The PI's ARM investigation (DE-IA02-02ER63318) developed a physically-based subgrid-scale saturation representation that fully considers the direct interactions of the parameterized subgrid-scale motions with subgrid-scale cloud microphysical and radiative processes. Major accomplishments under the support of that interagency agreement are summarized below. Details of these accomplishments can be found in the publications mentioned in the text.

- Dr. Anning Cheng and the PI investigated physical insight into the fully-prognostic third-order turbulence closure (Cheng et al. 2004) used in the UCLA/LaRC CSRM (Krueger 1988; Xu and Randall 1995) and simplified it to a partially-prognostic third-order turbulence closure, which only predicts the third moments of vertical velocity, liquid-water potential temperature and total water mixing ratio. The benefits of this partially-prognostic closure include the elimination of a spurious "liquid-water oscillation" (Cheng et al. 2004) and the reduction of computational cost by a factor of two (Cheng and Xu 2005). A joint double-Gaussian probability density function (PDF) is used to represent subgrid-scale fluctuations that are not resolved by the CSRM at a typical grid size of 1-2 km. The new model is able to realistically simulate shallow cumulus clouds and their transition to deep convective clouds.
- The PI successfully completed the joint GCSS[1]/ARM CSRM and Single-Column Model (SCM) intercomparison project. This is a very successful intercomparison project under the GCSS or ARM program. This effort led to the publication of two journal articles (Xu et al. 2002; Xie et al. 2002). A major conclusion of this intercomparison study is that CSRMs perform much better than SCMs in general. Cloud microphysics parameterization is identified as the major reason for the differences among the participating CSRMs.
- The PI and his group were active participants of the ARM Case 4 intercomparison project (Spring 2000 Intensive Operational Period; IOP). Two of the four participating CSRMs were from our group. The PI wrote one paper for the intercomparison project that is related to the simulation of shallow frontal clouds (Xu et al. 2005), and significantly contributed to the other paper describing the simulation of deep frontal clouds (Xie et al. 2005). Xu et al. (2005) pointed out several important deficiencies in cloud parameterizations used in SCMs and CSRMs.

1. GEWEX (Global Energy and Water-cycle EXperiment) Cloud System Study (Browning 1994; Randall et al. 2003b).

DISCLAIMER

- The PI provided CSRM simulated data sets for other Cloud Parameterization and Modeling (CPM) Working Group (WG) members to perform model evaluation against cloud statistics from the ARM measurements (Luo et al. 2003; Jakob et al. 2004) and to understand the physics of next-generation cloud parameterization (Klein et al. 2005; Pincus et al. 2005). Dr. Yali Luo, who is currently a member of the PI's group, also used the CSRM and ARM data to evaluate cumulus and cirrus cloud parameterizations in the NCEP SCM (Luo et al. 2005).
- The PI examined the impacts of the cloud overlap and horizontally-uniform hydrometeor assumptions on diagnostic radiative properties using detailed outputs from the UCLA/LaRC CSRM (Xu 2005). It is found that the cloud overlap assumption impacts the diagnosis more significantly than the uniform hydrometeor assumption for all radiative fluxes.

Refereed publications (numerous conference presentations are not listed, for brevity):

Xie, S. C., K.-M. Xu, and coauthors, 2002: Intercomparison and evaluation of cumulus parameterizations under summertime midlatitude continental conditions. *Q. J. Roy. Meteor. Soc.* **128,** 1095-1135.

Xu, K.-M., and coauthors, 2002: An intercomparison of cloud-resolving models with the ARM summer 1997 IOP data. *Q. J. Roy. Meteor. Soc.*, **128,** 593-624.

Luo, Y., S. K. Krueger, G. G. Mace, and K.-M. Xu, 2003: Cirrus cloud properties from a cloud-resolving model simulation compared to cloud radar observations. *J. Atmos. Sci.*, **60**, 610-525.

Jakob, C., R. Pincus, C. Hannay, and K.-M. Xu, 2004: The use of cloud radar observations for model evaluation: A probabilistic approach. *J. Geophys. Res.*, **109**, D03202, doi: 10.1029/2003JD003473.

Cheng, A., K.-M. Xu, and J.-C. Golaz, 2004: The liquid-water oscillation in modeling boundary-layer cumuli with third-order turbulence closure models. *J. Atmos. Sci.*, **61,** 1621-1629.

Xu, K.-M., 2005: The sensitivity of diagnostic radiative properties to cloud microphysics among cloud-resolving model simulations. *J. Atmos. Sci.*, **62,** 1241-1254.

Klein, S. A., R. Pincus, C. Hannay, and K.-M. Xu, 2005: How might a statistical cloud scheme be coupled to a mass-flux convection scheme? *J. Geophys. Res.*, **110,** D15S06, doi: 10.1029/2004JD005017.

Pincus, R., C. Hannay, S. A. Klein, K.-M. Xu, and R. Hemler, 2005: Overlap assumptions for assumed-PDF cloud schemes in large scale models. *J. Geophys. Res.*, **110,** doi: 10.1029/2004JD005100, in press.

Xie, S., and coauthors (including K.-M. Xu), 2005: Simulations of midlatitude frontal clouds by SCMs and CRMs during the ARM March 2000 Cloud IOP. *J. Geophys. Res.*, **110,** D15S03, doi: 10.1029/2004JD005119.

Xu, K.-M., and coauthors, 2005: Modeling springtime shallow frontal clouds with cloud-resolving and single-column models. *J. Geophys. Res.*, **110,** D15S04, doi: 10.1029/2004JD005153.

Cheng, A., and K.-M. Xu, 2006: Simulation of shallow cumuli and their transition to deep convective clouds by cloud-resolving models with different third-order turbulence closures. *Q. J. Roy. Meteor. Soc.*, **132,** 359-382.