Network images of drainage channels in sea spray icing by MR microscopy

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Abstract

An MR imaging system was developed to visualize brine drainage channels in sea spray icing. Brine pockets trapped in spray-ice matrices during ice growth are structural features of sea spray icing. Brine in the spray ice sample had drained out; therefore, using a suction pump, we filled the air gaps in the drainage channels with dodecane. In the experiments, 0.5–1.0 h was necessary to accumulate signals sufficient to obtain a 3-D micro-image; the image matrix comprised 128\textsuperscript{3} voxels (each voxel was 200 \textmu m per side). The MIP view showed that sea spray icing has a developed drainage-channel network structure.

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1. Introduction

Reduced visibility due to sea spray ice accretion is a major problem for the operation of northern harbor lighthouses. Spray icing also causes marine disasters for trawlers and vessels in cold areas. Brine pockets trapped in spray-ice matrices during ice growth are a structural features of sea spray icing. Salt entrapment and brine drainage control the growth rate and physical properties of spray ice.

Recent studies have investigated the physical properties and growth mechanism of sea spray ice \cite{1–3}. Since NMR is sensitive to brine, mixtures of brine and ice dispray contrasting images \cite{4–7}. We are unaware of studies on sea spray icing using MRI. We developed an NMR imaging system with a temperature-controlled chamber to visualize the 3-D drainage-channel structure in sea spray ice.

2. Methods

An NMR imaging system comprising a 4.74-tesla, 89-mm, vertical-bore superconducting magnet and an actively shielded gradient coil generated three-dimensional microscopic images \cite{8} using 3-D gradient echoes. The image matrix comprised 128\textsuperscript{3} voxels (each voxel was 200 \textmu m per side). Since the spray ice grew during high tide and in strong-wind weather conditions, sampling the growing ice accretion was difficult. Samples were obtained from ice accretion on a breakwater lighthouse in calm weather conditions when brine in the spray ice had drained out. Therefore, using a suction pump, we filled the air gaps in the drainage channels with dodecane (C\textsubscript{12}H\textsubscript{26}). Signals sufficient to locate the brine pockets were derived from dodecane doped with iron acetylacetonate C\textsubscript{15}H\textsubscript{21}O\textsubscript{6}Fe \cite{9}.

To reduce noise, we accumulated signals for 0.5-1.0 h. The prolonged measurement period, necessitated using the specimen-cooling system developed for snow-structure measurement. MR imaging of spherical ice and dodecane indicated a negligible magnetic susceptibility artifact between ice and dodecane \cite{9}.

3. Results

3.1. Sea spray ice in nature

Samples were obtained from ice accretion on an Atsuta Harbor lighthouse on the west coast of Hokkaido, Japan.
A northwesterly wind generated spray on the sea-facing side of the harbor, the spray drifted intermittently toward the lighthouse. Icing grew on the leeward side of the lighthouse and the presence of growth rings is suggested (Fig. 1). The 2-8 \%e salinity of the samples indicates that the brine in the spray ice had almost drained out.

Since the NMR signal from ice was negligible compared with that from dodecane, the drainage channels appear as bright regions (Fig. 2).

We visualized the drainage channels using MIP and 3-D rendering. The spray ice thickness of 5 mm (Fig. 3) indicates that the sea spray icing has a developed drainage-channel network structure.

### 3.2. Laboratory ice-accretion experiments

Brine pockets and channel formations in the wet growth of spray ice were investigated. The apparatus was arranged in a cold room (-10 °C). Dual-spray nozzles supplied small water particles (~0.1 mm diameter) that were drifted to a film specimen. Wind speed during the experiment was 2-3 m/s. Supplied water salinity was ~35\%. Icing occurred on the windward side of the film. The presence of brine pockets and channelized networks in the accreted ice was confirmed. The outer surface showed remarkable irregularities.

The spray ice was 1.2 mm thick (Fig. 4). Bright regions indicate brine pockets replaced by dodecane. Channelized...
networks in artificial spray ice were identified although typical drainage-channel development of natural spray ice was not reproduced.

4. Conclusions

An MR imaging system was developed to visualize brine drainage channels in sea spray icing. Brine in the spray ice had already drained out; therefore, using a suction pump, we filled the air gaps in the drainage channels with dodecane. The MIP view showed that sea spray icing has a developed drainage-channel network structure.

Conversely, a channelized brine network was confirmed in the artificial spray ice, although the drainage-channel development was not reproduced. This variance is possibly due to the spray ice growth mechanism.

Quantitative analyses necessitates direct comparisons of the ratio of open channels with dodecane and closed channels with brine; nevertheless, this experiment shows that the drainage-channel structure in sea spray ice can be imaged using MR microscopy.

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References