Deformation-induced melting in the margins of the West-Antarctic ice streams

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Collaborators:

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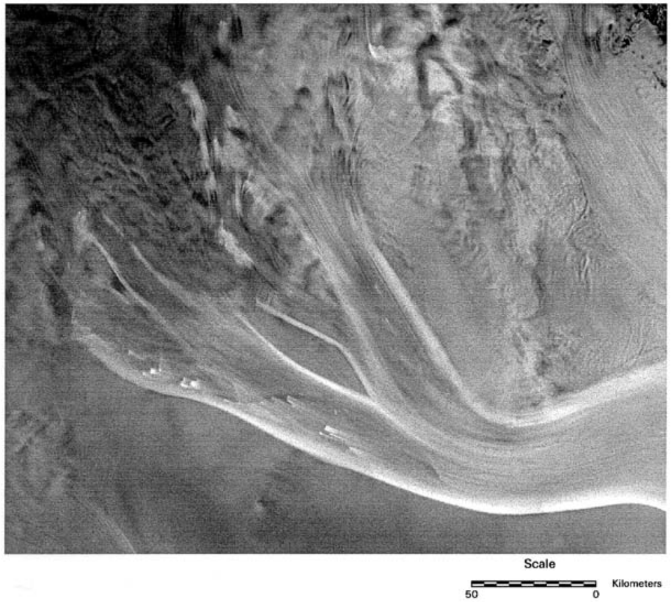
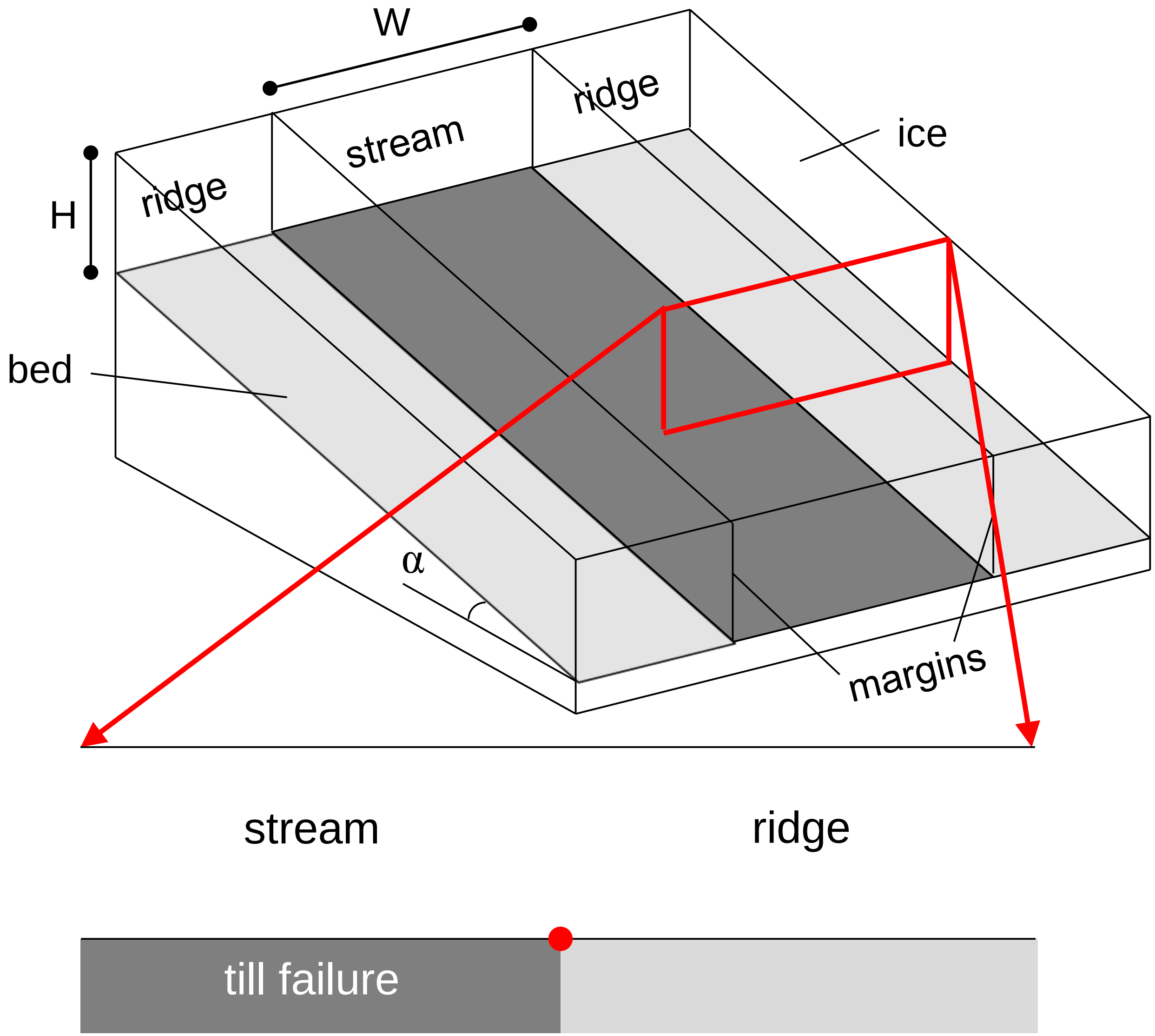
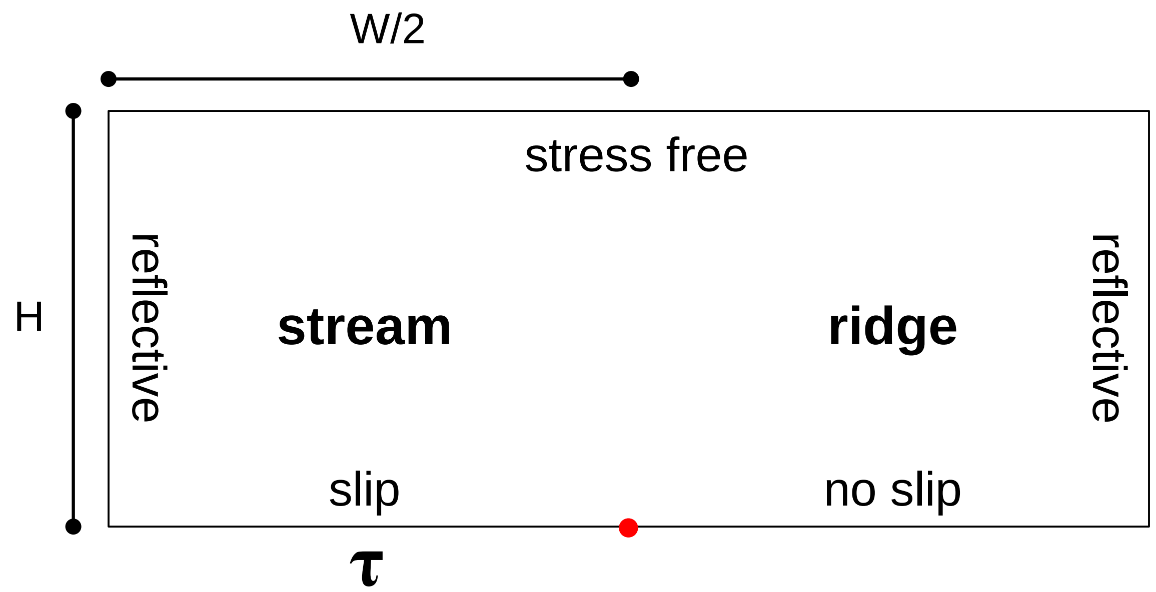


Till failure



Alley, 1986; Iverson et al. 1998; Tulaczyk, 1999

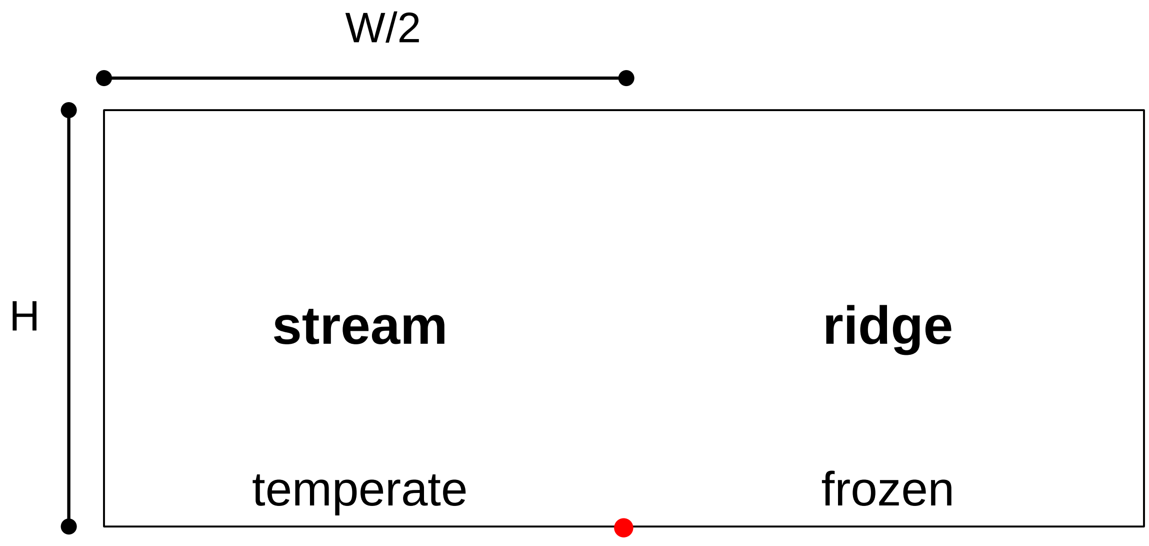
Mechanical model



$$\frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial u}{\partial z}\right)+\rho g\sin(\alpha)=0$$

$$\dot{\epsilon}=\dot{\epsilon}_D+\dot{\epsilon}_G=A_D\tau+A_G\tau^3$$

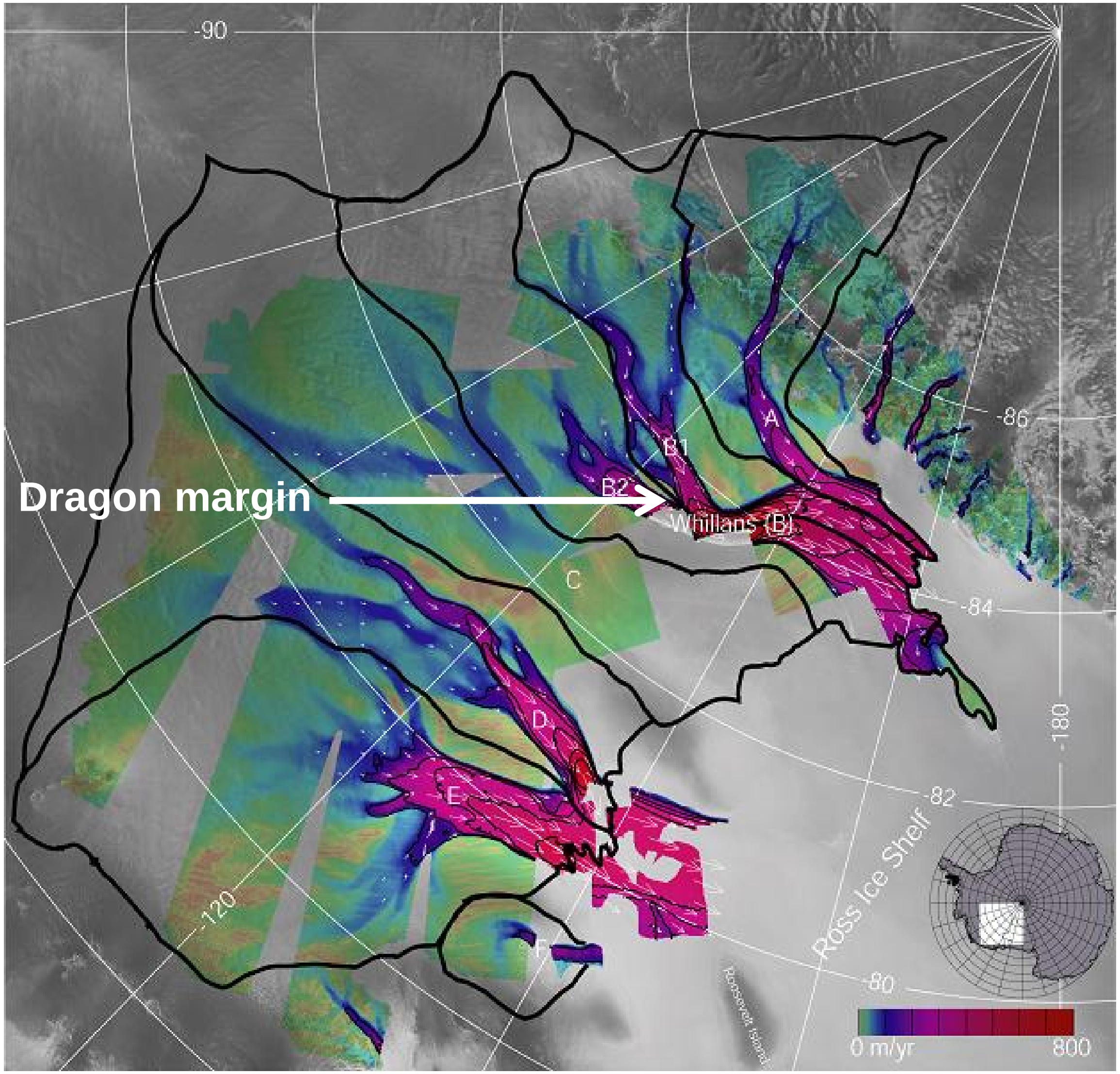
Thermal model



$$\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+\rho c\left(v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)+2\tau_E\dot{\epsilon}_E-L\dot{m}=0$$

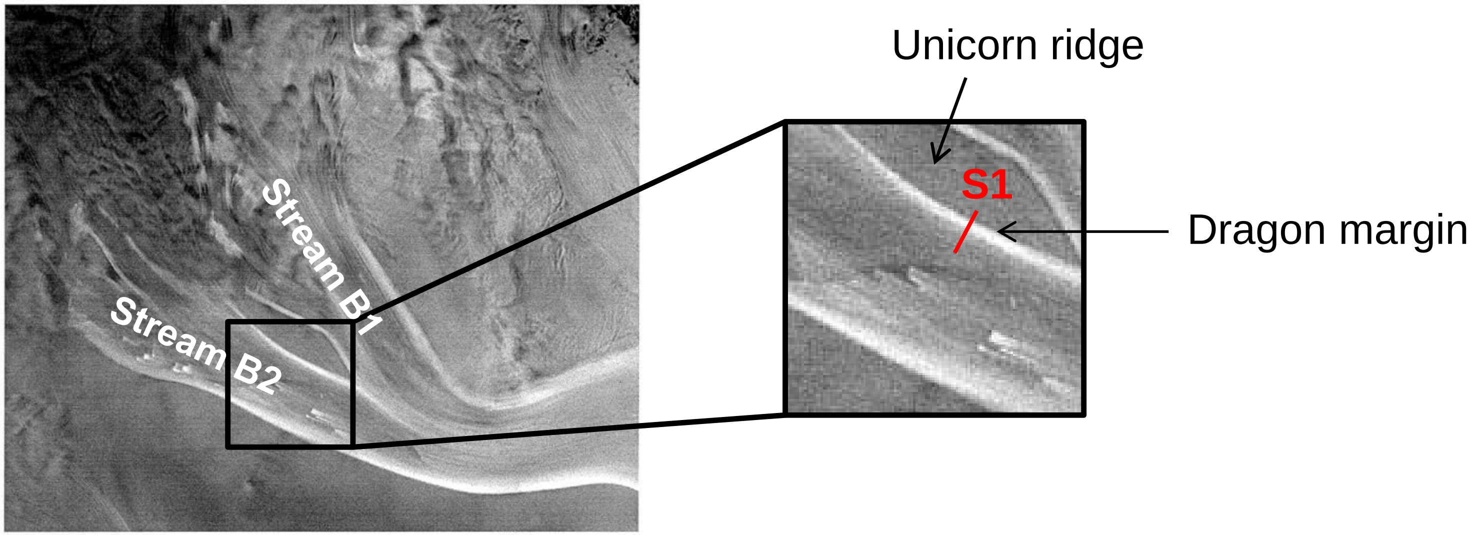
$$\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+\rho c\left(v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)+\left(1-H(T-T_m)\right)2\tau_E\dot{\epsilon}_E=0$$

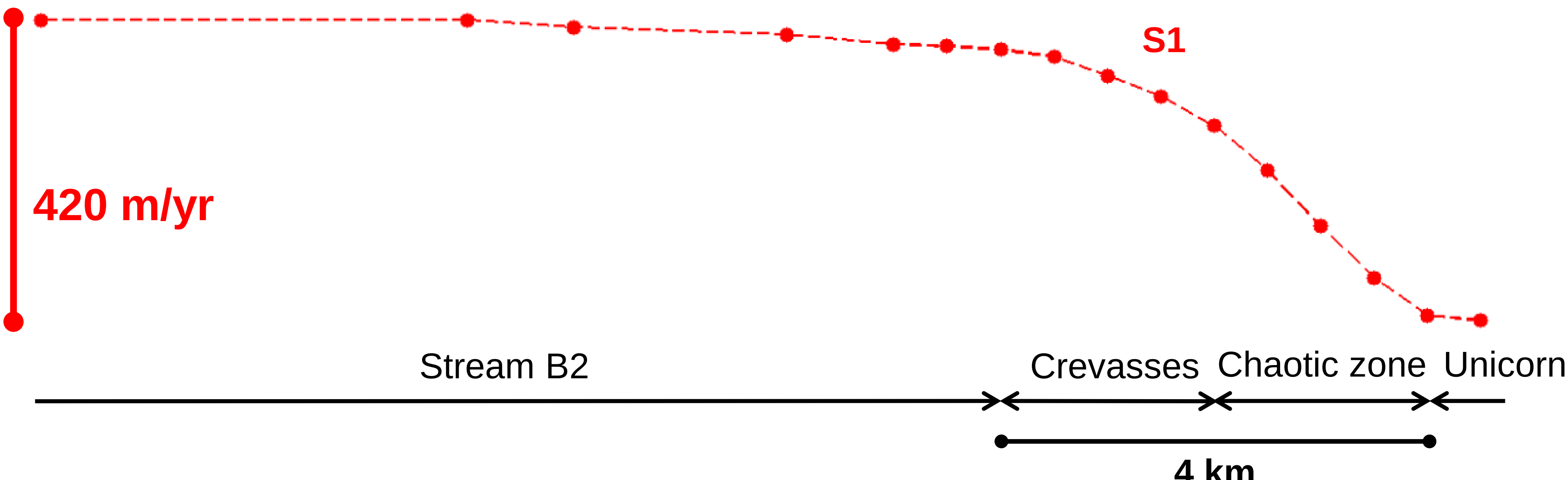
Test case: Dragon margin



Source: Joughin and Tulaczyk, 2002

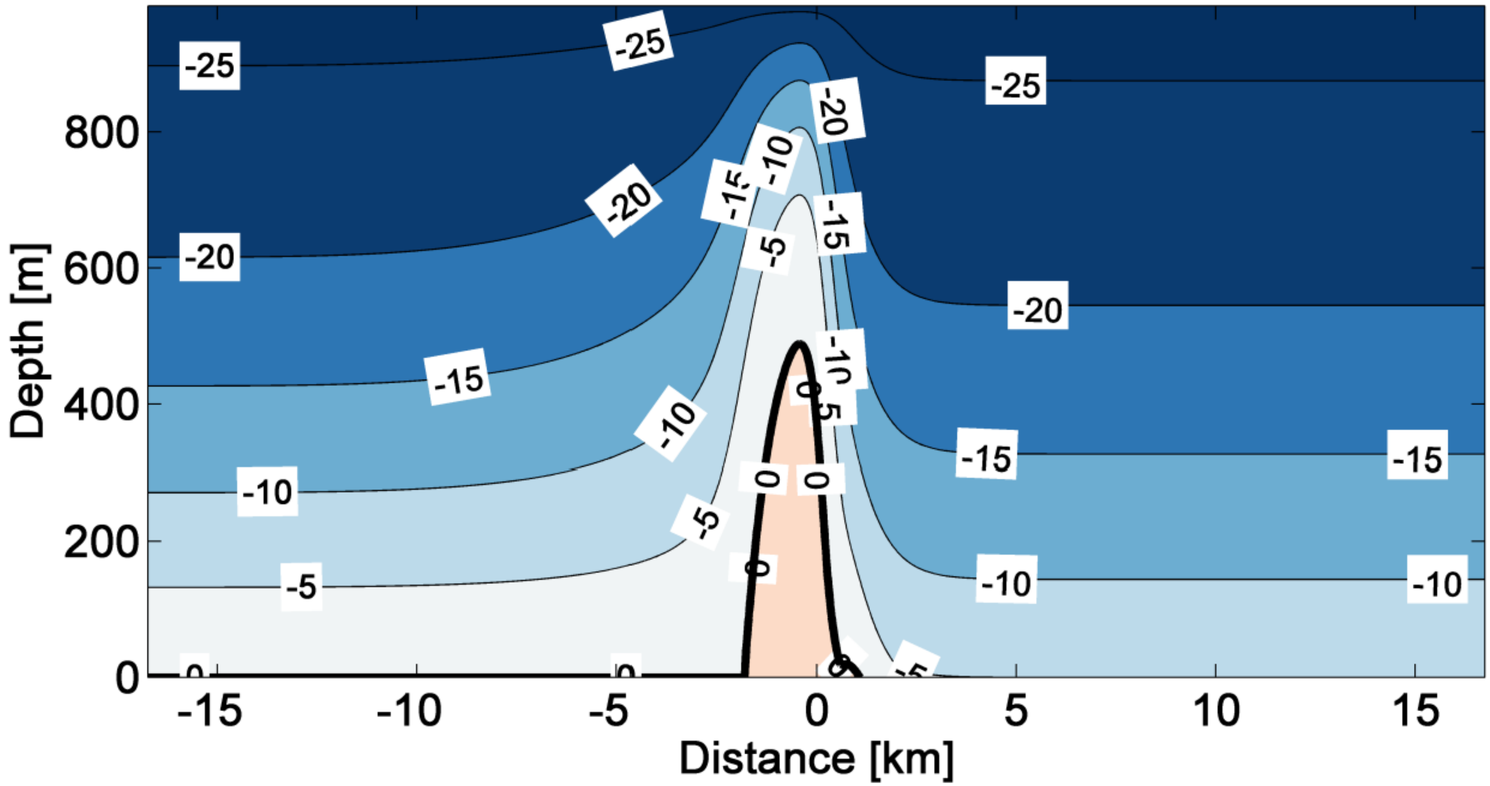
Testing the model – Velocity data

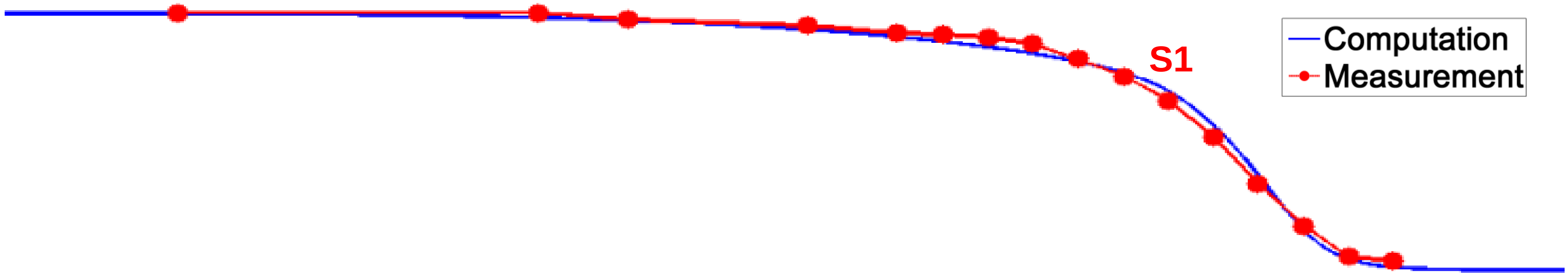




Top: Radarset Antarctic Mapping Project, Bottom: Echelmeyer and Harrison, 1999

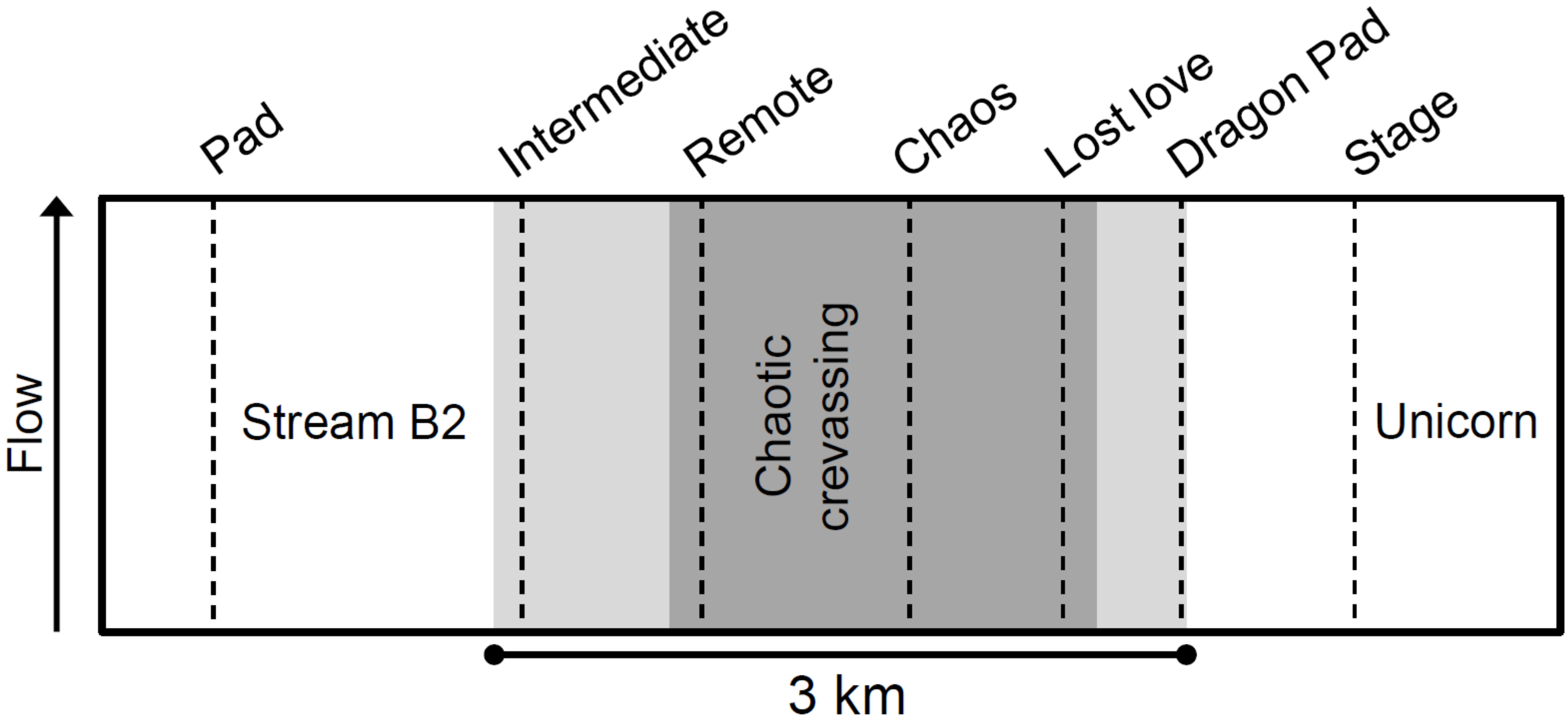
Reproducing velocity data





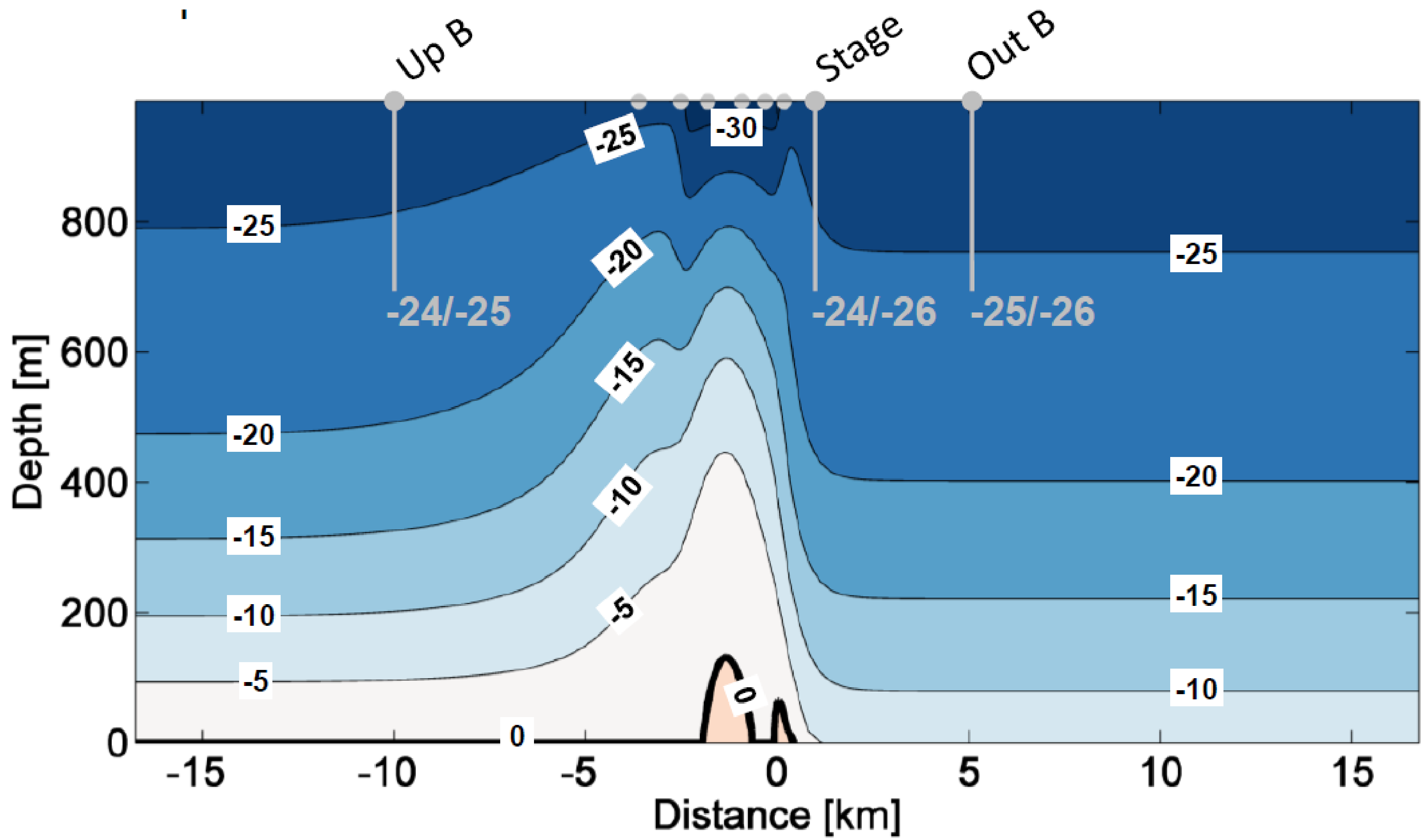
Observational data: Echelmeyer and Harrison, 1999

Testing the model - Temperature data

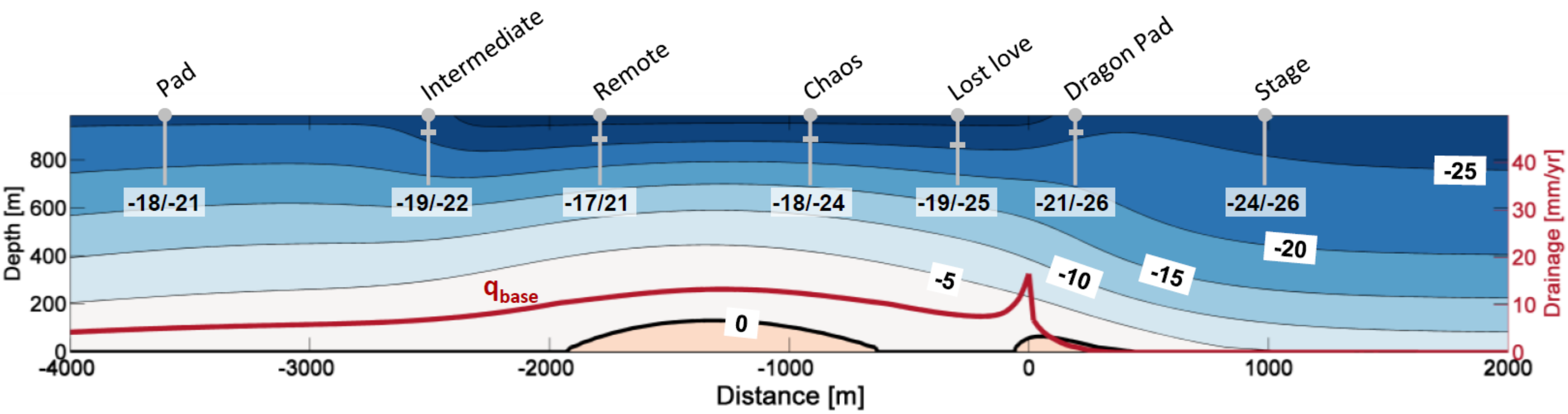


Harrison et al., 1998

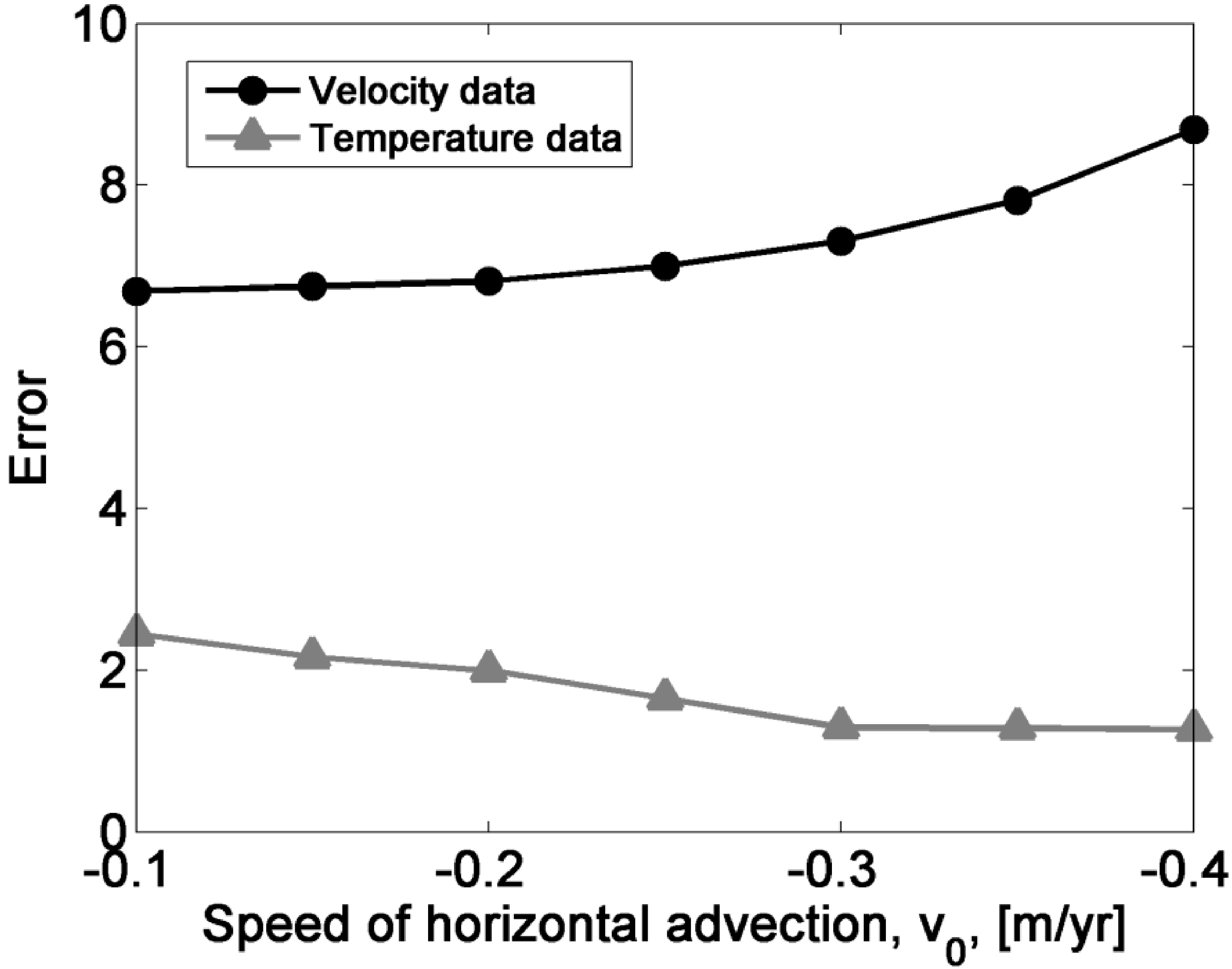
Reproducing temperature (far-field)



Reproducing temperature (near-field)

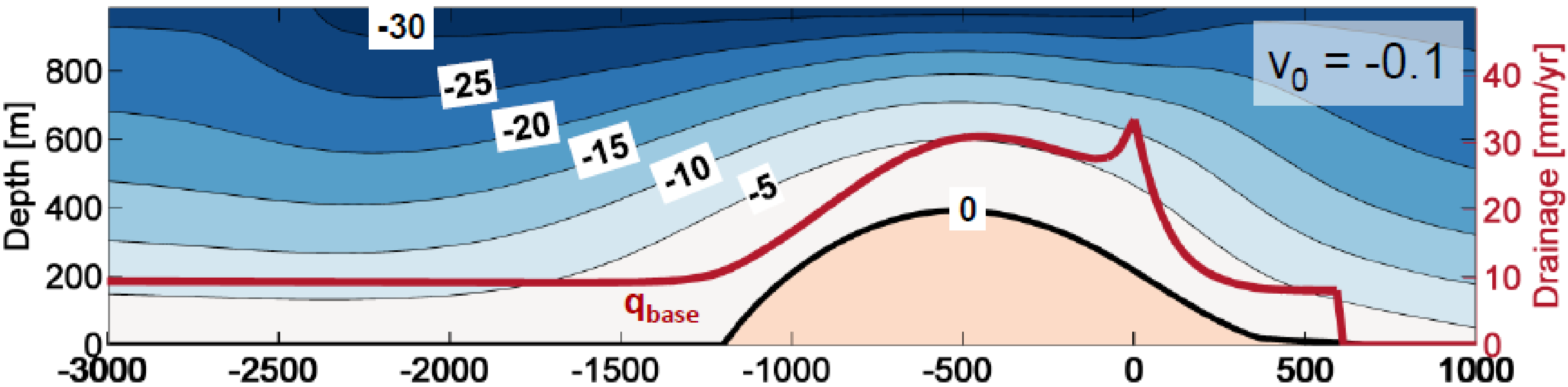


Error in reproducing both data sets simultaneously

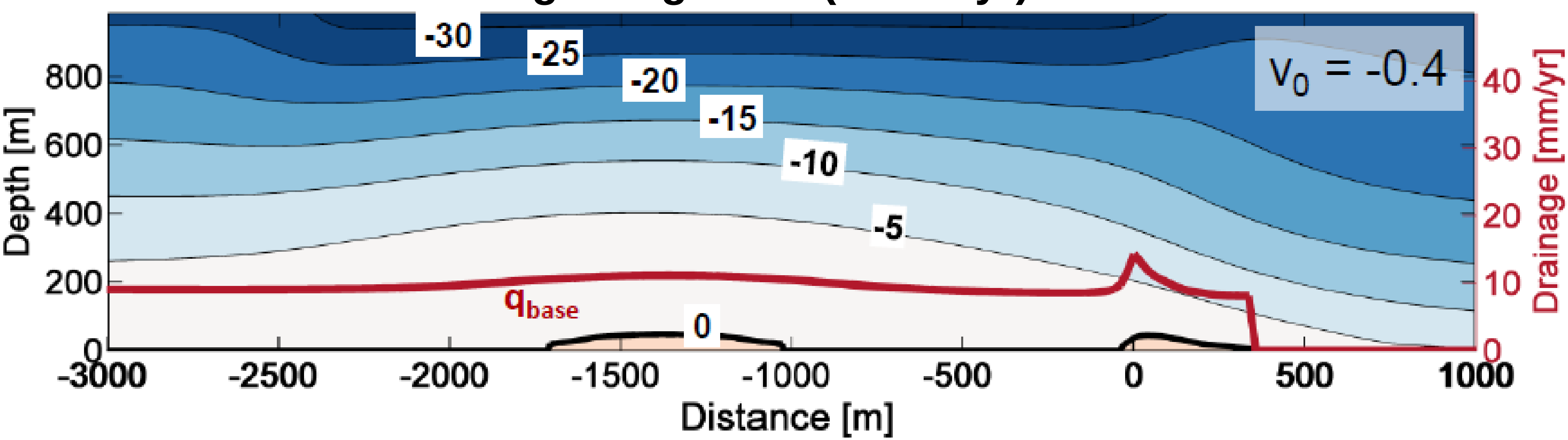


Temperate zones for different migration rates

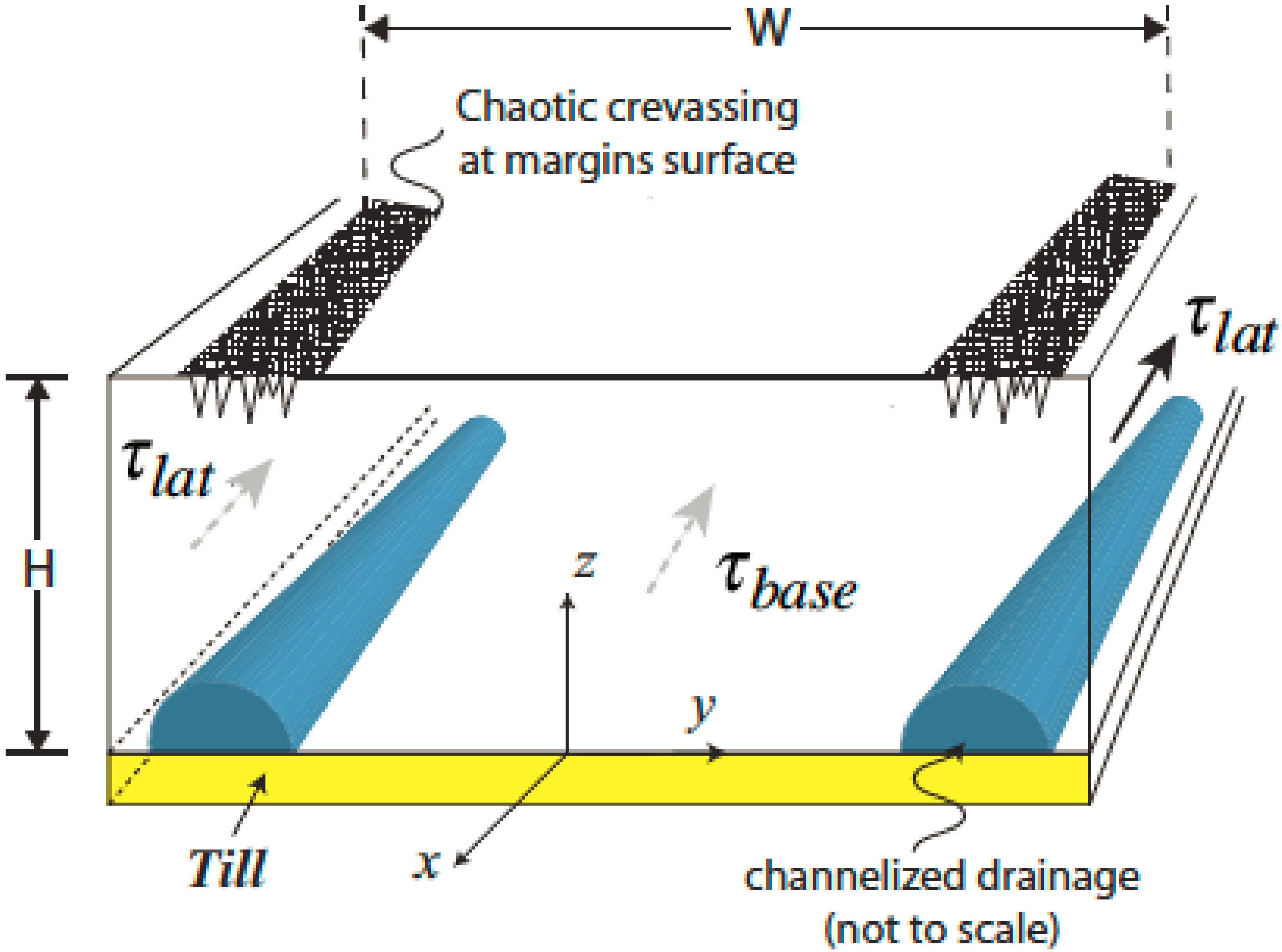
Slow rate of outward margin migration (-0.1 m/yr)



Fast rate of outward margin migration (-0.4 m/yr)



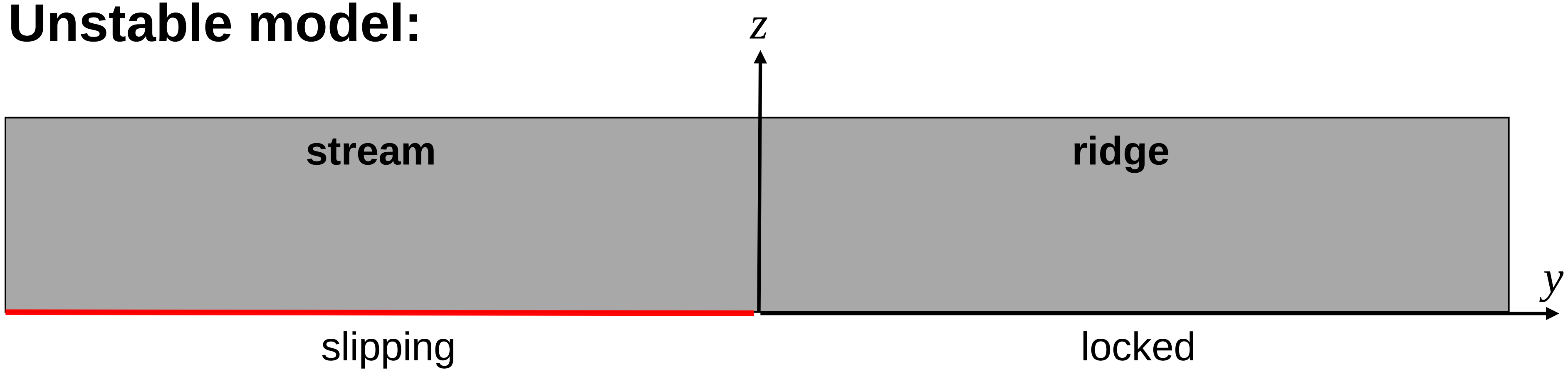
Channelized drainage systems in shear margins?



Source: Perol and Rice, 2012

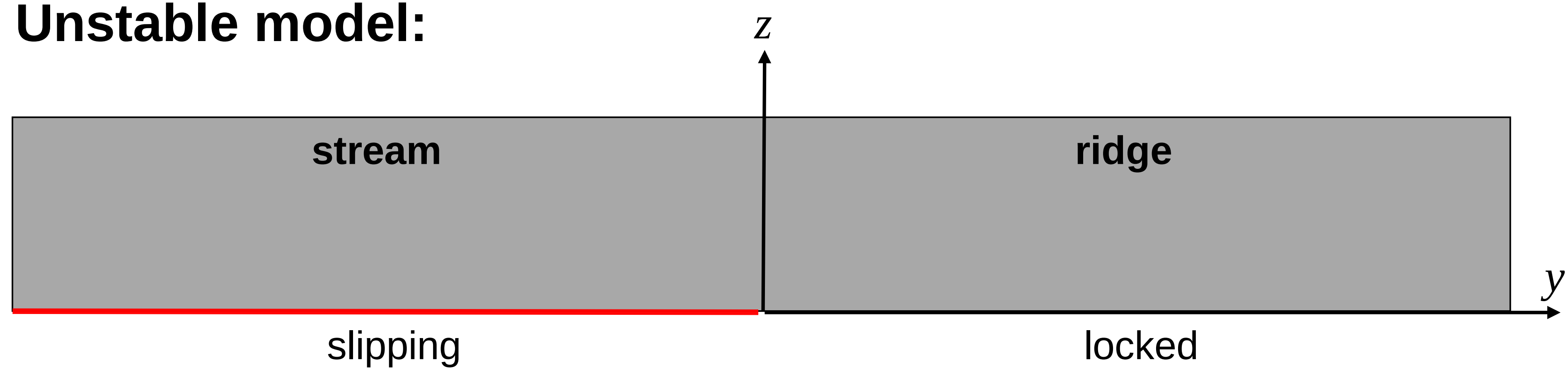
Dynamic ramifications of channel formation

Unstable model:

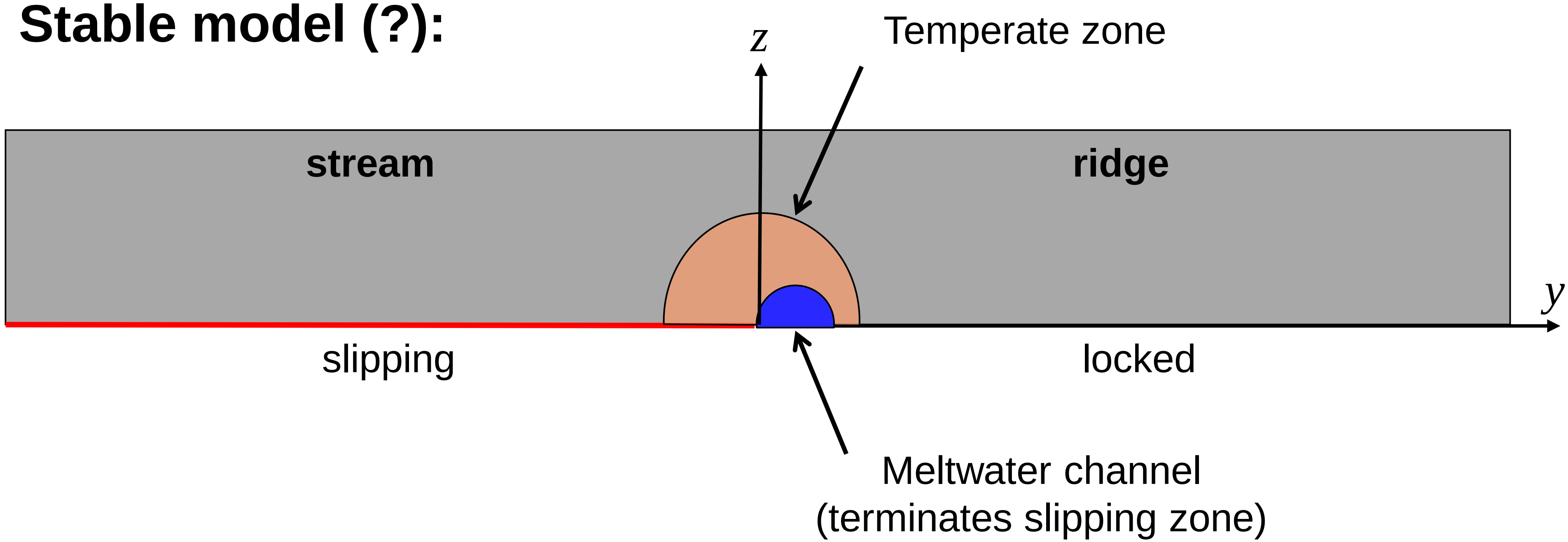


Dynamic ramifications of channel formation

Unstable model:



Stable model (?):



Conclusions

1. The shear margins of active ice streams are probably partially molten.

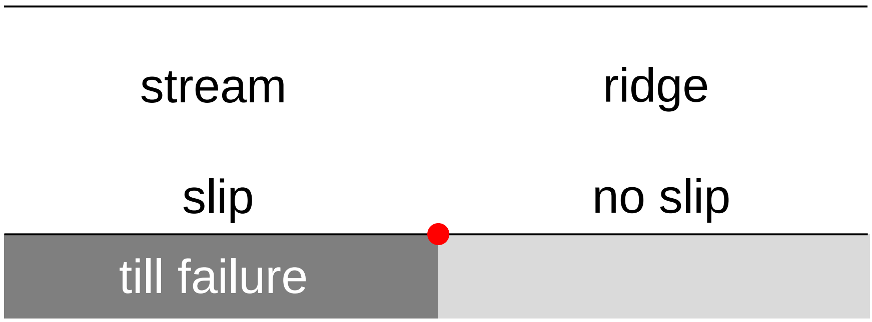
2. We expect creation of significant amounts of meltwater.

3. Where the meltwater is generated depends sensitively on the migration rate of the margin.

4. Channel formation could explain locking.

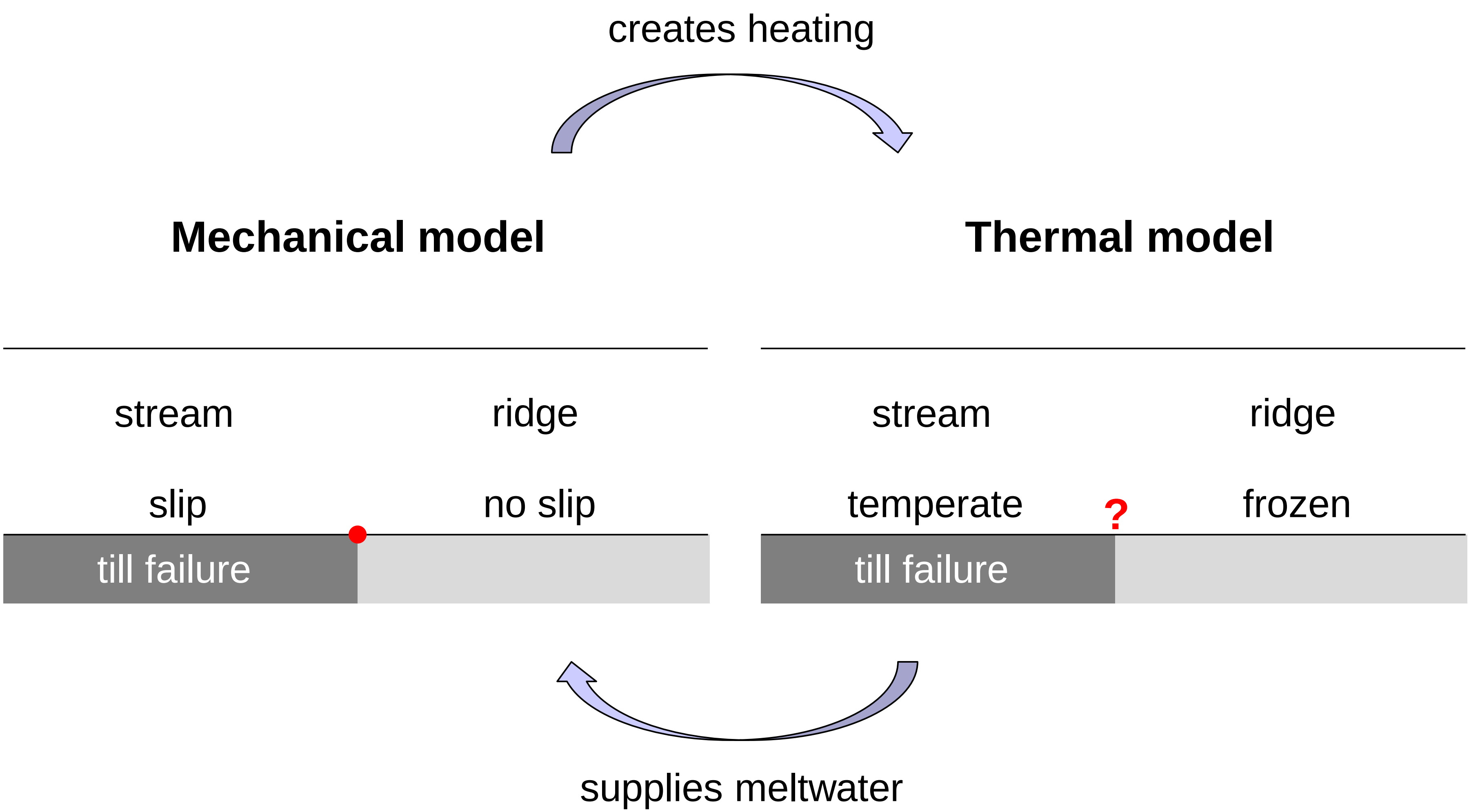
Thermomechanical coupling

Mechanical model



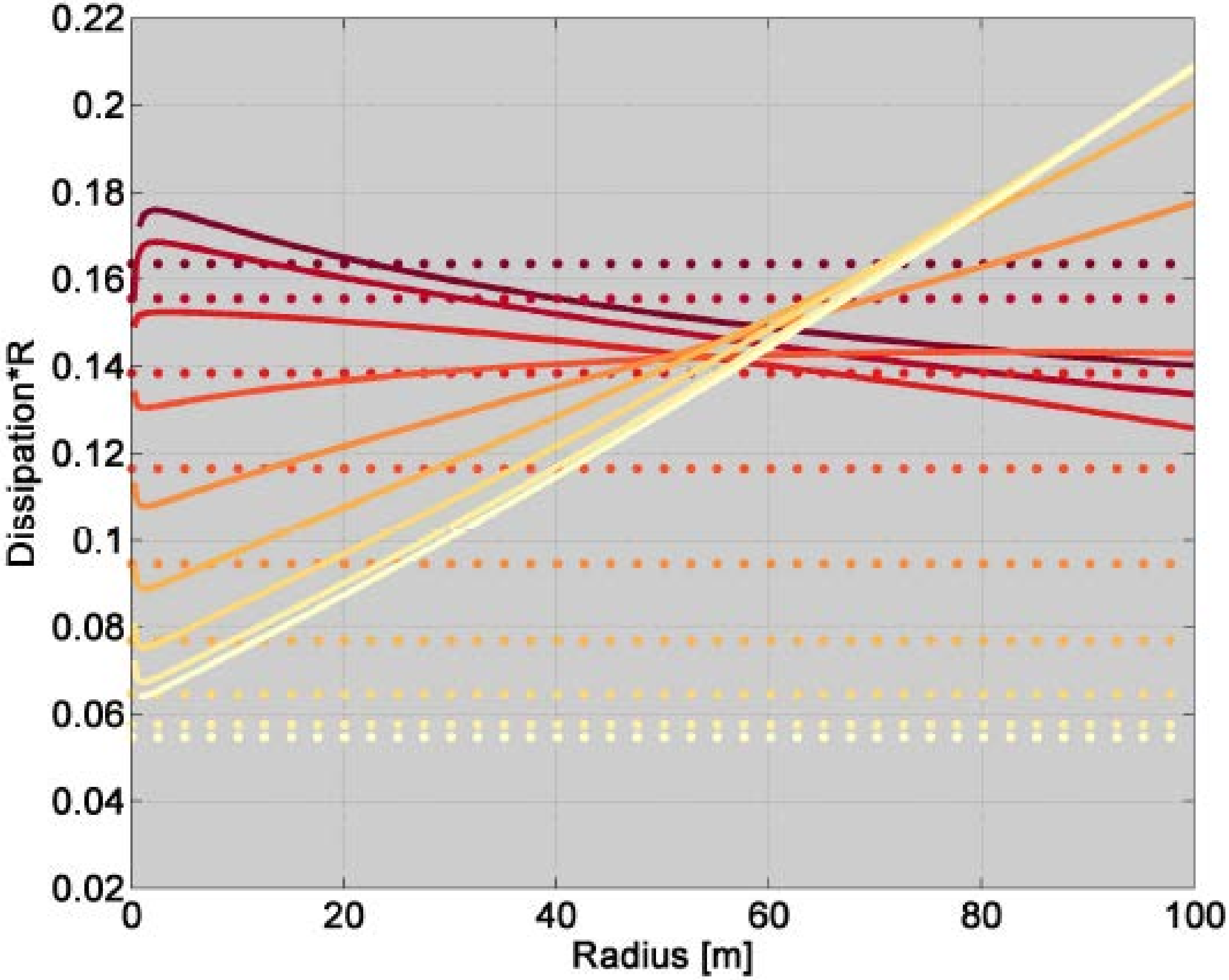
Iverson et al. 1998; Tulaczyk, 1999

Thermomechanical coupling



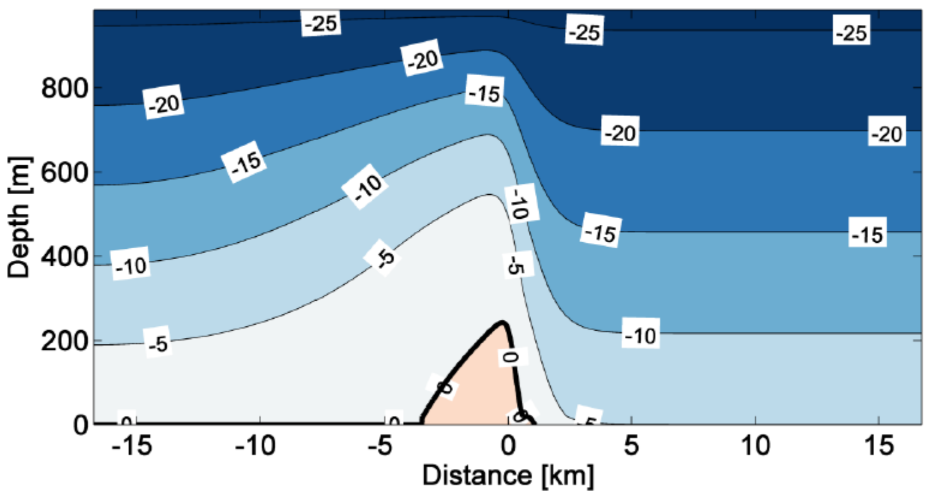
Iverson et al. 1998; Tulaczyk, 1999

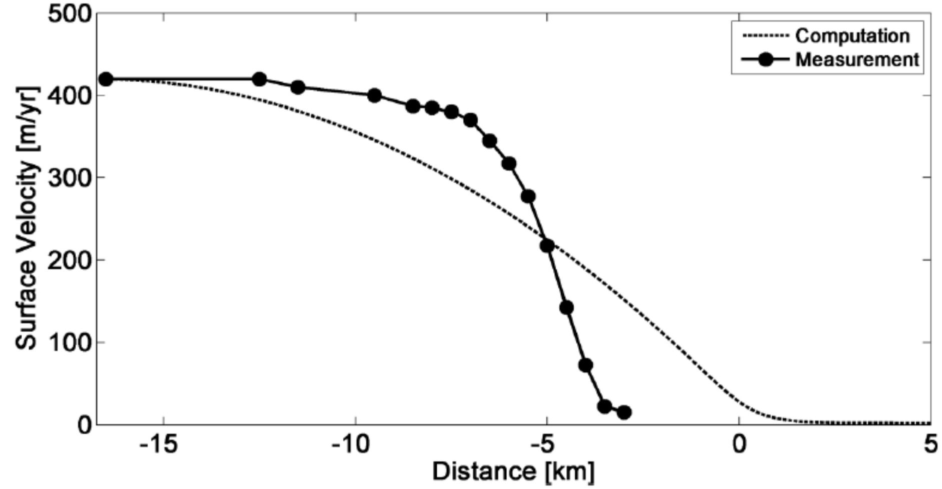
Benchmark computation



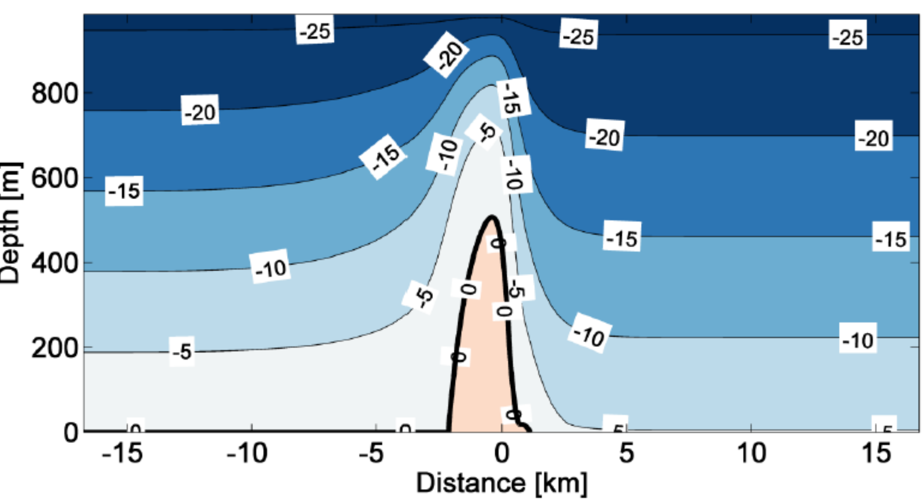
The importance of rheology

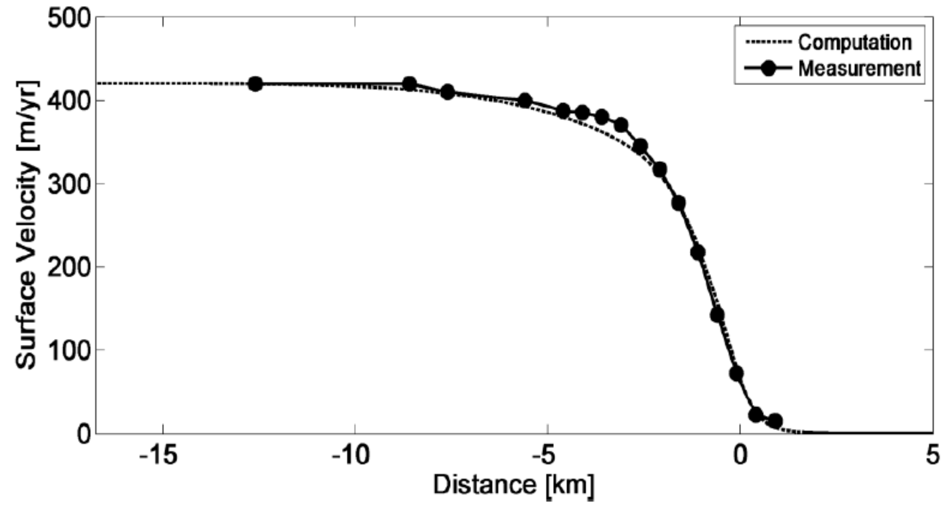
Newtonian rheology



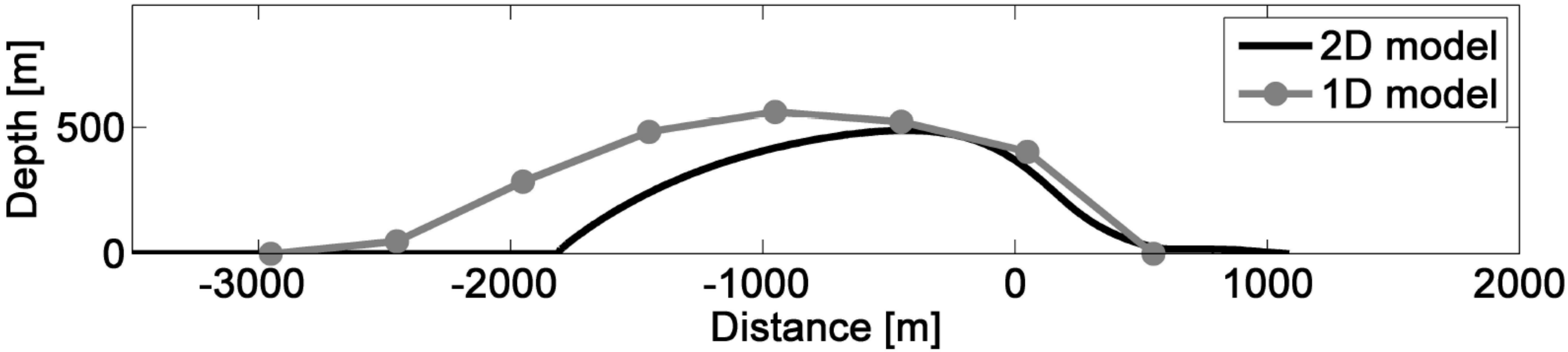


Creep rheology





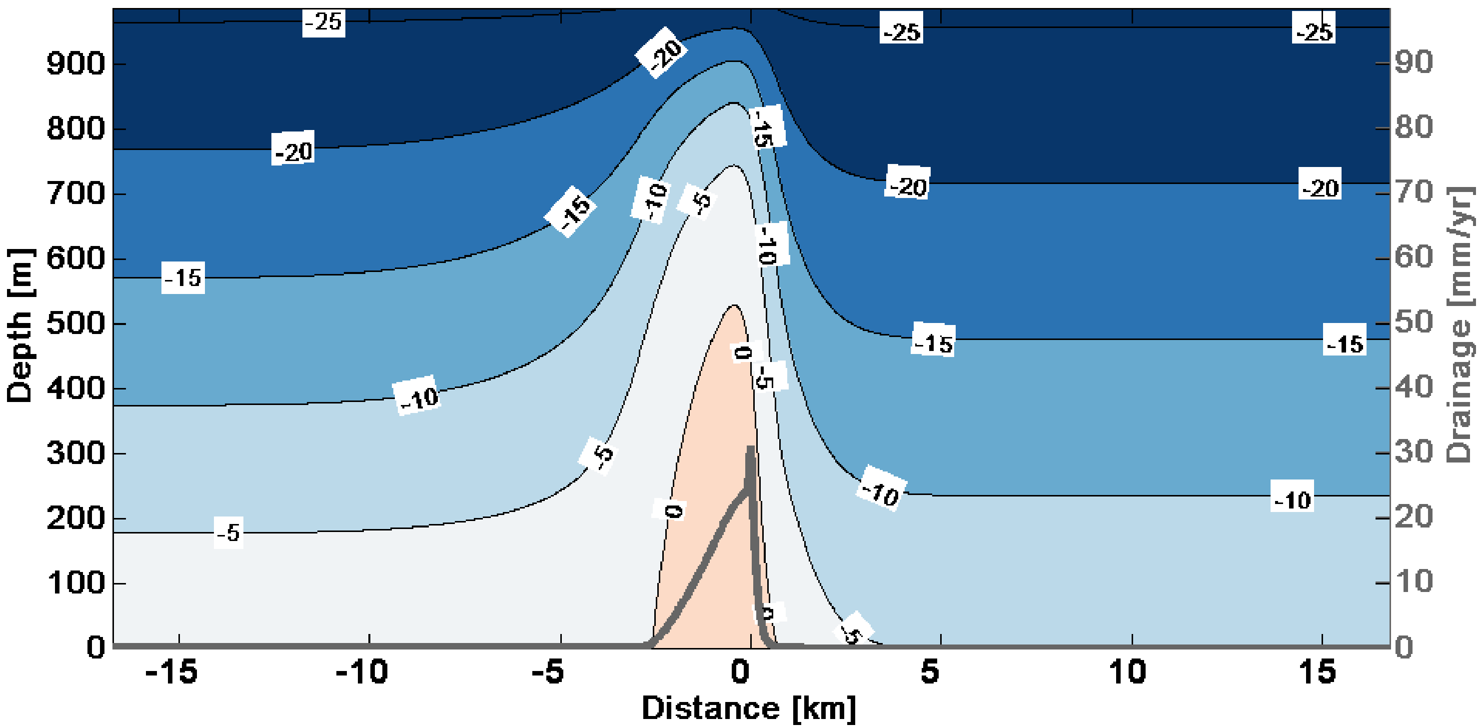
Comparison with 1D model (from Perol and Rice)



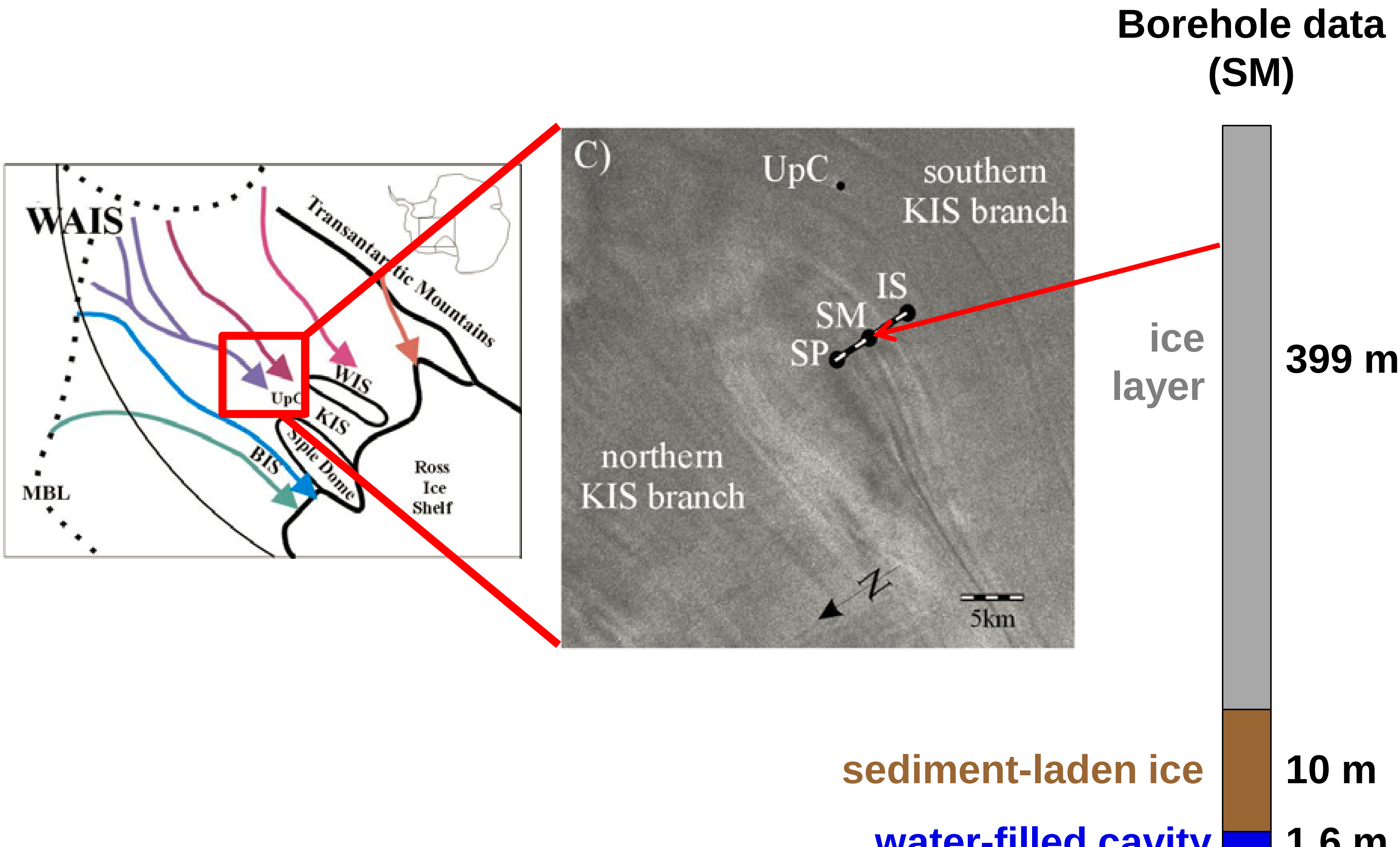
Estimating meltwater production

Mass balance: $$\frac{\partial q_y}{\partial y} + \frac{\partial q_z}{\partial z} = -\frac{2\tau\dot{\epsilon}}{\rho_w L}$$

Meltwater flux: $$q_{base} = -\int_0^{H_m} \frac{\dot{m}}{\rho_w}\mathrm{dz} = -\int_0^{H_m} \frac{2\tau\dot{\epsilon}}{L\rho_w}\mathrm{dz}$$



Observational evidence (Kamb ice stream)



Modified after Vogel PhD Thesis, 2004; Vogel et al. GRL, 2005

Observational evidence (Clarke et al. 2000)

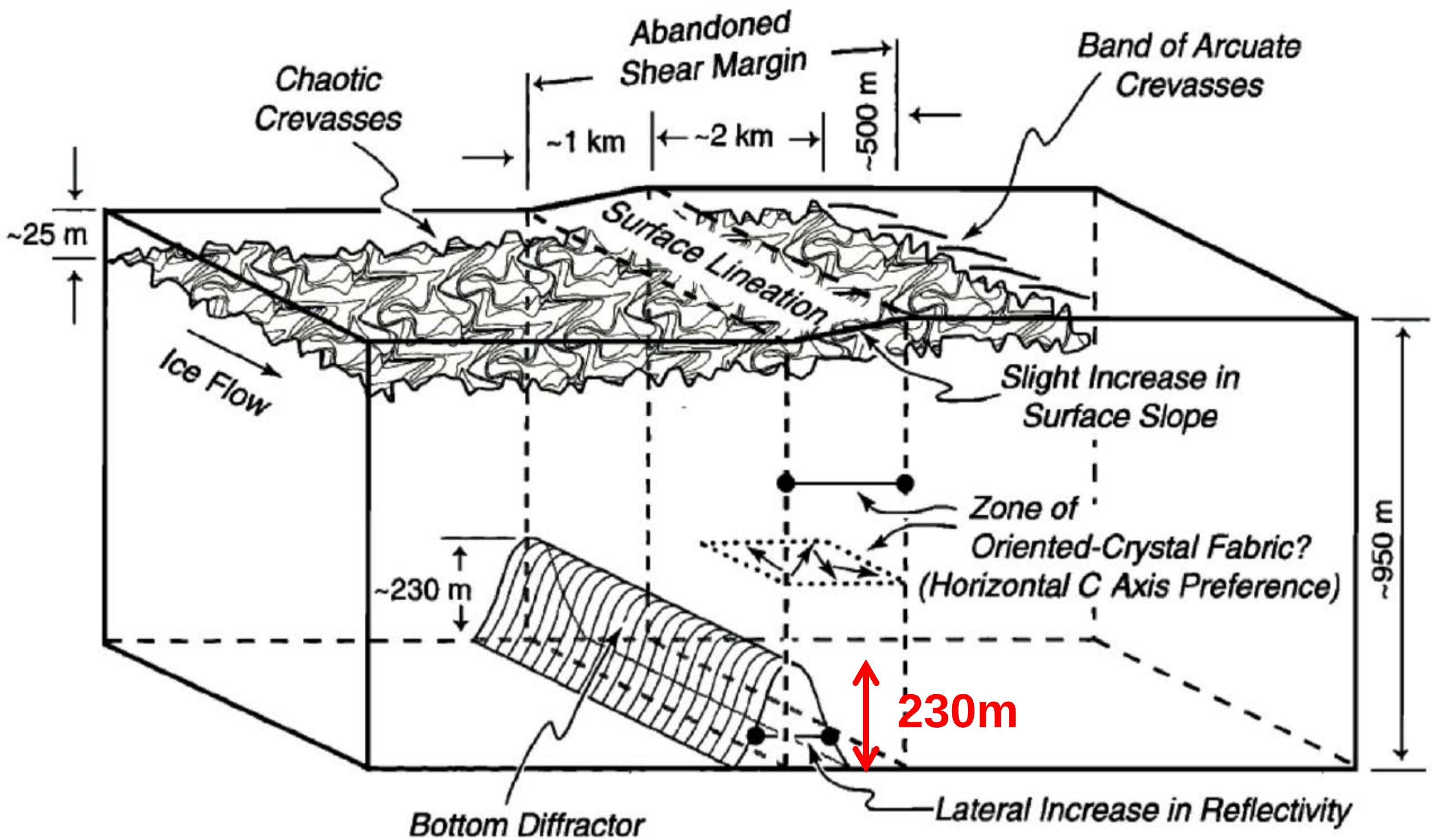


Figure by Clarke et al. 2000