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Preliminary Investigations on the Influence of Rain on the Production, Concentration, and Vertical Distribution of Sea Salt Aerosol

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During the Humidity Exchange Over the Sea Main Experiment (HEXMAX) in October–November 1986, the vertical profile of a sea salt aerosol measured at 4.5 m, 12 m, and 18.3 m elevations, and its size distribution at 12 m elevation were investigated. Several data sets were collected under conditions of rainfall into the sea. These data indicate that the mass of marine aerosol is dramatically enhanced when the wind speed exceeds about 10 m s^{-1}. The vertical distribution of sea salt aerosol measured under such conditions showed a substantial mass accumulation within a few meters over the sea. With increasing wind speed, a marked shift in the size distribution of sea salt aerosol mass toward smaller particles, as well as a gradual shift toward larger sizes of particles, was observed. This indicates that under rainy and windy weather conditions, the direct splashing of raindrops and the bursting of bubbles produced as a result of drop impact may greatly enhance exchange processes between the air and the sea.

INTRODUCTION

Several marine aerosol production mechanisms can be identified. These include (1) the bursting of air bubbles at the sea surface, most prominently coupled with the presence of whitecaps [*Woodcock*, 1953; *Blanchard*, 1963; *Lovett*, 1978; *Garbalewski*, 1980; *Monahan et al.*, 1983 and other authors]; (2) atmospheric precipitation [*Blanchard and Woodcock*, 1957]; (3) the mechanical disruption of the sea surface roughness elements [*Monahan et al.*, 1983; *Marks*, 1988]; (4) wave breaking in coastal zones or at obstacles, such as icebergs [*Marks*, 1980]; and (5) wave amplification [*Resch*, 1982]. Droplet formation processes may also be modified by other meteorological and oceanographic conditions, such as the degree of saturation of oxygen in seawater [*Stramska et al.*, 1990], the static stability at the air-sea interface [*Monahan*, 1971; *Marks*, 1987], and water contaminants [*Blanchard*, 1963; *Woolf*, 1988].

To date, only the first of these mechanisms has been the subject of several field and laboratory experiments. Very little is known of aerosol production by the other mechanisms. This paper suggests the necessity of also regarding atmospheric precipitation as a primary marine aerosol production mechanism.

A literature search shows that only one laboratory investigation [*Blanchard and Woodcock*, 1957] was focused on this subject. In that paper the authors introduced the possibility that marine aerosols can be produced either directly from the impact of raindrops or from bubbles produced in the surface water as a result of droplet impact. Direct production of bubbles by raindrops appeared to increase with drop size. They observed that 3-mm-diameter drops produced about 100–200 bubbles, while 4.7-mm drops produced 200–400 bubbles. The bubbles from drops were carried down in a vortex ring motion to depths of 20–40 mm. With increasing drop size, the vortex motion of the bubbles and depth of penetration decreased.

The indirect production of bubbles by raindrops occurred when the daughter drops produced by the splash of raindrops fell back into the sea. The authors estimated that a drop of 5-mm diameter might be expected to produce nearly 900 splash drops of a size larger than 0.1 mm. They estimated production of airborne nuclei as about 14×10^4 m^{-2} s^{-1} for moderate rain intensities. However, this topic needs more thorough investigation using modern particle counters.

Bubble entrainment by the impact of raindrops has been the subject of numerous experiments aimed at elucidating underwater noise spectra [e.g., *Prosperetti et al.*, 1989]. A characteristic spectral peak at a frequency around 14 kHz has been established. It is argued that only raindrops in a restricted size range may have a high probability of entraining bubbles in surface water.

Subsequently, the first field observations of rain-mediated marine aerosol production and of the vertical distribution of sea salt aerosol are presented.

MEASUREMENTS AND ANALYSIS

The data were collected during the Humidity Exchange Over the Sea (HEXOS) Main Experiment (HEXMAX) in October–November 1986 from the Dutch research platform *Noordwijk*, located 9 km offshore in the North Sea. HEXMAX was the main effort of the HEXOS family of experiments focused on humidity exchange over the sea under moderate to high wind speeds.

This particular subprogram was designed to study the vertical profile of the total mass concentration of sea salt aerosol mass based on measurements at three heights, of approximately 4.5-m, 12-m, and 18.3-m elevation, and the sea salt aerosol size distribution at 12-m elevation. The five size classes corresponding to the five stages of impactor are characterized by the particle diameter end points of 7.2–30.0 μm, 3.0–7.2 μm, 1.5–3.0 μm, 0.95–1.5 μm, and 0.49–0.95 μm.

To collect the data for the vertical profiles, experimenters used a semi-isokinetic air sampling system with adjustable air speed at the inlet of the aerosol sample holders. The size distribution of sea salt aerosol aggregates was measured using a high volume cascade impactor (Model Sierra 230) at the 12-m elevation. Sampling units collected aerosols on Whatman 41 filters during 0.5- to 3-hour-long exposure periods, depending on air advection, and wind speed.

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