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The relationship between flow field and isochrone layers in a steady ice sheet

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Internal layers in ice sheet, which can be measured by radio-echo sounding, provide a rich but indirect information on the velocity field. A central problematic is then: how can we use these observations to constrain ice flow models? First, we examine here the relationship between velocity field and isochrone geometry along a steady flow-line of an ice sheet. The method is analytical and based upon the stream function and its vertically normalized form, the normalized stream function (NSF). We show that the slope of the isochrones is the slope of the iso-NSF lines, plus a path term which is the cumulative result of the past trajectory of the ice particles. We illustrate this path term in three different examples: varying basal melting, varying basal sliding (Weertman effect) and varying velocity profile around a divide (Raymond effect). The path term generally counteracts the slope of the iso-NSF lines. In the case of the Raymond effect, it can even lead to depressions surrounding the bumps if the transition from dome to flank velocity profile is sufficiently abrupt. Finally, we show how practically the velocity field can be inferred from the internal layers when boundary condition are known.