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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Evaluating WRF-Chem aerosol indirect effects in Southeast Pacific marine stratocumulus during VOCALS-REx" *by* P. E. Saide et al.

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Response to Anonymous Referee 1

We appreciate your comments. Referee 1 requests that "For a publication in ACP, the authors should forcefully prove me wrong by showing that the manuscript provides significant, non-trivial scientific insight that transcends previously published works by more than merely incremental steps. In particular, it should be shown how it adds meaningful knowledge or understanding beyond the work of Yang et al. (2011)." We take this invitation to promptly point out the novel features of this article to subsequent reviewers, and provide the basis for further substantive appraisals of the article's sci-

entific merits. We regret that these important contributions were not more obvious in the submitted manuscript, and we plan to revise the text and abstract to more clearly highlight these important contributions and to reflect the reviewer's editorial comments.

We agree with the reviewer that including aerosol re-suspension would make for a more complete simulation, and we would certainly have done so were it not so far beyond the scope of this experiment. Adding re-suspension is a non-trivial long-term development project, and is already under development by other groups at NCAR NESL/PNNL, so there's little reason to duplicate that effort. Rather, our current WRF-Chem development focuses on building the adjoint of the model.

In our study, we systematically evaluate indirect effects in WRF-Chem through parametric and structural sensitivity analyses. We evaluate these against observations over an extensive range of parameters important for indirect effects. We feel that any two of these eight novel contributions would warrant inclusion in Atmospheric Chemistry & Physics, and all transcend the analysis presented by Yang et al.:

1. Large uncertainties remain in modeling of aerosol indirect effects. Previous studies that have incorporated aerosol indirect effects in models have found that results with indirect effects included tend to agree better to observations (see 3rd paragraph in the introduction). In the WRF-Chem framework, to "not use" indirect effects is to assume a prescribed droplet number for the whole domain making model differences between these two runs (with and without indirect effects) very large. We know that indirect effects are real, so not including them is not physically correct (but including them has associated uncertainties). In our work we go one step further and compare two simulations with different aerosol loads coming from using two different WRF-Chem configurations, both with indirect effects included. As these two simulations generate different clouds properties, we compare them and attribute differences in a consistent way to established aerosol indirect effects that, which to our knowledge has not been done before for a full mesoscale simulation. Moreover, as observations are available in the study region, we use them to show that the simulation with aerosols loads closer

to the observations actually produces cloud properties that are in better agreement to clouds observations. This fact reduces WRF-Chem aerosol indirect effect uncertainties to a point far beyond the first-order "meteorology with and without indirect effects" question that others have previously addressed.

2. We quantify how aerosol deposition processes affect aerosols and their impacts on clouds in the region. This is an important and basic question as indirect effects in models are all over the place (see the error bar in aerosol indirect effect from the 2007 IPCC report). We have found no prior documentation of the effects of model aerosol deposition treatment on aerosol-cloud interactions in persistent low stratocumulus decks over the eastern tropical oceans, so quantifying the importance of this process on clouds is a novel contribution. Moreover, few regional or global climate or chemical transport models include re-suspension after evaporation, so these results inform a broad range of attempts to better resolve these low cloud regimes in particular and aerosol concentrations and indirect effects in general.

3. We provide the first documentation of model inputs, parameterizations, and configurations required to realistically simulate SO2 burden, cloud height, thickness, etc., for representing contemporary conditions in the Southeast Pacific at the regional scale. This is, in fact, a new and important contribution because it's essential to quantifying the degree to which model structure affects the modeling system's ability to resolve processes, their spatial gradients and temporal evolution. Otherwise, ad hoc choices limit the modeling system's net performance. These myriad issues have not been documented for VOCALS or for any regions with persistent low stratocumulus. An important VOCALS activity is to serve as testbed for modeling experiments, and WRF-Chem is one of the primary tools in use by several groups of VOCALS participants to study aerosol-cloud interactions. Documenting the conditions under which the model can best represent observations is crucial to enable WRF-Chem modelers to subsequently focus on process questions. For instance, persistent biases in MBL depth found by Andrejczuk et al. (2011) are not intrinsic to the WRF model, and are resolved by the

configuration described in our paper (e.g. increased spin up time).

4. Each different configuration of WRF-Chem leads to a fundamentally different simulated evolution of the atmosphere, and more than 20 different choices in model structure affect the simulation of marine stratocumulus and the direct, indirect, and semi-direct effects of aerosols. It's essential to quantify this structural sensitivity, and the modeling system we employ is fundamentally different from the WRF-Chem model used by Yang et al. We employed different microphysical parameterizations, PBL closure schemes, vertical and horizontal resolution, and quantified how microphysical scheme affects liquid water path and rain rate. We contrast our results with Yang's results highlighting the differences, identifying reasons for these differences and proposing ways to improve parameterizations to resolve additional processes and get to an overall better prediction.

5. We provide the first complete multi-platform evaluation for a regional simulation of clouds and aerosols (other than their mass) for the VOCALS-REx campaign, using three aircraft platforms (BAE, G1, C-130) and ship-based observations (NOAA Ron Brown). We also evaluate model performance for meteorological and atmospheric chemistry state variables that have never before been simulated in this region, including decoupling state, trace gas concentrations (carbon monoxide, ozone), cloud aerosol composition, cloud water ionic balance and radar reflectivities. These are all crucial to fully quantifying regional model performance in this tightly coupled system.

6. We provide the first quantification of local model performance for stratocumulus properties and their hourly evolution against ship-based measurements, aircraft observations and satellite retrievals, and use these many case studies to explain how aerosols and model processes affect system response. Some examples include the time series evolution of cloud heights (Fig. 4), description of an offshore pollution transport episode (Fig 8), drizzle/aerosol variability in a single flight (Fig 9), and instantaneous evidence of aerosol indirect effects (Fig. 10).

7. This study answers important questions posed by prior VOCALS observational and modeling studies. In doing so, we have cited 24 studies related to VOCALS, including 20 of the 31 articles in the ACP VOCALS special issue at the date of submission. For instance, we show that model SO2 underestimation is due to a problem in SO2 to SO4 conversion rates, model aerosol underestimation in the remote region is mainly due to wet scavenging and the lack of re-suspension, absence of nitrate in AMS measurements is due to displacement by SO4 in fine mode aerosol, central Chile pollution influences 20 S aerosol and clouds, and the underestimation of rain rates in Yang et al is due to an the auto-conversion parameterization in Morrison microphysics, which is remedied by the Lin implementation.

8. We introduce a new model performance metric for directly comparing the simulation of aerosols with their effects on clouds. This supports combined evaluation of the "cause and effect" in aerosol impacts on clouds across spatial scales and regions.

References

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