

Ice Stream B Margin Revisited

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Abstract

Ice stream margins are some of the most interesting natural ice dynamics laboratories. Large temperature differences between the base and the surface of the ice stream cause large variations in the ice flow parameter. Ice traversing the margins is exposed to large strains. This is expected to lead to an alignment of c-axis and a consequent softening of the ice in lateral shear. Echelmeyer and others (1994) used a finite element model to show that the very steep velocity gradients across the ice stream margin could only be reproduced if the ice in the margins is up to ten times softer than the adjacent ice sheet ice. We repeated this modeling effort using a more accurate ice stream geometry, and adjusting the ice flow parameters for ice temperatures that have been measured in the mean time. Reproducing the measured surface velocity profiles still requires enhancement factors of about ten. Since the temperature effects have been accounted for we conclude that these enhancement factors are due to fabric changes in the marginal ice.

Method

A commercial Finite Element package (FEMLAB(R)) was adapted to solve the non-linear ice flow equations. The method solves for all three velocity components and their gradients in a plane. It does not account for out-of-plane velocity gradients, however. It is possible to specify velocities or stresses at the model boundaries. The model geometry was taken from Echelmeyer and Harrison (1999). It shows an increase in ice thickness from about 900 m on the ice sheet to about 1100 m at the center of the ice stream. The surface slope is very low (.0013). We used Glen's flow law with a flow law exponent of 3, and a temperature dependent flow rate factor according to Paterson (1994). Average temperatures were specified in 20 sub-domains (Figure 1). They were compiled from measurements by Engelhardt (unpublished), Engelhardt and Kamb (1994), and Harrison and others (1998). A notable feature of the temperature field are the cold surface temperatures at the ice stream margin due to pooling of cold air in the crevasses (Harrison and others, 1998).

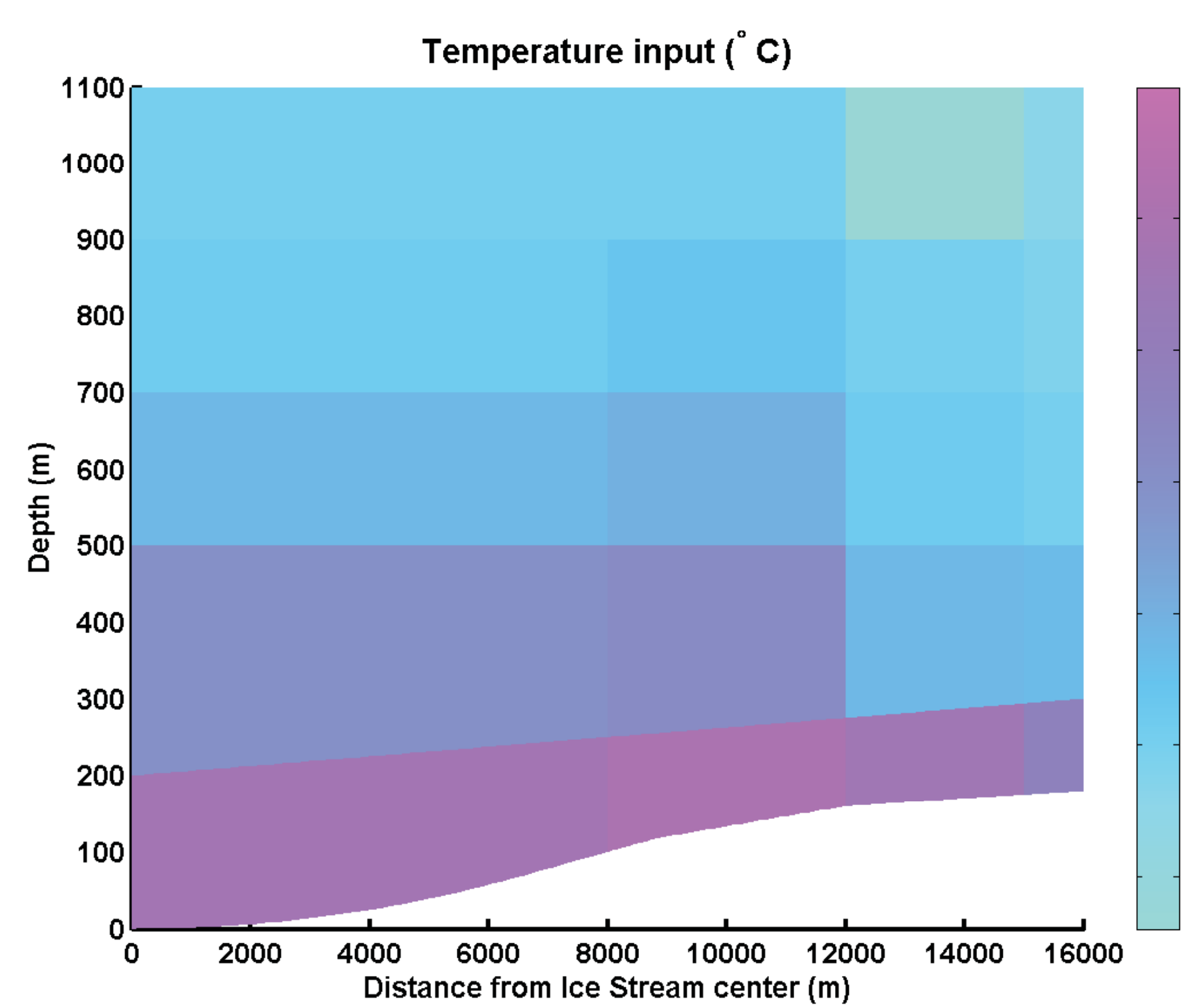


Figure 1: The temperature field used in the model. Average temperatures were specified for 20 sub-domains. The figure also shows the geometry used in the model. Note the vertical exaggeration.

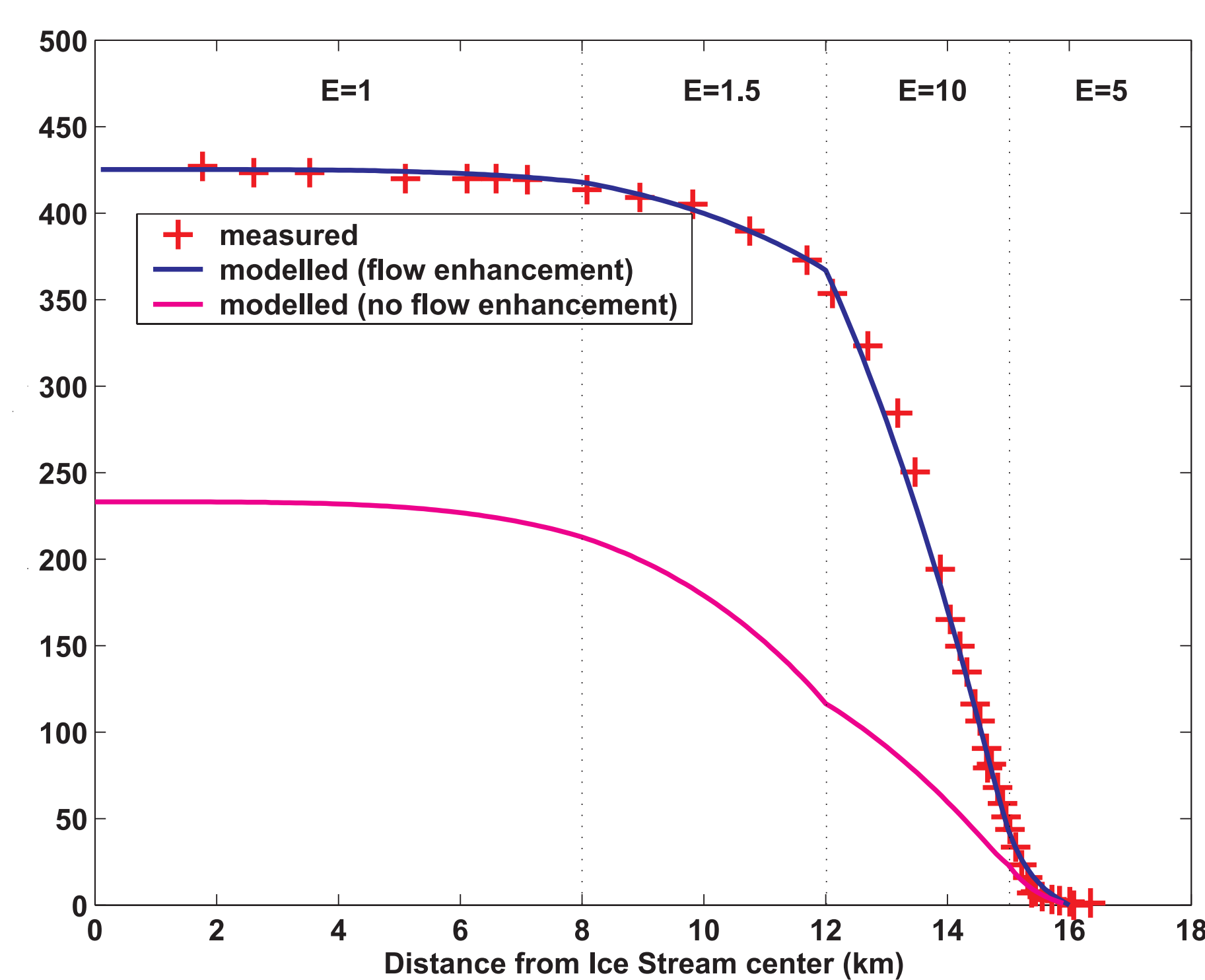


Figure 2: Measured and modeled velocity profiles. Also indicated are the (vertically constant) values for the enhancement factor used in the best-fit model. The model with no enhancement and zero basal shear stress (pink line) fails to reproduce the high speeds measured at center of the ice stream.

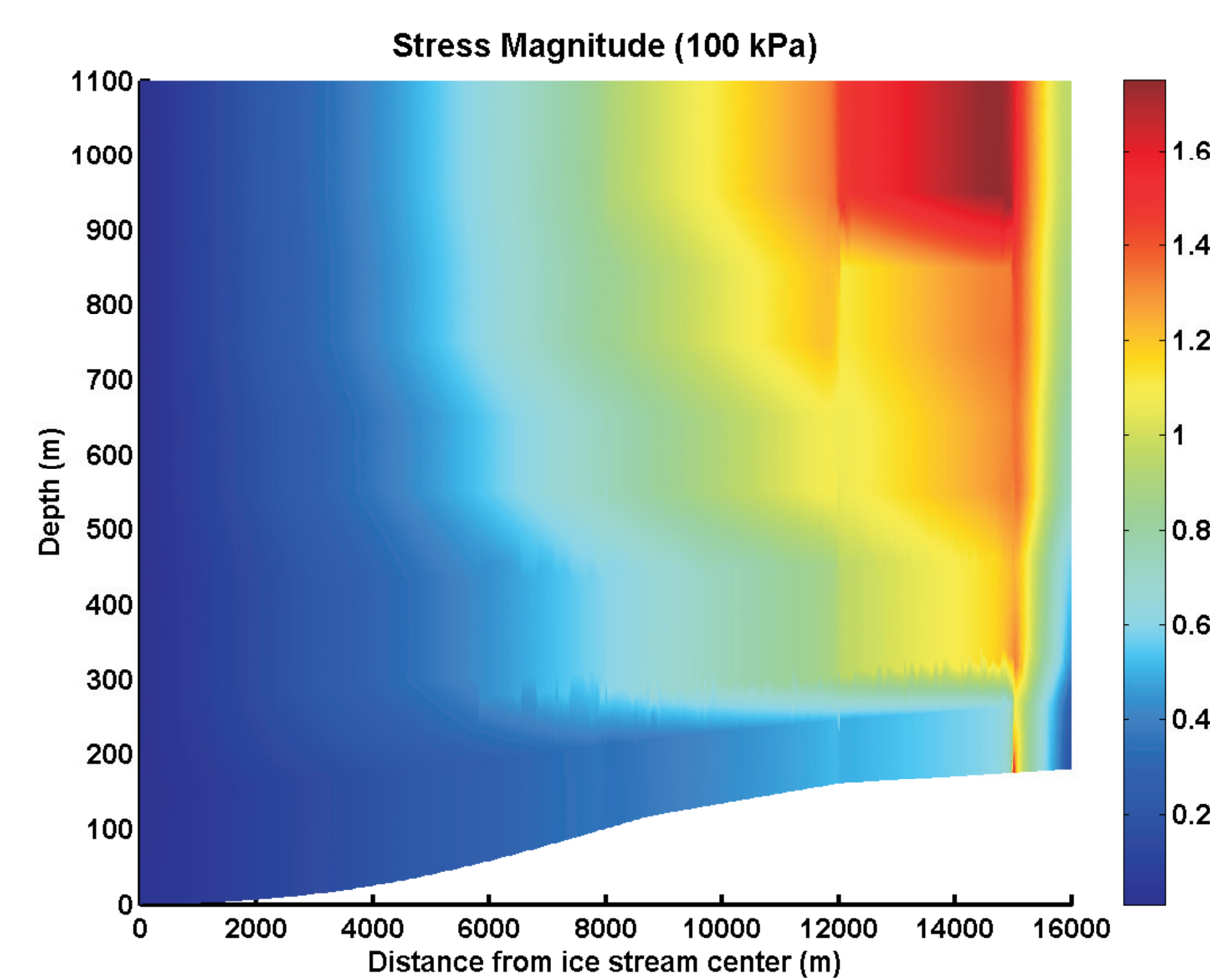


Figure 3: Stress magnitude. Note the stress concentration at the surface of the ice stream margin. This is due to the particularly cold and stiff ice found there.

Results

A first model run assuming zero basal shear stress in the ice stream (Figure 2, pink line) fails to reproduce the measured velocity profile (Fig. 2, red crosses). Some flow enhancement is clearly needed to obtain the high center velocities. We attempted to fit the measured velocity profile by introducing a vertically constant flow enhancement factor and a constant basal shear stress. These quantities cannot be tuned independently, but in general, the flow enhancement is determined by the steepness of the velocity gradient at the margin, and the basal shear stress limits the center velocity. Our best fit model (Fig. 2, blue line) was calculated using the enhancement factors indicated in the figure, and an average basal shear stress of 3.5 kPa. Figure 3 shows the stress magnitude (square root of the second stress invariant). It demonstrates the importance of the margin in the ice stream force balance. Particularly high stresses occur in the cold zone near the surface of the margins. In the best-fit model the margin provides 70% of the flow resistance. This is in agreement with earlier results (e.g. Echelmeyer and others, 1994; Whillans and Van der Veen, 1997).

References

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