Final Report of Project DE-SC0000721

Project title: Use of ARM observations and numerical models to determine radiative and latent heating profiles of mesoscale convective systems for general circulation models

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This three-year project, in cooperation with Professor Bob Houze at University of Washington, has been successfully finished as planned. Both ARM (the Atmospheric Radiation Measurement Program) data and cloud-resolving model (CRM) simulations were used to identify the water budgets of clouds observed in two international field campaigns. The research results achieved shed light on several key processes of clouds in climate change (or general circulation models), which are summarized below.

1. Revealed the effect of mineral dust on mesoscale convective systems (MCSs)

Two international field campaigns near a desert and a tropical coast provided unique data to drive and evaluate CRM simulations, which are TWP-ICE (the Tropical Warm Pool International Cloud Experiment) and AMMA (the African Monsoon Multidisciplinary Analysis). Studies of the two campaign data were contrasted, revealing that much mineral dust can bring about large MCSs via ice nucleation and clouds. This result was reported as a PI presentation in the 3rd ASR Science Team meeting held in Arlington, Virginia in March 2012. A paper on the studies was published in *the Journal of the Atmospheric Sciences* (Zeng et al. 2013).

2. Identified the effect of convective downdrafts on ice crystal concentration

Using the large-scale forcing data from TWP-ICE, ARM-SGP (the Southern Great Plains) and other field campaigns, Goddard CRM simulations were carried out in comparison with radar and satellite observations. The comparison between model and observations revealed that convective downdrafts could increase ice crystal concentration by up to three or four orders, which is a key to quantitatively represent the indirect effects of ice nuclei, a kind of aerosol, on clouds and radiation in the Tropics. This result was published in *the Journal of the Atmospheric Sciences* (Zeng et al. 2011) and summarized in the DOE/ASR Research Highlights Summaries (see http://www.arm.gov/science/highlights/RMjY5/view).

3. Used radar observations to evaluate model simulations

In cooperation with Profs. Bob Houze at University of Washington and Steven Rutledge at Colorado State University, numerical model results were evaluated with observations from W- and C-band radars and CloudSat/TRMM satellites. These studies exhibited some shortcomings of current numerical models, such as too little of thin anvil clouds, directing the future improvement of cloud microphysics parameterization in CRMs. Two papers of Powell et al (2012) and Zeng et al. (2013), summarizing these studies, were published in the *Journal of the Atmospheric Sciences*.

4. Analyzed the water budgets of MCSs

Using ARM data from TWP-ICE, ARM-SGP and other field campaigns, the Goddard CRM simulations were carried out to analyze the water budgets of clouds from TWP-ICE and AMMA. The simulations generated a set of datasets on clouds and radiation, which are available http://cloud.gsfc.nasa.gov/.

The cloud datasets were available for modelers and other researchers aiming to improve the representation of cloud processes in multi-scale modeling frameworks, GCMs and climate models. Special datasets, such as 3D cloud distributions every six minutes for TWP-ICE, were requested and generated for ARM/ASR investigators. Data server records show that 86,206 datasets were downloaded by 120 users between April of 2010 and January of 2012.

5. MMF simulations

The Goddard MMF (multi-scale modeling framework) has been improved by coupling with the Goddard Land Information System (LIS) and the Goddard Earth Observing System Model, Version 5 (GOES5). It has also been optimized on NASA HEC supercomputers and can be run over 4000 CPUs.

The improved MMF with high horizontal resolution (1 x 1 degree) is currently being applied to cases covering 2005 and 2006. The results show that the spatial distribution pattern of precipitation rate is well simulated by the MMF through comparisons with satellite retrievals from the CMOPRH and GPCP data sets. In addition, the MMF results were compared with three reanalyses (MERRA, ERA-Interim and CFSR). Although the MMF tends to produce a higher precipitation rate over some topical regions, it actually well captures the variations in the zonal and meridional means. Among the three reanalyses, ERA-Interim seems to have values close to those of the satellite retrievals especially for GPCP.

It is interesting to note that the MMF obtained the best results in the rain forest of Africa even better than those of CFSR and ERA-Interim, when compared to CMORPH. MERRA fails to capture the precipitation in this region. We are now collaborating with Steve Rutledge (CSU) to validate the model results for AMMA

6. MC3E and the diurnal variation of precipitation processes

The Midlatitude Continental Convective Clouds Experiment (MC3E) was a joint field campaign between the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility and the NASA Global Precipitation Measurement (GPM) mission Ground Validation (GV) program. It took place in central Oklahoma during the period April 22 _ June 6, 2011. Some of its major objectives involve the use of CRMs in precipitation science such as: (1) testing the fidelity of CRM simulations via intensive statistical comparisons between simulated and observed cloud properties and latent heating fields for a variety of case types, (2) establishing the limits of CRM space-time integration capabilities for quantitative precipitation estimates, and (3) supporting the development and refinement of physically-based GMI, DPR, and DPR-GMI combined retrieval algorithms using ground-based GPM GV Ku-Ka band radar and CRM simulations.

The NASA unified WRF model (nu-WRF) was used for real time forecasts during the field campaign, and ten precipitation events were selected for post mission simulations. These events include well-organized squall lines, scattered storms and quasi-linear storms. A paper focused on the diurnal variation of precipitation will be submitted in September 2012. The major highlights are as follows:

a. The results indicate that NU-WRF model could capture observed diurnal variation of rainfall (composite not individual);
b. NU-WRF model could simulate two different types (propagating and local type) of the diurnal variation of rainfall;
c. NU-WRF model simulation show very good agreement with observation in terms of precipitation pattern (linear MCS), radar reflectivity (a second low peak – shallow convection);
d. NU-WRF model simulation indicates that the cool-pool dynamic is the main physical process for MCS propagation speed;
e. Surface heat fluxes (including land surface model and initial surface condition) do not play a major role in phase of diurnal variation (change rainfall amount slightly);
f. Terrain effect is important for initial stage of MCS (rainfall is increased and close to observation by increasing the terrain height that is also close to observed);
g. Diurnal variation of radiation is not important for the simulated variation of rainfall.

Publications:

Zeng, X., W.-K. Tao, S. Powell, R. Houze, Jr., P. Ciesielski, N. Guy, H. Pierce and T. Matsui, 2012: A comparison of the water budgets between clouds from AMMA and TWP-ICE. *J. Atmos. Sci.*, **70**, 487-503.

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Zeng, X., W.-K. Tao, T. Matsui, S. Xie, S. Lang, M. Zhang, D. Starr, and X. Li, 2011: Estimating the Ice Crystal Enhancement Factor in the Tropics. *J. Atmos. Sci*., **68**, 1424-1434.

Conferences:

Zeng, X., W.-K. Tao, S. Powell, R. Houze, Jr., P. Ciesielski, N. Guy, H. Pierce and T. Matsui, 2012: Comparison of water budget between AMMA and TWP-ICE clouds. The 3rd Annual ASR Science Team Meeting. Arlington, Virginia, Mar. 12-16, 2012.

Zeng, X., W.-K. Tao, S. Powell, R. A. Houze Jr., and P. Ciesielski, 2011: Comparing the water budgets between AMMA and TWP-ICE clouds. Fall 2011 ASR Working Group Meeting. Annapolis, September 12-16, 2011.

Zeng, X. et al., 2011: Introducing ice nuclei into turbulence parameterizations in CRMs. Fall 2011 ASR Working Group Meeting. Annapolis, September 12-16, 2011.