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Interactive Comment

Interactive comment on "Small-scale disturbances in the stratigraphy of the NEEM ice core: observations and numerical model simulations" *by* D. Jansen et al.

Anonymous Referee #1

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The paper is interesting and important, and should be published. The data are fascinating, and the modeling provides insights. However, I believe that additional issues should be addressed, and that the terminology should be considered more carefully.

Terminology is not the most important issue, but I will start with the question of whether these features should be called "kink bands". This is a matter of convention and does not control the physics. However, I strongly advise against calling these "kink bands". The authors provide the quote "Kink-bands [...] can be expected to form in any statistically homogeneous rock which has a high degree of anisotropy and which is compressed in a direction parallel to the foliation" (Cobbold et al., 1971)." Most workers

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would immediately identify the layering in ice as the dominant foliation. Over time, there is stretching along that foliation and compression perpendicular to it, exactly reversed from the usual expectation of kink bands. The original usage of “kink band” in Orowan (1942) was for features formed in single-crystal compression parallel to the glide plane, but the features here originate almost perpendicular to the mean dominant glide planes of the crystals. Analog experiments have included workers generating kink bands in decks of cards by squeezing along the cards rather than perpendicular to them. (The Orowan, 1942, Nature paper (no. 3788, p. 643) is fascinating, and does include a hypothetical kink band with stress applied at 45 degrees to the glide planes as well as the observed bands with stress parallel to the glide planes.)

The authors go on to state “When compressed parallel to foliation, the initial inclination of the kink bands is 45 degrees relative to the foliation. The ELLE model results show a similar feature: for the single maximum fabric vertical stripes develop in the first deformation stages, which only show a slight deviation of the c-axis from the vertical orientation.” With the foliation horizontal, the ELLE model results start with near-vertical bands, not at 45 degrees as expected for kink bands. Furthermore, most definitions of kink bands note their tendency to occur in conjugate pairs, but the features in the ice cores do not form conjugate pairs, instead always having the same sense relative to the shear field. Using “kink band” for these features is highly likely to give most readers an initial idea about formation processes that is wrong.

The definition of “kink band” as used in the full literature is sufficiently broad that one cannot absolutely insist that the usage here is wrong. But, the usage here is misleading, and should be avoided.

Moving to more interesting issues, the modeling uses simple shear only. This is fine as a starting point, but is certainly wrong. The authors are correct that basal shear increases downward and layer thinning decreases, but the folds very clearly form at a depth where layer thinning is significant. Stronger wording is needed that the experiments may generate hypotheses but cannot truly test them because stresses and

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strain rates are omitted that may be important.

Perhaps more importantly, by enforcing simple shear, the model does not allow the folds to affect the flow at the 10-cm scale. The existence of a “stripe” of differently oriented grains in a small volume must affect the stresses or the strain rates nearby, and likely both, because of the flow response to the differences in c-axis fabric and possibly other important factors. In turn, if simple shear were to exist far from a stripe, the deformation near the stripe likely would have additional components, and as suggested by Alley et al. (1997), these components might contribute to growth of the folds and perhaps to larger-scale deformation. This limitation should be noted more explicitly; many processes that may be important to fold behavior are not allowed in the modeling.

The authors note that the ELLE simulations cause stripes to form, but do not explain what occurs at the grain-scale level in ELLE. Do the stripes initially arise from the random alignments that occur occasionally in a set-up such as that used? And if so, do interactions among these then strengthen the stripes over time by affecting orientations of grains in a nascent stripe or just beyond the end? The prior work of Alley et al. (1997) addressed these issues, and found an important role for them and for the third-dimensional interactions that are ignored in the 2-d treatment here. Additional discussion should be added.

The authors state “The later onset of folding in the deeper ice cores shows that higher shear strain is required to produce visible folding due to the higher overburden pressure.” Overburden pressure is almost certainly irrelevant, aside from a very small activation-volume effect on deformation; most ice-flow modeling omits overburden pressure entirely and focuses only on the local deviatoric stresses.

The authors state “The mechanism of kinking as a trigger for stratigraphic disturbances has already been suggested by Samyn et al. (2011).” True, but the role of these features as contributors to stratigraphic disturbances was a central theme in earlier work, including Alley et al. (1997), which grew out of the GRIP-GISP2 intercomparison effort and involved coauthor Kipfstuhl (Alley, R.B., A.J. Gow, S.J. Johnsen, J. Kipfstuhl, D.A. Meese and Th. Thorsteinsson. 1995. Comparison of deep ice cores. Nature 373(6513), 393-394). The consistency of shear sense noted in the previous paragraph in the new manuscript also was noted in that 1995 work for the GRIP and GISP2 cores.

Overall, this work presents important new data, of higher quality than in prior work. The use of ELLE also greatly improves on some parts of prior work, but with the difficulty that the stress state used almost certainly omits important effects. The larger picture of some aspects of their formation, their possible growth and how this might affect fold offset, and their larger role in the ice sheet are not addressed despite their importance. So, significant revision is required, but the good work surely merits publication.

Interactive comment on The Cryosphere Discuss., 9, 5817, 2015.