MODELING CLOUD PROCESSES USING THE QUADRATURE METHOD OF MOMENTS

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1. Introduction

The method of moments (MOM) allows the moments of a droplet size spectrum to be tracked directly in a simulation in place of having to track the distribution itself. The method has been used in cloud physics since the sixties with closure of the moment evolution equations obtained using assumed forms (typically Laguerre or log-normal) for the droplet size distribution [1].

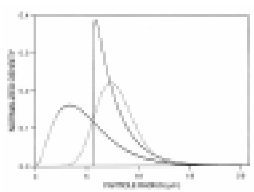
New approaches to closure have been developed in more recent years through the use of quadrature methods. The resulting quadrature method of moments (QMOM) enables closure under arbitrary growth laws without requiring an assumed form for the size distribution [2]. The QMOM has been applied to a number of problems requiring solution of the general dynamic equation for particle population balance and has recently been incorporated as an aerosol module into the NASA GISS global climate model [3].

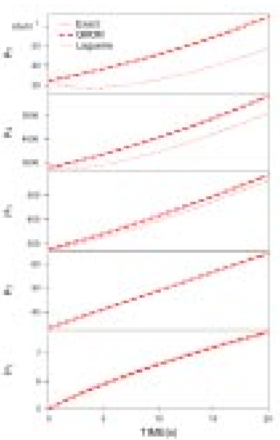
This poster presents a preliminary evaluation of QMOM use in cloud microphysical process simulation. Panel 2 gives a general illustration of QMOM applied to diffusion-controlled growth. Panel 3 applies the method to the much more difficult simulation of droplet evolution in turbulent clouds with droplets undergoing random fluctuations in growth/evaporation rate. Panels 4 and 5 describe turbulent coagulation/coalescence of cloud droplets and its effect on aerosol mixing state. QMOM accuracy is benchmarked by comparing with Monte-Carlo calculations using the particle-resolved simulation platform developed by Nicole Riemer and colleagues at UIUC.

2. Evolution of moments during diffusion-controlled growth

Below: Particle size distributions for growth of water drops at T=278K and fixed saturation S=1.01. Dotted curve, initial normalized K-M distribution with mean particle radius of 5 micron. Solid curve, exact distribution after 20s. Dashed-dotted curve, Laguerre distribution parameterized by the moments 0 through 2 after propagation to t=20s using the classic Laguerre closure method. (Even through initially the distribution has the assumed functional form it doesn't remain this way for long.

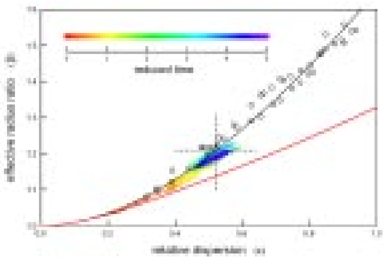
Right: Comparing moments obtained by the QMOM, which for this problem is exact for even-order moments, with the moments from Laguerre closure.





3. QMOM simulation of turbulent evaporation and growth

Unlike the previous example, this is a particularly difficult case for QMOM simulation: Turbulence fluctuations in S cause fluctuations in droplet growth/evaporation rates can easily result in negative particle radii an the required boundary conditions at r = 0 are notoriously difficult to impose using moment methods.

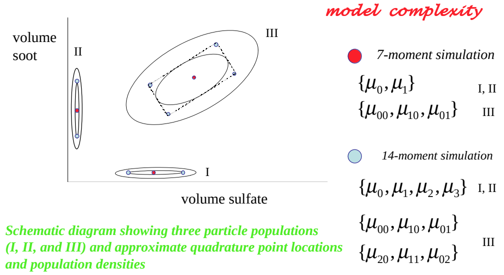


Color points show relative dispersion (standard deviation divided by the mean for the radial distribution) and effective radius ratio (ratio of the third to second radial moments divided by the cube-root of the third radial moment) from Monte Carlo simulation of an evolving 100 drop distribution as a function of reduced time [4]. Open circles, results from measurements of droplet size distributions in marine and continental clouds. Solid black curve, analytic results for family of Weibull distributions. Red curve, 5-moment Gauss-Radau QMOM simulation. Significant error occurs when the initial monodisperse distribution begins to reach the r = 0 boundary. Problem can be eliminated by constraining the droplet distribution to evolve in Weibull form (like early MOM). This expedient may not be bad given the demonstrated agreement between the Weibull family of distributions, Monte-Carlo simulation, and measurement .

4. QMOM VALIDATION USING PARTICLE-RESOLVED SIMULATION OF AEROSOL MIXING IN TURBULENT CLOUDS

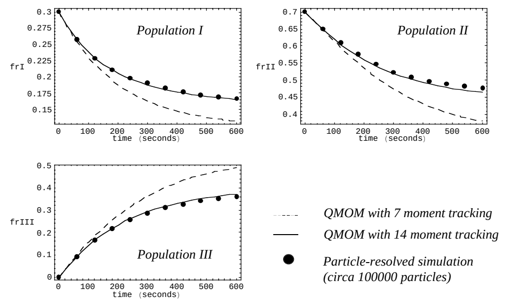
Ling Leng, Wei Zhu, Robert McGraw (QMOM)
Nicole Reimer (Particle Resolved Simulation)

Testing quadrature schemes of different model complexity



Schematic diagram showing three particle populations (I, II, and III) and approximate quadrature point locations and population densities

EVOLUTION OF PARTICLE NUMBER FRACTION



QMOM simulations on laptop in under 1 second

5. Summary

Moments of the cloud droplet distribution encapsulate an accurate description of cloud microphysical properties [5] and are efficiently computed for use as tracers to represent both aerosols and clouds and their interactions in global models. For this purpose QMOM simulation offers an attractive alternative to the more common sectional and modal methods with unique advantages for working in higher dimensions [3]. Of all the approaches available, the QMOM is by far the best suited to track the general mixing states of multivariate particle populations - such as populations of particles having mixed size, shape, and composition.

Acknowledgements

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References

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