Poster # 132

THE UNIVERSITY OF ARIZONA

Evaluate Autoconversion and Accretion Enhancement Factors in GCM Warm-rain Parameterizations using Ground-based Observations

U.S. DEPARTMENT OF ENERGY
Office of Science

Peng Wu[1], Baike Xi[1](baikex@email.arizona.edu), Xiquan Dong[1], and Zhibo Zhang[2]
[1]Department of Hydrology and Atmospheric Sciences, University of Arizona, Tucson, Arizona, USA
[2]Physics Department, The University of Maryland, Baltimore County, Maryland, USA

Introduction

1. **Global climate models (*GCMs*) *are found to produce precipitation too frequent and too light compared to observations,***
2. **Autoconversion mainly account for precipitation initiation and accretion mainly contributes to precipitation intensity,**
3. Autoconversion and accretion rates are functions of grid-mean cloud water mixing ratio (q_c) and number concentration (N_c) and rain water mixing ratio (q_r),
4. Enhancement factors (E_{auto} and E_{accr}) are introduced when considering sub-grid scale variabilities of cloud and precipitation properties,
5. ***Different distributions of q_c, N_c, and q_r would lead to different values of Es and result in different precipitation frequencies and intensity.***
6. ***Constant values are used in GCMs with $E_{auto} = 3.2$ and $E_{auto} = 1.07$,***
7. Ground-based observations have not been applied to assess the dependence of E_{auto} and E_{accr} on sub-grid scale variabilities and their effects on simulated precipitation rate, which is the purpose of this study.

Methodology

Autoconversion and accretion rates in GCMs are parameterized as :

$$\left(\frac{\partial q_r}{\partial t}\right)_{auto} = 1350 q_c^{2.47} N_c^{-1.79} \quad (1)$$

$$\left(\frac{\partial q_r}{\partial t}\right)_{accr} = 67 (q_c q_r)^{1.15} \quad (2)$$

Assume Gamma distributions for sub-grid scale cloud water and particle number concentration:

$$P(x) = \frac{\alpha^{\nu}}{\Gamma(\nu)} x^{\nu-1} e^{-\alpha x}, \quad (3)$$

where x is q_c or N_c with grid-mean quantity μ, $\alpha = \nu/\mu$ is the scale parameter, ν is shape parameter.
Integrate Eq. (1) over Eq. (3):

$$\left(\frac{\partial q_r}{\partial t}\right)_{auto} = 1350 \mu_{q_c}^{2.47} \mu_{N_c}^{-1.79} \frac{\Gamma(\nu_{q_c}+2.47)}{\Gamma(2.47)\nu_{q_c}^{2.47}} = 1350 \mu_{q_c}^{2.47} \mu_{N_c}^{-1.79} \frac{\Gamma(\nu_{N_c}-1.79)}{\Gamma(-1.79)\nu_{N_c}^{-1.79}} \quad (4)$$

Compare Eqs. (4) with Eq. (1), we get the autoconversion enhancement factors with respect to qc and Nc:

$$\boldsymbol{E_{auto}} = \frac{\Gamma(\nu_{q_c}+2.47)}{\Gamma(2.47)\nu_{q_c}^{2.47}} \ \mathbf{or} \ \frac{\Gamma(\nu_{N_c}-1.79)}{\Gamma(-1.79)\nu_{N_c}^{-1.79}} \quad (5)$$

Similarly, by including the correlation coefficient (ρ) of q_c and q_r, we get:

$$E_{accr} = \left(1+\frac{1}{\nu_{q_c}}\right)^{\frac{1.15^2-1.15}{2}} \left(1+\frac{1}{\nu_{q_r}}\right)^{\frac{1.15^2-1.15}{2}} \exp\left(\rho 1.15^2 \sqrt{ln\left(1+\frac{1}{\nu_{q_c}}\right) ln\left(1+\frac{1}{\nu_{q_r}}\right)}\right)$$
(6)

Assume 10 m s^{-1} horizontal wind, different time-windows corresponding to different model grid sizes, e.g., 2-hour interval corresponds to 72 km grid.

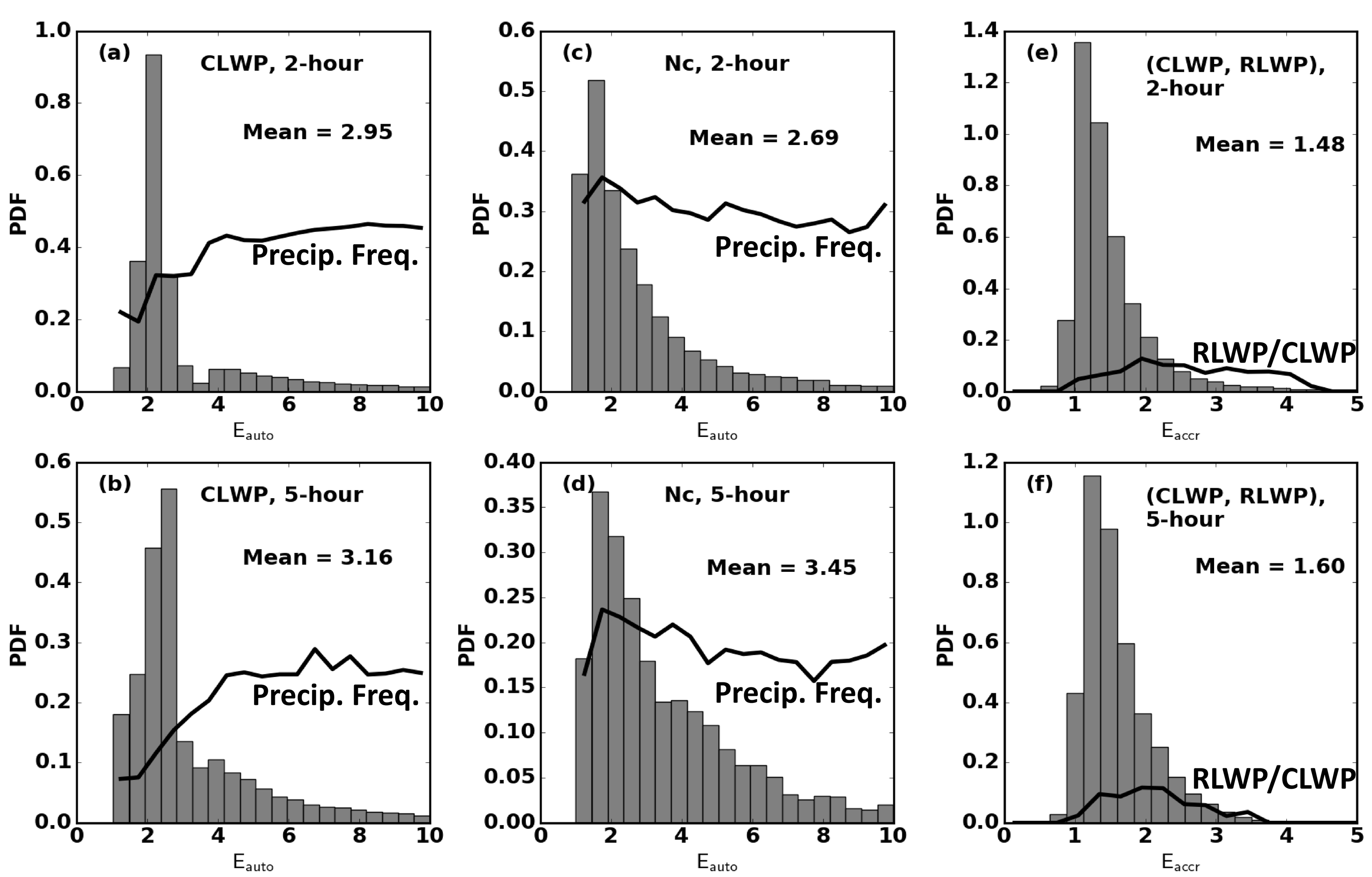
Scientific Questions

1. How do E_{auto} and E_{auto} depend on sub-grid scale variabilities of cloud and precipitation properties?
2. How do the two enhancement factors change with model resolutions?
3. What are the characteristics of the two enhancement factors under different boundary layer conditions (stable vs unstable)?

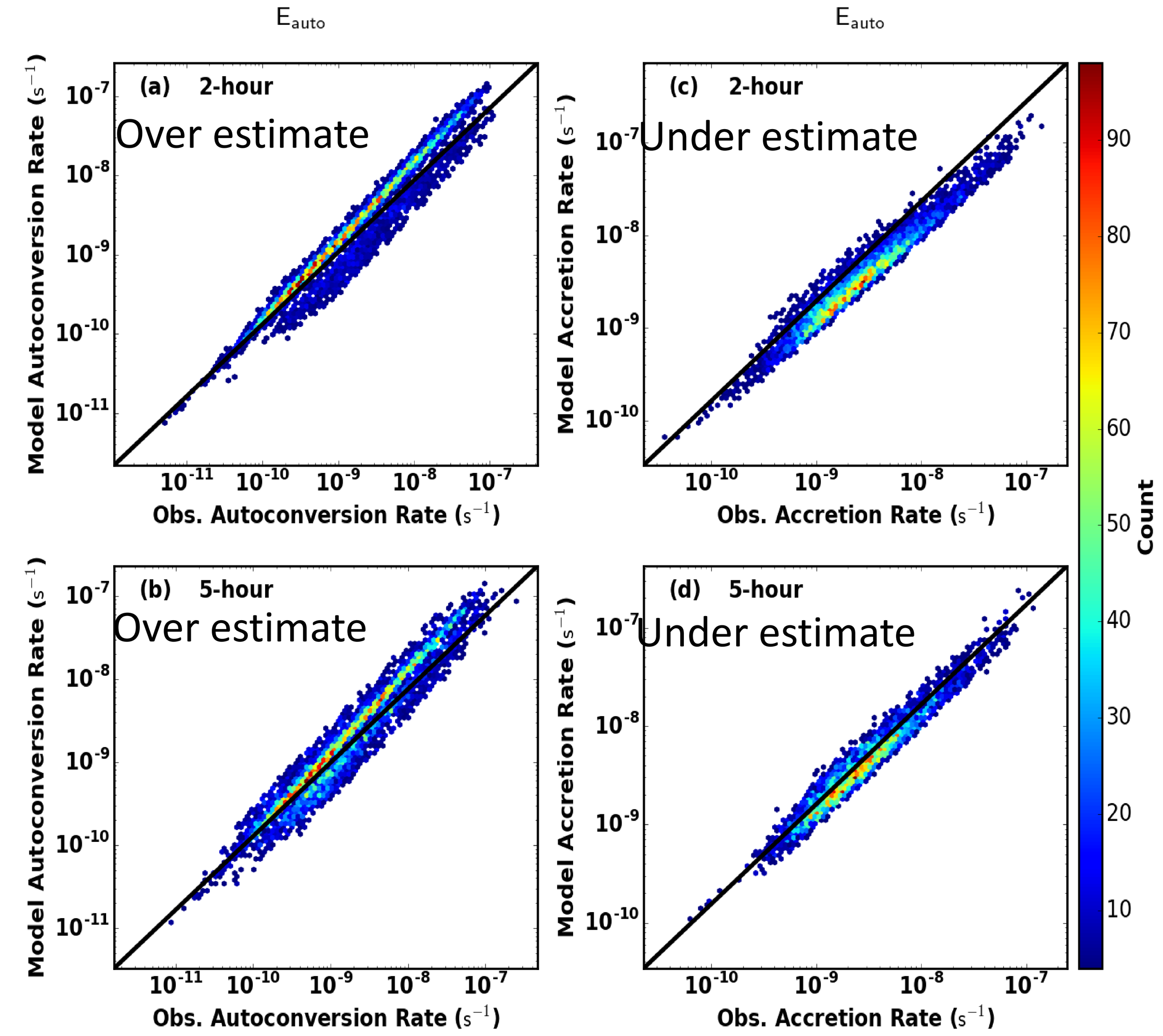
Data

Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Mobile Facility (AMF), Clouds, Aerosols and Precipitation in the Marine Boundary Layer (**CAP-MBL**) campaign on the northern coast of Graciosa Island (39.09°N, 28.03°W) from June 2009 to December 2010. Detailed description of observations and retrievals can be found in Dong et al. (2014a&b) and Wu et al. (2015).

Results



- **(a & b) E_{auto} shows bimodal distribution with mode at ~2 and second peak at ~4. Precipitation frequency increases from E_{auto} = 1 to 4 then keep relatively const.**
- **(c & d) E_{auto} shows single mode at ~2, and precipitation frequent does not show similar trend as in (a&b). The average value is same as in (a&b)**
- **(e & f) E_{accr} has mode at ~1.5 and right skewed, RLWP/CLWP increases with E_{accr} and then decreases, suggesting a possible existence of an optimal state for rain drop collection process**



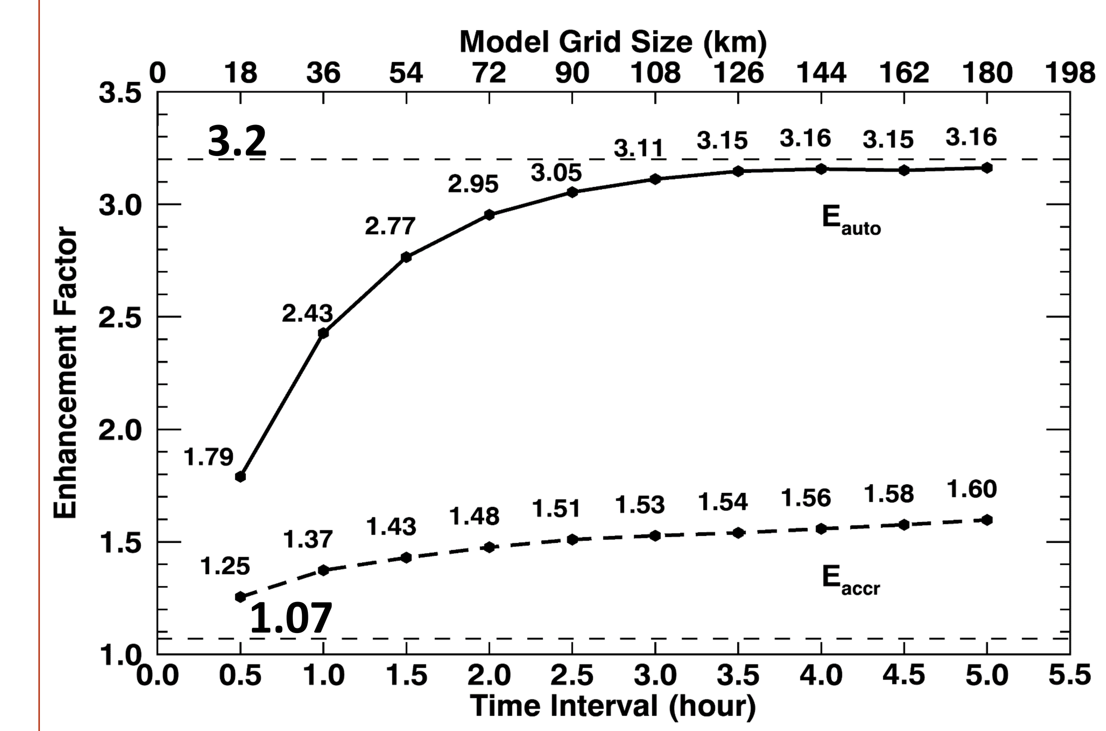
Too frequent **Too light**

	LTS (K)	LWP ≤ 75 g m^{-2} (E_{auto}/E_{accr})	LWP > 75 g m^{-2} (E_{auto}/E_{accr})
stable	> 18	2.31/1.40	2.58/1.49
mid-stable	(13.5, 18)	2.56/1.43	2.98/1.63
unstable	< 13.5	4.15/1.51	6.17/1.70

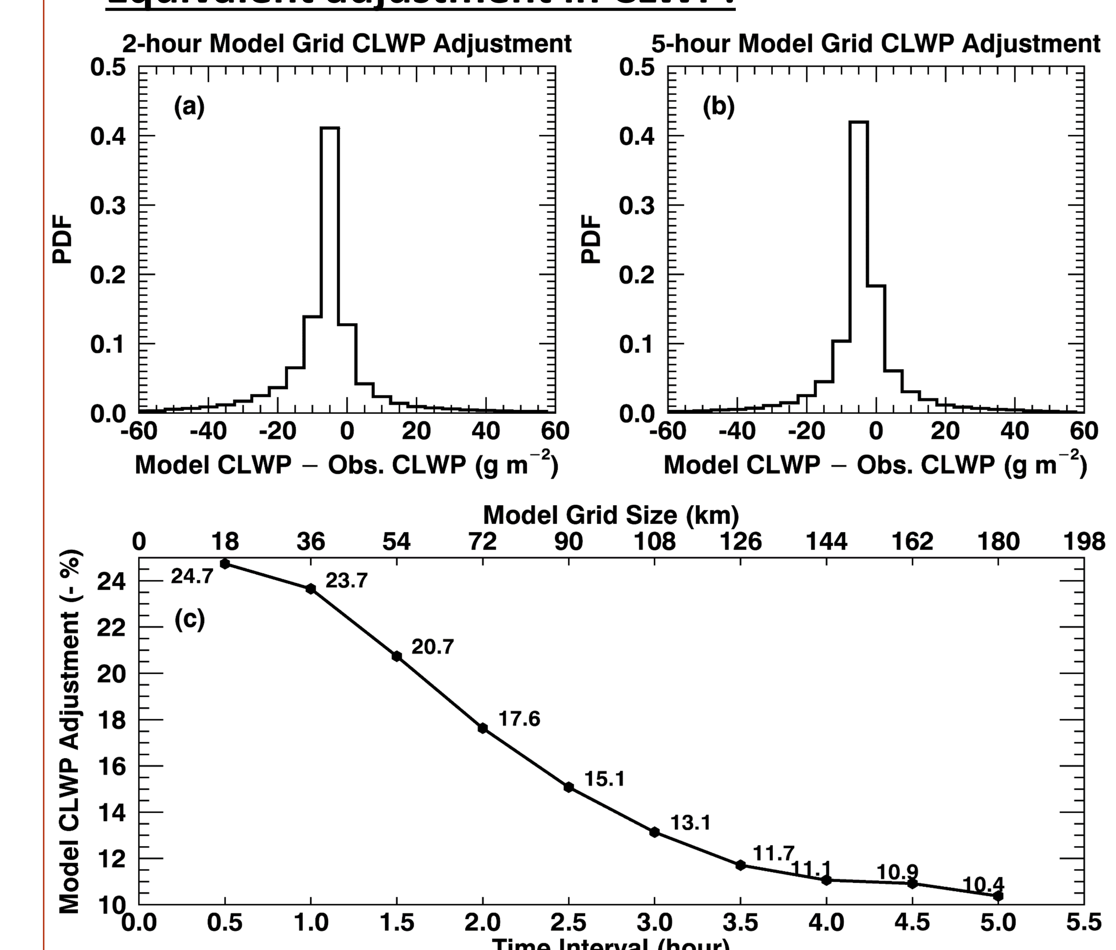
	LTS (K)	LWP ≤ 75 g m^{-2} (E_{auto}/E_{accr})	LWP > 75 g m^{-2} (E_{auto}/E_{accr})
stable	> 18	2.89/1.53	3.02/1.63
mid-stable	(13.5, 18)	3.01/1.61	3.15/1.65
unstable	< 13.5	5.80/1.64	7.20/1.74

Enhancement factors should be regime-dependent

Results



Equivalent adjustment in CLWP:



Summary

1. **Too large *E_{auto}* → too frequent precipitation,**
2. **Too small *E_{accr}* → too light precipitation,**
3. **Both enhancement factors are regime-dependent (BL stability, CLWP, etc.),**
4. **Values of enhancement factors also depend on model spatial resolution.**

Note

This study only provides an quantitative assessment of the dependence of E_{auto} and E_{accr} on sub-grid scale variabilities. Other parameters and processes, such as the properties of underling surface, aerosol properties and environmental humidity and wind shear can also affect precipitation rate and are beyond the scope of this study.

References

1. Dong, X., B. Xi, A. Kennedy, P. Minnis and R. Wood (2014a), A 19-month Marine Aerosol-Cloud_Radiation Properties derived from DOE ARM AMF deployment at the Azores: Part I: Cloud Fraction and Single-layered MBL cloud Properties, *J. Climate, 27*, doi:10.1175/JCLI-D-13-00553.1.
2. Dong, X., B. Xi, and P. Wu (2014b), Investigation of Diurnal Variation of MBL Cloud Microphysical Properties at the Azores, J. Climate, 27, 8827-8835.
3. Lebsock, M., H. Morrison, and A. Gettelman (2013), Microphysical implications of cloud-precipitation covariance derived from satellite remote sensing, J. Geophys. Res. Atmos., 118, 6521–6533, doi:10.1002/jgrd.50347.
4. Morrison, H., and A. Gettelman (2008), A new two-moment bulk stratiform cloud microphysics scheme in the Community Atmospheric Model (CAM3), Part I: Description and Numerical Tests, J. Clim., 21, 3642–3659, doi:10.1175/2008JCLI2105.1.
5. Wu, P., X. Dong and B. Xi (2015), Marine boundary layer drizzle properties and their impact on cloud property retrieval, Atmos. Meas. Tech., 8, 3555–3562. doi: 10.5194/amt-8-3555-2015.

Acknowledgements

The ground-based measurements were obtained from the Atmospheric Radiation Measurement (ARM) Program sponsored by the U.S. Department of Energy (DOE) Office of Energy Research, Office of Health and Environmental Research, Environmental Sciences Division. The data can be downloaded from http://www.archive.arm.gov/.