SHORTER CONTRIBUTION

Freezing nuclei in marine waters

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1. Introduction

Inorganic soil materials (Isono et al., 1959; Mason, 1960) and extraterrestrial meteoritic particles (Bowen, 1956; Bigg, 1963) have been suggested as possible sources of atmospheric ice nuclei which play important roles in the production of precipitation. Recently, decomposition products of terrestrial vegetation (Schnell & Vali, 1972) have been shown to be good ice nucleators and these sources were found to be world-wide (Schnell & Vali, 1973) with the abundance of the nuclei dependent upon local climate.

As an extension of the research on the land sources of nuclei, it seemed desirable to examine whether sources of nuclei might also exist in the oceans. Samples of surface seawater were collected in the Pacific Ocean off Vancouver, B.C., Canada (January) and Huntington Beach, California, USA (June); in the Caribbean off Nassau, Bahamas (April) and in the Atlantic at Bedford, Nova Scotia, Canada (May). The freezing nucleus contents (drop freezing technique) of the samples were determined within two hours to three days of sample collection following the technique given by Vali (1971).

2. Results

From the results shown in Fig. 1 it may be seen that the Bedford samples (curve 4) exhibited considerably greater freezing nucleus concentrations than seawater from the other areas (curves 1, 2, 3). Beford Basin had experienced a "bloom period" of phytoplankton growth just prior to sample collection so the possibility suggested itself that the high concentration of nuclei might be related to this fact.

Masses of plankton and associated detritus were sieved from the top two feet of the ocean surface at Bedford. Sieving was done with ship-towed 20 μm plankton nets which were allowed to saturate so that even the smallest particles would collect on them. Analysis showed that 95% (by mass) of the captured material was phytoplankton and 5% zooplankton. No accurate measurements were made of the amount of organic debris in the samples though it appeared from microscopic examination that this mass was greater than the living component. A portion of the moist captured material was prepared for freezing nucleus measurements (within two hours of collection) by reinserting one gram of material into 100 g of the original seawater (i.e., seawater shown in curve 4). The mixture was agitated, allowed to settle for five minutes and then filtered through coarse paper. The turbid filtrate was tested for freezing nucleus content and yielded curve 5 in Fig. 1. The difference between curves 4 and 5 (ratio of 10^3 in concentration at $-10°C$) shows that there indeed are nuclei associated with the plankton matter and suggests that the original activity in this seawater sample was also due to the presence of plankton matter. These nuclei are referred to in the following as ocean-derived nuclei (ODN).

Seawater has a melting point depression of 2°C due to dissolved salts. The inherent nucleating ability of the plankton material can be better evaluated by suspending the sample in distilled water—one gram of plankton matter in 100 g of distilled water yielded the spectrum given by curve 6 in Fig. 1 (the concentration

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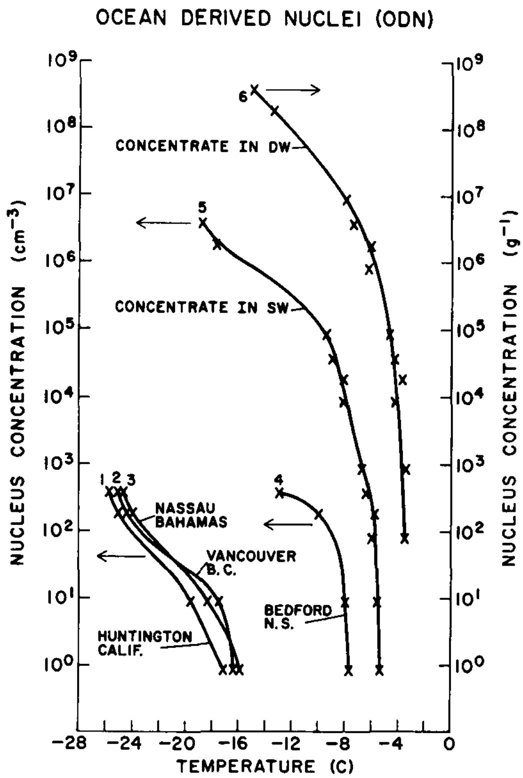

Fig. 1. Freezing nucleus spectra of seawater of low activity (curves 1, 2 and 3) and high activity (curve 4). Activity of plankton concentrate from Bedford Basin is given by curves 5 and 6.

here is expressed per unit mass of solid matter). It may be seen that one gram of Bedford Basin sievings contained nuclei active even at $-3.5°C$, and 10^7 nuclei per gram were active at $-10°C$.

The seawater samples were kept at room temperature for seven months and their freezing nucleus contents were measured periodically. Within three weeks the concentration in the Bedford sample (curve 4) had deteriorated to 1% of its former value, and after seven months, this sample had a nucleus spectrum similar to the low-ODN samples (curves 1, 2, and 3) which showed no change at all over the same period. A portion of the Bedford sample was stored frozen over the same period; there was no loss of freezing nucleus activity in this sample. Tests have shown the ODN to be less than 1 μm in diameter (membrane filtration), susceptible to heat (destroyed at 95°C) and easily aerosolized and recovered with nucleation activity intact. These characteristics of ODN are similar to those for leaf-derived nuclei (LDN) (Schnell & Vali, 1972 and 1973).

3. Discussion and conclusions

The transfer of material from the oceans to the atmosphere is well documented. Specifically for organic matter, Blanchard (1964) found that bubbles bursting at a water surface could eject high concentrations of organic material into the atmosphere. Goetz (1965) captured sub-micron-sized organic particles emanating from oceanic areas. ZoBell & Matthews (1936) and Stevenson & Collier (1962) showed that air above oceans contained numerous micro-organisms indigenous to marine waters. Research into the source of organic compounds found in snow and rain falling in New Zealand (Wilson, 1959) and in Sweden (Newman et al., 1959) suggested a marine source for the materials.

Atmospheric ice nuclei measurements over the southern seas were reported by Bigg (1973) for a three-year period. His data showed the presence of bands of high concentrations of airborne ice nuclei along latitudes 40° and 55° S; these bands coincide with zones of the highest primary marine production in the world (Fairbridge, 1966). This correlation supports (although does not uniquely prove) our suggestion.

In summary, the evidence indicates that oceans harbor, in association with phytoplankton, copious numbers of active freezing nuclei. These nuclei may contribute strongly to the local concentrations of atmospheric ice nuclei in regions of high primary oceanic productivity and may also add to the general global background of ice nuclei.

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