Response to interactive comments by anonymous referee #1

We would like to thank the reviewer for his suggestions regarding the manuscript. On the basis of these comments we have made numerous changes to the original text. Please find a response to each of the suggestions below.

-G1: The LWP tendency is made up of five terms which compensate to yield a small residual, both in the original simulation and in the differences between the sensitivity simulations. As the authors note, the budget in Fig. 1b might lead the reader to believe that the subsidence is a negligible contributor to the LWP tendency budget, but the whole point of the paper is to show how LWP does depend on subsidence. If the authors can make a more persuasive case for the quantitative utility of the budget in explaining their results, that would strengthen the paper. In particular, the statements in the conclusions, e. g. 17242 L24-17425 L2, are well known and don't require justification with an LWP tendency equation.

Our study is strongly motivated by the results of Sandu and Stevens (2011). They did not explain why the lifetime of stratocumulus is extended if the subsidence is decreased and as a result the entrainment rate increases. In particular, more entrainment would be expected to cause a more rapid thinning of the cloud layer. This puzzling aspect can be understood by considering all terms in the LWP budget. Putting the Base and Entrainment fluxes in one single term will obscure the fact that even though the entrainment rate increases, the cloud thinning tendency due to entrainment decreases.

Another important motivation for this study is the decoupling of the boundary layer during the transition. Some studies have suggested that the decoupling will lead to a thinning of the stratocumulus clouds as it tends to diminish the upward transport of moisture to the cloud layer. For example, in the seminal paper by Bretherton and Wyant (1999) it is written that "Penetrative entrainment of dry and warm free tropospheric air by the cumuli evaporates most of the liquid water in their updrafts before it can be detrained as stratocumulus cloud, so cloud amount gradually decreases (Bretherton 1992; W97).". Our analysis clearly shows the separate contributions of entrainment and cloud base fluxes as a response to changes in the subsidence.

Textual changes have been made throughout the manuscript and we have added a figure showing the contribution of the entrainment deepening term in the LWP budget (Figure 6), as well as the LHF for the sensitivity simulations (Figure 7) to bring out these messages more clearly.

-G2: In interpreting their results, the authors should note that the 'Base' term in the LWP tendency partitioning (Eq. 3) is inseparably linked to entrainment, since there can be no entrainment drying and warming without corresponding turbulent fluxes below the inversion. Thus, except perhaps for one illustrative example, only the sum of these strongly compensating terms ('Turb'?) should be plotted. This has the conceptual advantage of isolating all the turbulent contributions to LWP tendency into one term. At the end of section 5, the authors finally reach this conclusion themselves in noting the cloud base and entrainment sensitivities of LWP tendency to subsidence rate nearly add to zero.

We deliberately choose to separate the cloud base and cloud top fluxes as it is a priori not clear how their magnitudes relate to each other. The entrainment rate is among others controlled by the net radiative loss in the cloud layer, the inversion stability and the strength of convective updrafts in the cloud layer. On the other hand, the cloud base fluxes are to some extent governed by the surface flux values. Our current analysis enables us to determine whether the stratocumulus cloud thins during a stratocumulus transition 1) due to decoupling of the boundary layer that would strongly

reduce the input of humidity to the cloud layer or 2) due to a steady increase of the drying and warming of the stratocumulus layer as a result of enhanced entrainment. These two mechanisms have been proposed frequently in literature as the main causes for stratocumulus cloud thinning. We emphasize this among others by adding the following lines:
“The Ent and Base terms in Figure 1b are strongly anticorrelated, which is made particularly clear by the peaks that occur for both terms after approximately 22 hours. The magnitudes of these turbulence-driven tendencies are approximately equal during the first half of the simulation, so that they cancel to a large extent. Interestingly, the Base term remains roughly constant throughout most of the simulation suggesting that decoupling of the boundary layer does not significantly affect the transport of humidity to the stratocumulus cloud. The magnitude of the entrainment term, on the other hand, continues to increase throughout most of the simulation so that it becomes almost twice as large as the Base term during the second half of the transition. This can be explained from the magnitude of Δq_t that gradually increases by the combined effects of the increasing sea surface temperature and large-scale subsidence that slowly dries the free troposphere Van der Dussen et al. (2014).”

Another reason to maintain the decomposition is that we believe it is helpful for understanding and interpreting results from large-scale models which generally have difficulties in a faithful representation of the stratocumulus to cumulus transition. A similar LWP analysis for such models may shed some light on the question which of the components of the LWP budget needs to be improved. We would like to stress that in a recent paper by Ghonima et al. (2015, JAS) our budget analysis has been discussed to be a very useful approach for understanding and predicting the cloud layer evolution.

Specific comments
- 17233 Eq. 5: Should there be a factor ‘*h*’ in front of the parenthesis to give the right hand side units of LWP tendency?

The units in Eq. (5) are correct as they are, which can be shown as follows. The units for the individual variables in the first term of the equation are:

$$[\mathrm{Ent}] = \frac{\mathrm{kg}}{\mathrm{m}^2\mathrm{s}}$$

$$[\rho] = \frac{\mathrm{kg}}{\mathrm{m}^3}$$

$$[w_e] = \frac{\mathrm{m}}{\mathrm{s}}$$

$$[\Delta q_t] = \frac{\mathrm{kg}}{\mathrm{kg}}$$

$$[\eta] = -$$

Substitution of these units in Eq. 5 gives the following for the first term:

$$\frac{\mathrm{kg}}{\mathrm{m}^2\mathrm{s}} = \frac{\cancel{\mathrm{kg}}}{\mathrm{m}^{\cancel{3}2}} \frac{\cancel{\mathrm{m}}}{\mathrm{s}} \frac{\mathrm{kg}}{\cancel{\mathrm{kg}}}.$$

This can also readily be shown for the other two terms in Eq. (5). Furthermore, Ghonima et al. (2015) checked the LWP tendency equation with a similar equation derived by Wood (2007) and found them to be in good agreement.

-17242 L10-11: Are the authors implying that there is a fundamental reason that the entrainment and cloud base contributions to LWP tendency should add to zero? If not, one could argue that this conclusion is just due to a coincidental cancellation between two other terms and is therefore not particularly meaningful. If so, please explain why the combined entrainment/base contribution should be negligibly small.

We believe this is a key finding and the reviewer's comment actually suggests that we have not been clear enough about this point. We found that even though the entrainment rate increased, the cloud

thinning tendency was reduced for weaker subsidence cases. This could not have been anticipated a priori, and was neither noticed by Sandu and Stevens. We made the discussion on this point more clear in the text:
“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 greater than for the reference simulation. This effect opposes the cloud thinning due to entrainment warming and drying, and causes the entrainment contribution to LWP for the lowest subsidence case to be positive (i.e. with respect to the reference case).”

We added Figure 6 in which the three terms that together constitute the contribution of entrainment to the LWP tendency are separately plotted to make the discussion easier to follow.

In a steady state situation (see e.g. Blossey et al. 2013, JAMES) and in the absence of source and sink terms, the cloud base contribution should cancel the entrainment contribution. However, there is no physical reason why they should balance during Lagrangian transitions. This is visible in Figure 1b, which shows that during the second half of the simulation the magnitude of the entrainment term is approximately a factor of two larger than that of the cloud base flux term. We added some discussion on this point (see the response to G2 above).

Furthermore, we added some discussion on the cancellation between the two terms:
“The sum of both contributions is therefore almost zero. This can be understood as follows. Enhanced entrainment will also cause enhancement of the cloud base fluxes as the entrained air sinks downward through the cloud layer. Similarly, strong updrafts through cloud base lead to enhanced entrainment when the updraft reaches and overshoots the inversion layer. Such anticorrelated behavior causes the cancellation of the entrainment and cloud base terms in the sensitivity experiments.”