Reply to Referee #2

We appreciate the comments and suggestion of the reviewer. The careful inspection of our manuscript gave us the opportunity to improve the quality of our work. The reviewer's comments are addressed below:

1. This manuscript details an investigation of differences in CERES-like Aqua MODIS liquid water cloud effective radius retrievals at 2.1 and 3.8**um**, and corresponding liquid water path (LWP), as a function of cloud fraction (CF) and spatial heterogeneity. While the relationships shown generally support findings from previous investigations, the authors do not convince that using AMSR-E LWP yields significant new insights (other than as a screening mechanism for excluding precipitating clouds), nor do they make the case that LWP is a suitable proxy for cloud dynamics (as implied by the title). I therefore recommend major revisions.

We agree with the reviewer that the premise of our manuscript, spatial heterogeneities can bias the satellite cloud retrievals, is not novel. While we properly acknowledge this in our manuscript, we attempt to answer the question whether the MODIS effective radii differences are dominated by the spatial heterogeneities or the cloud vertical structure. Because the cloud microphysical vertical structure is tightly related to the regional/large scale atmospheric processes (see Wood et al., 2011), we use an independent retrieval of LWP for isolating different dynamical patterns. While the use of LWP for studying meteorological processes is new to the remote sensing community, LWP-based analysis have been commonly utilized by the cloud-aerosol interaction community (e.g. McComiskey) to isolate aerosols from cloud dynamical effects. A second point to take into account is that our physical interpretation of the satellite retrievals mostly comes from in-situ observations during VOCALS-REx (Painemal and Zuidema, 2011). Our results for homogeneous clouds are qualitatively consistent with VOCALS-REx in two ways: 1) effective radii are larger at the cloud top (i.e., $r_{e3.8} > r_{e2.1}$), and 2) this pattern is unaffected by LWP, which mostly modulates the magnitude of effective radius. Because we share in part the reviewer's concern about the title, we have replaced "cloud dynamics" by "liquid water path".

The reviewer is correct that moderate/large precipitation is screened in our analysis, nevertheless drizzle occurrence for LWP < 150 gm^{-2} have been documented in numerous satellite and in-situ studies (e.g. Leon et al., 2008;Kubar et al., 2008, Painemal and Zuidema, 2011).

Specific Comments:

2. p. 12728, line 25: Is the heterogeneity index calculated using the same pixel sampling as the PSSF (i.e., every other scan line and fourth element), or using all MODIS pixels within a CERES footprint?

We compute the index from the PSSF sampling. See the next response.

3. p. 12728, line 28: Should be more specific that the Hs used in Zhang and Platnick (2011) is calculated from the 250m 0.86**um** reflectances, and was introduced by Liang et

al. (2009).
We agree with the reviewer that our heterogeneity definition requires a more detailed explanation. We write in our latest manuscript:

"We computed a heterogeneity index H_σ, defined as the ratio of the standard deviation to the mean MODIS 0.64-µm 1-km reflectance at the PSSF resolution (~20 km at nadir) using the 1 x 4 sampling of the PSSF. We note that H_σ defined here differs from that in Liang et al. (2009), which was calculated at a 1-km resolution from the 250-m 0.86-µm MODIS reflectances."

4. Fig. 2b,c: Should use the same color scale for both effective radius plots.
Our new Fig 2b and c share the same color scale.

5. p. 12730, line 15: Does the larger LWP "yield" (i.e., cause) more vigorous up and down drafts, etc., or is it associated with such dynamics/cloud processes?
In our recent manuscript we wrote:

"For cloudy scenes, when CF > 98%, an LWP-dependent analysis is relevant because one should expect a relationship between LWP, H_σ, and the cloud vertical structure. LWP has been recognized as a cloud macrophysical property (e.g. Wood 2012), as it is the manifestation of different forcing parameters such as: sea surface temperature, divergence, humidity, and atmospheric stability (e.g. Stevens and Brenguier, 2009). LWP and in-cloud turbulence (updrafts) are linked because a LWP increase produces stronger cloud top radiative cooling, which in turn favors the turbulence production. Moreover, increasing LWP associated with boundary layer deepening (e.g. Painemal et al., 2013) should facilitate droplet size condensational growth. All these factors modify the cloud droplet activation and growth, affecting the droplet size, the vertical structure, and drizzle generation. The use of LWP as a proxy for the cloud dynamics has also been applied for isolating the cloud-aerosol interactions from those factors associated with the regional circulation and cloud dynamics (e.g. McComiskey and Feingold, 2012; and references therein). "

6. p. 12730, lines 23-24: Stating agreement with the two previous studies is a little misleading, as Zhang and Platnick (2011) found little change in re3.8 as a function of subpixel heterogeneity, while Zhang et al. (2012) found smaller 3D RT effects at 3.8**um** compared to 2.1**um**.

In addition to the reviewer's comments, Zhang and Platnick (2011) only focuses on MODIS satellite retrievals, and therefore it better fits the discussion in our manuscript. In our latest manuscript, we mostly emphasize the results within Zhang and Platnick (2011).

7. Figs. 4 and 5: I'm assuming these figures are for footprints with CF > 98% (as in Fig. 3)? Should specify this in the text.
The reviewer is correct. We modified the text accordingly.

8. p. 12732, lines 6-8: I don't think this statement can be made on the basis of Fig. 4 alone. Certainly the optical thickness is also increasing with increasing LWP, regardless of the heterogeneity index.

We included a new figure 4, where we show a bias transition between coastal and offshore clouds, in order to reinforce the idea that horizontal heterogeneity modulates MODIS LWP, especially far offshore, where clouds tend to possess large LWP. We add the following paragraph:

"Given the westward gradients in Δr_e and $H\sigma$ observed in Fig. 1, we analyze further the impact of using $r_{e3.8}$ and $r_{e2.1}$ in the computation of MODIS LWP (Eq. 1), in the context of spatial heterogeneities. Figures 4a and 4b show histograms for the biases between AMSR-E and MODIS LWP, for a 4˚x3˚ coastal (centered at 76.75˚W,23.75˚S) and offshore (centered at 97.75˚W, 23.75˚S) region, respectively. The blue histogram indicates LWP differences calculated using daily $r_{e3.8}$ ($LWP_{3.8}$), whereas its red counterpart makes use of $r_{e2.1}$ ($LWP_{2.1}$). Coastal histograms (Fig. 4a) show a narrow distribution, in part because LWP tends to be small near the coast. In addition, the histograms do not suggest meaningful differences between AMSR-E and MODIS retrievals, whether they are calculated with $LWP_{3.8}$ or $LWP_{2.1}$ (mean biases -7.5 and -5.6 gm^{-2}). In contrast, offshore histograms (Fig. 4b) are broader, with a shift toward larger positive bias for $LWP_{AMSR\text{-}E}$-$LWP_{3.8}$ relative to $LWP_{AMSR\text{-}E}$-$LWP_{2.1}$. The mean AMSR-E/MODIS biases are 9.6 and 1.4 gm^{-2} for $LWP_{3.8}$ and $LWP_{2.1}$, respectively. Interestingly, the differences between Figs. 4a and 4b are accompanied by contrasting changes in Hσ (Fig. 4c). Coastal and offshore regions yield distinctive values of Hσ, with a distribution mode of 0.15 for coastal clouds (Fig. 4c, gray line), and 0.25 for far offshore clouds (black line). The MODIS LWP and Hσ relationship is further emphasized in Fig. 4d where mean Hσ values and the mean differences between $LWP_{3.8}$ and $LWP_{2.1}$ are shown as a function of longitude. The $LWP_{3.8}$-$LWP_{2.1}$ zonal gradients are concomitant with Hσ increases, indicating a distinctive bias compensation between both r_e's and τ to changes in heterogeneities. We explore this idea in more detail by taking averages of all the binned MODIS variables over the study region (constructed from $LWP_{AMSR\text{-}E}$) as a function of H_σ bins."

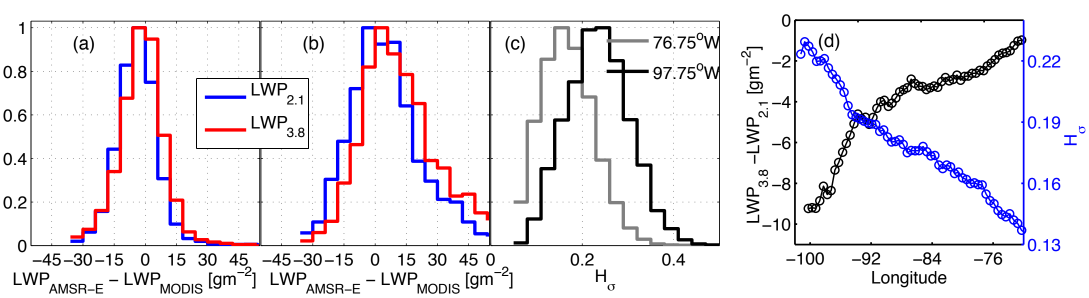

Figure 4: Normalized histograms for the differences between AMSR-E and MODIS LWP for two 4˚x3˚ regions: a) coastal area centered at 76.75˚W, 23.75˚S, and b) offshore area centered at 97.75˚W, 23.75˚S. Red and blue histograms correspond to $LWP_{AMSR\text{-}E}$-$LWP_{3.8}$ and $LWP_{AMSR\text{-}E}$-$LWP_{2.1}$, respectively. c) Normalized $H\sigma$ histograms for the coastal (gray) and offshore (black) regions in Figs. 4a and b. d) Mean westward variation

of H_σ (blue) and $LWP_{3.8}$-$LWP_{2.1}$ along 21.25˚-26.25˚S. Figures are constructed from cloudy scenes only (CF>98%).

9. p. 12732, lines 24-25: Table 1 values are not necessary for explaining the smaller changes in LWP2.1 with increasing heterogeneity index – the smaller increases of re3.8 with increasing heterogeneity index (and decreasing optical thickness) shown in Fig. 5a is sufficient.

Perhaps the reviewer is correct; nevertheless table 1 makes the discussion much easier.

10. p. 12734, lines 1-3: This statement, presumably referring to Figs. 4 and 5, is unsupported by the presented results. The increasing heterogeneity index in Fig. 4 cannot be considered equivalent to the increase of the heterogeneity index along the x-axis in Fig. 5. As the authors show in Table 1, LWP changes are dominated by changes in cloud optical thickness, thus there cannot be a "rapid decrease of optical thickness with heterogeneity index as the AMSR-E LWP increases."

We rephrase this statement:

"The smaller values of MODIS LWP relative to the AMSR-E values, when $r_{e2.1}$ greatly exceeds $r_{e3.8}$, are associated with the rapid decrease of τ with H_σ (relative to homogeneous scenes with the same AMSR-E LWP) that tends to occur with rising AMSR-E LWP."

11. Technical Corrections:

p 12726, line 25: singular "retrieval error" instead of plural "retrievals error"

p. 12727, line 6: remove comma from "3.8**um** channels, provides"

p. 12727, line 22: "used to generate the Clouds..."

p. 12729, line 4: need degree symbol after 0.5

We have corrected the manuscript accordingly, thanks.