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"Evolution in Cloud Population Statistics of the MJO: From AMIE Field Observations to Global Cloud-Permitting Models"

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Summary

Motivated by the success of the AMIE/DYNAMO field campaign, which collected unprecedented observations of cloud and precipitation from the tropical Indian Ocean in Octber 2011 – March 2012, this project explored how such observations can be applied to assist the development of global cloud-permitting models through evaluating and correcting model biases in cloud statistics. The main accomplishment of this project were made in four categories: generating observational products for model evaluation, using AMIE/DYNAMO observations to validate global model simulations, using AMIE/DYNAMO observations in numerical studies of cloud-permitting models, and providing leadership in the field. Results from this project provide valuable information for building a seamless bridge between DOE ASR program's component on process level understanding of cloud processes in the tropics and RGCM focus on global variability and regional extremes. In particular, experience gained from this project would be directly applicable to evaluation and improvements of ACME, especially as it transitions to a non-hydrostatic variable resolution model.

1. Background

Reducing biases in tropical cloud and precipitation simulated by global weather and climate models remains an unmet challenge. Errors in reproducing the Madden-Julian Oscillation (MJO) by these global models are highly indicative of this challenge. Global cloud-permitting models (CPMs), although still in their infancy, offer a promising new alternative approach for simulating and predicting weather and climate in the future. To fully realize their potentials, their parameterizations for the boundary layer, shallow convection, radiation, cloud microphysics, and sub-filter-scale turbulence must be improved. Identifying and addressing the main sources of cloud and precipitation biases in CPMs is a high priority for their development. This cannot be done without observations.

The AMIE/DYNAMO field campaign, supported by DOE, NOAA, NSF, and ONR, took place over the equatorial central Indian and western Pacific Oceans in October 2011 – March 2012. It collected unprecedented data that can be uniquely applied to model improvement. The radars, soundings, and other instruments successfully observed the structure, microphysics, and evolution of the cloud population of different types (precipitating and nonprecipitating, deep and shallow, organized and isolated) and their embedding atmospheric environment at different stages of two MJO events. These AMIE/ DYNAMO field observations provide new opportunities of holistic cloud and precipitation validation for CPM simulations under different large-scale conditions associated with the MJO.

The objective of this project is to apply the AMIE/DYNAMO observations to the development of global CPMs and, by establishing this direct connection between the two, to assist the effort of reducing global CPMs' tropical cloud and precipitation biases in the context of the MJO.

The general approach of this project is to:
(a) Combine measurements from various AMIE/DYNAMO instruments to build observed cloud statistics unavailable from any single instrument;
(b) Apply the AMIE/DYNAMO cloud statistics, augmented by satellite data, to validate simulations by global CPMs under different large-scale conditions associated with various stages of the MJO;
(c) Use a hierarchy of CPMs with different domains, cloud microphysics, and forcing to help isolate possible main sources of cloud and precipitation biases in global CPM simulations and to reduce the biases.

2. Accomplishment

The main accomplishment of this project are:

(1) Development of new observational products that are needed for evaluation and validation of numerical modes.

(2) Using observations to validate global model simulations

(3) Using observation in numerical studies of cloud-permitting models

(4) Providing leadership in the field

2.1 New observational products

Persistent and focused efforts are required to maximize the utility of the rich body of AMIE/DYNAMO observations to numerical models in the aspect of cloud statistics. In this project, we have used the AMIE/DYNAMO observations to derive several products that were not available previously for applications of validation and verification of cloud statistics in numerical models. These products include a three-dimensional structure of precipitation features based on radar data (Ahmed et al. 2016), an automated estimates of light rain using the Ka-band ARM zenith radar (Chandra et al. 2015), estimates of stratiform and convective precipitation based on data from multi-wavelength radars (Deng et al, 2014), a measure of cold pools (Feng et al. 2015), a method of estimating moistening by shallow cloud (Zermeno et al. 2015), and a method of tracing Lagrangian motions of moisture (Hannah et al. 2016).

2.2 validation of global model simulations

Using the AMIE/DYNAMO observations in model validation and verification was done in two approaches. The first is for global models that require parameterization of cumulus convection. In this regard, the following have been accomplished:

(a) The AMIE/DYNAMO observations were combined with ARM observations from its Tropical Western Pacific sites in validating low cloud statistics produced by a global climate (CAM5). Systematic biases in the model in the diurnal cycle and monthly means were documented and possible reason for the biases (moisture fluxes across the top of the boundary layer) were proposed (Chandra et al 2015).

(b) The AMIE/DYNAMO observations were used to examine the dependence of subgrid-scale vertical transport on resolution in convection parameterization for global models. This study concludes that for cumulus parameterization to be highly scale independent so it can be used in models of variable grids, stochastic treatment of convection needs to be included (Xiao et al 2015).

(c) A global model was used to develop a mechanism-denial approach to isolate effects of the mean state in numerical experiment (Ma and Kuang 2016).

2.3 Using observation in numerical studies of cloud-permitting models

The core of this project is to use the AMIE/DYNAMO observations to assist the development of global-cloud permitting models. For this, we have first applied the AMIE/DYNAMO observations to regional cloud-permitting models and global variable-

resolution models to accumulate experience for applications to global-cloud permitting models, which are very expensive to run.

(a) Investigate model biases. In a regional cloud-permitting model, excessive precipitation exists during relatively dry periods in observations. This bias of excessive precipitation is related to errors in simulated cloud radiative feedbacks and convection–surface wind interactions. This bias also exists in a global variable-resolution model with a high-resolution region centered over the tropical Indian Ocean (Hagos et al. 2016). Model biases are sensitive to parameterization of microphysics (Hagos et al. 2014b), turbulence and surface processes (Qian et al 2016), and the diurnal cycle (Hagos et al. 2016). The frequency of shallow-to-deep convection transitions is sensitive to midlevel moisture and large-scale uplift; Convective scale moisture variability and uplift, and large-scale zonal advection play secondary roles (Hagos et al 2014a).

(b) Quantify the roles of different type of clouds in moist processes. Applying a new approach of identifying column-confined and large-scale processes, we first used the AMIE/DYNAMO observations to validate a cloud-permitting model simulations of cloud statistics and then used the model to investigate roles of different types of cloud in moist processes. The results are summarized in Fig. 1. In essence, the systematic evolution in cloud population from convectively inactive to active periods of the MJO lead to a gradual shift in cloud-induced moistening of the atmosphere. The role of cloud in the moisture processes is dominated by the large-scale circulation after convection has fully developed and start moving eastward.

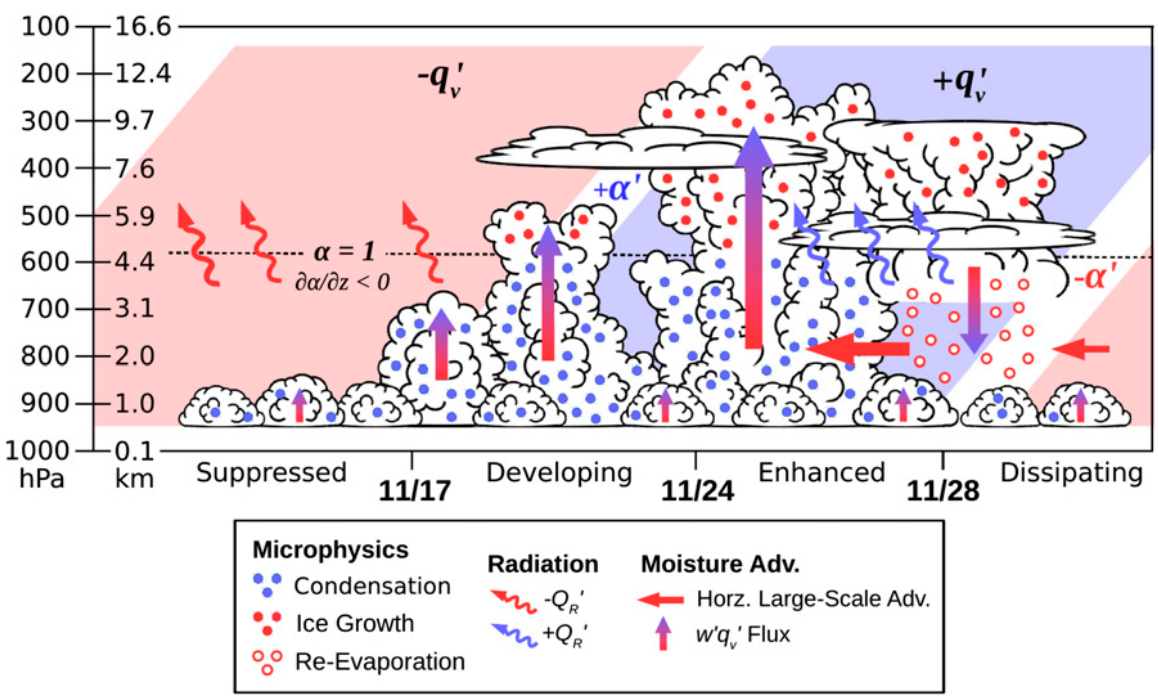

Figure 1 Summary of the contribution of different physical processes and cloud types to the evolution of moisture in the simulated MJO event. Red (blue) indicates processes that dry (moisten). The $w'q'_v$ vectors indicate the orientation of the moisture flux, while the shading indicates either moisture flux convergence (blue) or divergence (red). From Janiga and Zhang (2016).

(c) Simulate the MJO in a locally refined cloud-permitting global model (NCAR MPAS). Because of the computational demand, we were able to carry out only two 9-day simulations at 50 km global refined to 3 km local grid size over the Indian Ocean. These simulations are supplemented by a suite of simulations carried out for 17 days at 15 km and 60 km to test sensitivities of parameterizations (Grell-Freitas and Tiedtke) to grid size, and test how well they represented an MJO event. We found, among others, model simulations are sensitive to interaction between shallow and deep cumulus parameterization, in addition to resolution and other physical parameterization schemes. The main conclusion is that in global cloud-permitting models, parameterization of shallow cumulus and microphysics will be the main source of errors and biases (Pilon et al. 2016).

2.4 Leadership in the field

In addition to the scientific endeavor, this project supported its PI to provide needed leadership in the field of MJO studies. With the experience learned from this project, the PI was able to summarize the progress made and pointed out the future direction of this field (Yoneyama et al 2013, Zhang 2013, Zhang et al 2013). The PI is now leading the international YMC program, which include several intensive and extended observing periods in the region of the Indo-Pacific Maritime Continent. This program continues the effort of the AMIE/DYNAMO field campaign to further our understanding of the MJO, its propagation over the Maritime Continent, and consequential global impact. DOE is supporting one of the YMC observing activities.

3. Synthesis

Results from this project unambiguously demonstrate the value of major field campaigns with multiple agency's support and international participation. Multiple instrument suites and long deployment duration enable the collection of observations that otherwise would be impossible. More importantly, this project provides direct evidence for the utilities of such observations to benefit development of high-resolution numerical models for environmental prediction and assessment. The variety and depth with which the AMIE/DUYNAMO observations were applied to modeling studies in this project are results of visions from the PI team and program managers. Persistent and continuous efforts of data analysis and integration with modeling activities are essential to maximize the value of field observations to optimize their benefit to the development of numerical models.

4. Long-term perspectives

Results from this project provide valuable information for building a seamless bridge between DOE ASR program's component on process level understanding of cloud processes in the tropics and RGCM focus on global variability and regional extremes. In particular, experience gained from this project would assist evaluation and improvements of ACME, especially as it transitions to a non-hydrostatic variable resolution model. Knowledge from this project are also directly applicable to other national and international programs, such as the Sub-seasonal to Seasonal Seamless Prediction Project (S2S), Year of Maritime Continent (YMC), and CLIVAR climate process teams (CPTs).

5. Publications of this project

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