Reply to Referee #2

We greatly appreciate your insightful comment on our paper. We have revised our results and manuscript according to your comment. The revised manuscript now considers the influence of gravitational acceleration. Below we answer your comment.

[Referee's criticism]

The authors have used direct numerical simulations of turbulence with Lagrangian particles having finite inertia (Stokes number), but have neglected the gravitational sedimentation term. This is justified by referring to a 2017 paper in which the authors showed that the gravitational sedimentation effect is small (< 1 dB for the size and turbulence ranges of interest). The 2017 paper, however, deals only with monodisperse droplet populations, and it is reasonably well established that a key signature of gravitational settling for low-Stokes-number particle clustering is reduction of the bi-disperse radial distribution function. The effect is similar to the bi-disperse clustering effect described in the theoretical treatment of Chun et al. (2005, see their section 2.3). It leads to saturation of the power-law dependence of the bi-disperse radial distribution function. This cross-over scale is discussed by the authors in section 4.1, but the role of gravity in modifying that is not discussed. The radial distribution function is directly and quantitatively connected to the Bragg signature, so it is very likely that the sedimentation-induced saturation effect will be a first-order effect. The saturation effect resulting from particle settling has been confirmed in subsequent DNS and experimental studies (e.g., Ireland et al. "The effect of Reynolds number on inertial particle dynamics in isotropic turbulence. Part 2. Simulations with gravitational effects" J. Fluid Mechanics 2016, see their section 4.2; Lu et al. "Clustering of settling charged particles in turbulence: theory and experiments" New J. Physics 2010, see their section 4).

We agree that gravitational settling must be considered for reliable modeling of turbulent clustering of cloud droplets. We had expected that numerous DNS experiments are necessary to parameterize the settling influence, but we have succeeded in incorporating the gravitational setting influence into our parameterization since you introduced the useful papers to us. The modeling of the influence of gravitational settling is described in Subsection 4.3 and the reliability of the model is confirmed in Fig. 7 (b). The radar echo simulation in Fig. 9 has been obtained with the updated model that considers the gravitational settling. It has confirmed that the influence of turbulent clustering is still significant even if the gravitational settling is considered.

In our previous work (Matsuda et al., 2014), we confirmed that the influence on the power spectrum for monodispersed droplets is insignificant for $S_{\mathrm{v}} < 3$, where S_{v} is the settling parameter defined by the ratio of the terminal velocity to the Kolmogorov velocity. However, it is true that gravitational settling modifies the cross-over length of the bidisperse RDF. Lu et al. (2010) analytically proposed the cross-over length for gravitational settling bidisperse particles. Following this analysis, we have modified our parameterization for the critical wavenumber ξ_{c} in Eq. (32) to consider the settling influence on the coherence. Since ξ_{c} is inversely proportional to the cross-over length, we propose the following correction based on the equation of Lu et al. (2010):

$$\xi_c = \frac{0.191}{|\mathrm{St}_1 - \mathrm{St}_2|}\left[1 + \frac{1}{3a_0}\mathrm{Fr}^{-2}\right]^{-1/2}.$$

In order to confirm the reliability of the parametrization, we have performed additional DNSs for polydisperse droplets considering the gravitational settling. As shown in Fig. 7 (b), $E^*_{\mathrm{r3np}}(\xi)$ values obtained by the additional DNSs are smaller than those for the case without gravitational settling at large wavenumbers, indicating that the coherence model is more important than the case without gravitational settling. $E^*_{\mathrm{r3np}}(\xi)$ values predicted by the modified parameterization show good agreement with those of the DNS results with gravitational settling. We have also confirmed that the RMS error e_{RMS} evaluated by Eq. (39) remains smaller than 1 dB even for the case with gravitational settling. These results indicate that the modified parameterization can predict the influence of turbulent clustering for polydisperse droplets considering the gravity effect within 1 dB error.

We have added Subsection 4.3 to explain the modeling of the gravitational settling influence. We have also modified the computational condition in Subsection 3.1. The clustering influence in Figure 9 is also updated using the parameterization considering the gravitational settling influence. The results confirm that the influence of turbulent clustering is still significant even if the gravitational acceleration is considered.