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Drag on a sphere in moving temperate ice

D. Cohen, N. R. Iverson, and J. Byers
Department of Geological and Atmospheric Sciences, Iowa State University, Ames, IA, 50011, USA (dcohen@iastate.edu)

Glacier dynamics, sediment transport, and erosion are controlled in part by forces at the interface between basal ice and bedrock. One such force is the drag ice exerts on the bed as it slides past bedrock obstacles. Another is the contact force between a clast and the bedrock. These forces affect many processes, such as basal friction that regulates sliding speed, slip resistance and associated seismic stick-slip, and abrasion that controls rates of erosion, landscape evolution, and production of sediment. Direct field or laboratory measurements of these forces are lacking. Here we report laboratory measurements of the drag force on a sphere in ice (physically analogous to ice sliding past a hemispheric obstacle) and describe future experiments in which the contact force between the same sphere and a flat bed will be measured.

A single apparatus was designed to measure drag in the two experiments. The apparatus consists of a cylindrical polycarbonate vessel, 24 cm high and 20 cm in diameter, containing ice at the melting temperature. A hydraulic press keeps the pressure in the ice at 1.0–1.5 MPa. Ice temperature is controlled by circulating a fluid at a precise temperature in channels inside the polycarbonate vessel and in its lid. Ice moves downward inside the polycarbonate chamber by melting at its base. The melt rate is controlled by circulating another fluid through the bed. The temperatures of both fluids are controlled to within ± 0.01 K by two independent external circulating baths. To measure the drag force for the case of an isolated sphere, it is suspended on Kevlar filaments attached to a load cell above the apparatus. The sphere—50 mm in diameter and plastic to suppress regelation—remains fixed as ice melts at the bottom of the cylinder and moves past the sphere. To measure the contact force for the case of a sphere on the bed, the sphere presses on a ceramic rod that transmits the load through the bed to a load cell beneath the apparatus. Temperature is monitored with thermistors at the ice-bed interface and in the ice. Ice motion is measured with a LVDT. Water pressure at the ice-bed interface is measured with two piezometers. Three drains in the bed remove melt water. The water pressure underneath the sphere is controlled by a valve in the bed.

For the case of an isolated sphere, drag forces were between 90 and 840 N for ice velocities between 0.1 and 2.4 mm d^{-1}, respectively. Comparison of these values with a numerical model of Newtonian ice flow past a sphere yields an ice viscosity of 8.5×10^{10} Pa s, in accord with other measurements. Comparison of the data with a model with power-law rheology indicated that ice behaved near-Newtonian at low ice velocities (0.1 mm d^{-1}) but with a Glen's exponent near 3 at higher velocities.