ON THE REPRESENTATION OF DROPLET COALESCENCE AND AUTOCONVERSION FOR REALISTIC CLOUD SIZE DISTRIBUTIONS

W. C. Hsieh1, H. Jonsson2, G. Buzorius3, R. C. Flagan4,5, J. H. Seinfeld4,5, and A. Nenes1,6

1 Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA
2 CIRPAS, Naval Postgraduate School, Monterey, CA
3 Meteorology, Naval Postgraduate School, Monterey, CA
4 Environmental Science and Engineering, California Institute of Technology, Pasadena, CA
5 Chemical Engineering, California Institute of Technology, Pasadena, CA
6 Chemical and Biomolecular Engineering, Georgia Institute of Technology, Atlanta, GA

1. INTRODUCTION
Studies of anthropogenic climate change have shown that large predictive uncertainty arises from the incomplete representation of cloud microphysical processes, especially autoconversion of cloudwater to rain [e.g., Lohmann and Feichter, 2005].

If the droplet size distribution is known, the autoconversion rate, \( A \), can be computed from the Stochastic Collection Equation (SCE) [Pruppacher and Klett, 1997]:

\[
A = \int_{0}^{\infty} \left( \int_{0}^{x} K(x, x') n(x') dx' \right) n(x) dx
\]

where \( K(x, x') \) is the collection kernel, \( n(x) \) is the drop size distribution (DSD). The lack of explicit cloud microphysics in Global Climate Models (GCMs) prohibit the explicit usage of SCE; instead, GCMs use simple parameterizations of the collection process (the rate-limiting step for precipitation formation), and express autoconversion rate in terms of liquid water content (LWC) [Kessler, 1969], cloud droplet number concentration (CDNC) [Manton and Cotton, 1977; Rotstayn, 1997; Khairoutdinov and Kogan, 2000], and dispersion of the droplet size distribution [Beheng, 1994; Cohard and Pinty, 2000; Liu and Daum, 2004].

In this work, we evaluate autoconversion parameterizations against explicit calculations using SCE. Uncertainty in autoconversion rate that arise from neglecting the effects of turbulence and from fitting ambient DSD to a gamma distribution is explored. The DSD used for the evaluations are obtained from in-situ observations of clouds.

2. OBSERVATION DATASETS
Cloud droplet size distributions used in this study were collected aboard the CIRPAS Twin Otter aircraft (http://www.cirpas.org/) during two field campaigns: CRYSTAL-FACE in Key West, FL (July 2002) and CSTRIPE in Monterey, CA (July 2003). Measurements taken during CRYSTAL-FACE were low-level cumuliform clouds [Conant et al., 2004; VanReken et al., 2003], while marine stratocumulus clouds were primarily sampled during CSTRIPE [Meskhidze et al., 2005]. In both campaigns, the binned droplet size distributions were measured with a Cloud and Aerosol Spectrometer (CAS) optical probe and a Forward Scattering Spectrometer Probe (FSSP). The observed DSDs ranged between 1 to 25 \( \mu \)m in radius; haze droplets (less than 1 \( \mu \)m) and their impact on collection is not considered. We used transect-average for SCE calculations; 164 transects are available from CRYSTAL-FACE, and, 52 from CSTRIPE.

3. AUTOCONVERSION PARAMETERIZATIONS USED
The parameterization schemes used in this study include (1) MC, [Manton and Cotton, 1977]; (2) BH [Beheng, 1994]; (3) KK, [Khairoutdinov and Kogan, 2000]; (4) LD4 and (5) LD6, which correspond to the P4 and P6 formulations of Liu and Daum [2004].
4. PARAMETERIZATIONS VS. SCE WITH MEASURED DSD
The comparison of autoconversion rates predicted by parameterizations and SCE calculations for CRYSTAL-FACE DSDs is shown in Figure 1. LD6 systematically overestimates autoconversion, because it provides total coalescence (i.e., total coalescence rate from droplets of all sizes) and not autoconversion (i.e., the rate of production of drizzle droplets). On average, LD6 overpredicts autoconversion by a factor of 47 for CRYSTAL-FACE, and a factor of 4 for CSTRIPE clouds.

The large difference between SCE and parameterizations is also seen when using the DSD from the CSTRIPE stratocumulus dataset (not shown here). Of all parameterizations considered, KK tends to show the least autoconversion bias. The BH parameterization is not included in Figure 1, because the data used in this study are outside its region of applicability.

5. HYDROLOGICALLY IMPORTANT CLOUDS
Conversion rates vary five orders of magnitude in the CRYSTAL-FACE and four orders of magnitude for CSTRIPE datasets. Not all of this dynamic range is "hydrologically important", so we focus our parameterization evaluation for clouds closest to a precipitating state. The timescale for forming rain, $\tau_{\text{rain}} = \text{LWC}/A$, is used for evaluating the probability of precipitation; clouds with $\tau_{\text{rain}} \sim 0.1$ h (a typical lifetime of an individual cloud) and 10 h (the lifetime of a stratuscumulus layer) are hydrologically important as they can precipitate within their lifetime. For these clouds, errors in autoconversion can difference between a precipitating and non-precipitating cloud.

Compared to SCE, LD6 tends to underestimate $\tau_{\text{rain}}$ (because autoconversion rate is overestimated) by a factor of $0.36 \pm 0.56$ and $1.08 \pm 0.80$ for CRYSTAL-FACE and CSTRIPE, respectively. The remaining parameterizations tend to overestimate $\tau_{\text{rain}}$ by up to a factor of 100.

6. SCE WITH TURBULENT KERNEL
Turbulence can enhance coalescence rate [Pruppacher and Klett, 1997] and is also important on cloud droplet size distribution evolution [Riemer and Wexler, 2005]. Its impact on autoconversion rates is estimated by using the turbulence kernel of Zhou et al. [2001]. We compare autoconversion rates...
obtained from SCE integration with gravitational and turbulent kernels. For CRYSTAL-FACE cloud size distributions, the average autoconversion rate with the turbulent kernel is a factor of $1.2 \pm 0.6$ greater than the average value obtained using the gravitational kernel only. When applied to CSTRIPE clouds, turbulence, compared to gravitation alone, enhances autoconversion by a factor of $1.5 \pm 0.4$. Our results show that enhancement of turbulence is within the inherent uncertainty of autoconversion parameterizations.

REFERENCES


ACKNOWLEDGMENTS

This research was funded by the Department of Energy, an NSF CAREER award and a graduate teaching assistantship. This work was also funded by the office of Nowel Research under grant N00014-04-1-0118. The authors wish to thank Dr. A. Bott for providing the SCE code. ICCP support for participating in conference is also acknowledged.