

Variations in Air-ice Drag Coefficient Due to Ice Surface Roughness

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ABSTRACT

Wind profiles collected by satellite-tracked ice beacons and ice surface roughness data by a helicopter-borne laser altimeter are used to study variation in the air-ice drag coefficient due to surface roughness of the pack ice in Canada's Gulf of the St. Lawrence. The results show that the air-ice drag coefficient referenced to 10 m (C_{10}) varied by an order of magnitude from 0.5×10^{-3} over smooth ice with above-freezing air temperatures to 5.4×10^{-3} over rough ice with below-freezing air temperatures. This range includes the value of 2.8×10^{-3} used by ice-ocean modelers to forecast ice drift along the Canadian east coast. Laser data showed that the root-mean-square (rms) elevation was 0.07 m for the smooth ice and 0.29 m for the rough ice. Linearly relating the roughness to the drag coefficient appears promising, but more data are required. With remotely sensed imagery increasing its capability to the classification of ice types and ice roughness conditions, variable drag coefficients based on imagery may become available for ice-ocean models.

INTRODUCTION

Although variations in the air-ice drag coefficient, C_{10} , have been measured for a wide range of ice conditions (Overland, 1985; Andreas et al., 2001), accurate measurements of surface roughness, ice concentration and floe size with which to relate to the drag coefficients are generally not available. In some cases, such as the Weddell Sea pack ice, the roughness is mainly caused by the snowdrifts, whose pattern and thus C_{10} vary as the varying wind continually reshapes the snow topography (Andreas and Chaffey, 1995). Using visual estimates of ice concentration and floe size, the coefficient is highest in the marginal ice zone when the ice concentration is 8/10, and the pack ice consists of brash ice and small floes, which provide more ice edges per unit area (Anderson, 1987). A similar peak in C_{10} was seen in the year-long Beaufort Sea data in August 1998, when the lead and pond fractions are maximized (Andreas et al., 2001). For large floes in the Beaufort Sea, C_{10} was linearly related to the root-mean-square surface elevation measured with a level and rod (Banke et al., 1980). Helicopter-borne laser altimeters and video cameras can monitor surface roughness, ice concentration and floe size to the accuracy and spatial intervals required to relate variations in the wind profile properties to surface roughness and ice concentration (Lalumiere et al., 2000). Numerical ice-ocean models are now capable of following particles and their properties within numerical grids (Flato, 1993; Sayed and Carrieres, 1999) so that models can employ and benefit from air-ice and ice-water drag coefficient parameterisations that are based on observed ice properties. In addition, remotely sensed imagery may be able to provide on a larger scale a means to identify and track different pack-ice properties, such as the roughness and ice concentration required in the parameterisation of drag coefficients. The object

of this paper is to present the results of a field program investigating the variability of the air-ice drag coefficient due to variations in ice roughness and ice concentration as observed with a helicopter-borne video/laser system. Both temperature and wind profiles from upcoming surveys will investigate the additional influence of the atmospheric stability on the drag coefficient.

FIELD WORK

During the winter of 1998–99, a field program was started in the southern Gulf of the St. Lawrence, Canada (Fig. 1), utilizing Canadian Coast Guard BO-105 helicopters to deploy satellite-tracked ice beacons instrumented with R&M Young anemometers, and to collect ice property data with helicopter-borne sensors. Although the observation program is continuing, this paper will deal only with the 1998–99 data, when 2 different sites were occupied. One site was north of Prince Edward Island (PEI) on a small floe surrounded by rough pack ice; the other was southwest of PEI in Northumberland Strait on a smooth, large ice floe surrounded by similar floes.

The site north of PEI was in a large, rough pack-ice area characterised in the RADARSAT SAR image of February 26, 1999 (Fig. 2) by a number of bright leads presumably containing brash ice, and by an absence of large flat floes. For about a week before deployment, pack ice north of PEI was compacted against the coast by northerly winds. The pack ice in the vicinity of the site was heavily ridged and contained only a limited number of flat floes large enough to land on and deploy beacons. Fig. 3 shows a photograph of the site and beacons. The floe consisted of a flat, 30-m \times 50-m pan surrounded by ridges up to 1.5 m high, with a mean height of 0.8 m from 14 samples. The mean thickness of the undeformed, level section of the floe was 0.52 m, from 5 auger-hole measurements. Wind profile data were collected at this site on February 22–27, after which the pack ice around the site was blown to the north away from the Island. All air temperatures from the Confederation Bridge, Charlottetown airport and Magdalen Islands (Fig. 1) increased from daily mean lows of -15°C on February 22 and 23 to 0°C on February 27, as a warm front from the south pushed the cold Arctic air mass northward (Fig. 4).

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KEY WORDS: Air-ice drag coefficient, wind speed, pack ice, ice roughness, ice concentration.