The Effect of Rain on Air-Water Gas Exchange

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Abstract

The relationship between gas transfer velocity and rain rate was investigated at NASA's Rain-Sea Interaction Facility (RSIF) using several SF₆ evasion experiments. During each experiment, a water tank below the rain simulator was supersaturated with SF₆, a synthetic gas, and the gas transfer velocities were calculated from the measured decrease in SF₆ concentration with time. The results from experiments with 18 different rain rates (7 to 110 mm h⁻¹) and 1 of 2 dropsizes (2.8 or 4.2 mm diameter) confirm a significant and systematic enhancement of air-water gas exchange by rainfall. The gas transfer velocities derived from our experiment were related to the kinetic energy flux calculated from the rain rate and dropsize. The relationship obtained for mono-dropsize rain at the RSIF was extrapolated to natural rain using the kinetic energy flux of natural
rain calculated from the Marshall-Palmer raindrop size distribution. Results of laboratory experiments at RSIF were compared to field observations made during a tropical rainstorm in Miami, Florida and show good agreement between laboratory and field data.
Figure 1: SF$_6$ concentration as a function of time during a typical experiment (log scale). The rain rate for this experiment was 82.2 mm h$^{-1}$ with 4.2 mm drops corresponding to a KEF of 0.91 J m$^{-2}$s$^{-1}$. Open squares = dilution (model) and filled circles = gas exchange plus dilution (measured). Gas exchange and dilution contributed 82% and 18% to the observed decrease in SF$_6$ concentration, respectively.
Figure 2: (a) Relationship between rain rate $R$ and gas transfer velocity $k(600)$. Circles = 2.8 mm drops; triangles = 4.2 mm drops. Enhancement due to 2.8 mm drops is typically 83% of 4.2 mm
drops. (b) Relationship between kinetic energy flux KEF and gas transfer velocity $k(600)$. Filled symbols = experiments with overflow; open symbols = experiments with no overflow; circles = 2.8 mm drops; triangles = 4.2 mm drops. The 2nd order polynomial fit to the data points is $k(600) = 2.94 + 77.45 \text{ KEF} - 25.81 \text{ KEF}^2$ ($r^2=0.992$).
Figure 3: (a) Comparison of relationships between rain rate $R_n$ and gas transfer velocity $k(600)$ (for between 0 and 25 mm h$^{-1}$): Dotted line from Banks et al. (1984); dashed-dotted line from Belanger
and Korzun (1991); solid line from this study (equation 20). (b) Relationships between rain rate $R_n$ and gas transfer velocity $k(600)$ derived from the Marshall-Palmer raindrop size distribution (equation 20).
Figure 4: SF$_6$ concentration decrease in the two pools with time (log scale) along with the rain rate during the Miami field experiment. Open squares = control; open circles = SF$_6$ evasion experiment; filled squares = rain rate (1 minute averages).
Figure 5: (a) Comparison of field and laboratory data on the relationship between kinetic energy flux KEF and gas transfer velocity $k(600)$. Open circles = laboratory experiments at RSIF
and filled squares = field data obtained in Miami, Florida. (b) Comparison of field and laboratory data on the relationship between rain rate $R_n$ and gas transfer velocity $k(600)$. Line = this study (equation 20); squares = field data obtained in Miami, Florida.