Review of Lebsock and Witte, 2023.

This paper examines the dependence of the k-value (k=(rv/re)^3, where rv is volume mean radius and re is the effective radius) of cloud droplet size distributions upon the cloud droplet concentration (Nd) using aircraft data. A parameterization is developed to describe the dependency. This dependency leads to biases in the retrieval of Nd using MODIS retrieved re and cloud optical depth using the adiabatic cloud assumption since a constant k value is generally assumed for such retrievals. The biases due to assuming a constant k value of 0.8 are quantified using MODIS data subset to the CloudSat ground track (MAC06S0 dataset), presumably at ~1km resolution (although this is not clear from the text – see comments below).

The science seems sound and the paper is very well written. The only thing missing is a little more discussion on how this might combine with some of the other potential biases relating to the precipitation, the k value and associated droplet distribution widths, and some discussion on the implications for climate models (which relates to the behaviour at larger spatial scales).

Major points

It would be good to discuss the effect of k variability and the presence of precipitation on the MODIS retrievals of re. MODIS assumes a modified gamma distribution for cloud droplets for the radiative models used for its retrievals of re. The variation of k will also affect this and may lead to biases in re that would be likely to have a strong influence on Nd retrievals. The presence of a precipitation mode might also affect the retrieved re and hence Nd retrievals. I don't expect you to investigate the effect of this, but it would be worth mentioning in the discussion perhaps. Correcting for this bias could therefore either enhance or reduce the bias discussed in the paper being reviewed. Section 2.4.4. of Grosvenor et al. (2018) contains some useful discussion on this. From the information given there it seems likely that in precipitating regions neglecting the rain mode is likely to lead to an underestimate of Nd. These are likely to be regions with broader droplet distributions (low k) and the presence of a precipitation mode may therefore enhance the error seen in your paper since you also show an underestimate of Nd in such regions. In regions of high k the assumption by the MODIS retrieval of k=0.72 is likely to lead to an underestimate of Nd due to the DSD width assumption in the re retrieval, whereas your paper shows a positive Nd bias in such regions.

Zhang, Z. B., Ackerman, A. S., Feingold, G., Platnick, S., Pincus, R., & Xue, H. W. (2012). Effects of cloud horizontal inhomogeneity and drizzle on remote sensing of cloud droplet effective radius: Case studies based on large-eddy simulations. Journal of Geophysical Research, 117, D19208. https://doi.org/10.1029/2012JD017655

Zhang, Z. (2013). On the sensitivity of cloud effective radius retrieval based on spectral method to bi-modal droplet size distribution: A semi-analytical model. Journal of Quantitative Spectroscopy & Radiative Transfer, 129, 79–88. https://doi.org/10.1016/j.jqsrt.2013.05.033

These papers might be useful for the discussion of drizzle effects too at line 70.

Some climate models use the parameterization of Liu (Y. Liu, P. H. Daum, H. Guo, and Y. Peng. Dispersion bias, dispersion effect and the aerosol-cloud conundrum. Environ. Res. Lett., 3:045021, 2008.), and other similar papers from those authours. For example the UK Earth System Model (UKESM) as described in Mulcahy (2018;

https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2018MS001464). It would be good to discuss the fact that this could also be important for climate models in the introduction. It would also be useful to discuss what the implications of the results of your paper are for such climate models – this would probably relate to the issue of the scale dependence. The Liu and Daum parameterization has the opposite dependence of k on N to your parameterization, although the scales of a climate model grid box are much larger (1x1 degree or so, so around 100km). The impact may depend on the details of how SW radiative fluxes are calculated in the climate models (e.g., using grid-box wide values or sub columns, etc.).

Minor points

Eqns.3 to 6 – you should probably make it clear that you are summing over the different size bins of the droplet probes with subscript i values for the bin quantities (n(r), r, Δr) and you should say what n(r), rmin and rmax refer to. Also, Eqn. 6 switches to using a capital N for n(r).

L146 – "15 pixel (± 5 km) swath" – this is a bit confusing since MODIS pixels for re at least are usually 1km across. Should it be 10 pixels, or ± 7.5 km? Otherwise it would be good to explain this in the text. You should also say what the resolution of the MODIS data that you are using is.

L225 – since you reduce the weighting of the campaigns with more sample points in order to get more equal representation between the campaigns, would a straight average of the three curves not achieve something similar?

Fig. 5 – it seems like a 2d histogram would be better than the scatter points (or contours with different colours for each campaign if wanting to separate them). You should also say what the scatter points are in the caption.

Typos

L45 – Heymfield -> Heymsfield

L69 - that collision coalescence process -> that the collision coalescence process

l79 - at low values N -> at low values of N

L86 - measurements of drops size distribution -> measurements of droplet size distributions

L268 - difference -> differences