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Analytical solutions for the effect of topography, accumulation rate and lateral flow divergence on isochrone layer geometry

F. Parrenin (1,2), R. Hindmarsh (3), F. Rémy (2)

(1) LGGE, Grenoble, France parrenin@ujf-grenoble.fr, (2) LEGOS, Toulouse, France. , (3) BAS, Cambridge, UK.

The effect of spatial variations in ice thickness, accumulation rate and lateral flow-line divergence on radar-detected isochrone geometry in ice sheets are computed using an analytical method, under assumptions of a steady-state ice sheet geometry, a steady-state accumulation pattern, and a horizontally uniform velocity shape function. By using a new coordinate transform, we show that the slope of the isochrones (with a normalised vertical coordinate) depends on three terms: a principal term which determines the sign of the slope and two scale factors which can modify only the amplitude of the slope. The principal term depends only on a local characteristic time (ice thickness divided by accumulation ratio minus melting ratio) between the initial and final positions of the ice particle. For plug flow, only the initial and final values have an influence. Further applications are a demonstration of how the vertical velocity profile can be deduced from sharp changes in isochrone slopes induced by abrupt steps in bedrock or mass balance along a flow-line, and we also demonstrate ways the new coordinate system may be used to test the accuracy of numerical flow models.