Atmos. Chem. Phys. Discuss., 8, S2589–S2593, 2008
www.atmos-chem-phys-discuss.net/8/S2589/2008/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Relationship between drizzle rate, liquid water path and dropletconcentration at the scale of a stratocumulus cloud system" *by* O. Geoffroy et al.

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Received and published: 13 May 2008

General Comments: The authors present a good description of several state-of-the-art bulk parameterizations used in models to represent precipitation formation in stratocumulus clouds. They discuss these parameterizations in the context of field experiments and find support for a scaling of the precipitation rate with liquid water path and droplet concentration when averaged over the large domain of a GCM grid. The authors provide a clear discussion of model grid scale and the widespread (but undesirable) tuning of model parameters in order to preserve agreement with observations of precipitation rate over different cloud scales. Finally, the authors compare their results with large

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eddy simulation, finding that the empirical parameterizations are not fortuitous but instead capture, in the mean, effects of cloud physical processes.

The paper presents a historical overview of bulk parameterization schemes as applied to warm clouds, discussing separation of the hydrometeor population into cloud droplets and precipitating particles and improvements that take into account cloud droplet concentration (CDNC) - giving the models some capability to asses the impact of aerosol indirect effects on cloud properties. Most significantly the authors discuss scale, concluding that instead of extending bulk microphysical parameterizations designed for cloud resolving models (CRMs) to the coarser resolution of GCMs, development should focus on specific parameterizations that represent the mean precipitation production from an ensemble of clouds These valued considerations bring into focus the highly questionable practice of tuning, to which the following specific comments are addressed.

Specific Comments: The modern trend is to at least move in the direction of basing cloud parameterizations on microphysics. Unfortunately this noble goal is to a large extent undermined by tuning. Consider for example, as the authors do, the critical droplet radius, rc, beyond which droplets enter the collection regime and rapidly grow to fall velocity size. The recent nucleation theory of drizzle initiation develops a physically based characterization of rc and shows how this key length scale largely determines drizzle rate [1]. An autoconversion parameterization based on this theory has also been developed [2] and compared with field measurements [3]. Estimates of critical radius, expressed in terms of liquid water volume fraction (L), CDNC, and a turbulence parameter, are typically in the 20-30 micron range; well beyond the average size of typical cloud droplets (ravg = circa 10 micron). Now a key cloud property controlling the drizzle rate is the ratio of the critical to average droplet size: rc/ravg. Generally the smaller this ratio, the lower the barrier to drizzle formation. Lower barriers enhance both drizzle probability and drizzle rate (the rate saturates as rc/ravg approaches values near unity from above). Under conditions that rc and ravg are of comparable size, the previously

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metastable cloud is predicted to enter an unstable regime characterized by vanishing of the drizzle barrier. Drizzle occurs spontaneously in this unstable (spinodal-like) regime, albeit with very different properties (for example with an anti-Albrecht second indirect aerosol effect) than found in the metastable (activated) regime [1].

The usually stated justification for tuning is based on the fact that the drizzle rate is a highly nonlinear, threshold like, function of its controlling variables (CDNC, L, and rc), thus magnifying the importance of fluctuations and/or heterogenieties in the distribution of these variable. This has the result that averaging heterogeniety over larger scales results in significantly lower drizzle rates. But just as tuning either L or CDNC to restore a reasonable average rate is unacceptable (as this is clearly tinkering with the microphysics), one should also not tune rc. As the microphysical underpinnings of the critical radius and its role in drizzle initiation become better understood, one losses the ability to tune this quantity without conspicuous changes to the physics itself.

Recent field measurements suggests that in marine stratus clouds drizzle forms near cloud top where L is greatest [3], so averaging even over a single cloud volume is not good practice. As the authors make clear in their study rc has to decease as one averages over larger and larger scales from LES to CRM to GCM. Some GCMs assign values as small as 5-8 microns to the critical radius making this quantity even smaller than ravg. Were the critical radius actually this small, the entire cloud fraction would drizzle everywhere throughout its volume; a result contradicted both by field measurements and by our present understanding of the nonlinear microphysics of drizzle formation.

So what is the way out? Perhaps one can still preserve the microphysics, as generally derived from considerations that apply on the local cubic meter scale, and use probability distribution functions (pdfs) and/or joint probability distribution functions (jpdfs) of local fields to map from the local microphysical scale to a probabilistic representation of subgrid cloud properties at the LES, CRM, and GCM scales. The assignment of a cloud fraction to each grid cell of a GCM based on relative humidity is already a step in this direction. A more definitive step is an idea suggested by Rotstayn, namely his

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introduction of a triangular pdf for the total water mixing ratio (q) [4]. In the traditional schemes autoconversion takes place whenever the mean in-cloud value of q exceeds a threshold (qcrit) determined by rc. In the pdf scheme the assumed sub-grid moisture distribution is applied in each grid box to determine the fraction of cloud volume in which q$>$qcrit , and only in that smaller volume can autoconversion occur. The change enables the tuned rc to be adjusted back to larger values - in the right direction, albeit not to the 20-30 micron range predicted under stratus conditions by the nucleation-based drizzle theory. Further progress will likely require use of jpdfs in terms of at least two variable, for example q and CDNC (or perhaps L and CDNC), from which sampled fields can be generated and fed into microphysical-based expressions yielding derived pdfs for spatio-temporal variations in drizzle rate. While this procedure eliminates any need for tuning the physics- as physical parameters entering the rate expression are not adjusted - it does require estimation of the jpdf itself. Fortunately the jpdfs should be much easier to introduce in a form consistent with meteorological/thermodynamic constraints and cloud microphysics, while also representing the ensemble properties of different cloud types. Advances in remote sensing, including 3D cloud tomography [5] and satellite inference of droplet number concentration [6] might be best suited, in conjunction with in-situ field sampling, to assemble the data base of information needed to develop/refine the necessary jpdfs and to characterize their variation with meteorological conditions and cloud type.

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Interactive comment on Atmos. Chem. Phys. Discuss., 8, 3921, 2008.

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