Review of "Global Observations of Aerosol Indirect Effects from Marine Liquid Clouds" by Casey J. Wall et al.

This study quantifies SW flux perturbation arising from aerosol-cloud interactions and decomposes the flux perturbations into three components, namely the Twomey effect, LWP adjustment and CF adjustment, for global marine liquid clouds, using a combination of satellite observations, reanalysis and a radiative transfer model (RTM). These sensitivity estimates are then used to constrain ERFaci using GCMs' estimates of PI to PD aerosol changes. Their assessment framework is adopted from a previous study by the lead author (Wall et al. 2022), where TOA SW flux anomalies due to changes in marine liquid cloud properties are regressed against 7 cloud controlling factors (CCFs), including 6 key large-scale meteorological factors and one aerosol indicator, to assess the SW flux sensitivity to aerosol perturbations while controlling confounding meteorology. The innovative aspects of the current study are: i) a decomposing technique adapted from cloud-feedback literature that uses joint histograms of LWP-r_e, instead of COT-CTP as in Wall et al. (2022), to estimate SW flux anomalies and individual components, although an RTM is required to enable the decomposition, ii) the use of Nd as an aerosol indicator, in addition to sulfate aerosol. They found that radiative forcing associated with cloud adjustments is stronger than previously believed and provided a stringent constrain on ERFaci, compared to recent assessments.

This study is no doubt publishable with profound impact and significant contributions to the ACI and ERFaci communities. The manuscript is well written and easy to follow, and the detailed documentation of methodology, framework validation, and uncertainty quantification is greatly appreciated. That said, I do have a few points that I would like the authors to consider and address first before publication.

Key questions/concerns:

1. Regarding the multilinear regression (MLR) method, it seems a bit concerning to learn that MLR was only able to explain less than half of the variance in R'. To me, this points to several possibilities, i) non-linear contributions from the predictors, very likely to be associated with the aerosol indicators, ii) co-linearity among CCFs, a recent work by H. Andersen et al. (2023, ACPD, the lead author of this study is a co-author) addresses this issue, iii) dependence of R' on CCFs of a larger scale, i.e. larger than 5°x5°. In other words, cloud properties may have a memory of the upstream conditions (e.g. Lewis et al. 2023 JClimate). The statistical learning framework used in Ceppi and Nowack (2021, PNAS) addressed this concern.
   I wonder if the authors have taken these possibilities and methodologies into consideration, and if yes, what's the rationale to stick with the MLR framework?

2. The last condition (viii) implemented for Nd selection is a bit concerning, to me at least, which essentially uses the Nd from convective core regions to represent the Nd of the entire cloud. This will no doubt boost the representativeness of Nd on CCN, but not necessarily providing the true characterization of the Nd of these clouds, as the entrainment process that also affects Nd will be biasedly accounted if only convective cores are selected. I wonder how sensitive is your partial()/partial(Nd) sensitivities to the implementation of this last condition?

If the goal is to use Nd to represent CCN as much as possible without worrying about the Nd characterization of the entire cloud, I think the reader will appreciate if this is clearly indicated in the main text.

3. I agree with the authors on the statement around lines 139-140 that, to date, no global observational studies have simultaneously estimated the three components individually. That said, there are a few that estimated intrinsic (Twomey + LWP adjustment, essentially albedo adjustment) and extrinsic sensitivities/forcings, e.g. Chen et al. (2014) and Christensen et al. (2016, 2017). More recently, Zhang & Feingold (2023, ACP) provided a bottom-up observational assessment on the temporally resolved intrinsic sensitivity (albedo susceptibility) that also controls for confounding meteorology. Since the individual components in this study is easily additive, I wonder if the authors could provide the intrinsic and extrinsic sensitivity and forcing estimates so that they can be easily compared with existing estimates?

4. Since Wall et al. (2022) is a recently published high impact study that uses a very similar assessment framework, I think it would be necessary to discuss the improvement/advantage or confidence gained by using this updated framework and reconcile the results from the previous study with that of the current study, especially the apparent stronger cloud fraction adjustment which leads to an overall more negative ERFaci (by ~0.7 W/m^2) in the current study.

Other comments:

- Lines 33-34, These cloud macrophysical adjustments have been documented in literature, please provide appropriate references.
- Line 43, it would be nice to briefly summarize what have been done along this path (i.e. existing studies/efforts on constraining ERF_{aci} using satellite observations), one example is the lead author's recent study (Wall et al. 2022). What is the motivation to update the framework with this re-LWP histogram (other than enabling decomposition) and the impact of trading CERES observations with a RTM, as this is the key novelty of the current study.
- Line 154, reference?
- Lines 165-167, a bit surprising to see no indication of precip-suppression induced LWP increase, perhaps due to the cld vs cld+pcl filtering, I think the reader will appreciate some discussion along this line.
- Lines 176-177, to aggregate to global scale, don't you have to weight the regression coefficient by the frequency of occurrence of liquid cloud at each gird/location?
- Line 202, to be accurate, this assessment uses observations, reanalysis and a radiative transfer model.
- Line 267, I believe there is some sampling bias towards higher Nd, when regressing against Nd.
- Lines 327-328, Shouldn't this overestimation be taken into account when constraining ERFaci? Could you propagate this bias into your final ERFaci estimates, or, is there a reasoning for the final ERFaci estimates not being affect by this bias?
- Fig. 2-3, the unit labeling should reflect the fact that these are sensitivities values, not actual flux perturbations, i.e. unit in $W\ m^{-2}$ per unit increase in ln(s) or ln(Nd) (or $W\ m^{-2}\ ln(s/Nd)^{-1}$).
- Please correct the year of Feingold et al. (2021, ACP) to 2022.

Reference

- Wall, C. J., et al.: Assessing Effective Radiative Forcing from Aerosol–Cloud Interactions over the Global Ocean. Proc. Natl. Acad. Sci. U.S.A., 119(46). https://doi.org/10.1073/pnas.2210481119, 2022.
- Andersen, H., Cermak, J., Douglas, A., Myers, T. A., Nowack, P., Stier, P., Wall, C. J., and Wilson Kemsley, S.: Sensitivities of cloud radiative effects to large-scale meteorology and aerosols from global observations, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2023-1283, 2023.
- Ceppi, P. & Nowack, P. Observational evidence that cloud feedback amplifies global warming. Proc. Natl Acad. Sci. USA 118, e2026290118 (2021).
- Lewis, H., G. Bellon, and T. Dinh, 2023: Upstream Large-Scale Control of Subtropical Low-Cloud Climatology. J. Climate, 36, 3289–3303, https://doi.org/10.1175/JCLI-D-22-0676.1.
- Chen, Y.-C., Christensen, M., Stephens, G. L., and Seinfeld, J. H.: Satellite-based estimate of global aerosol–cloud radiative forcing by marine warm clouds, Nature Geosci., 7, 643–646, https://doi.org/10.1038/ngeo2214, 2014.
- Christensen, M.W., Y.-C. Chen, and G.L. Stephens, 2016a: Aerosol indirect effect dictated by liquid clouds. Journal of Geophysical Research: Atmospheres, 121(24), 14636–14650, doi:10.1002/2016jd025245.
- Christensen, M.W. et al., 2017: Unveiling aerosol–cloud interactions – Part 1: Cloud contamination in satellite products enhances the aerosol indirect forcing estimate. Atmospheric Chemistry and Physics, 17(21), 13151–13164, doi:10.5194/acp-17-13151-2017.
- Zhang, J. and Feingold, G.: Distinct regional meteorological influences on low-cloud albedo susceptibility over global marine stratocumulus regions, Atmos. Chem. Phys., 23, 1073–1090, https://doi.org/10.5194/acp-23-1073-2023, 2023.
- Feingold, G., Goren, T., and Yamaguchi, T.: Quantifying albedo susceptibility biases in shallow clouds, Atmos. Chem. Phys., 22, 3303–3319, https://doi.org/10.5194/acp-22-3303-2022, 2022.