Final report on DOE ASR project (DE-SC0008679, Oct 2015)

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Below is a summary of our research activities on this project:

1. We have embedded a Lagrangian Parcel Dispersion Model (LPDM) into the model that we use for Large-Eddy Simulations, parallelized it, and developed the analysis routines to process the output. We have fully validated our Lagrangian Parcel Dispersion Model (LPDM), including the treatment of subgrid scale diffusion as a random walk. This allows us to trace the movement of air parcels, and form a Lagrangian view of convection that nicely complements the Eulerian statistics.

2. We have looked into improving and extending our parameterizations based on stochastically entraining parcels, developed previously for shallow convection. This line of research has a few threads. Firstly, we have been refining the treatment of the entrainment process. We have designed a test problem motivated by nonlinear aqueous sulfur chemistry (the oxidation of SO_2 by H_2O_2 into sulfuric acid in clouds), which has helped to expose issues of entrainment for slowly moving air parcels that were hidden previous. The paper on oxidation of SO_2 by H_2O_2 has been submitted (Nie et al., submitted). Secondly, we have explored ways to improve our treatment in the subcloud layer, in particular the penetrative entrainment at the cloud base and the diffusive effects by small eddies. We have identified potential ways of improvement but have not tested them out yet. Lastly, we have been looking at LES outputs to explore physical ways to incorporate precipitation and cold pools into our stochastic parcel model. These effects will be key to the transition from shallow to deep convection.

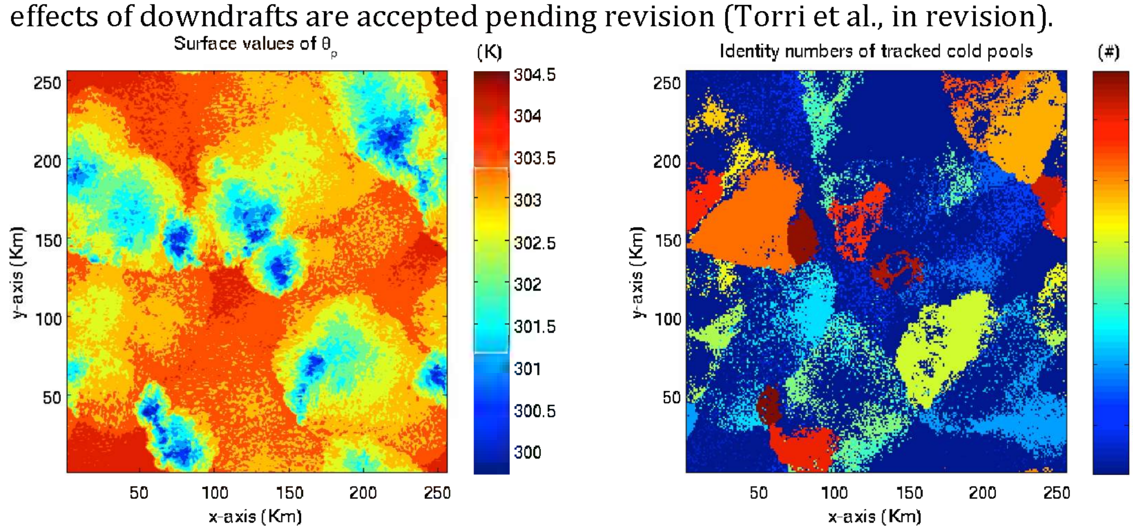
3. This grant also supported our effort on a paper where we compared cumulus parameterizations and cloud resolving models in terms of their linear response functions (Herman and Kuang, 2013). This work will help us (and the community) to better evaluate and develop cumulus parameterization.

4. Following our previous work that developed a mapping framework that extends the bulk plume models, we have applied the LPDM to shallow convection, deep convection with and without convective organization to better characterize their dynamics and the transition between them. More specifically:

    a. We have separated contributions from buoyancy and mechanical forcing. This involved decomposing the pressure field into one that is required by continuity and consistent with buoyancy forcing and one that is consistent with the advection and diffusion of momentum. With this and the Lagrangian tracking, we can now construct the full Lagrangian history of particles.

b. We then apply our diagnostics to examine the physical processes by which cumulus convection response to perturbations. We bin the Lagrangian particles based on the percentiles in terms of their detrainment heights. This has proven to be an effective way to examine how particle trajectory and properties respond to small perturbations to the large-scale temperature and moisture profiles. We have also explored the difference between organized and unorganized convection, a subject of much interest to the ASR program. These results were presented as the AMS conference on tropical meteorology and hurricanes and the AMS conference on cloud physics. A paper describing the results for shallow cumuli is about to be submitted (Tian et al, to be submitted). Results on deep convection, and the difference between organized and unorganized convection, will be presented in future publications.

5. We have devised a novel way of using the LPDM to identify cold pools, an area identified as of great interest by the ASR community. Our algorithm has a number of advantages and in particular can handle merging cold pools more gracefully than existing techniques. An example of the cold pool identification is shown in the Figure below. This technique has been used to address the role of thermodynamic versus mechanical lifting by cold pools. The results are published in Torri et al. (2015). Another paper looking at the effects of downdrafts are accepted pending revision (Torri et al., in revision).



6. A paper was published in the Proceeding of the National Academy of Science (PNAS), entitled Fig and Rain in the Amazon: by Anber, Gentine, Wang and Sobel. In this paper we demonstrate that we can for the first time correctly reproduce both the diurnal and seasonal cycle of the hydrologic cycle in the Amazon using a strategy opposite to climate models, which typically fail to represent those diurnal and seasonal cycles. Indeed climate models tend to

exhibit rain too early in the day and generally have peak evapotranspiration in the wet season and not in the dry season as observed with eddy covariance towers. We used high-resolution cloud-resolving models (1km), which can explicitly represent convection, with a parameterized large-scale circulation, using the Weak Temperature Approximation (Sobel and Bretherton 2001). Using this strategy we can correctly reproduce all the surface fluxes (precipitation, radiation, evapotranspiration and sensible heat flux) and their seasonality as well as their diurnal cycle.

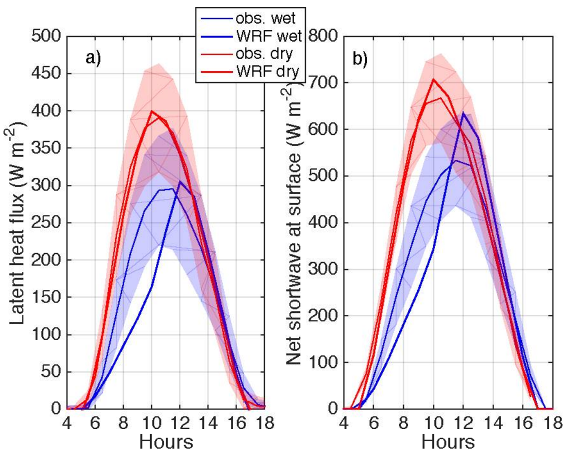


Figure 2. Surface latent and net shortwave heat fluxes as modeled by WRF with the Weak Temperature Gradient compared with observations.

In addition we showed that the main cause of the wet season is the presence of an early morning fog, which insulate the surface from top of the atmosphere shortwave radiation. In essence this fog makes the day shorter because radiation cannot penetrate to the surface in the early morning. This is why all fluxes are reduced in the wet season compared to the dry season.

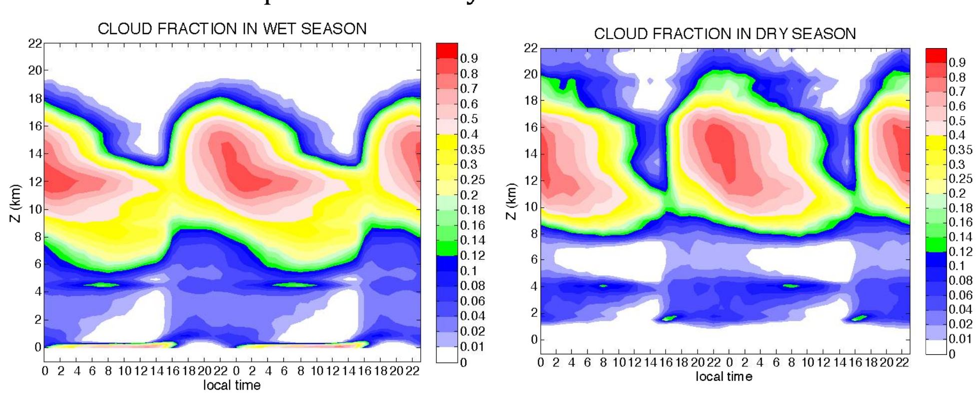


Figure 3. Diurnal cycle of cloud cover profile in the wet (left) and dry (right) season.

We believe that those are important results to better comprehend the switch from the dry to wet season, and we are now continuing the work in that direction to investigate the transition.

7. Collaboration between the co-PI and the PI led to a manuscript to Geophysical Research letters (in revision) (Gentine, Garelli, Park, Nie, Torri and Kuang) investigating the life cycle of cold pools and the role of surface diabatic heating on those fluxes. This diabatic heating is due to the fact that cold pools are much colder than the surface and thus produce substantial heat flux underneath them because of the important turbulent instability there. We show that surface heating can kill cold pols and reduce the number of large cold pools and the organization of convection. The effect is pretty dramatic over land where the entire distribution of cold pools is modified, and the cold pools are much warmer and more humid with surface diabatic heating below the cold pools. The PI and the co-PI continue to work together on parameterization of cold pools.

Publications:

1. Anbar, Gentine, Wang, and Sobel, 2015: Fog and rain in the Amazon. *Proceedings of the National Academy of Sciences*, doi: 10.1073/pnas.1505077112.

2. Gentine, P., A. Garelli, S.B. Park, J. Nie, G. Torri, Z. Kuang, Role of surface heat fluxes underneath cold pools, Geophys. Res. Letters, in revision

3. Herman M. J., and Z. Kuang, Linear response functions of two convective parameterization schemes, J. Advances in Modeling Earth Systems, 5, 510-541, doi:10.1002/jame.20037. (2013)

4. Nie, J., Z. Kuang, D. Jacob, J. Guo, Representing effects of aqueous phase reactions in shallow cumuli in global models, J. Geophys. Res., submitted.

5. Tian, Y., Z. Kuang, J. Nie, Probing the responses of moist convection to large-scale temperature perturbations using a Lagrangian Particle Dispersion Model: mixing in shallow convection, to be submitted.

6. Torri, G. and Z. Kuang, A Lagrangian study of precipitation-driven downdrafts, J. Atmos. Sci., in revision

7. Torri, G., Z. Kuang, Y. Tian, Mechanisms for convection triggering by cold pools, Geophys. Res. Letts., 42, doi: 10.1002/2015GL063227, 2015