of humidity Δq_t decreases as subsidence is weakened as is shown in Figure 4a. This decrease exceeds 0.5 g kg^{-1} at the end of the simulations, which causes the entrainment drying term in Figure 6a to be practically identical for all three cases, despite the difference in the entrainment velocities."