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Effect of Mantle Rheology on Viscous Heating induced during Ice Sheet Cycles

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Hanyk et al. (2005) studied the viscous shear heating in the mantle induced by the surface loading and unloading of a parabolic-shaped Laurentide-size ice sheet. They found that for linear rheology, viscous heating is mainly concentrated below the ice sheet. The depth extent of the heating in the mantle is determined by the viscosity distribution. Also, the magnitude of viscous heating is significantly affected by the rate of ice thickness change. However, only one ice sheet has been considered in their work and the interactions between ice sheets and ocean loading have been neglected. Furthermore, only linear rheology has been considered, although they suggested that non-Newtonian rheology may have a stronger effect.

Here we follow Hanyk et al. (2005) and computed the viscous dissipation for viscoelastic models using the finite element methodology of Wu (2004) and van der Wal et al. (2010). However, the global ICE6G model (Peltier et al. 2015) with realistic oceans is used here to provide the surface loading. In addition, viscous heating in non-linear rheology, composite rheology, in addition to linear rheology with uniform or VM5a profile are computed and compared.

Our results for linear rheology mainly confirm the findings of Hanyk et al. (2005). For both non-linear and composite rheologies, viscous heating is also mainly distributed near and under the ice sheets, but, more concentrated; depending on the horizontal dimension of the ice sheet, it can extend into the lower mantle, but for some of the time, not as deep as that for linear rheology. For composite rheology, the viscous heating is dominated by the effect of non-linear relation between the stress and the strain. The ice history controls the time when the local maximum in viscous heating appears. However, the magnitude of the viscous heating is affected by mantle rheology as well as the ice loading. Due to viscosity stratification, the shape of the region with high viscous heating in model VM5a is a little more irregular than that from uniform viscosity model. However, peak heating in the VM5a model is as big as 22.5 times that of the chondritic radiogenic heating, and is much bigger than that from linear rheology with uniform viscosity (3.95 times the chondritic radiogenic heating), non-linear rheology model (10.14 times) and composite rheology model (10.04 times). Applications of viscous heating will also be discussed.

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