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FY 2010 Second Quarter Report Evaluation of the Liu-Daum-McGraw (LDM) Drizzle Threshold Parameterization using Measurements from the VAMOS Ocean-Cloud-Atmosphere Land Study (VOCALS) Field Campaign

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1.0 Statement of the Metric

Metric for Quarter 2: Evaluate LDM (Liu, Daum, McGraw) drizzle threshold parameterization for a range of cloud conditions by comparing the threshold function computed using measurements of cloud droplet number concentration and cloud liquid water content to measurements of drizzle droplet number concentrations and/or drizzle water content.

Product Definition/Description: Report on results from model comparisons of threshold function versus measurements.

2.0 Introduction

During October and November 2008, Brookhaven National Laboratory (BNL) participated in VOCALS (VAMOS Ocean-Cloud-Atmosphere Land Study), a multi-agency, multi-national atmospheric sampling field campaign conducted over the Pacific Ocean off the coast of Arica, Chile. Support for BNL came from the U.S. DOE's Atmospheric Science Program (ASP) which is now part of the Atmospheric System Research (ASR) program following a merger with DOE's Atmospheric Radiation (ARM) Program. A description of the VOCALS field campaign can be found at

http://www.eol.ucar.edu/projects/vocals/

Archived data products are at:

ftp://ftp.asd.bnl.gov/pub/ASP Field Programs/2008VOCALS/Processed_Data/

See the First-Quarter Metric Report for a full description of the various files posted. To meet the goals of the second-quarter metric we require two of the files listed under this link. They are listed in Table 1.

Table 1. Archived Data used in Second-Quarter Metric.

Data	Files	Last Modified
Cloud droplet spectra	CASPart	5/20/2009
Drizzle spectra	CIPPart	5/20/2009

2.1 Defining the Parameterization

The LDM parameterization is a new parameterization based on the idea that drizzle formation is a statistical barrier-crossing phenomenon that transforms cloud droplets to much larger drizzle size at a rate dependent on turbulent diffusion, droplet collection efficiency, and properties of the underlying cloud droplet size distribution. The predicted threshold function for drizzle formation is given by Equations 2.1 and 2.2 (Liu et al. 2005):

$$x_c = 9.7 \times 10^{-17} N_D^{3/2} L^{-2} . \tag{2.1}$$

On the right-hand side N_D is the cloud droplet number concentration (cm^{-3}) and L is the non-dimensional volume fraction occupied by cloud the droplets (cm^3 cm^{-3}). L does not include drizzle.

$$T_{LDM} = \frac{1}{2}(x_c^2 + 2x_c + 2)(1 + x_c)\exp(-2x_c). \qquad (2.2)$$

Eq. 2.1 defines x_c, the reduced critical mass, which is equal to the ratio of the critical droplet mass to the mean cloud droplet mass. At the critical size fluxes for droplet growth by accretion (collection of smaller drops) and vapor condensation and droplet reduction by evaporation are in balance (See McGraw and Liu 2003, McGraw and Liu 2004 for the underlying theory.) Eq. 2.2 defines the threshold function T_{LDM} in terms of x_c (Liu et al. 2005).

3.0 Results

The data needed to evaluate T_{LDM} are contain in the CASPart files (Table 1): N_D is from the column headed "CAS tot N2", which sums populations throughout the bin diameter range from 1.66 to 56.3 microns. L is the total droplet volume fraction from the column labeled "CAS tot V", which sums droplet volume throughout the bin diameter range from 0.679 to 56.3 microns. Note that the difference in lower size limit is unimportant because the volume of droplets in diameter range 0.679 to 1.66 microns is an insignificant fraction of the total cloud droplet volume.

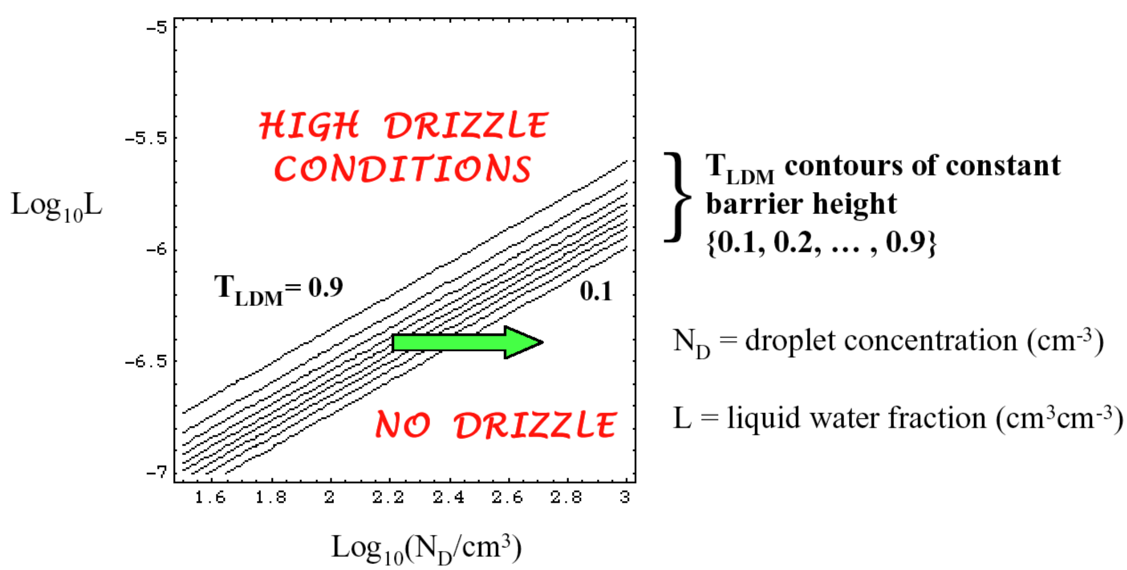

Figure 1. Comparison format. Contours of the LDM threshold function (solid lines) separate high drizzle and drizzle-free cloud conditions. An L value of 10^{-6} corresponds to about 1gram of cloud water per cubic meter. The arrow shows the affect of increasing cloud droplet concentration on suppression of the drizzle rate. The term "barrier height" refers to the drizzle nucleation barrier height = $2x_c/3$. See Eq. 2.1 and McGraw and Liu 2004 for a more complete description.

The data needed to evaluate drizzle drop number and/or volume are contained in the CIPPart files (Table 1). Here we report results in terms of the drizzle drop number concentration (units cm^{-3}). Drizzle is defined as the sum over CIP bin diameters from 52.5 to 922.5 micron. Note some (insignificant) overlap with cloud at the lower end of the drizzle spectrum and rejection of the largest bin (922.5-937.5 micron), which seems to have some spurious behavior.

We report results using the LDM diagram comparison format shown in Figure 1.

3.1 Selection of Cases

To meet our objective of testing the parameterization for a range of cloud conditions we chose three rather different cases: Case 1—a cloudy day with drizzle (10/28/08); Case 2—a cloudy day without drizzle (10/29/08); and Case 3—the heaviest drizzle day (11/01/08). CASPart and CIPPart files contain size spectra collected at 1-second intervals and 10-second time averages. Here we report comparisons using the 10-second averaged cloud and drizzle droplet spectra.

3.1.1 Case 1—Cloudy Day with Drizzle (10/28/08)

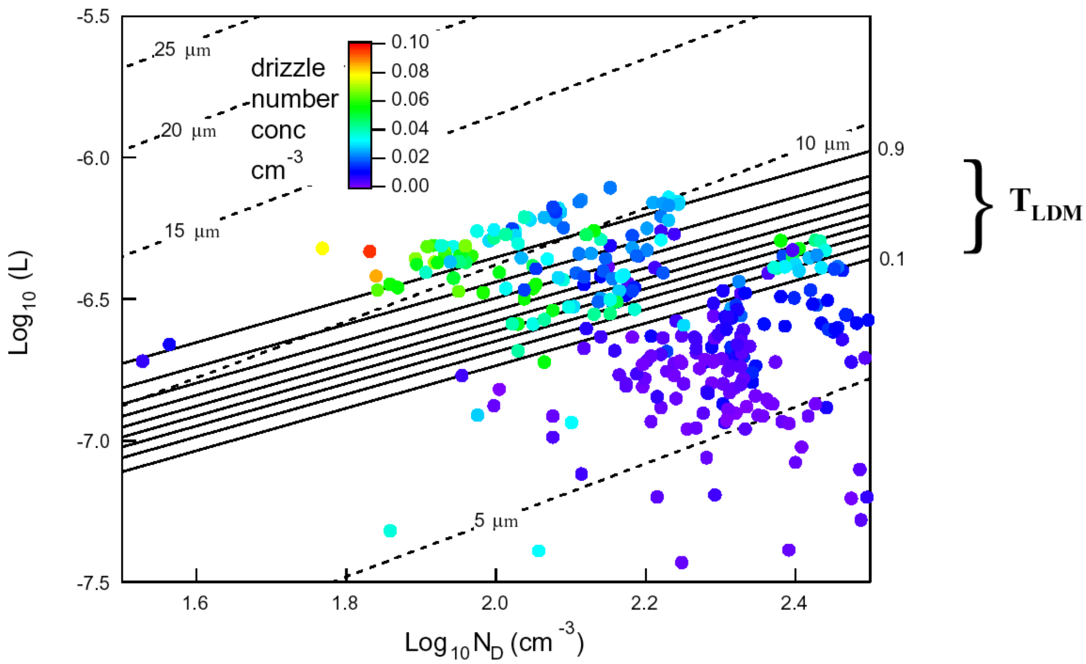

Figure 2. Contours of the LDM threshold function and mean cloud droplet radius. Solid lines, LDM threshold function: contour values from 0.1 (bottom) to 0.9 (top) in increments of 0.1. Dashed lines, mean cloud droplet radius: contours bottom to top (2, 5, 10, 15, 20, and 25) micron. Markers show CAS cloud data (diameters from 1.66 to 56.3 microns) rainbow colored according to drizzle drop number concentrations from the CIP data (red highest numbers, blue lowest).

We conclude from Figure 2 that the LDM threshold function is generally a good indicator of conditions where drizzle is formed. Exceptional points near 0.9 LDM contour line include those in the left portion of the figure corresponding to distributions having very low droplet number concentration, which might be an indication of aircraft sampling averaging cloud and non-cloud parcels, and several low drizzle (light blue) points above the 0.9 LDM contour line further to the right side of the figure. For the latter case we have no firm explanation but note that these points are associated with very narrow cloud droplet size distributions. The light blue and green points indicate the presence of small amounts of drizzle in the low-to-no drizzle regime are to be expected when precipitation produced higher up in the cloud falls through the sample region.

3.1.2 Case 2—Cloudy Day without Drizzle (10/29/08)

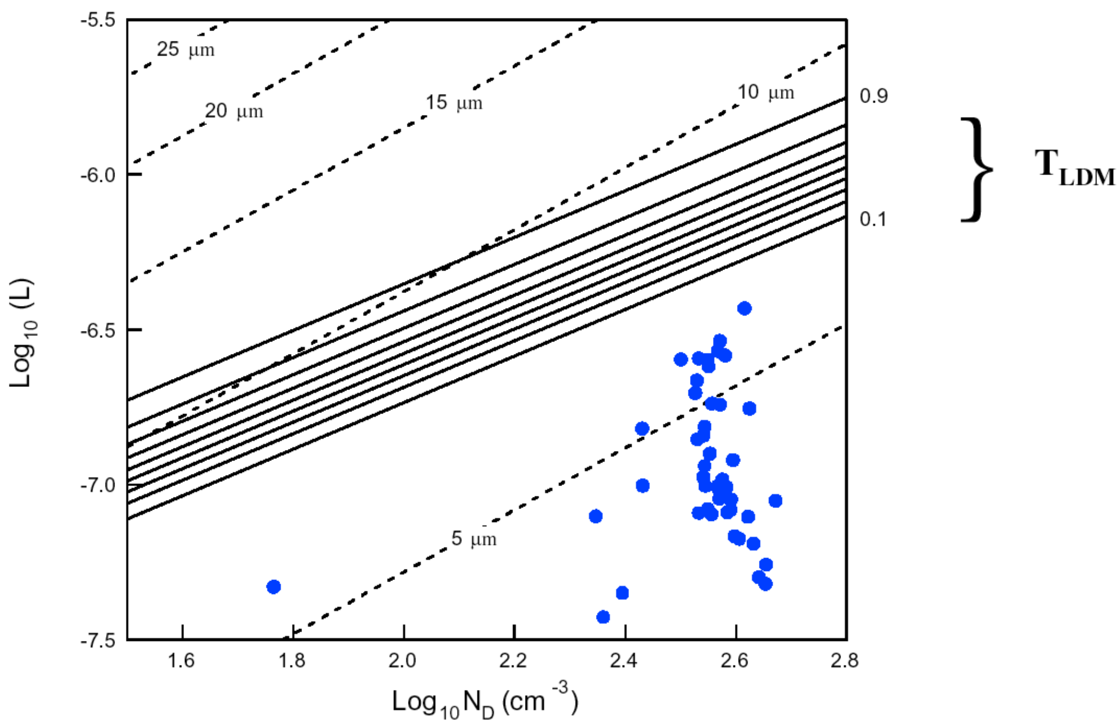

Figure 3. Same as Figure 2 except for a non-drizzle cloud day.

The high cloud droplet number concentrations are indicative of continental air mass on this day. Here the data points (blue) lie below the drizzle threshold as expected from the model.

3.1.3 Case 3—Heaviest Drizzle Day (11/01/08)

This day shows very high drizzle concentrations in regions that are below threshold (Figure 4 below). As was the case to a much lesser degree in Figure 1, this effect likely results from drizzle falling into the sampled cloud region from higher drizzle formation regions of the cloud.

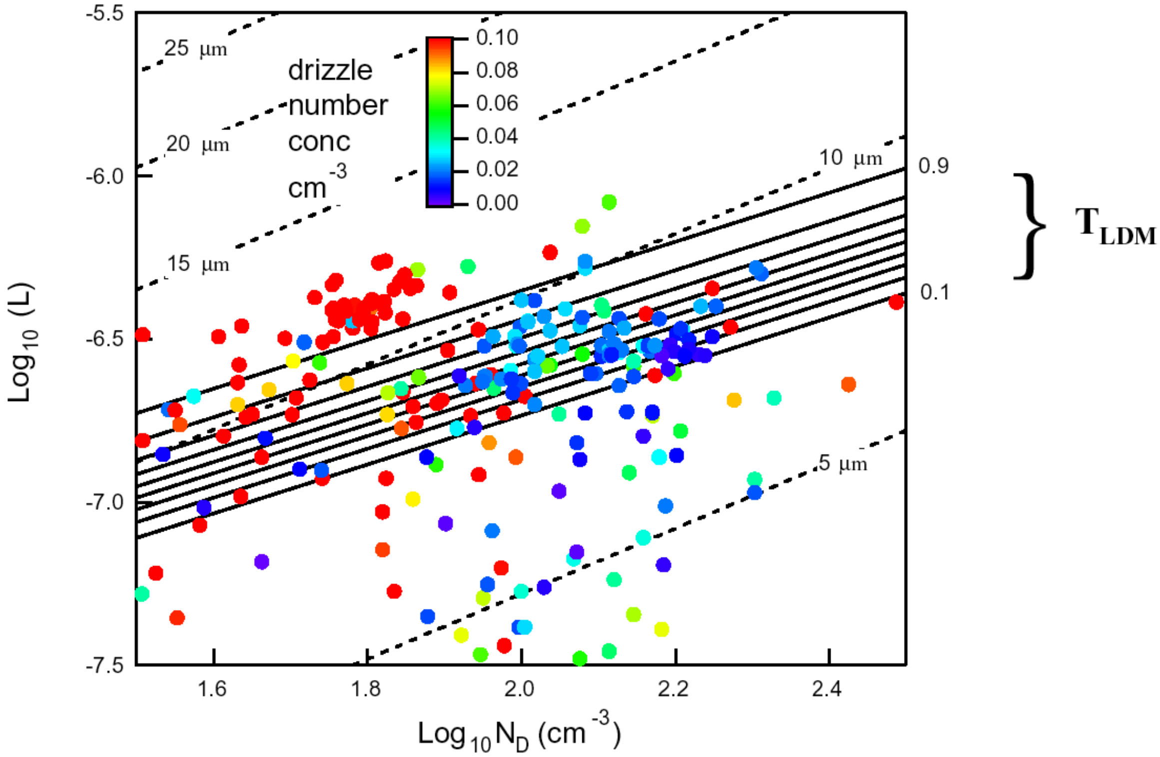

Figure 4. Same as Figures 2 and 3 but for the heaviest drizzle day.

4.0 Summary

The LDM drizzle threshold parameterization was evaluated for three cases that together span a wide range of cloud conditions. This report summarizes the results from this evaluation. From each 10-second averaged cloud sample we abstract the cloud droplet number concentration and cloud liquid water content from the CAS measurements. From this information we compute the threshold function using Equations 2.1 and 2.2. Alternatively, for values of the threshold function in the crossover regime between high drizzle and no drizzle, we can simply read off the threshold function using the solid contour lines shown in Figures 2–4. These figures provide three-dimensional comparisons between observation and prediction with color used to represent the third dimension—namely the observed drizzle droplet number concentration obtained from the CIP data.

We find that in general the LDM threshold function does a good-to-excellent job predicting cloud conditions that allow a classification into drizzle and non-drizzle regimes from the measurements. Drizzle drop number concentrations are highest where the threshold function is highest and absent where it is low. Under steady state conditions, the drizzle drop concentration when multiplied by the droplet loss rate should provide an estimate of the steady-state drizzle formation (or nucleation) rate. These and similar relations provide handles into predicting loss of cloud liquid water content and cloud lifetime reduction due to precipitation. Such logical extensions of the present metric are a current focus of research and will be included in future reports.

5.0 References

Liu, Y, PH Daum, and RL McGraw. 2005. "Size truncation effect, threshold behavior, and a new type of autoconversion parameterization." *Geophysical Research Letters* 32, L11811, 1–5.

McGraw, R, and Y Liu. 2003. "Kinetic potential and barrier crossing: A model for warm cloud drizzle formation." *Physical Review Letters* 90, 018501, 1–4.

McGraw, R, and Y Liu. 2004. "Analytic formulation and parameterization of the kinetic potential theory for drizzle formation." *Physical Review E* 70, 031606, 1–13.