The Cryosphere Discuss.,
doi:10.5194/tc-2016-272-RC1, 2016

The Cryosphere
Discussions
Open Access

Interactive comment on “Numerical homogenization of the viscoplastic behavior of snow based on X-ray tomography images” *by* Antoine Wautier et al.

Anonymous Referee #1

Received and published: 20 December 2016

Reviewer comments on: Numerical homogenization of the viscoplastic behavior of snow based on X-ray tomography images

Authors Antoine Wautier, Christian Geindreau, and Frédéric Flin

Background The authors apply a technique whereby information on the 3D microscopic structure of snow obtained from X-ray tomography can be “homogenized” to develop a macroscale theory of snow viscoplastic deformation under various loading regimes. Homogenization involves taking the inhomogeneous 3D microstructure of a volume of snow that is sufficiently large such that the variations in mechanical behavior at the microscopic scale are averaged over the volume element to yield mechanical behavior that is representative of the whole (representative volume element; RVE), or contin-

Printer-friendly version

Discussion paper

uum scale, material. It is a method to incorporate the influences of microscopic scale structure, properties and processes into a continuum description of the material. For snow, this technique was applied by Wautier et al. (2015) to estimate the elastic RVE properties using the homogenization process (i.e., converting the 3D image of snow microstructure into a gridded finite element model and applying loading at the outer boundaries of the RVE sample and determining the averaged elastic deformation response over the sample volume. This works well for elastic response, as the elastic compliance matrix is general enough to account for anisotropic behaviors, which are identified in the homogenization process. For non-elastic behavior the situation is much more challenging as the initial microscopic structure is only the starting point of deformation and it is necessary to develop an deformation evolution algorithm as a function of loading/strain rate for the RVE to use in the continuum scale model.

The authors use the homogenization process and laboratory tests on ice and snow to develop parameters for their adaptation of a viscoplastic model (Abouaf, 1985) then compare the model output to their laboratory test results with generally good agreement. They also make further qualitative comparison to data from Bartelt and von Moose (2000).

Review Efforts to develop viscous models for snow deformation have been ongoing since the earliest days of snow mechanical properties studies (the authors list but a few). So far the models all have two things in common, they are able to well represent laboratory test data yet are unable to describe actual snow behavior in a general way, even with the increasing model complexity that has developed over time. The reason for this is that most viscous, viscoelastic, and viscoplastic models consist of complex functions with numerous free parameters that can be adjusted to obtain theoretical agreement for even the most complex observed behavior. The difficulty is that the models lack accurate physics and are essentially empirical or semi-empirical by design. This works well for the purpose that the models are generally developed, which is to describe engineered materials with well-defined and repeatable material behavior.

This does not mean that such models are not useful for representing snow behavior in limited situations. When one has some confidence that model parameterizations will produce behavior within known limits and acceptable engineering accuracy over a limited time period the usefulness of viscous, viscoelastic and viscoplastic models as an engineering tool has been demonstrated. To develop continuum theories that can provide more accurate predictive behavior of snow deformation over longer time periods that capture the influence of microscopic structure, mechanical properties, and deformation processes it is necessary to get the microscale physics right during the homogenization process. While the authors recognize the importance in improving the microscale physics they do not do so in this work. The difficulty in relating microscale structure and processes to continuum scale is one that the research community studying granular materials is also struggling with (Walsh et al., 2007).

There are several fundamental difficulties with the current paper: 1. The authors indicate that the macroscopic mechanical behavior of snow strongly depends on its microstructure, which is mainly characterized by its density, topology, external loading (elastic, visco-plastic, brittle-failure) temperature and applied strain-rate. What is missing from the list are the mechanical processes that occur at the microscale (e.g., grain boundary sliding, bond breakage, bond sintering and re-sintering after breakage and particle rearrangement; ignoring metamorphic changes) that are critical to define the evolution of the snow under defined loading (or strain rate) conditions in the RVE. Knowledge of the microstructure is only the starting point to define an evolution function. It is the explicit microscale mechanical processes that determine how snow deformation evolves within the RVE and the model described in the current work does not, and cannot, accurately represent the microscale mechanical processes necessary to develop and RVE evolution function. 2. The Abouaf (1985) viscoplastic model used in the current work appears to be primarily porosity dependent and the authors do not provide a clear description of how the homogenized snow microstructure is incorporated into the model. The free parameters of the model include four parameters in two porosity dependent functions, neither of which appear to incorporate microscale mechanical processes. There are continuum scale models specifically developed to incorporate observed micro-scale measurement that might prove more suitable to this effort, if an appropriate evolution function can be determined. 3. The finite element method applied in the paper is not capable of accurately simulating the important micro-scale mechanical processes involved in the RVE deformation (primarily, grain boundary sliding and particle rearrangement). The only techniques that have demonstrated the ability to represent the micro-scale processes in snow to-date are the discrete element method (DEM) (Johnson and Hopkins, 2005; Hagenmuller et al., 2015) and the deformable DEM (Johnson, 1998). The authors mistakenly indicate that DEM models are only useful for simulating grain breakage and grain rearrangement. With appropriate interaction rules at the grain level the DEM is capable of modeling pretty much any physical process limited only by computational capability, which continue to improve at a rapid rate.

Reference Abouaf, M. (1985). Modélisation de la compaction de poudres métalliques frittées, Ph.D. thesis, 1985.

Bartelt, P. and von Moos, M. (2000). Triaxial tests to determine a microstructure-based snow viscosity law, Annals of Glaciology, 31, 457–462.

Hagenmuller, P., Chambon, G., and Naaim, M. (2015). Microstructure-based modeling of snow mechanics: a discrete element approach, Cryosphere, 20 9, 1969–1982,

Johnson, J. B. and M. A. Hopkins (2005). "Identifying microstructural deformation mechanisms in snow using discrete element modeling." Journal of Glaciology 51: 432-442.

Johnson, J. B. (1998). "A preliminary numerical investigation of the micromechanics of snow compaction." Annals of Glaciology 26: 51-54.

Walsh, S. D. C., et al. (2007). "Development of micromechanical models for granular media." Granular Matter 9: 337-352.

Wautier, A., Geindreau, C., and Flin, F. (2015). Linking snow microstructure to its macroscopic elastic stiffness tensor: A numerical homogenization method and its application to 3-D images from X-ray tomography, Geophysical Research Letters, 42, 8031–8041.

Interactive comment on The Cryosphere Discuss., doi:10.5194/tc-2016-272, 2016.