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Introduction

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Modelling of sea-ice phenomena

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1. Introduction

The focus of the present theme issue is on significant recent advances in the understanding and modelling of floating sea ice. This also follows an extended and concerted research programme held in late 2017 at the Isaac Newton Institute in which the mathematics of sea-ice phenomena was addressed. Other forms of ice are included where they help with the phenomenological and/or methodological understanding of sea-ice behaviour. The heart of the theme here is associated with consistent modelling of facets of sea-ice mechanics and thermodynamics, as well as sea-ice interactions with fluids and solids. Particular studies are on multi-scale modelling of ice characteristics and behaviour, ice–fluid interaction, coupled problems of ice-structure interaction, and ice fracture and cracks. Environmental aspects of ice-related problems are included when they relate to sea-ice mechanics, and congruent industrial icing problems are also discussed.

The topic is appropriate for a theme issue because of its depth, breadth and timeliness. The content is of a fully inter-disciplinary nature throughout. The new developments presented and discussed hinge on the advances of modelling of ice-related problems giving an appropriate level of both physical and mathematical rigour to such problems. The theme aims to help towards

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defining a state of the art in floating ice research, but especially sea ice, drawing on contemporary wisdom for the full range of natural ice types on the Earth including other manifestations of freshwater ice where they assist thinking. This describes problems that have required the urgent attention of mathematicians and physicists and it speaks to a scientific network on ice research in order to help coordinated efforts to tackle existing and future problems. Parts of the work here are centred on relatively poorly explored areas. The theme brings together researchers from different fields (including those from disciplines not exclusively directly related to ice problems, such as fracture mechanics) in groups on modern problems of ice dynamics, to formulate new models and to discuss strategies for their solutions. The theme also brings new specialists with new ideas and non-standard approaches and techniques to the challenging problems of ice mechanics. The recommendations and other outcomes of this theme issue are to be disseminated to the industrial and academic communities. In bringing together researchers from applied mathematics and specialists on ice physics and congruent fields, with a focus on appropriate modelling of ice-related effects and phenomena, we aim to distinguish the more scientific aspects of ice-related problems, to draw modelling talent together, and interest the network uniting all such problems and corresponding developments into one picture.

There is a strong history of polar exploration and ice research. More countries are active in industrial applications and theoretical support of ice-related problems. Nowadays industry is looking to the polar regions for new oil/gas fields. Wind, wave and tidal energy converters can be installed in areas affected by ice. Ice-induced damage to wind turbine blades and power lines is reported regularly. Climate changes are making ice problems ever-more important, and various countries are leading many aspects of climate modelling and climate sea-ice model development. Other important industrial applications are aircraft icing and vehicle icing, where again modelling and analysis advance understanding and prediction. There is substantial industry interest in ice/fluid interactions, on airborne or seaborne vehicles and on exposed structures in storms. Important subjects concern the impact and break-up of flying ice lumps and shards, the formation of ice on solid surfaces during impacts, ice shedding and bouncing along wet or dry surfaces, often involving multiple complex events. These require understanding of air–water–ice interactions with or without an accompanying solid surface and accommodating phase transitions. Similarly interactions between floating ice plates and man-made structures (ships, offshore platforms, wind turbine blades, aircraft) are of particular importance. In the Arctic particularly, the many effects of floating ice are an everyday constituent of operational environments. Consistent models of sea-ice rheology and microstructure evolution based on first physical principles will form the basis of new climate-model representations valid under a broad range of environmental conditions. The likely impact is thus through benefits to the scientific community and industry. There could well be wider public interest given the well-publicized rapid reduction of sea ice in the Artic and the implications of this for local communities, trade, mineral exploitation, ecology and tourism. This might extend to influence on policy decisions.

The modelling that is addressed in the theme issue comprises major contributions from researchers in mathematics, physics, engineering, environmental, computational and analytical fields along with observations, applied to sea-ice phenomena. The expertise is brought together in an inherently cross-disciplinary way. The list of authors and titles covers four areas within the theme. The first of these is *Ice fracture and cracks*. All types of floating ice contain cracks that span a range of scales. The theory of cracks in different classes of ice, with account for inclusions and potentially the presence of fluid, will be addressed from an enhanced mathematical and physical basis. The second is *Coupled problems of ice-structure interaction.* Free-boundary problems of ice-cover dynamics and statics, icing and hail impact, models of interaction between ice and offshore structures with ice crushing, breaking of ice, working on ice and ice-induced vibrations are the focus of this area. Third is *Ice–fluid interaction*. Models of floating ice behaviour in waves for homogeneous and stratified fluids, flows in the ice skeleton and mass transport, ice drift, thermodynamics and hydrodynamics of flows under a floating ice cover are described in this area. The fourth area is *Multi-scale modelling of ice characteristics and behaviour*, an area which relates to the rheology of ice, ice crushing, poroelastic and viscoelastic models of ice, homogenization techniques, percolation theory and variational formulations.

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