



## **Sea-ice hazards, associated risks and implications for human activities in the Arctic**

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Polar sea ice serves important functions in the Earth system, including as climate regulator, habitat for diverse biological communities, or substrate and platform for a range of human activities. Subsumed under the concept of sea-ice services, polar ice covers are associated with benefits and risks of harm to ecosystems and people. Recent changes in Arctic ice extent, thickness and mobility have transformed services derived from sea ice. We summarize how these changes have diminished some benefits derived from the ice cover, while increasing others. More important, growing maritime activities in the North and a changing ice cover drive a need for better understanding of sea-ice hazards and the risk they represent in the context of human activities in the Arctic. Three major aspects of this problem are: (1) Broader risks associated with a rapid reduction in summer ice extent, such as geographic shifts in marine ecosystems and warming of submarine permafrost and adjacent land; (2) hazards resulting from changes in sea ice extent and dynamics such as increased coastal erosion and threats to infrastructure; and (3) risks derived from the combination of sea-ice hazards and human activities such as shipping or offshore resource development. Problem (1) is typically seen as a slow-onset hazard that requires a response in the form of mitigation and adaptation. At the same time, the importance of linkages between summer sea-ice reduction to processes outside of the Arctic has only recently emerged (such as atmospheric circulation patterns and extreme weather events) and remains difficult to quantify. Hazards and risks subsumed under (2) and (3) are more localized but with potentially major ecological and socio-economic consequences beyond the Arctic. Drawing on examples from our research in Alaska, we review and illustrate key aspects of sea-ice hazards in terms of risks to ecosystems, people and infrastructure in the coastal zone and Arctic shelf seas. In the Pacific Arctic sector, major reductions in summer sea ice extent and presence of multiyear ice have exposed large stretches of coastline to warmer waters and increased fetch, contributing to increased coastal erosion and thermal subsidence of permafrost. Changing ice dynamics, with reductions in the persistence and stability of shorefast ice and increases in sediment transport by sea ice, aggravate these processes. A case study from our coastal ice observatory at Barrow, Alaska in conjunction with analysis of remote sensing data on coastal ice persistence and stability illustrates some of these processes. For maritime activities, sea-ice hazards can result in substantial risks, e.g., of major oil spills or accidents, if conflated with faults or failures of equipment, procedures or decision-making. Our current understanding of key sea-ice processes that govern its role as a hazard needs to be updated in light of rapid changes in Arctic marine environments. This will be illustrated by examples drawn from a study to provide baseline data in the evaluation of threats to coastal and offshore infrastructure.