Spatio-temporal evolution of the Greenland ice sheet and associated deformation of the Earth: a multi-technic geodetic approach

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The evolution of the Greenland Ice Sheet (GIS) is an important indicator of climate change and driver of sea level rise. However, providing accurate GIS ice mass balance remains a challenge today. Here, we propose to combine a unique set of geodetic measurements to improve our knowledge of the GIS spatial and temporal evolution. We attempt at reconciling satellite observations of ice volume with regional GNSS velocities estimates and time variable space gravity measurements over the 2003-2009 and 2011-2015 periods. The GIS mass variations are inferred from satellite altimetry for large ice sheets (IceSat and CryoSat-2; Sorensen et al.,2018, Simonsen et al.,2017) and digital elevation models (DEMs) generated from multiple satellite archives for peripheral glaciers (Hugonnet et al.,2020), associated with IMAU-FDM firn model (Ligtenberg et al., 2011). The spatial and temporal variations of the gravity field are given by the GRACE mission for which we use a solution where smaller wavelength signals are preserved (Prevost et al., 2019).

To resolve short wavelengths load variations affecting the displacement of nearby GNSS stations, we use Green's functions for vertical crustal displacements assuming purely elastic Earth properties (Martens et al., 2019). We first assume that the deformation is entirely due to recent ice melting and show that vertical elastic displacements predicted by our refined ice loading model, while in good agreement with observations in some regions, cannot explain observations overall. In particular, observations and model disagree in the Southeastern and the Northern parts of Greenland.

We then explore potential viscoelastic deformation associated with short-term rheology of the asthenosphere induced by recent ice melting that could explain the observed GNSS displacements. We define a history of ice loading from 1900 to 2009 using both in situ and satellite altimetric measurements, compute today's associated viscoelastic deformation for various mantle rheologies and discuss the potential contribution of ice melting since the little ice age to current observations. Remaining differences between observations and viscoelastic models may reflect a viscoelastic deformation induced by glacial isostatic adjustment. We discuss implications in terms of regional rheological constraints, and impact on estimates of present-day GIS ice mass budget.


