GFDL ARM Project Technical Report

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Abstract

This report briefly summarizes the progress made by ARM postdoctoral fellow, Yanluan Lin, at GFDL during the period from October 2008 to present. Several ARM datasets have been used for GFDL model evaluation, understanding, and improvement. This includes a new ice fall speed parameterization with riming impact and its test in GFDL AM3, evaluation of model cloud and radiation diurnal and seasonal variation using ARM CMBE data, model ice water content evaluation using ARM cirrus data, and coordination of the TWP-ICE global model intercomparison. The work illustrates the potential and importance of ARM data for GCM evaluation, understanding, and ultimately, improvement of GCM cloud and radiation parameterizations. Future work includes evaluation and improvement of the new dynamics-PDF cloud scheme and aerosol activation in the GFDL model.

Since its implementation in 1990, DOE ARM program has collected an unprecedented set of long-term cloud, aerosol, and radiation measurements at several ARM Climate Research Facility (ACRF) sites. These measurements provide a wealth of data for GCM evaluation and improvement. In addition, various objective-oriented field experiments conducted by ARM, such as Mixed-phase Arctic Cloud Experiment (M-PACE), TWP-ICE, etc., also provide comprehensive datasets for various process level modeling studies. This report highlights the progress made via the cooperation between GFDL and ARM.

1. Parameterization of riming intensity and its impact on ice fall speed using ARM data

Riming within mixed-phase clouds can have a large impact on weather and climate simulations of clouds and precipitation. The increase of ice particle fall speed due to riming has not been considered in most General Circulation Models (GCMs), and many weather models only consider ice particles that are either unrimed or heavily rimed (not in terms of a continuum of riming amount). Using the Atmospheric Radiation Measurement (ARM) program dataset at Southern Great Plains (SGP) of the United States, a new parameterization for riming is derived, which includes a diagnosed rimed mass fraction and its impact on the ice particle fall speed. When evaluated against a vertical-pointing Doppler radar for the case of stratiform mixed-phase clouds, the new parameterization produces better ice fall speeds than a conventional parameterization (Fig.1). The new parameterization has been tested in the recently developed Geophysical Fluid Dynamics Laboratory (GFDL) atmospheric model (AM3) using simulations with prescribed sea surface temperature (SST). Compared with the standard simulation, the new parameterization increases ice amount aloft by 20-50% globally, which reduces the global mean outgoing longwave radiation (OLR) by ~2.8 Wm^{-2} and the top of atmosphere (TOA) short-wave absorption by ~1.5 Wm^{-2}. Global mean precipitation is also slightly reduced, especially over the tropics. Overall, the new parameterization produces a comparable climatology with the standard simulation and improves the physical basis for using a fall velocity larger than the conventional parameterization in the current AM3. A manuscript (Lin et al. 2010) describing this work is in the revision phase for a peer-reviewed journal.

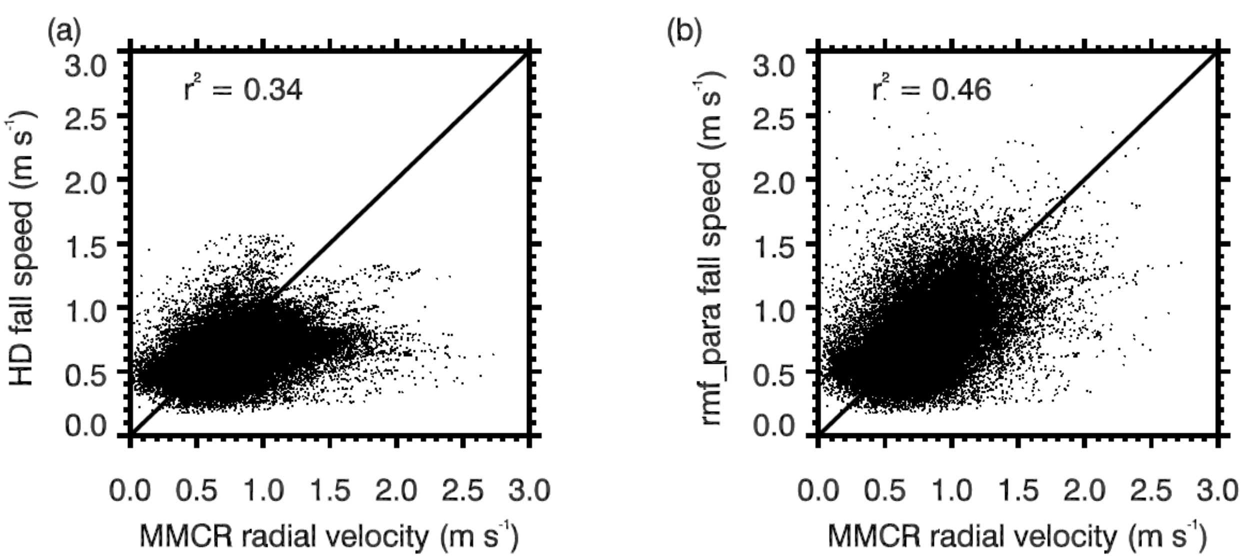

Figure 1. (a) Scatter plot of the observed Doppler velocities from the MMCR at SGP for stratiform mixed-phase clouds against the ice fall velocities derived using Heymsfield and Donner (1990) formula; (b) Same as (a), but shows the ice fall velocities considering riming impact as in Lin et al. (2010).

2. A new bulk microphysical scheme that includes riming intensity and temperature dependent ice

characteristics

The previously derived riming intensity parameterization has been used in a new bulk microphysical scheme implemented in WRF, which includes riming intensity and temperature-dependent ice characteristics. The new scheme represents a continuous spectrum, from pristine ice particles to heavily-rimed particles and graupel, using one prognostic variable (precipitating ice or PI) rather than two separate variables (snow and graupel). In contrast to most existing parameterization schemes that use fixed empirical relationships to describe ice particles, general formulations are proposed to consider the influences of riming intensity and temperature on the projected area, mass, and fall velocity of PI particles. The proposed formulations are able to cover the variations of empirical coefficients found in previous observational studies. The new scheme also reduces the number of parameterized microphysical processes by ~50% as compared to the conventional 6-category BMPs and thus it is more computationally efficient. The new scheme has been implemented in the Weather Research and Forecasting (WRF) model and compared with three other schemes for two events during the Improvement of Microphysical Parameterization through Observational Verification Experiment (IMPROVE-2) over the central Oregon Cascades. The new scheme produces comparable surface precipitation forecasts as other more complicated bulk microphysical parameterizations. The new scheme reduces the snow amounts aloft as compared to other WRF schemes and compares better with observations, especially for an event with moderate riming aloft. Sensitivity tests suggest that both reduced snow depositional growth rate and more efficient fallout due to riming contribute to the reduction of ice water content aloft in the new scheme, with the larger impact coming from the partially rimed snow and fallout. A manuscript describing the new scheme (Lin and Colle 2010) is in revision for a peer-reviewed journal.

3. Use ARM Climate Modeling Best Estimate (CMBE, Xie et al. 2010) data for model diagnosis and evaluation.

ARM CMBE data helps identify some model systematic biases, such as summer warm and dry bias over the Great Plains and associated sensible and latent heat flux bias (Fig. 2 and Golaz et al. 2009). The analysis also helps identify sources of bias in the complex interplay between cloud, precipitation, radiation, and land processes. For example, Figure 2 indicates that the initial precipitation underprediction in June leads to the model's dry and warm bias peaking in July and August over the Great Plains. This suggests that it is the precipitation bias triggers the soil moisture-precipitation feedback. In addition, a standard diagnostic package using CMBE data for GFDL model has also been developed. For example, Figure 3 shows the CMBE and GFDL AM2 diurnal and seasonal variation of cloud fraction at SGP and Manus, respectively. Though AM2 well captures the nocturnal upper tropospheric cloud fraction maximum, it is unable to reproduce the development of shallow convection during the day at SGP in JJA. At western Pacific warm pool (Manus), AM2 captures the cloud occurrence seasonal variation with upper tropospheric cloud fraction overpredicted. These analyses suggest the directions for model improvement.

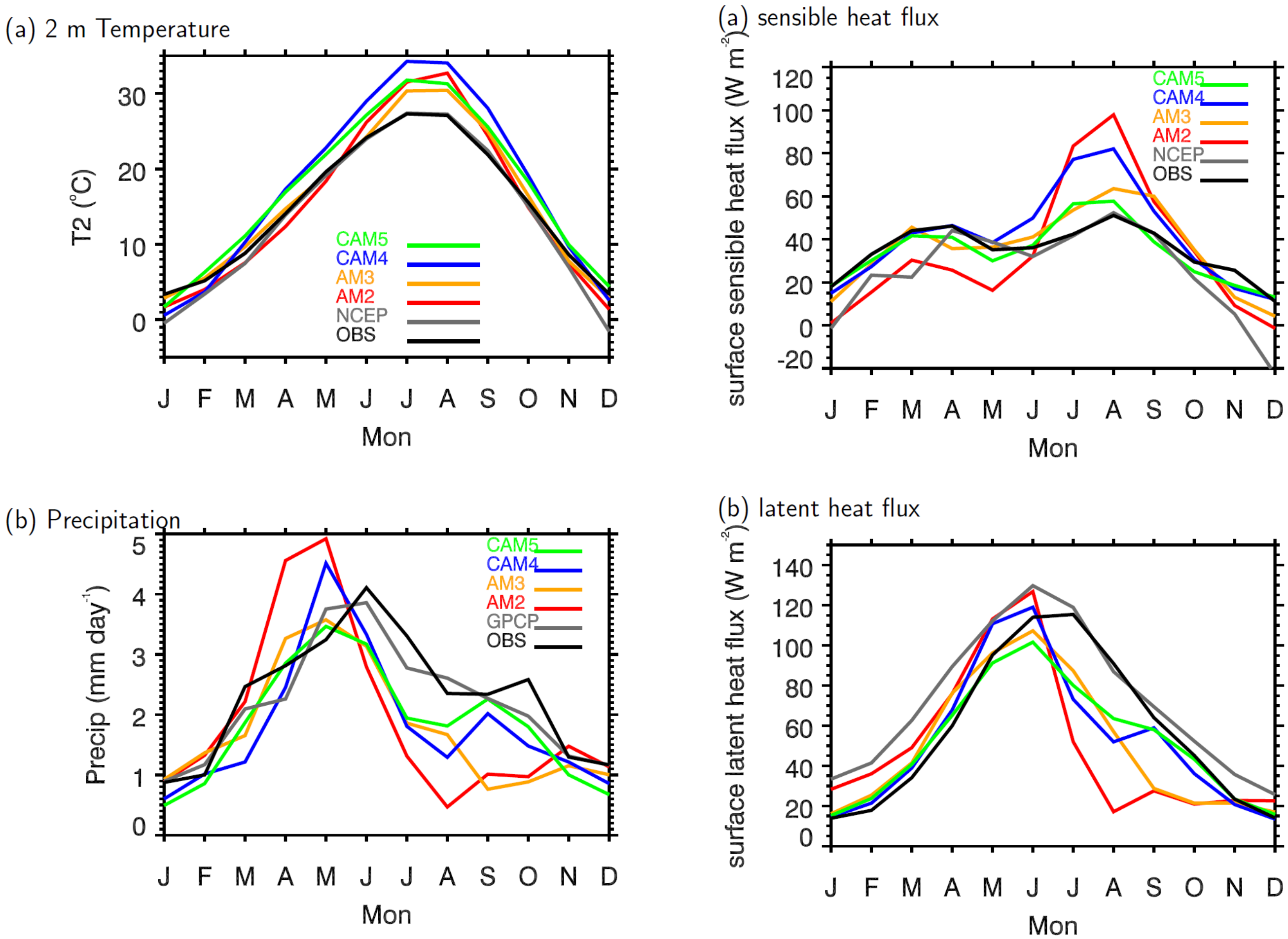

Figure 2. Seasonal variation of 2 m temperature, precipitation, sensible and latent heat flux at SGP from GFDL AM2, AM3, NCAR CAM4 and CAM5 (CAM data provided by Minghua Zhang), CMBE, and NCEP-NCAR reanalysis.

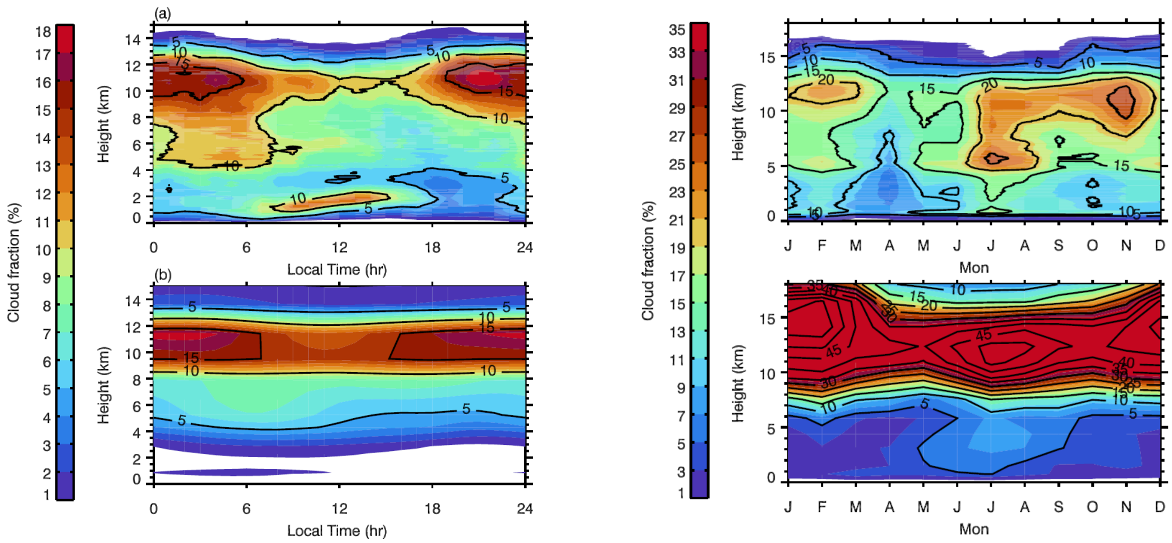

Figure 3. Observed and GFDL AM2 diurnal cycle of cloud fraction during the summer months (June, July, and August averages) from 1996 to 2007 at SGP (left, from Xie et al. 2010). Observed and AM2 cloud fraction seasonal variation at Manus (right).

4. TWP-ICE ARM GCSS intercomparison project

As part of the ARM/GCSS TWP-ICE model intercomparison effort, CCPP-ARM Parameterization Testbed (CAPT)-type simulations from seven modeling centers (NCAR, ECMWF, UKMO, JMA, GME, GFDL, and IAP) are analyzed and compared with observations collected during the TWP-ICE experiment. Figure 4 shows the observed and model cloud fraction during the experiment. Observations show three distinct regimes associated with different cloud distributions. Though models are able to capture the cloud fraction variations associated with the three regimes, differences among models are large and warrant further investigation. Further investigation will assess the resolution impact with a focus on the model cloud, radiation and precipitation performances. The intercomparison also emphasizes the model's performance in the three different synoptic regimes (active monsoon, break monsoon, and dry period). A manuscript (Lin et al. 2010) is in preparation as part of the intercomparison effort.

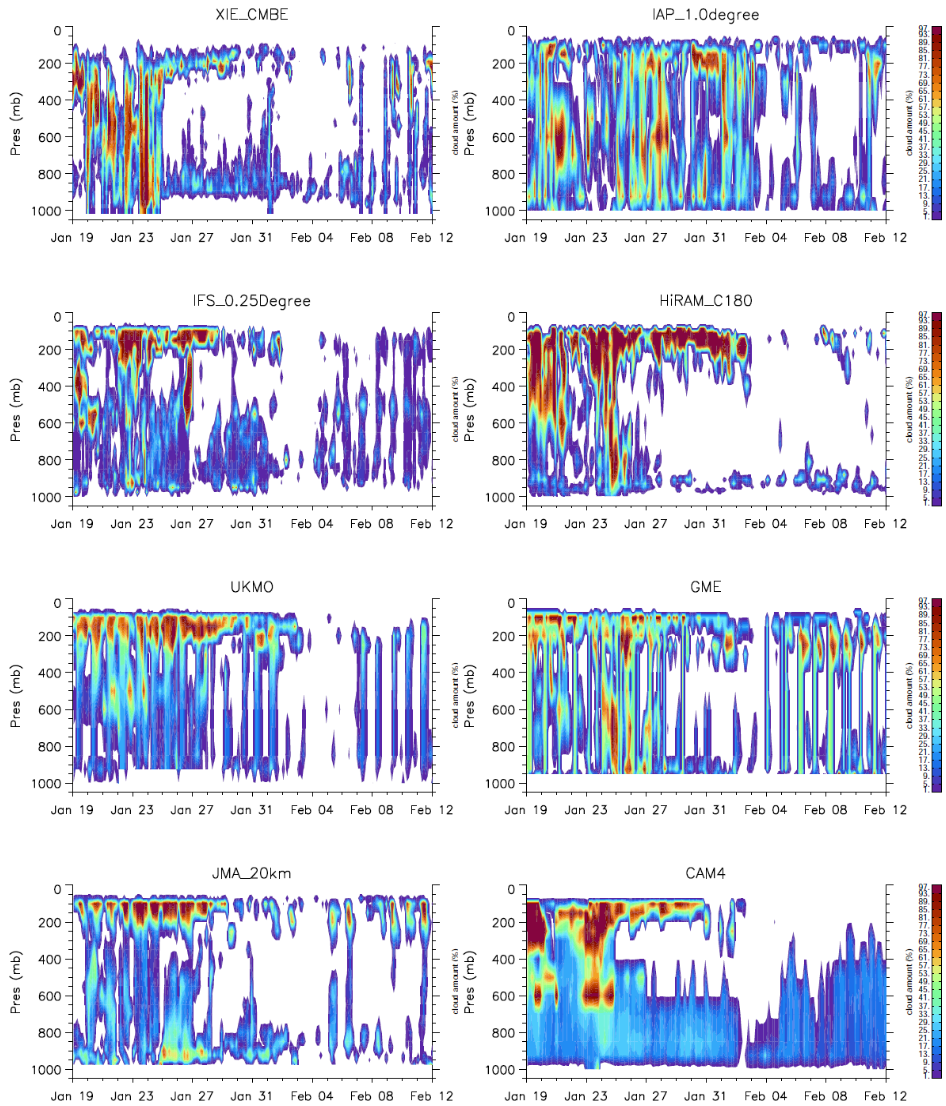

Figure 4. Cloud fraction observed during the TWP-ICE field experiment and the global model forecasts using the CAPT approach at the closest point to Darwin (left: observations from CMBE, ECMWF integrated forecast system (IFS), UK Met office (UKMO), and Japan Meteorology Agency (JMA), right:

Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences, GFDL High resolution Atmospheric Model (HiRAM), global numerical weather prediction model GME of the German Meteorological Service, and NCAR Community Atmospheric Model version 4 (CAM4)).

5. Evaluation of tropical ice cloud, radiation, and precipitation in GFDL AM2 using ARM, ISCCP, CloudSat, and TRMM data.

Tropical ice cloud, intimately associated with deep convection and in situ ascent, impacts both shortwave and longwave radiation at the top of atmosphere (TOA). Ice water path varies by two orders of magnitude among GCMs compared in Waliser et al. (2009). This implies TOA radiation balance in GCMs is well-constrained, but the associated clouds are not. Using CloudSat and ARM cirrus data (Deng and Mace, 2008), ice water content from GFDL AM2 (GFDL GAMDT, 2004) using different convective parameterizations and cloud schemes are evaluated. It is found AM2 using HiRAM (Zhao et al. 2009) physics has ~ 4 times larger IWC than the standard AM2 over the tropics. A series of stand-alone radiative calculations were conducted to quantify the relative impact of ice water content and cloud fraction on the model TOA radiative fluxes. By compositing the large-scale cloud fraction, microphysical properties, and TOA radiation based on model large-scale and convective precipitation rates (Fig. 5), respectively, it is found that model has significantly larger cloud fraction and IWC associated with large-scale precipitation than that with convective precipitation for the same total precipitation rate. Thus, a strong dependence of ice water content on the partitioning of model large-scale and convective precipitation over the tropics is evident. A manuscript (Lin et al. 2010) summarizing the study and results is in preparation.

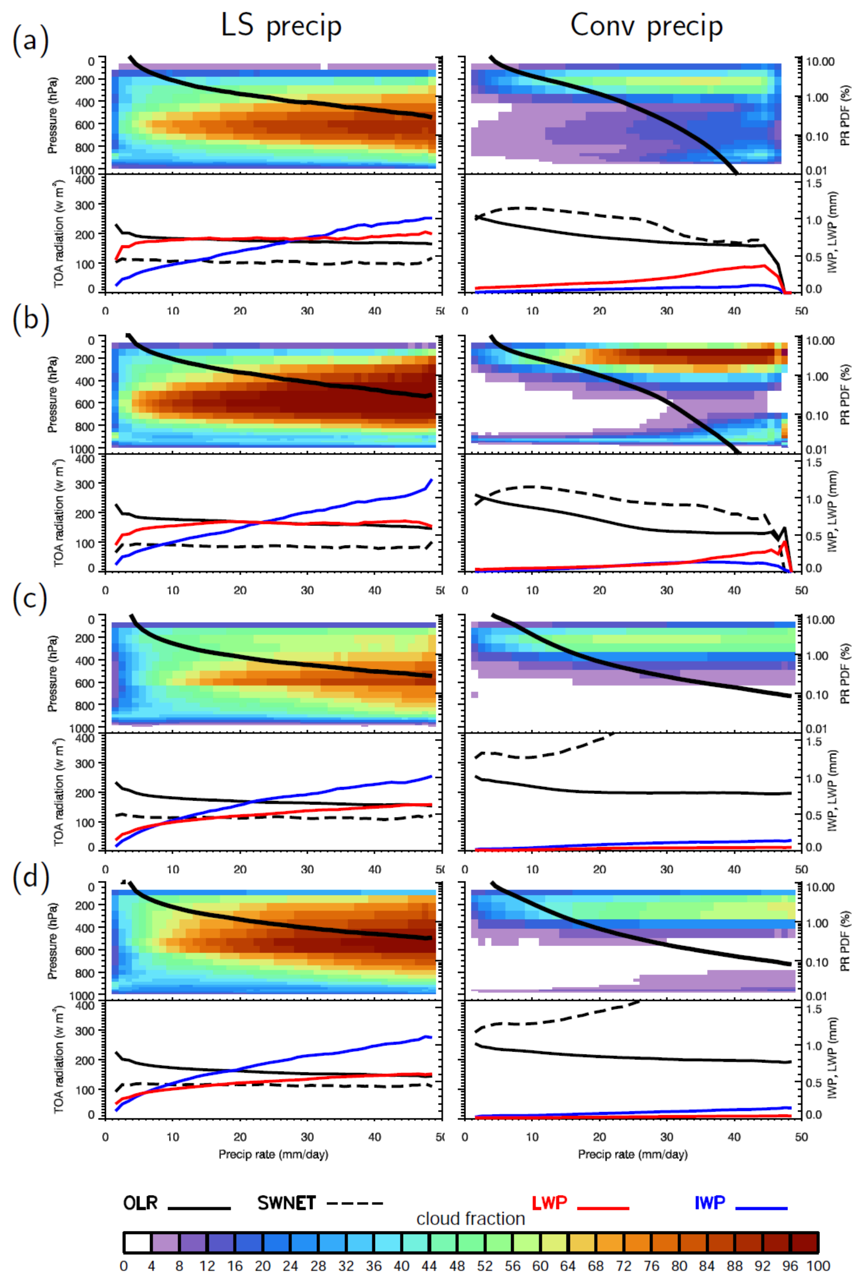

Figure 5. Cloud fraction (color shaded), LWP, IWP, TOA net shortwave, and OLR composited based on large-scale and convective precipitation rate (every 1 mm/day) over the tropics (30S-30N) using 3-h model output for (a) standard AM2 using relaxed Arakawa and Schubert (RAS) and Tiedtke scheme with prognosed cloud fraction, (b) AM2 using RAS and Tiedtke with diagnostic cloud fraction as used in high

resolution AM (HiRAM, Zhao et al. 2009), (c) AM2 using University of Washington (UW) shallow convection scheme (Bretherton et al. 2004) as modified in HiRAM and Tiedtke scheme with prognosed cloud fraction, and (d) AM2 using UW scheme and Tiedtke scheme with diagnosed cloud fraction. Thick solid lines are normalized probability density function (PDF) of precipitation rate.

6. On-going and future work

GFDL has been implementing a dynamics-PDF cloud scheme (Golaz et al. 2002) with new aerosol activation parameterizations (Ming et al. 2007; Guo et al. 2010). Recent and on-going ARM field experiments (MASRAD, CAP-MBL, etc.) have collected collocated intensive aerosol and cloud measurements. With more reliable vertical motion retrievals becoming available for various types of clouds, ARM will provide the most complete observations for the evaluation and improvement of these new parameterizations. In addition, we are also actively involved in the DOE FASTER project by participating with our SCM and by performing CAPT testing and simulations.

References

Bretherton, C. S., J. R. McCaa, and H. Grenier, 2004: A new parameterization for shallow cumulus convection and its application to marine subtropical cloud-topped boundary layers. Part I: Description and 1D results. *Mon. Wea. Rev.*, **132**, 864–882.

Deng, M., and G. G. Mace, 2008: Cirrus cloud microphysical properties and air motion statistics using cloud radar Doppler moments: Water content, particle size, and sedimentation relationships.

Geophys. Res. Letter., **35**, L17808, doi:10.1029/2008GL035054.

Golaz, J.-C., V.E. Larson, and W.R., Cotton, 2002: A PDF-based model for boundary layer clouds. Part I: Method and model description. *J. Atmos. Sci.*, **59**, 3540-3551.

Golaz, J.-C., Y. Lin, S. Malyshev, and S. Xie, 2009: Comparing GFDL GCM model output with ARM CMBE dataset: Diurnal cycle. ARM science team meeting, Louisville.

Guo, H., Golaz, J.-C., Donner, L. J., Larson, V. E., Schanen, D. P., and Griffin, B. M., 2010: A dynamic probability density function treatment of cloud mass and number concentrations for low level clouds in GFDL SCM/GCM. *Geosci. Model Dev. Discuss.*, **3**, 541-568, doi:10.5194/gmdd-3-541-2010.

Heymsfield, A. J., and L. J. Donner, 1990: A scheme for parameterizing ice-cloud water content in general circulation models, *J. Atmos. Sci.*, **47**, 1865–1877.

Lin, Y., and B.A. Colle, 2010: A new bulk microphysical scheme that includes riming intensity and temperature dependent ice characteristics. *Mon. Wea. Rev.*, in revision.

Lin, Y., L. J. Donner, and B. A. Colle, 2010: Parameterization of riming intensity and its impact on ice fall speed using ARM data. *Mon. Wea. Rev.*, in revision.

Lin, Y., M. Zhao, Y. Ming, J.-C Golaz, L. Donner, V. Ramaswamy, D. Waliser, and M. Deng, 2010: Tropical ice cloud, precipitation, and radiation in observations and GCM. *In preparation.*

Lin, Y., and Coauthors, 2010: TWP-ICE global model forecast intercomparison: Resolution impact and diurnal cycle. *In preparation*.

Mace, G.G, and Coauthors, 2006: Cloud radiative forcing at the Atmospheric Radiation Measurement Program Climate Research Facility: 1. Technique, validation, and comparison to satellite-derived diagnostic quantities. *J. Geophys. Res.*, **111**, doi:10.1029/2005JD005921.

Ming, Y., V. Ramaswamy, L.J. Donner, V.T.J Phillips, S.A. Klein, P.A. Ginoux, and L.W. Horowitz, 2007: Modeling the interaction between aerosols and liquid water cloud with a self-consistent cloud scheme in a general circulation model. *J. Atmos. Sci.*, **64**, 1189-1209.

Xie, S., and Coauthors, 2010: ARM Climate Modeling Best Estimate Data - *A new data product for climate modelers. Bull. Amer. Meteor. Soc.,* ***91****, 13-20.*

Waliser, D. E., and Coauthors, 2009: Cloud ice: A climate model challenge with signs and expectations of progress. *J. Geophys. Res*., **114**, D00A21, doi:10.1029/2008JD010015.

Zhao, M., I. M., Held, S.-J. Lin, and G.A. Vecchi, 2009: Simulation of global hurricane climatology, interannual variability, and response to global warming using a 50-km resolution GCM. *J. Clim.*, **33**, 6653-6678.

Bibliography of Papers and Conference Reports Supported by Project 0013852

Lin, Y., L. Donner, J.-C. Golaz, M. Zhao, S. Klein, S. Xie, G. Mace, and M. Deng, 2009: A bridge between ARM data and GCM evaluation and improvement. Presentation at ARM Science Team Meeting, 2009.

Lin, Y., L. Donner, J.-C. Golaz, S. Klein, S. Xie, M. Deng, G. Mace, 2009: A New Ice Fall Speed Parameterization Considering Riming and Its Tests in GFDL GCM. Poster at ARM Science Team Meeting, 2009.

Golaz, J.-C., Y. Lin, S. Malyshev, and S. Xie, 2009: Comparing GFDL GCM model output with ARM CMBE dataset: Diurnal cycle. ARM science team meeting, 2009.

Lin, Y., L. Donner, and J.-C. Golaz, 2009: Tropical ice clouds in ISCCP, CloudSat, ARM, AM2 and AM3. Poster at Gordon Research Conference on radiation & climate, 2009.

Lin, Y., and TWP-ICE global model intercomparison group, 2009:TWP-ICE NWP intercomparison: Status and update. Presentation at ARM cloud modeling workshop, 2009.

Lin, Y., M. Zhao, Y. Ming, J.-C. Golaz, L. Donner, V. Ramaswamy, D. Waliser, and M. Deng, 2010: Cloud, precipitation, and TOA radiation in observations and GFDL AGCM. Poster at 1st ASR science team meeting, 2010.

Lin, Y., and L. Donner, 2010: Composite analysis of GFDL SCM: Implications for FASTER. Presentation at 1st ASR Science Team Meeting, 2010.

Lin, Y., and TWP-ICE global model intercomparison group, 2010: TWP-ICE NWP intercomparison: Dry intrusion and resolution impact. Presentation at 1st ASR Science Team Meeting, 2010.

Lin, Y., and B.A. Colle, 2010: A new bulk microphysical scheme that includes riming intensity and temperature dependent ice characteristics. *Mon. Wea. Rev.*, in revision.

Lin, Y., L. J. Donner, and B. A. Colle, 2010: Parameterization of riming intensity and its impact on ice fall speed using ARM data. *Mon. Wea. Rev.*, in revision.

Lin, Y., M. Zhao, Y. Ming, J.-C. Golaz, L. Donner, V. Ramaswamy, D. Waliser, and M. Deng, 2010: Tropical ice cloud, precipitation, and radiation in observations and GCM. *In preparation.*

Lin, Y., and Coauthors, 2010: TWP-ICE global model forecast intercomparison: Resolution impact and diurnal cycle. *In preparation*.