3A.3 SEA SPRAY DROPLET MEASUREMENTS IN HURRICANES FABIAN AND ISABEL

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1. INTRODUCTION

Present parameterizations of air-sea fluxes are reasonably valid up to wind speeds of about 25 m/s. Extrapolation of these parameterizations to higher wind speeds are inconsistent with theoretical analyses of the strength of tropical cyclones [*Emmanuel*, 1995]. One major issue is the relative balance of momentum and scalar (heat/moisture) transfers. It is speculated that this balance is affected by evaporation of sea spray droplets at high wind speeds (u>25 ms^{-1}). At high wind speeds, the ocean is a major source of droplets produced by bursting bubbles and spume (i.e., the shearing off of wave tops) to the lower troposphere [*Edson et al.*, 1999]. Droplets may play a large role in latent heat transfer between the ocean and atmosphere [*Andreas et al.*, 1998; *Edson et al.*, 1999] and under extremely high winds such as found in hurricanes, may also have a large effect on the air-sea exchange of momentum. However, the relative importance of droplets in air-sea interaction at high wind speeds is largely unknown, due in large part to the difficulty in measuring droplet concentrations at high wind speeds [*Makin*, 1998]. If droplet concentrations were available, existing models of the atmospheric boundary layer (ABL) incorporating droplet dynamics could be employed to understand droplet-mediated fluxes.

The fundamental parameter required for representing the effect of sea spray on air-sea exchange processes is the size dependent *source function* for droplets (Fairall et al., 1994), or number of droplets of a given size produced at the sea surface per unit surface area per unit time as a function of wind speed. Because the source function cannot be measured directly at present, it must be estimated from the height-dependent number-size distribution of droplets, $n(r, z)$ (i.e., the number of droplets of given radius per unit volume of air per increment of radius at height z) and a model for the atmospheric boundary layer that incorporates droplet dynamics [*Kepert et al.*, 1999]. However, progress in determining the source function has been frustrated due to the difficulty of measuring $n(r, z)$. The present droplet parameterizations are based on very limited field data and inferences from various laboratory studies.

This paper describes recent measurements with an aircraft-mounted particle-sizing instrument during the Coupled Boundary Layer/Air-Sea Transfer (CBLAST) field program conducted on the NOAA WP-3 aircraft in the fall of 2003.

2. DROPLET MEASUREMENTS

The CBLAST flights used the Cloud Imaging Probe, CIP from Droplet Measurement Technologies (DMT). The CIP is a technology based on a linear array of light detecting diodes. As it transits the beam, the particle casts a shadow across the array and the size is deduced from the number of diodes that are occulted. This technique is a fairly mature technology and numerous papers have been written on deriving accurate droplet size information (*Baumgardner and Korolev*, 1997). Droplets are sized from 25 to 1550 μm diameter in 62 equally spaced 25 μm diameter bins.

Droplet data were obtained in low-altitude level flight segments (step descents) nominally between rainbands in hurricanes Fabian (Sept. 2, 3, and 4) and Isabel (Sept. 12 and 13). Steps were done at altitudes ranging from 66 to 760 m; wind speeds at 100 m were typically 29 ms^{-1}(equivalent to a 10-m wind speed of 24 ms^{-1}). The shortest step was 84 s and the longest was 1000 s; the typical step was about 300 s.

3. DATA ANALYSIS

Droplet concentrations are computed from droplet counts in each size bin using the expression

$$n(r) = \frac{TotalCounts(r)}{a\,U\,dt\,dr}$$

where U is true airspeed in cms^{-1}, dt the sample time interval, dr the sample radius bin width (12.5 μm), and a the size-dependent sample cross-sectional area in cm^2 (provided by the manufacturer). For this analysis, concentrations were computed for each step run yielding a set of 40 droplet spectra.

For the simple case of a near-surface source of droplets where the profile is a result of the balance of upward turbulent diffusion versus mean gravitational settling, the concentration at height z can be related to the concentration at height h

$$n(r,z) = n(r,h)\left(\frac{h}{z}\right)^{\frac{V_g}{\kappa u_*}}$$

where V_g is the size-dependent droplet fall velocity, κ is von Karman's constant, and u_* the friction velocity. Thus the concentration is expected to have a power-law decrease with altitude. For these data (u_* about 1.1 ms^{-1} based on mean wind speed), the powers are, for example, 1.5 and 3.4 for 100 and 200 μm radius droplets.

Fig. 1 shows the measured and expected concentration profiles for 100 μm droplets for each flight. The flights on Sept. 3, 4, and 12 indicate concentrations increasing with altitude, which we take as an indication of drizzle or possibly sea spray produced elsewhere in a stronger part of the storm and then advected into the region at altitude. Such conditions are not relevant to our attempts to relate sea spray droplet concentrations to local production, so we have used only the Sept. 2 and 13 flights for the remaining analysis.

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Given the wind speeds at the location of the step profiles, the counting statistics do not favor a detailed analysis of height dependencies. In Fig. 2 we show the sum of all droplets counted in the 10 usable profiles at altitudes less than 250 m (about 1 hour of data). The median droplet count (also shown) is 0 for droplets larger than 400 µm and significantly exceeds 1 only for droplets smaller than 100 µm. These results are shown in Fig. 3 for the concentration spectrum where the red line is the sum of two exponential distributions with radius modes of 10 and 100 µm.

The concentrations at r≈100 are consistent with near-surface measurements (e.g., De Leeuw, 1990), but the mean curve implies many more large droplets (r>500). At this writing it is unknown if this represents unexpected physics or a measurement/conceptual problem but we have yet to examine other sources of data from the flights.

ACKNOWLEDGMENTS

This work is directly supported by the Office of Naval Research and the NOAA Office of Global Programs. Thanks to Terry Lynch, Eric Uhlhorn, Pete Black, and many other members of the CBLAST P-3 team.

REFERENCES

Andreas, E. L., 1998: A new spray generation function for wind speeds up to 32 m/s. *J. Phys. Oceanogr.*, **28**, 2175-2184.

Baumgardner, D., and A. Korolev, 1997: Airspeed corrections for optical array probe sample volumes. *J. Atmos. Oceanic Tech.*, **14**, 1224-1229.

De Leeuw, G., 1990: Profiling of aerosol concentrations, particle size distributions and relative humidity in the atmospheric surface layer over the North Sea. Tellus, 42B, 342-354.

Edson, J.B., T. Paluskiewicz, L. Vincent, L. Goodman, T. Curtin, J. Hollister, and M. Colton, 1999: *Coupled Marine Boundary Layers and Air-Sea Interaction Initiative: Combining Process Studies, Simulations, and Numerical Models*, Office of Naval Research, Arlington.

Emanuel, K. A., 1995: Sensitivity of tropical cyclones to surface exchange coefficients and a revised steady-state model incorporating eye dynamics. *J. Atmos. Sci.*, **52**, 3969-3976.

Fairall, C. W., J. D. Kepert, and G. H. Holland, 1994: The effect of sea spray on surface energy transports over the ocean. *Glob. Atmos. Ocean System*, **2**, 121-142

Kepert, J.D., C.W. Fairall, and J.-W. Bao, 1999: Modelling the interaction between the atmospheric boundary layer and evaporating sea spray droplets, in *Air-Sea Fluxes of Momentum, Heat and Chemicals*, edited by G. Geernaert, Kluwer Academic Publishers, Norwell.

Makin, V. K., 1998: Air-sea exchange of heat in the presence of wind waves and spray. *J. Geophys. Res.*, **103**, 1137-1152.

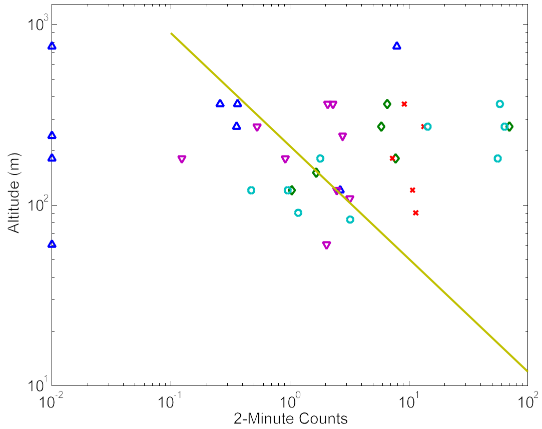

Figure 1. Droplet concentration at r=100 µm. Symbols for Sept. : 2 - upward triangle; 3 - diamond; 4 - x; 12 - o; 13 - downward triangle, line - expected profile.

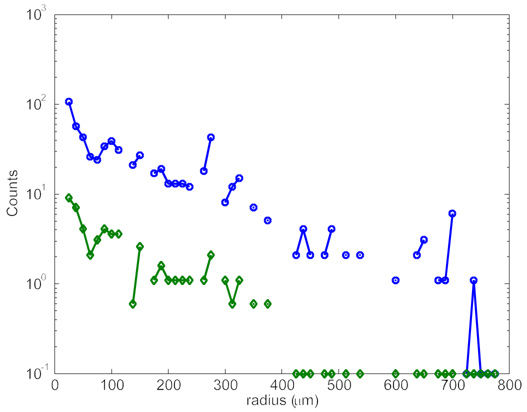

Figure 2. Droplet counts as a function of size for 10 level runs on Sept. 2 and 14: circle - total counts and diamond - median counts. A value of 0.1 has been added to indicate zero counts

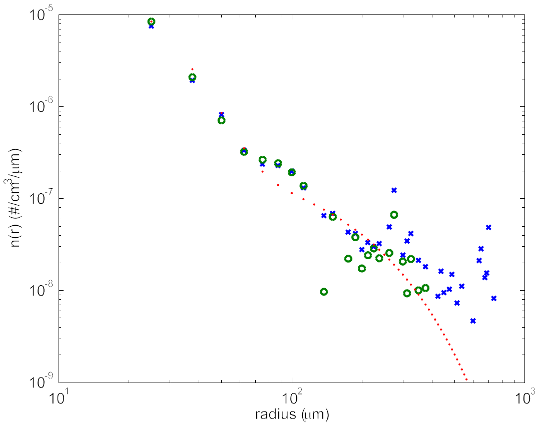

Figure 3. Droplet concentration spectrum combining 10 level runs below 250 m altitude: o - median; x - mean.