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An Heuristic Freezing Spray Model of Vessel Icing

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ABSTRACT

An heuristic model of vessel spray icing is presented. A spray/air heat balance is applied under one of two assumptions: the first, that the spray supercools; and the second, that the spray is nucleated. The nucleated spray model produces theoretical icing rates 300% to 400% greater than the supercooled version. In this way, a mechanism for severe icing is proposed. The environmental conditions leading to nucleated spray are not certain but near-freezing sea-surface temperatures, low air temperatures, and snow are suspected. The supercooled and nucleated models perform well against data and other icing models.

INTRODUCTION

In January 1955, the loss of the trawlers *Lorella* and *Roderigo* to freezing spray in the fishing grounds north of Iceland (Hay, 1956) signalled the beginning of over three decades of investigation into the vessel icing problem. The need for effective vessel icing forecasts continues to increase with activity in high-latitude oceans. Various methods of vessel spray icing prediction have been developed over the years, including those of Kachurin et al. (1974), Stallabrass (1980), Overland et al. (1986), Zakrzewski and Lozowski (1987), Horjen (1989) and Blackmore et al. (1989).

Most spray icing algorithms may be categorized as either statistical models (SM), statistical-physical models (SPM), or physical-empirical models (PEM). The SM does not account for the physics of the icing process except insofar as the wise choice of input parameters is a matter of physics. Like the SM, the SPM assumes that forecast icing events will differ little from events in the data set. However, the SPM uses a physical model around which the statistics are organized, hoping thereby to produce a better predictor. These core physical models have, in some cases, been surprisingly complex, with little to demonstrate that such complexity is essential to model performance. The PEM is typically a more recent approach, with a fuller overview of the physical processes of vessel icing and reduced dependence on icing data sets. The modeller may have a greater sense of control but may need to invoke a proliferation of model assumptions, and possibly may end with as much or more empirical dependence as the SPM. Blackmore and Lozowski (1992) provide further comments on some of these modelling issues.

The present work introduces a PEM based on a framework of vessel icing physics, and yet more concise than many simple SPMs or PEMs. The empirical component of the model describes the vessel's spray generation and is based on field data. As an heuristic model it has been conceived for the purpose of investigating as many aspects of ship icing as possible. In this paper the model is described, its performance compared with data and other models, its sensitivity examined, and finally a mechanism for severe icing postulated and explored.

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BASIC MODEL ASSUMPTIONS

In an attempt to increase usefulness, many vessel icing models maintain generality by neglecting vessel size and shape. We suggest simplicity as an alternative, and model vessel shape and size above the water line by the vessel's length, L, beam, B, and freeboard, F_B. The resulting rectangular parallelepiped collects only a portion of the spray generated by ship/wave interaction and accretes ice only on the upper rectangular surface. The portion of spray not collected by the vessel is returned to the sea. The portion collected by the vessel is assumed to pass through vertically oriented access "windows" on the perimeter of the upper surface. The wind is assumed to accelerate this spray in such a way that it passes through the access window and impinges on the rectangular upper surface representing the vessel's topside. The total flux of brine is a product of the spray flux intensity and the upwind projected area of the access window. This area depends on the vessel's length, beam and encountering angle, which is defined as the angle between the direction of wave travel and the direction of the ship's heading. The encountering angle is 180° for head seas, 90° for beam seas, and 0° for following seas.

The model avoids the complication of cyclical spray generation due to periodic encounter with waves by assuming continuous spray. This simplification may have important ramifications. Brown and Roebber (1985) suggest that the rapid temporal variations in spray observed over vessels are likely to have a significant effect on the mass and energy transfers at the ice accretion surface. Modelling these processes is difficult, but modelling intermittent spray delivery itself may be even more difficult, since the frequency, intensity and distribution of spray probably depend in a complex way on seastate, vessel operation and hull design. It is to avoid such difficult modelling problems that continuous spray is assumed.

The complexities inherent in the dynamic and thermodynamic evolution of sea spray are sidestepped by assuming that the attainment of dynamic and thermodynamic equilibrium is complete by the time the spray passes the access window and impinges on the vessel. Thermodynamic equilibrium here means that the entrained air, which is initially at the ambient temperature, T_a, comes to thermal equilibrium with the spray brine. The temperature of the spray envelope over the vessel, T_s, therefore, is assumed to be the temperature of both the air and brine in the spray downwind of the access window. In this way, the spray brine undergoes cooling from the sea-surface temperature, T_{ss}, to