ENHANCEMENT OF COALESCENCE DUE TO DROPLET INERTIA IN TURBULENT CLOUDS

Steven K. Krueger,1* Jaekyoon Oh,1 and Alan R. Kerstein2
1 University of Utah, Salt Lake City, Utah, USA
2 Sandia National Laboratories, Livermore, California, USA

1. INTRODUCTION

The EMPM (Explicit Mixing Parcel Model) predicts the evolving in-cloud variability of temperature and water vapor mixing ratio due to entrainment and finite-rate turbulent mixing using a 1D representation of a rising cloudy parcel (Krueger et al. 1997). The 1D formulation allows the model to resolve fine-scale variability down to the smallest turbulent scales (about 1 mm). The EMPM calculates the growth of thousands of individual cloud droplets based on each droplet’s local environment (Su et al. 1998).

In the EMPM, turbulent advection of fluid is implemented by rearranging the fluid cells. Each permutation represents an individual turbulent eddy, and is called a “triplet map.” This implementation of the triplet map captures flow processes as small as the smallest turbulent eddy (Kolmogorov microscale), but the response of small droplets to turbulence has important features at scales as small as the droplet radius. Namely, droplet motion relative to the fluid at scales less than the Kolmogorov microscale induces droplet clustering that is estimated to increase droplet collision rates significantly. We have developed (Kerstein and Krueger 2006), implemented, and tested a 3D triplet map for droplets that captures this clustering effect. We have also implemented a collision detection algorithm so that we can simulate collisions and coalescence between finite-inertia particles. Once the 3D droplet triplet map, along with stochastic collision and coalescence, are implemented in the EMPM, we will be able to investigate the relative roles that entrainment and mixing, droplet inertial effects, and ultragiant nuclei play in warm rain initiation in cumulus clouds.

*Corresponding author address: Department of Meteorology, University of Utah, Salt Lake City, UT 84112. E-mail: steve.krueger@utah.edu

2. 3D TRIPLET MAP FOR DROPLETS

In contrast to the original EMPM, each droplet now has a 3D spatial location that evolves with time. Droplet displacements are based on the triplet map applied at that instant to the fluid cells, but with the following modification. Droplets are displaced by amounts $(1 + S)D$, where $D$ is the displacement in $x$, $y$, or $z$ due to the (continuum) fluid triplet map, and the additional displacement $SD$ represents droplet slip (motion relative to the the fluid). Here $S$ is analogous to the droplet Stokes number $St$. The triplet map is applied to only one coordinate direction ($x$, $y$, or $z$) at time. The coordinate is randomly selected for each map.

Despite the simplicity, and consequent computational efficiency, of this representation of droplet slip compared to the low-St droplet momentum equation, it captures a key feature of droplet motions. To define this feature, consider two droplet size categories, 1 and 2. Analysis and simulations have demonstrated that the probability $p(r)$ of finding a type-2 droplet at a location a distance $r \ll \eta$ from a given type-1 droplet obeys $p(r) \sim r^{-c}S_1S_2$, where $c$ is an empirical coefficient and $St_j \ll 1$ are droplet Stokes numbers for $j = 1$ and 2. The droplet Stokes number is defined as the droplet response time times the mean velocity gradient. This increasing probability with decreasing $r$ is the signature of droplet clustering.

Kerstein and Krueger (2006) proved mathematically that the stated model obeys $p(r) \sim r^{-c'}S_1S_2$ to leading order in $S_j \ll 1$, where $S_j$ denotes assigned values of $S$ for a given droplet pair, $j = 1$ and 2, and the constant $c'$ is determined from the analysis. This implies a proportionality between $S_j$ and $St_j$ that recovers the known result, expressed in terms of $St_j$. This result is an advance in the theoretical understanding of droplet clustering as well as a demonstration of the practical
utility of the model.

Figure 1 illustrates the excellent agreement between our results using the 3D triplet map and DNS (direct numerical simulation) results obtained by Reade and Collins (2000). There is also good agreement with the DNS results obtained by Franklin et al. (2005, 2007) who included droplet sedimentation due to gravity.

ACKNOWLEDGMENTS. This material is based upon work supported by the National Science Foundation under Grant No. ATM-0346854.

REFERENCES


