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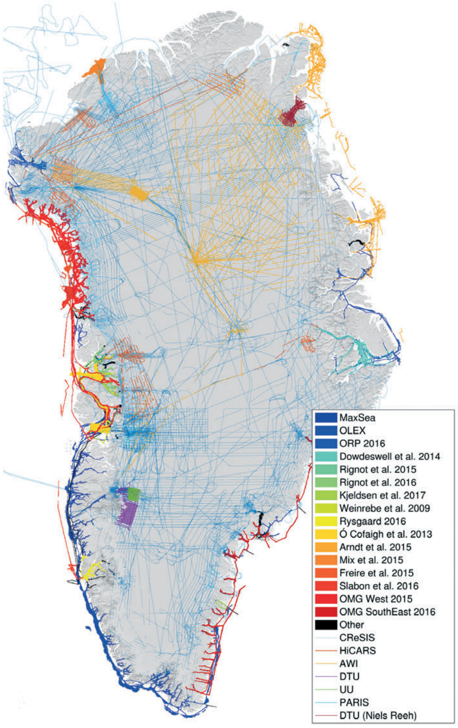

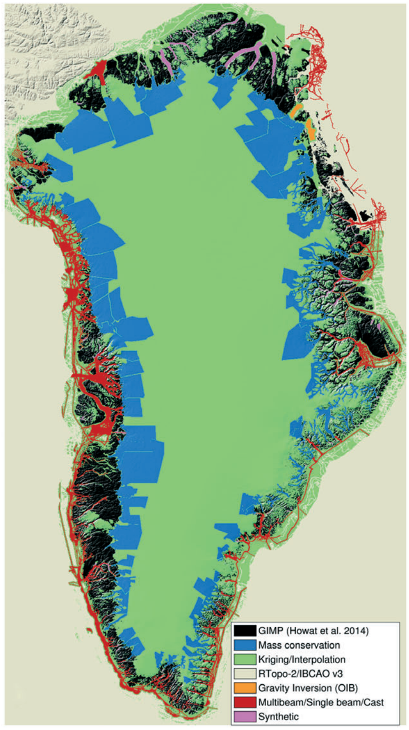

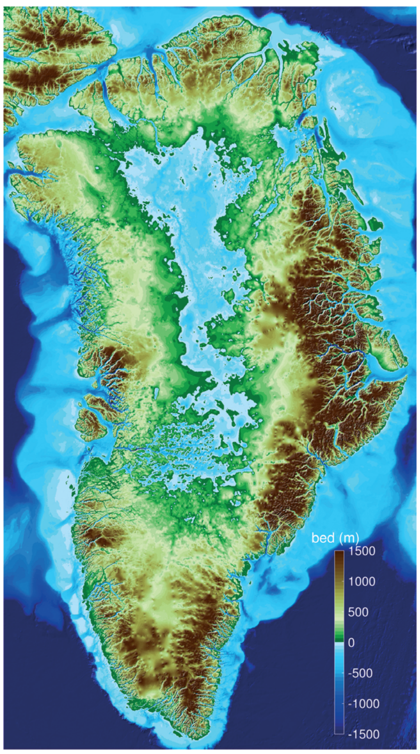

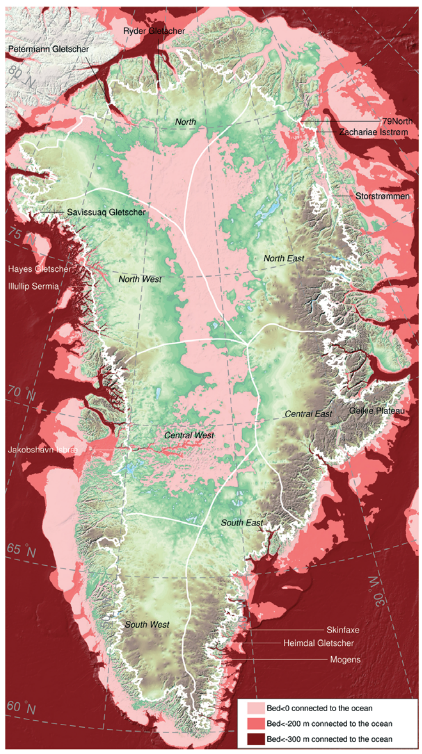

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Cover: Figures 1 and 2 from Morlighem et al. presenting a new high-resolution bed map of the Greenland ice sheet and ocean bathymetry, with a seamless transition across glacier termini. The map combines mass conservation and newly collected ocean bathymetry data from NASA's Oceans Melting Greenland (OMG) Mission and includes bathymetric data from previous marine surveys. See also Morlighem et al. [pp. 11,051–11,061, doi: 10.1002/2017GL074954].

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RESEARCH LETTER

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Key Points:

- Collisions between nanoscopic ice grains are explored using molecular dynamics simulations
- Collision-induced heating leads to grain melting in the interface of the colliding grains
- Collision dynamics is strongly influenced leading to grain sticking and deformation

Correspondence to:
H. M. Urbassek,
urbassek@rhrk.uni-kl.de

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Collision-Induced Melting in Collisions of Water Ice Nanograins: Strong Deformations and Prevention of Bouncing

Maureen L. Nietiadi[1], Philipp Umstätter[1], Iyad Alabd Alhafez[1], Yudi Rosandi[2], Eduardo M. Bringa[3], and Herbert M. Urbassek[1]

[1]Fachbereich Physik und Forschungszentrum OPTIMAS, Universität Kaiserslautern, Kaiserslautern, Germany, [2]Department of Geophysics, Universitas Padjadjaran, Jatinangor, Sumedang, Indonesia, [3]CONICET and Facultad de Ciencias Exactas y Naturales, Universidad Nacional de Cuyo, Mendoza, Argentina

Abstract Collisions between ice grains are ubiquitous in the outer solar system. The mechanics of such collisions is traditionally described by the elastic contact theory of adhesive spheres. Here we use molecular dynamics simulations to study collisions between nanometer-sized amorphous water ice grains. We demonstrate that the collision-induced heating leads to grain melting in the interface of the colliding grains. The large lateral deformations and grain sticking induced considerably modify available macroscopic collision models. We report on systematic increases of the contact radius, strong grain deformations, and the prevention of grain bouncing.

1. Introduction

In the outer solar system, ice particles are ubiquitous (Gudipati & Castillo-Rogez, 2013); they appear as interplanetary dust particles (Grün, 2007; Tielens, 2005), in planetary rings (Esposito, 2010), and in the dust tails of comets (Bentley et al., 2016; Langevin et al., 2016). In the early history of the solar system, they contributed to the protoplanetary disk from which ultimately planets, moons, and other bodies of the solar system emerged (Blum, 2010; Birnstiel et al., 2016). Collisions between such particles may lead to particle agglomeration or fragmentation and thus determine their size distribution (Bridges et al., 1996; Dominik & Tielens, 1997). In addition, also silicate dust particles may be covered by an ice layer the properties of which will be relevant for the collision outcome.

The description of grain collisions is usually based on the contact mechanics of elastic adhesive bodies, such as the Johnson-Kendall-Roberts (JKR) theory (Johnson et al., 1971). For the case of macroscopic ice grains — in the range of millimeters or above — this approach allows to describe experimental data successfully (Bridges et al., 1996; Higa et al., 1998; Schäfer et al., 2007; Krijt et al., 2013).

Wettlaufer (2010) proposed that ice melting can drastically influence the collision dynamics of water ice grains. He focused on collisions of larger bodies, and of small grains with large, meter-sized bodies. He found that apart from the low-speed fusion and the higher-speed bouncing regimes, at even higher speed the collision partners may agglomerate again (so-called reentrant agglomeration regime) due to collisional melting or other solid-solid phase transformations that dissipate collisional energy. His results are relevant for the physics of the protoplanetary disk as a model to prevent the so-called accretion bottleneck (Armitage, 2010), which lets meter-sized agglomerates lose contact with the disk and spiral fast into the central star thus preventing planet formation; due to the collisional fusion mechanism, meter-sized agglomerates can grow fast enough to avoid this bottleneck.

Collisions between nanoscopic ice grains, on the other side, are relevant for the initial stages of grain growth in the protoplanetary disk beyond the snow line, where small grains may grow through collisional accretion to larger objects (Chokshi et al., 1993; Dominik & Tielens, 1997). Collisional melting and the suppression of the bouncing regime may result in a faster buildup of larger agglomerates.

Here we explore to what extent the collision of nanoscopic ice particles can be described by macroscopic contact theory. Using molecular dynamics (MD) simulation, we show that collision-induced heating may melt