# Modelling the generation of marine aerosols at the sea surface*

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EDWARD C. MONAHAN
University of Connecticut,
Marine Sciences Institute,
Connecticut

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**Abstract**

The development of a model for the estimation of the local, instantaneous rate of sea spray production is presented.

## 1. Introduction

It has to date proved impossible to devise a method to measure directly the actual flux of aerosols up out of the sea surface, in circumstances where the surface was not sheltered, or conditions not otherwise modified from the natural state. Since, under all but the highest wind conditions, the marine aerosol particles are primarily produced by the bubble mediated mechanisms described by Blanchard (1963), it seems appropriate to construct a model that explicitly describes the droplets produced by oceanic whitecaps *ie* by the transient clusters of bubbles that appear on the sea surface as a consequence of wave breaking.

## 2. The model

The basic form of the sea surface aerosol generation model, where $\frac{\partial F_0}{\partial r}$ represents the number of aerosol droplets, *per* micrometer increment of

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droplet radius, produced *per* square meter of sea surface, *per* second, is as follows (Monahan *et al*, 1982):

$$\frac{\partial F_0}{\partial r} = \dot{W}\frac{\partial E}{\partial r}, \tag{1}$$

where $\dot{W}$ is the fraction of the sea surface from which whitecap bubble clusters disappear *per* second, and $\frac{\partial E}{\partial r}$ is the number of particles, *per* micrometer radius increment, produced during the decay of a unit area (1 $m^2$) of whitecap. Now $\dot{W}$ is given by (Monahan, 1971):

$$\dot{W} = W\tau^{-1}, \tag{2}$$

where $W$ is the instantaneous fraction of the sea surface covered by whitecaps, and $\tau$ is the time constant that defines the exponential rate of decay of the area of an individual whitecap. It should be noted that $W$ is a quantity that can only be evaluated from observations at sea (*eg* Monahan, 1971; Toba and Chaen, 1973; Bortkovskii, 1983) while $\tau$, whose value should ideally be assessed from cine-film or video observations of oceanic whitecaps, can also be determined from observations of small-scale whitecaps produced in the laboratory. A typical value of $\tau$ is 3.5 seconds.

The quantity $\frac{\partial E}{\partial r}$ is evaluated from measurements made in the laboratory whitecap simulation tank. The most recent results were obtained using a 3 m long tank with a deep central well. Two solitary waves, or under certain conditions, two bores, are caused to collide in the center of the tank (Monahan *et al*, 1982). The tank is covered with a plexiglas hood and the air beneath this hood is continuously circulated through filters so that there are negligible numbers of aerosol droplets present before a breaking/colliding wave event. The aerosol droplets injected into this enclosed volume of air during the decay of the whitecap produced in the simulation tank by a breaking wave are counted using a variety of aerosol counters/detectors. Specifically, $\partial E/\partial r$ is given by:

$$\frac{\partial E}{\partial r} = \Delta\left(\frac{\partial n}{\partial r}\right)A_0^{-1}, \tag{3}$$

where $\Delta\left(\frac{\partial n}{\partial r}\right)$ is the total number of aerosol particles, *per* micrometer radius increment, generated as a consequence of a single breaking wave event, and $A_0$ is the initial surface area, in square meters, of the resulting whitecap. A typical value for $A_0$ is 0.35 $m^2$.

The most recent version of $\Delta\left(\frac{\partial n}{\partial r}\right)$ is given by (Monahan *et al*, 1983):

$$\Delta\left(\frac{\partial n}{\partial r}\right)=4.40\cdot 10^5 r^{-3}(1+0.057 r^{1.05})\cdot 10^{1.19\, e^{-B^2}}, \tag{4}$$

where $r$ is the radius, in micrometers, of the marine aerosol droplets in equilibrium at $80^0/_0$ relative humidity, and $B$ is given by:

$$B=\frac{(0.380-\log r)}{0.650}.$$

The last term that must be quantified before this model can be used to assess the actual magnitude of the local, instantaneous, rate of marine aerosol production is $W$, the instantaneous whitecap coverage. Whitecap coverage is strongly dependent on 10 m elevation wind speed, $U$, for the reasons set forth in Wu (1979). Monahan and O'Muircheartaigh (1980) obtained the following optimal expression describing the dependence of $W$ upon $U$:

$$W=3.84\cdot 10^{-6}\cdot U^{3.41}. \tag{5}$$

## 3. Conclusions

The model described above has been used, with some success, as the sea surface source function in computer models of the sea salt aerosol population of the marine atmospheric boundary layer by Burk (1984) and by Stramska (1982, 1987).

Essentially, the same composite expression has recently been derived using a somewhat different modelling approach involving the initial bubble plume volume instead of the initial whitecap area (Monahan, 1986). A quite different, complementary approach to modelling the production of marine aerosols by whitecaps, incorporating measurements obtained in the laboratory from a covered weir/waterfall, has been set forth by Cipriano (1979) and Cipriano and Blanchard (1981).

All of the models developed to date deal primarily with the production of the supra-micrometer, essentially jet-droplet, aerosol. Recently, the gross production of sub-micrometer, primarily film-droplet, aerosol from laboratory whitecaps has been measured (Cipriano *et al*, 1987). The actual size spectrum of the film-droplets arising from the decay of a whitecap is yet to be described. At very high wind speeds, spume drops are produced directly by the mechanical disruption of wave crests (Monahan *et al*, 1986). The magnitude of this supplementary source of large spray drops has not yet been established.

Any future model of the aerosol production mediated by bubbles should take into account the observation that oceanic whitecap coverage depends on environmental factors in addition to wind speed (Bortkovskii, 1983; Monahan and O'Muircheartaigh, 1986).

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