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Talkative firn: extracting velocity information from kinematic inversion of internal layers

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Age-depth distributions of cold firn present a memory of spatio-temporal variations in accumulation at the surface and the velocity field. The surface deposited at a given time submerges and deforms depending on accumulation characteristics, flow velocities, firn densification and rheological properties. The structure of older surfaces in a cold ice body can be mapped by ice-penetrating radar surveys through reflections from isochronuous internal horizons, which can be dated by ice-core analysis. Of special interest to firn- and ice-core related studies are the trajectory fields of probed locations. This requires knowledge about the complete velocity field. However, as the constitutive relations for solid ice cannot easily be transferred and applied to firn, simple conventional flow modeling is not feasible. To circumvent rheological difficulties, a kinematic inverse model is presented to extract information on horizontal and vertical velocities from the age distribution. The model is solely based on advection and conservation of mass equations, which together with the known age distribution form a linear system of equations. The system is solved using singular value decomposition, thus yielding more insights into the structure of the problem and the solution compared to other inversion schemes. Model perfomence is tested with synthetic steady-state age distribution, calculated by a finite-difference model with prescribed advection velocities, density and accumulation profiles. Various kinds and different numbers of boundary conditions are used for inversion. Results indicate that the problem is well-posed and that the solutions are relatively stable. This encourages extended application of this kinematic approach, e.g. combination with different flow laws to determine rheological properties by inversion.