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SCIENCE DIRECT

Cold Regions Science and Technology 42 (2005) 41–51

cold regions science and technology

www.elsevier.com/locate/coldregions

Climate change impacts on the Beaufort shelf landfast ice

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Received 28 June 2004; accepted 1 December 2004

Abstract

We use a one-dimensional thermodynamic sea ice model and modified meteorological data from the Tuktoyaktuk station to simulate the thickness and duration of the landfast ice under possible climate change scenarios. An increase of 4 °C in surface air temperature and 100% in snow accumulation rate results in a 39-cm reduction in yearly maximum ice thickness and a 21-day reduction in ice duration. However, owing to large natural variability, even such a large (22%) change would require roughly 8 years to observe and confirm. Standard errors of ± 17 cm for maximum ice thickness and ± 9 days for ice duration were estimated by comparing the ice thickness simulated using meteorological forcing from 3 coastal stations. With respect to interannual variation in maximum ice thickness, only 2 of 6 pairs of coastal stations had correlation coefficients significant at the 95% confidence level. Low correlations are a consequence of varying snow accumulation amongst stations. This result emphasizes the urgent need for marine-based observations of solid precipitation for understanding change in the thickness of landfast sea ice.

Keywords: Beaufort Sea; Landfast ice; Climate change; Ice thickness

1. Introduction

Landfast ice is an important component of the seasonal ice regime off the Mackenzie River in the Beaufort Sea. It extends seaward from the coastline to where water is approximately 20 m deep and covers approximately 35×10^3 km^3 between 128° and 139° W longitude. Great shear and compression at the boundary between the landfast and moving pack create a zone of highly deformed ice–called the ‘stamukhi’–that is hundreds of kilometres long with ridges 10–20 m thick. The stamukhi forms an inverted dam that impounds river inflow to create a lake, named Lake Herlinveaux by Carmack and Macdonald (2002). A long, recurrent flaw lead typically forms seaward of the stamukhi.

The landfast ice and its associated components serve various natural, social and economic func-

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doi:10.1016/j.coldregions.2004.12.001

tions. It is a birthing platform for ring seals (Smith and Hammill, 1981). Lake Herlinveaux is a unique but poorly understood winter habitat for marine life (cf. Carmack and Macdonald, 2002). Timing of freeze-up and break-up is critical to migratory birds and mammals (Frost and Lowry, 1984). Open water associated with the flaw polynya provides a rich habitat and migration pathway for marine animals (cf. Bradstreet, 1982). The landfast ice acts as a natural barrier to protect the inshore seabed from ice-ridge scouring (Barnes et al., 1984) and the shoreline from wave-induced erosion. The ice road network joining Inuvik and Aklavik to Tuktoyaktuk is an important transportation corridor for Northern residents. Now, with demands for oil and gas development, there is growing interest in landfast ice as a platform for exploration and exploratory drilling. In recent years, for example, there has been increased use of ice roads for oil and gas exploration and for positioning of equipment. There is concern for the potential danger to seabed installations that the ice-ridge density at the edge of the landfast ice could pose. But there is little understanding about how this critical regime may respond to altered climate; indeed, landfast ice is not, at present, even incorporated in global climate models. The purpose of this work is to explore this issue by modelling the thickness of landfast ice under reasonable scenarios of climate variability.

Observed surface air temperature over the 20th century has warmed by about 5 °C/century (Anisimov and Fitzharris, 2001). Global climate models predict warmer future air temperature and more precipitation in the Arctic. The general consensus from the global climate models comparing the scenario for 2080 to that of the present in the 2001 ICPP report (Anisimov and Fitzharris, 2001), is that the increase in summer surface air temperature (0.5–4.5 °C) over the Arctic Ocean will be less than in winter (3.0–16.0 °C). Precipitation increase are also predicted to be greater in winter (2–45%) then in summer (2–25%).

In addition to temperature, ice growth and decay are extremely sensitive to snow cover. Snow depth is substantially different from one meteorological station to the next, and from land stations to stations on ice (Hanesiak et al., 1999). Variations in timing and amount of annual snowfall are found to be one of the main influences in landfast ice thickness variability (Flato and Brown, 1996; Brown and Cote, 1992). In this study, we quantify the changes in maximum ice thickness and ice duration that result from using meteorological forcing from several coastal stations in the Beaufort region, and use these to define uncertainty for the simulated ice thickness in climate change runs.

To assess the sensitivity of the landfast ice thickness and duration to changing surface air temperature and snow accumulation rate, we use the average annual cycles from 1970–2002. We increase the annual mean temperature by 1,2 4, and 8 °C, decrease it by 1, 2, and 4 °C, and increase the snow accumulation rate 5% to 300% and decrease it by 10% to 50%. Sensitivity to change is then examined using a response diagram, as was done by Brown and Cote (1992).

2. Sea ice model

The details of the model are given in Flato and Brown (1996). The model calculates the ice surface temperature using the surface energy balance, which is calculated using daily surface air temperature (SAT), wind speed, cloud amount, and relative humidity. Snowfall rate is also required as forcing. Using the ice surface temperature, the heat conduction through the ice is computed and then used to calculate changes in ice thickness. The model accounts for 'slush ice,' which occurs when the overlying snow cover has been submerged below the surface of the ocean. This portion of the submerged snow cover then turns into ice. The model outputs are daily ice thickness, duration of open water, and amount of slush ice formed. Note that the model only accumulates snowfall if ice is present and the air temperature is below freezing.

Because meteorological data over the landfast ice of the Beaufort Sea are insufficient, we use data from the closest land-based station; Tuktoyaktuk Airport (Tuk A) for 1970–2002, modified to force the ice model for the climate change scenarios. Present-day simulations are also carried out using 14 years of forcing from nearby stations. A map of the study area and locations of stations is shown in Fig. 1.

Precipitation is a difficult meteorological variable to measure accurately. Topography and snow drift