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This Week's Citation Classic®

Blanchard D C & Woodcock A H. Bubble formation and modification in the sea and its meteorological significance. *Tellus* 9:145-58, 1957.
[Woods Hole Oceanographic Institution, MA]

Bubbles bursting at the surface of the sea are the origin of the sea-salt aerosol. They are produced primarily by air entrained by breaking waves, but both raindrops and snowflakes can be important bubble producers. Calculation shows that small bubbles may go into solution before rising to the surface. [The *SCI*® indicates that this paper has been cited in over 160 publications.]

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Early in the 1950s my friend and colleague, Al Woodcock, published papers on the size distributions of the small sea-salt particles in the marine atmosphere[1] and presented a hypothesis that these particles were the nuclei for the formation of raindrops.[2] We were then at the Woods Hole Oceanographic Institution. Woodcock had been there since the *Atlantis*, the institution's new ketch-rigged research ship, made her maiden voyage across the Atlantic Ocean from Copenhagen in 1931; he was one of the crew then. I, on the other hand, was a relative latecomer to the institution, starting work there in 1951, a few weeks after receiving my MS in physics. My ignorance of marine meteorology was offset by my enthusiasm toward the exciting ideas Woodcock had formulated over the years relating sea-salt particles to raindrops.

It was evident that the salt particles began their journey into the atmosphere as small droplets of seawater, but the details were shrouded in mystery. How exactly were the droplets produced? Some evidence pointed to air bubbles bursting at the surface of the sea, so we took high-speed movies of bubble bursting and found that upon bubble collapse a jet of water rose rapidly upward from the bubble cavity to produce several droplets. These jet drops, plus film drops, another class of drops produced by the bubble,[3] appear to be the origin of most of the sea-salt aerosol.

But how are bubbles produced in the sea? This question led to the study that became our *Citation Classic*. We soon realized that anything that disturbed the surface waters produced bubbles, so we started experiments on bubble production by observing breaking waves and raindrops and snowflakes falling into the sea. The bubbles in breaking waves along the shore were captured and measured with a small bubble trap that we built. Those from snowflakes provided a special challenge. As we stood in a snowstorm holding a beaker of seawater, it seemed an eternity before a snowflake fell into the water. When one did, however, it was then a race against time to get a cover slip over the bubble and measure it under the microscope before it disappeared by going into solution. Bubble production by raindrops was simulated in the laboratory by dropping water drops from pipettes down a stairwell into a tank of seawater. New secretaries at the institution, watching these strange antics, sometimes doubted our sanity.

I suspect the reason this paper is so frequently cited is that it was the first to explore in detail the way in which bubbles are produced in the sea. Other researchers continue this work today. It is of interest not only to atmospheric scientists who study the sea-salt aerosol,[4] but also to the Navy and its concern with the interference by bubbles of the propagation of sound waves in the sea.[5]

1. **Woodcock A H.** Salt nuclei in marine air as a function of altitude and wind force. *J. Meteorology* 10:362-71, 1953. (Cited 140 times since 1955.)
2. ———. Atmospheric salt particles and raindrops. *J. Meteorology* 9:200-12, 1952. (Cited 55 times since 1955.)
3. **Blanchard D C.** The electrification of the atmosphere by particles from bubbles in the sea. *Prog. Oceanogr.* 1:71-202, 1963. (Cited 155 times.)
4. **Monahan E C.** The ocean as a source for atmospheric particles. (Buat-Menard P, ed.) *The role of air-sea exchange in geochemical cycling*. Norwell, MA: Reidel, 1986. p. 129-63.
5. **Crawford G B & Farmer D M.** On the spatial distribution of ocean bubbles. *J. Geophys. Res.—Oceans* 92:8231-43, 1987.

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