Journal of Geodynamics 48 (2009) 195–203

Contents lists available at ScienceDirect

Journal of Geodynamics

journal homepage: http://www.elsevier.com/locate/jog

Ground deformation and gravity variations modelled from present-day ice thinning in the vicinity of glaciers

A. Memin[a,*], Y. Rogister[a], J. Hinderer[a], M. Llubes[b], E. Berthier[b,c], J.-P. Boy[a]

[a] IPGS-EOST, CNRS/UdS, UMR 7516, 5 rue René Descartes, 67084 Strasbourg Cedex, France
[b] Université de Toulouse, UPS (OMP-PCA), LEGOS, 14 Av. Edouard Belin, 31400 Toulouse, France
[c] CNRS, LEGOS, 14 Avenue Ed. Belin, 31400 Toulouse, France

ARTICLE INFO

Keywords:
Ground tilt
Gravity variations
Elastic deformations
Present-day ice thinning

ABSTRACT

The solid Earth deforms because of post-glacial rebound due to the viscous relaxation following the last deglaciation but also because of present-day elastic deformation induced by ice thinning. In this paper, we compute elastic loading Green's function associated to the tilt of the ground in the vicinity of glaciers using a Love number formalism for a stratified non-rotating spherical Earth model. We compare this global approach with the plane approximation in terms of height, gravity and tilt changes as a function of the distance from the measurement point to the load. We find that Green's functions for the vertical displacement (resp. horizontal displacement, elastic part of the tilt) agree to within 1% up to ∼400 m (resp. 2 km, 5 km) from the glaciers. Two specific cases of ice thinning are considered: (1) the alpine glaciers of the Mont Blanc region (France) where ice-thickness variations are derived from differential digital elevation model analysis for the period 1979–2003; (2) the Svalbard (Norway) glaciers by considering the ice model SVAL. We show that the rates of ground tilt are well above the limit of detection of up-to-date long-base hydrostatic tiltmeters, which, if installed next to the glaciers, could be used to monitor the time evolution of ice thinning. We also show that the topography has a strong influence on the gravity variations near the glaciers.

1. Introduction

Since the end of the little ice age, most ice masses on Earth have experienced a reduction of their volume (Vincent et al., 2005; Rabatel et al., 2008) and, recently, an acceleration of the ice-thinning rates has been observed over many ice-covered areas (Meier et al., 2007). Rapid ice thinning has been reported on the Greenland (Howat et al., 2007; Stearns and Hamilton, 2007; Barletta et al., 2008; Slobbe et al., 2009) and the West Antarctic ice sheets (Cazenave, 2006; Rignot et al., 2008; Barletta et al., 2008; Horwath and Dietrich, 2009), large icefields in Patagonia and Alaska (Arendt et al., 2002; Rignot et al., 2003; Chen et al., 2006, 2007), ice caps in Iceland (Magnùsson et al., 2005), as well as on mountain glaciers, for instance in the Alps (Berthier et al., 2004), Svalbard (Kohler et al., 2007) or Himalaya (Berthier et al., 2007). Ice-thinning rates range from a few tenths of centimetres per year, in Svalbard, for instance (Kohler et al., 2007), to several meters per year such as in the French Alps (Berthier et al., 2004) and can reach more than 10 m per year in Greenland (Howat et al., 2007; Stearns and Hamilton, 2007).

Past and present-day ice thinning induce a deformation at the Earth surface that has been observed in GPS and gravity measurements close to the shrinking ice bodies (Pagli et al., 2007; Sato et al., 2006; Sjöberg et al., 2004; Khan et al., 2007). Knowing the current ice-thickness variations, from differential analysis of digital elevation models (DEMs), one can estimate the ground deformations and the gravity changes. Using the World Glacier Inventory database, Barletta et al. (2006) have shown that, in the European Alps, the highest elastic rebound (0.9 mm/yr) due to current ice melting is located in the Mont Blanc area. The reduction in ice volume also induces a tilt of the ground that, close enough to the glaciers, should be detectable by modern tiltmeters, which are already used for monitoring small deformation of the ground due to hydrological loads (e.g. Rerolle et al., 2006) or ocean tide loading (e.g. Llubes et al., 2008).

In this paper, we investigate the solid Earth deformation induced by the thinning of three glaciers in the Mont Blanc massif (Mer de Glace, Talêfre, Leschaux) and in Svalbard (Norway) in the Arctic. In the Alps, we consider ice-thinning rates derived from differential DEMs that provide a 24-year long evolution of the ice thickness (Berthier et al., 2004) whereas in Svalbard our analysis is based on the SVAL model (Hagedoorn and Wolf, 2003). We compute the subsequent Earth deformation, which includes the displacement of the ground and gravity variation, for both a spherical elastic

* Corresponding author. Tel.: + 33 3 68850034; fax: +33 3 68850291.
E-mail address: anthony.memin@unistra.fr (A. Memin).

0264-3707/$ – see front matter
doi:10.1016/j.jog.2009.09.006