Simulating the observational systems for box closure experiments: A pilot study

Jiwen Fan (PNNL), Ann Fridlind (NASA/GISS), Xiaowen Li (NASA/GSFC), Danny Rosenfeld (Hebrew University), Alexander Ryzhkov (NSSL), Marcus van Lier-Walqui (NASA/GISS), Philip Stier (University of Oxford, UK), Corinna Hoose (KIT, Germany)

Background

Cloud-mediated aerosol effects are recognized by the Intergovernmental Panel on Climate Change (IPCC) as one of the key sources of uncertainty in our knowledge of Earth's energy budget and anthropogenic climate forcing in particular. Aerosols and their interactions with clouds affect, sometimes substantially, Earth's energy budgets and hydrological cycle. It is imperative but challenging to quantify aerosol-cloud-precipitation-climate (ACPC) interactions and therefore reduce the uncertainty in anthropogenic climate forcing.

The essence of the parameterizations of diabatic processes in climate models is obtaining correct flux of materials and energy in all forms across the borders of the grid columns including surface and the top of atmosphere (TOA). Aerosols can change these fluxes in still poorly quantified ways. To meet the challenge of quantifying the aerosol cloud-mediated effects on the climate system, an ACPC initiative was established as a joint project of the International Geosphere–Biosphere Programme (IGBP) and the World Climate Research Program (WCRP). The goal of the ACPC initiative is to obtain a quantitative understanding of the interactions between aerosols, clouds and precipitation, and their role in the climate system, mainly by facilitating international cooperation and providing the conceptual framework of related research projects. Participants at the ACPC Workshop in April 2015 proposed that box closure field experiments are needed to measure the fluxes of energy, water, aerosols, and aerosol precursors in all their relevant forms in various cloud regimes, and quantify the ways these fluxes are affected by the variability in aerosol properties (Rosenfeld et al., 2014). To achieve closures of energy, mass, aerosols, and aerosol precursors, the required measurements would be grand and intensive, including various satellite, surface-based, and airborne observations. Execution of such a box closure field experiment requires a major effort of highly coordinated international cooperation, as it is beyond the possibility of any single research organization.

Such ambitious field experiments are successful only when the scientific community is sufficiently confident that they can deliver the desired results, and that the outcomes would reduce substantially the present uncertainties in climate model representations of aerosol-cloud-precipitation interactions. Major issues in the design of such a field experiment are identifying (a) the most favorable environmental and measurement conditions in which to site the experiment and demonstrating if changes due to cloud-aerosol interactions within a box are large enough to be detected by the available measurements, (b) the kinds of measurements and their point accuracies, (c) the spatial density and temporal frequencies of measurements that are required. To address these major issues, the ACPC Workshop participants also proposed that a pilot study be performed that utilizes high-resolution modeling to develop the optimum measurement strategy for the box closure field experiments.

Objectives of the pilot study

Quantifying aerosol impacts on deep convective clouds (DCC) is especially challenging but imperative to gain a better understanding of its role in the climate system. In this pilot study, through high-resolution (i.e., cloud–resolving) model simulations of real cases over a domain of the box that contains the full life cycle of a convective cloud system over the diurnal cycle under contrasting aerosol environments and at a minimum be of the size of a current climate model grid box, we can

(1) demonstrate if the targeted regime is an ideal location for exploring and quantifying aerosol-DCC interactions;

(2) optimize the temporal frequency and spatial density of the various measurements to achieve closure for energy, mass, aerosols, and aerosol precursors; and
(3) gain a clear understanding of the required measurements to further the understanding and achieve the closures, and to prioritize the measurements by ranking the budget terms obtained from the model simulations.

Recognizing that it is very important that the targeted regime has both large susceptibility to and variability of aerosols that is not correlated with meteorology, a group of scientists from US and Europe at the ACPC workshop recommended the Houston area as a starting point for the pilot study. The ARM Southern Great Plains (SGP) supersite is extraordinarily well-instrumented for observations of convection, for instance, but is not in the most susceptible regime to aerosol perturbations (Fan et al., 2012; 2013). The Houston area in summer, where storms in the afternoon are generally isolated convective systems and have very warm cloud bases, offers (a) a combination of polluted aerosols from the urban and industrial area of Houston and significantly lower background aerosol concentrations surrounding Houston, (b) aerosol sources that are not correlated with meteorology, and (c) weak synoptic forcing along with strong local triggering in the form of land-sea-lake contrasts and sea breeze fronts. This combination allows the manifestation of potentially large aerosol effects.

To insure that benchmark simulations are realistic, they must be carried out with the most detailed model configurations, and be constrained and evaluated with extensive observations. During August – September 2013, two field campaigns were conducted over the Houston region that provide valuable observational datasets to constrain and evaluate model simulations: SEAC4RS and Discover-AQ. Although both campaigns focus on aerosol and air quality, the observational datasets provide excellent constraints to aerosol sensitivity studies for our purpose. Discover-AQ also offers cloud observations that can be used to constrain and evaluate simulated clouds, but the measurement strategies for both field campaigns were not suitable to perform a closure study on aerosol-cloud interactions. The combination of aerosol perturbation with cloud susceptibility to aerosols within the NEXRAD dual-polarimetric radar network and lightning mapping array coverage, along with airborne measurements, and satellite data analysis from field campaigns, makes the Houston area uniquely suitable for conducting the pilot study of simulating the observing systems and improving understanding of aerosol impacts on deep convection.

Why DOE ARM/ASR?

At the ACPC workshop, the group of people (besides 8 coauthors here, there are Bill Lau, Zhanqing Li, and Leo Donner) reached a consensus that the most relevant programs for such study is DOE's ARM and ASR programs, since a major objective of the ARM/ASR programs is to investigate the impacts of aerosols on Earth energy budget and the climate system, and the ARM program has invested major resources at fixed and mobile sites as its main means of observing these effects. The outcome of such pilot study in quantifying the susceptibility of deep convective clouds to aerosols at the Houston area which is in the vicinity of SGP, would provide an incentive and scientific judgments to the ARM program to conduct future measurement studies in the Houston area to better realize the ARM mission of "improve the understanding and representation, in climate and earth system models, of clouds and aerosols as well as their interactions and coupling with the Earth's surface". After the completion of the pilot study, we will use the information to form the basis of the ACPC field campaign coordinated among multiple international institutions, which would include a component submitted as a proposal to ARM.

The intrinsic scientific values of such pilot study in quantifying the uncertainties of aerosol-deep convective cloud interactions and optimizing the measurement parameters and design are very high to the DOE ARM/ASR programs. The study would be of great help with prioritization of key measurements and formulation of optimal experiment designs for any potential field campaigns for aerosol-cloud-precipitation interaction studies. The closure calculations would serve as basis for the planning of potential international box closure field experiments.

Funding such a study will enable DOE to initiate and lead an international field campaign that could match the legacy GATE campaign. We seek funding to support some of the scientists from DOE, NASA, and NOAA. Scientists from Israel, UK, and Germany are collaborating on this pilot study. NASA will support a portion for the work that will be done by Fridlind. The Hebrew University of Jerusalem will support the time of Rosenfeld on this. Stier and Hoose will seek support from their countries for their commitments to this study.

Expected outcomes

- Quantification of the susceptibility of clouds to aerosols at the Houston area.
- Assessments of what and how aerosol and meteorological measurements should be designed in temporal and spatial characteristics for success of a box closure field experiment approach, to be supplemented by within-box cloud, precipitation and dynamics measurements that will allow constraint of key aerosol, cloud, and precipitation properties in simulations.
- Prioritization of key measurements and formulation of optimal experiment designs for potential field campaigns for aerosol-cloud-precipitation interaction studies that can be used to estimate the cost of a box closure field experiment.
- Presentations in the next international ACPC workshop on box closure experiment in April 2016 at Oxford, UK.
- A report to DOE ARM and ASR and at least two papers will be produced.

References

Fan, J., D. Rosenfeld, Y. Ding, L. R. Leung, and Z. Li (2012), Potential aerosol indirect effects on atmospheric circulation and radiative forcing through deep convection, Geophys. Res. Lett. 39: Article No. L09806. doi:10.1029/2012GL051851 doi:10.1029/2012GL051851.

Fan, J., L. R. Leung, D. Rosendeld, Q. Chen, Z. Li, H. Yu, and J. Zhang (2013), Microphysical Effects Determine Macrophysical Response for Aerosol Impacts on Deep Convective Clouds, Proc. Natl. Acad. Sci. USA, 110, 48, doi:10.1073/pnas.1316830110.

Rosenfeld, D., et al. (2014), Global observations of aerosol-cloud-precipitation- climate interactions, Rev. Geophys., 52,750–808, doi:10.1002/2013RG000441.