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Breakout group on shallow clouds

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Conclusion

Shallow cloud systems are key mediators of aerosol radiative forcing globally and yet there remains much uncertainty about these effects and the processes controlling them (Rosenfeld et al. 2014). This stems in part from an inability to fully understand and simulate the key contributing processes in large scale models, and from our limited ability to observationally constrain aerosol-mediated perturbations to energy and moisture budgets in shallow cloud systems. Many studies have attempted to quantify aerosol indirect forcing globally, but to help untangle aerosol effects on shallow systems, Stevens and Feingold (2009) recommend a shift of emphasis to regime-centered studies. Regional studies narrow down the complexities of dealing with multiple regimes, and carries several other advantages: (a) a regional-regime focus allows us to focus on higher resolution models that can more accurately represent some of the key cloud dynamical processes that are simply unresolved in climate models; (b) a region-regime focus is sufficiently localized that it is accessible to detailed field study but is at the same time meaningfully observed using satellites.

At the recent ACPC meeting, discussion centered on an iterative modelling study designed (a) to understand regional aerosol-induced perturbations to energy and moisture budgets and the processes controlling them; (b) to provide guidance for possible future field campaigns; (c) to ascertain the observability of aerosol impacts on TOA radiation and contributing cloud components/processes. Discussion focused on a first model intercomparison and evaluation project that would focus on an approximately month-long period at the regional scale (order 1000x1000 km). This length of simulation would allow us to investigate how changes in meteorology and aerosols project onto changes in the radiative forcing and energy/moisture budget terms. This understanding of this is crucial for detecting aerosol mediated changes in forcing/budget terms in a future field campaign. The month-long simulations would also be used also to provide boundary conditions for shorter simulations with higher resolution model (e.g. LES), and for such activities we envision close interplay with the GEWEX Atmospheric System Study (GASS)[1].

[1] We also intend to keep an eye on the ARM approach of continuous large-eddy simulations (following KNMI: Neggers et al., BAMS 2012) which might become very relevant to ACPC at a later stage. While the ARM Southern Great Plains (SGP) megasite will have a wealth of new spatiotemporal observations of clouds at high resolution, it is somewhat less relevant to global aerosol

Science Questions

The proposed activities aims to address the following important science questions

1. What is the magnitude of model-derived aerosol induced perturbations to regional energy and moisture budgets?
2. Do models agree on the geographical and temporal variability in these perturbations?
3. To what extent does spatiotemporal variability in the current climate inform us about these aerosol-induced perturbations?
4. What processes contribute to the modeled energy and moisture budget perturbations?
5. Are budget perturbations in large eddy simulations consistent with those from regional models?
6. Are such perturbations observable using current and future planned satellite and field observations?

Case selection and modelling approach

The marine stratocumulus cloud regime appeared the most appropriate one for such a study, since (a) an aerosol perturbation would yield the largest radiative forcing in this regime, (b) it is relatively well-studied and arguably less complex than e.g., trade-cumulus or Arctic mixed-phase cloud regimes.

A model intercomparison study should focus on an existing field campaign, because (a) data exist for model evaluation and (b) the initial- and boundary conditions for these are well defined. Having a characterization of the regional aerosol emissions and their application/implementation is important and needs careful attention, considering the experience with past model intercomparison studies where differences in emissions were found to dominate the cloud responses to aerosols.

Among the possible options, a quick and broad consensus was to select the VOCALS field campaign. A practical reason for this was that many of the participating modelling groups (c.f. Rob Wood's, Bernhard Vogel's, Annette Miltenberger's, Andrea Flossmann's and Graham Feingold's presentations) already have experience with this campaign. An interesting gradient in aerosol conditions exists between the near shore and off-shore regions. As well as being influenced by boundary layer aerosol sources, the stratocumulus decks are also frequently influenced from above by intermittent free-tropospheric aerosol plumes that originate from nearby land sources and possibly also from much further field. There is therefore a high degree of aerosol variability. An interesting aspect is the observed pockets of open cells indicating a role for drizzle, and therefore quite likely, the aerosol. A highly resolved (1 km) dedicated reanalysis from the UK MetOffice is available for initial- and boundary conditions. A loosely related (idealised) WMO cloud modelling workshop case exists from VOCALS, but it is not clear if this case will be run again (lead Wojtek Grabowski and Zach Lebo).

<u>Regional climate models</u> including interactive aerosols (plus chemistry) could run the full campaign period and domain (15 October – 16 November 2008; 12 – 35°S, 68.5 – 88°W; Wyant et al., ACP 2015). In these models, the aerosols would be spun up from the VOCALS emission dataset[2]. Two simulations (one with both natural and anthropogenic, and one with only natural emissions) would be conducted to identify the effect of anthropogenic aerosols and to help test whether situations in which there is no correlation between aerosols and meteorology are likely to occur. Sea salt would be computed interactively in the models. If possible, the uncertainty should be assessed through ensemble simulations with varying initial- and boundary conditions, but also natural and anthropogenic emissions. This allows assessing the susceptibility. Self-nesting will be applied to quantify the

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indirect effects because the marine low cloud regime is likely to be more sensitive and contribute more in terms of overall cloud-mediated aerosol forcing. Other sites (Graciosa, Azores) or future deployments of the ARM Mobile Facility in shallow cloud regimes could also present opportunities in future.

[2] Available at http://bio.cgrer.uiowa.edu/VOCA_emis/

dependence of the relevant processes on the spatial resolution of the model.
COSMO-ART (Bernhard Vogel), WRF-Chem (Rob Wood; also Andreas Muhlbauer) and UM-CASIM (Annette Miltenberger, Daniel Grosvenor et al.) have run the case and would be interested to contribute further.

Large-eddy simulations should run at resolutions of 50 to 100 m (horizontal) and thus the domain could cover about $(25\ km)^2$ and capture cloud organization. Doubly-periodic boundary conditions should be applied. It is still open how the forcing could be defined. Options are

(a) Eulerian from meso-scale model, e.g. research flight RF6, but only one end (the closed-cell north-eastern branch)

(b) trajectories from a mesoscale model (e. g. Annette Miltenberger) would allow for a Lagrangian approach. Lagrangian trajectories passing in the vicinity of the R/V Brown would provide opportunities to compare LES with ship data (Doppler lidar, radar, microwave radiometer, aerosol, etc.)

Contributors could be Andrea Flossmann, Graham Feingold, Andy Ackerman.

Diagnostics and observables

The focus of the study would be on radiation, especially top-of-atmosphere / top-of-model radiation fluxes. Water- and energy budgets should be quantified. Precipitation and albedo susceptibility metrics could be compared to observations.
A particular interest is in the perturbations of the budgets in the present-day vs. pre-industrial simulations.

Suggested model diagnostics:
Energy budget: Radiation profiles, fluxes at surface, TOM/TOA; surface turbulent fluxes, latent heat profiles, cloud base/boundary layer updraft spectra (relating to CCN activation).
Water budget: Water advection at lateral boundaries and TOM; precipitation and evaporation fluxes, precipitable water tendencies.
Cloud quantities: cloud fraction, LWP, cloud optical depth, N_d.
Aerosol quantities: CCN (at 0.1, 0.2, 0.4 and 0.8% wherever possible) AOD, Aerosol size distribution profiles per species.
Observables: Satellite simulator output (COSP, Bodas-Salcedo et al. BAMS 2011; including radar reflectivity, lidar backscatter and vertical velocity moments (Doppler), and MODIS and MISR cloud-top quantities)
CO budgets could help characterise cloud-top entrainment rates. Polarimetric radar irrelevant for drizzle.