Acceleration of Inland Ice via Longitudinal Coupling to Marginal Ice

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NATURAL ENVIRONMENT RESEARCH COUNCIL

Outline

- brief background on Greenland ice sheet (GIS)
- background on seasonal flow acceleration along the western flank of the GIS (the “Zwally effect”)
- a more general hypothesis for explaining the ZE
- testing this hypothesis using:
    - flow modeling
    - recent observations
- summary and conclusions

Ilulisat, Western Greenland

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Greenland Ice Sheet

- 6-7 meters of sea level equivalent
- mass loss through both calving and surface melting
- surface mass balance is likely to become negative with continued climate warming[1]
- ice sheet models[2,3] suggest that sustained warming of 3°C could “melt” the ice sheet
- If removed, GIS would likely NOT re-grow under current climate conditions[4]
- recent changes[5] suggest that the GIS may be more sensitive to climate change than previously thought, in particular w.r.t. ice dynamics

[1]IPCC (2007), [2]Greve (2000), [3]Huybrechts & DeWold (1999), [4]Toniazzo et. al (2004), [5]Alley et. al (2005)

Greenland Ice Sheet – recent changes

- acceleration, thinning, and retreat of numerous large outlet glaciers[1] on eastern and western flanks
- responsible for “mass loss” signal in gravity data at low elevations[2] and in near-coastal regions[3]?

[1]Rignot & Kanagaratnam (2006), [2]Luthcke et. al (2006), [3]Velicogna & Wahr (2006),

Greenland Ice Sheet – recent changes

For large, polar ice sheets, this process is generally thought to take many thousands of years (depending on advective vs. diffusive timescales for heatflow)

Atmospheric Forcing?

(2) change in basal boundary condition?
- increase in basal lubrication leads to faster sliding

Cause for changes in basal lubrication could include:

(1) increase in basal melting (through friction or geothermal)

(2) increase in **amount** of surface meltwater reaching the bed

(3) increase in the **access** of surface meltwater to the bed

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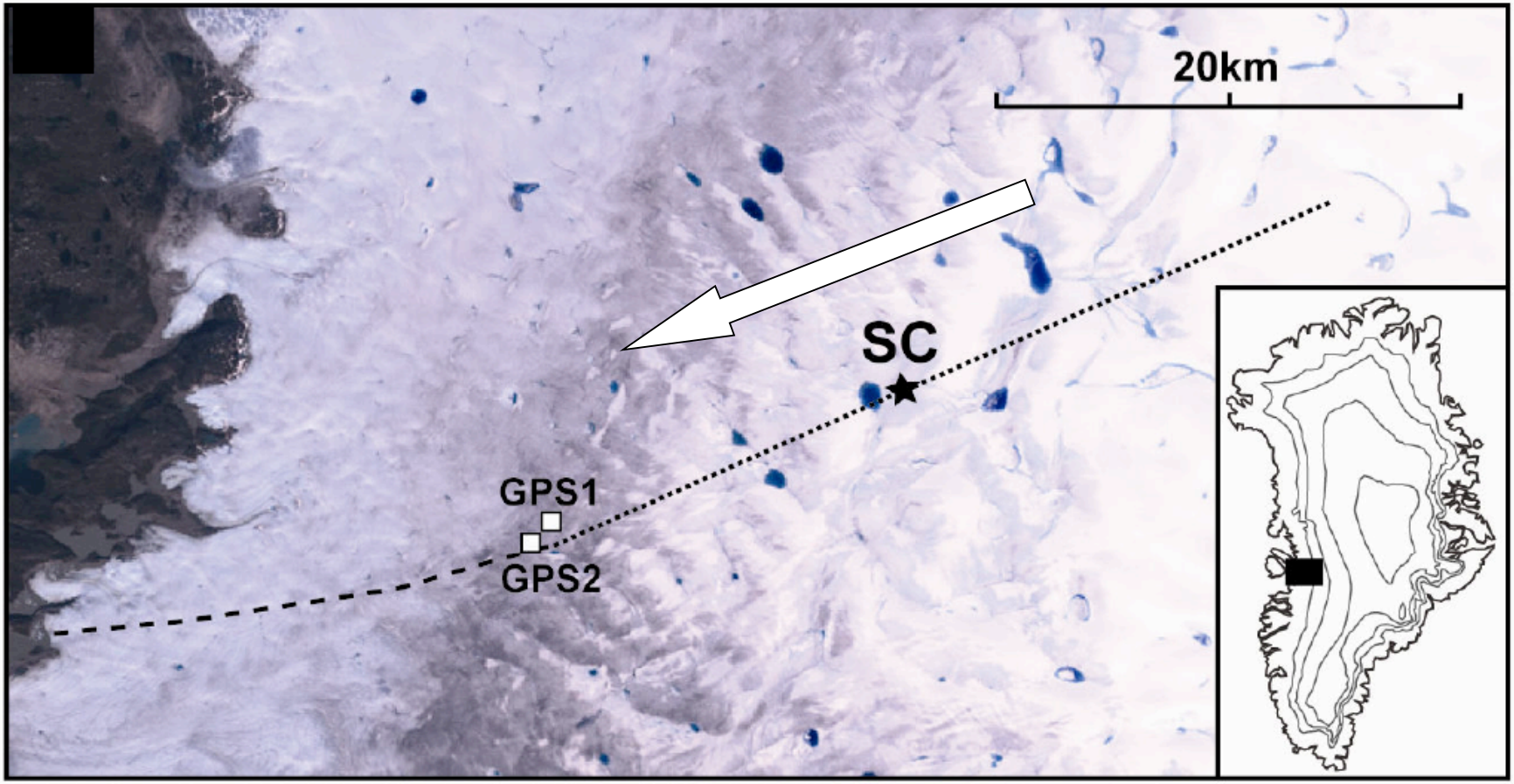
field camp, Southern Greenland

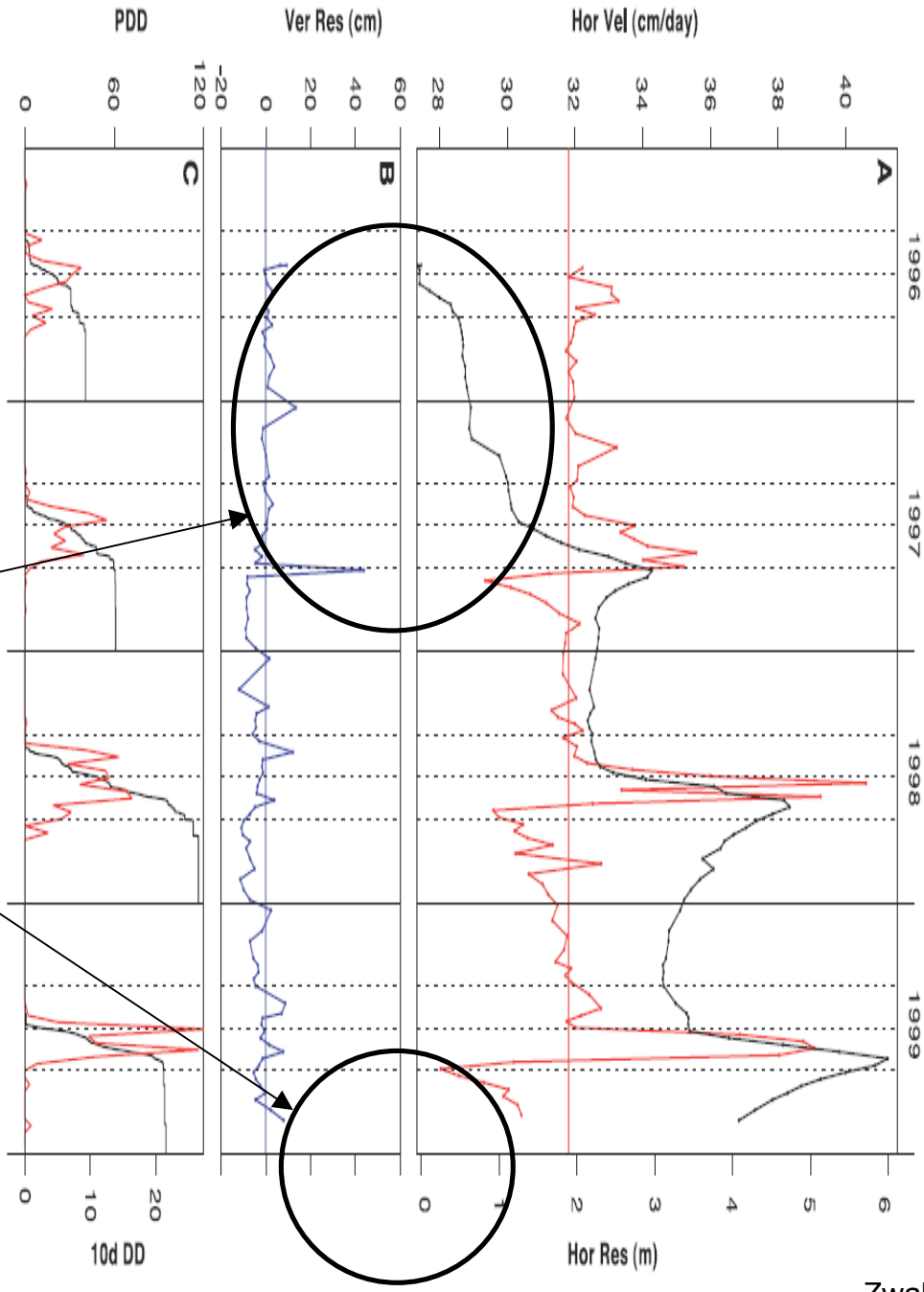
Seasonal acceleration on the western flank of the GIS

- short-term seasonal accelerations of 10-20% observed at Swiss Camp (SC), a site located ~40km inland from the western margin of the GIS[1]

[1]Zwally and others (2002)


20km
SC
GPS1
GPS2

accelerations of 10-20%, coincident with periods of increased surface melting

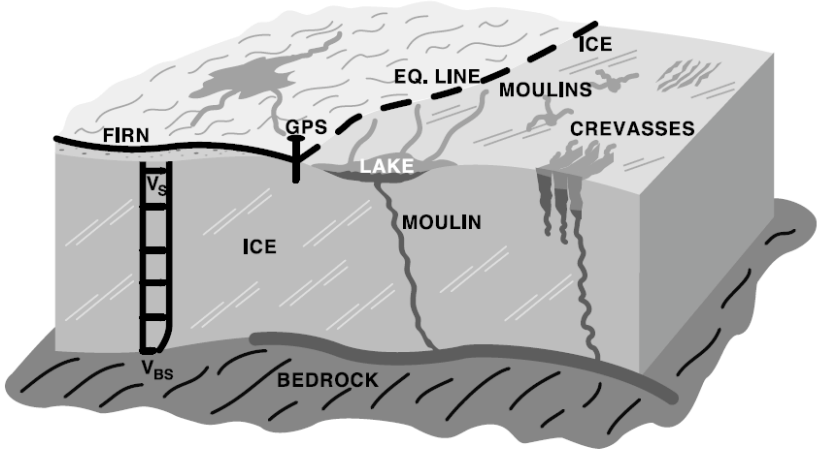


Zwally et. al (2002)

Science, vol. 297, July 2002

cover: Meltwater stream flowing into a moulin in the ablation zone of the Greenland ice sheet. Accelerations of ice flow in summer are closely related to variations in air temperature and surface melting, and indicate that meltwater quickly travels through 1000 m of ice and enhances basal sliding. These observations reveal a mechanism for dynamic response of ice sheets to climate change.

[Photo: R. J. Braithwaite]



Zwally and others (2002)

Questions

[1]Parizek and Alley (2004), [2]Alley and others (2005), [3]van der Veen (2007)

Seasonal accleration along western flank of GIS

Some observations after the fact:

(1) Zwally et. al (2002) interpretation is based on observations at a single location on the ice sheet (one GPS receiver)

(2) 10-20% is relatively small w.r.t. seasonal accelerations observed on other polar glaciers[1] and at other sites on the GIS[2,3]

[1]Bingham and others (2005), [2]Mohr and others (1998), [3]Rumrill and others (2006)

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field camp, central Greenland

Expanded Hypothesis

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field camp, central Greenland

Flow Modeling

Model:

- 2D flowband model solves equations for thermomechanical flow in plane-strain using Finite Volume Method[1]
- “sliding” through basal layer with power-law rheology (can parameterize basal motion due to hard or soft bed)

Boundary Conditions:

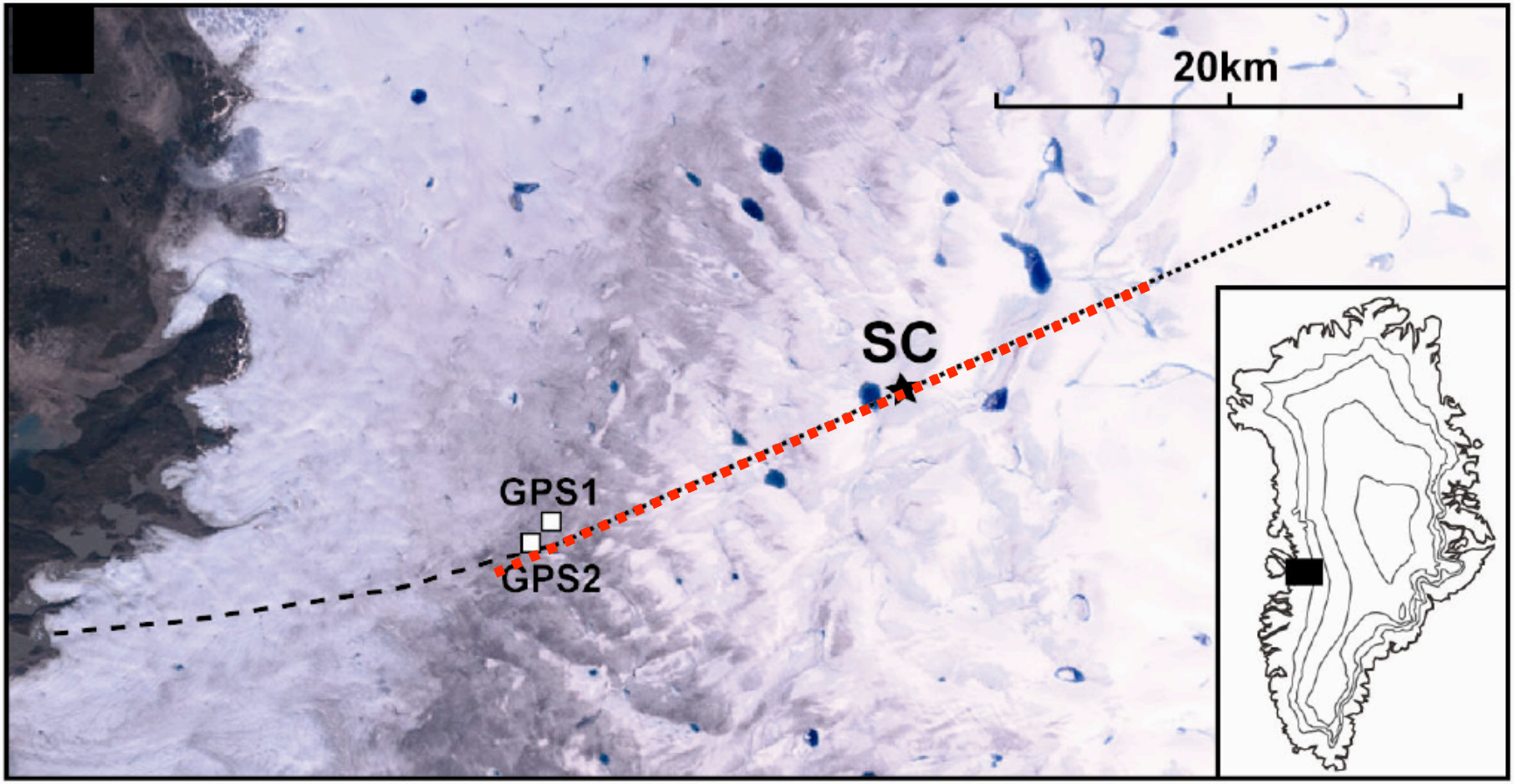
- zero flux at up/downstream boundary (hundreds of km upstream is flow divide, downstream is terminus)
- free surface
- no slip at base of sliding layer

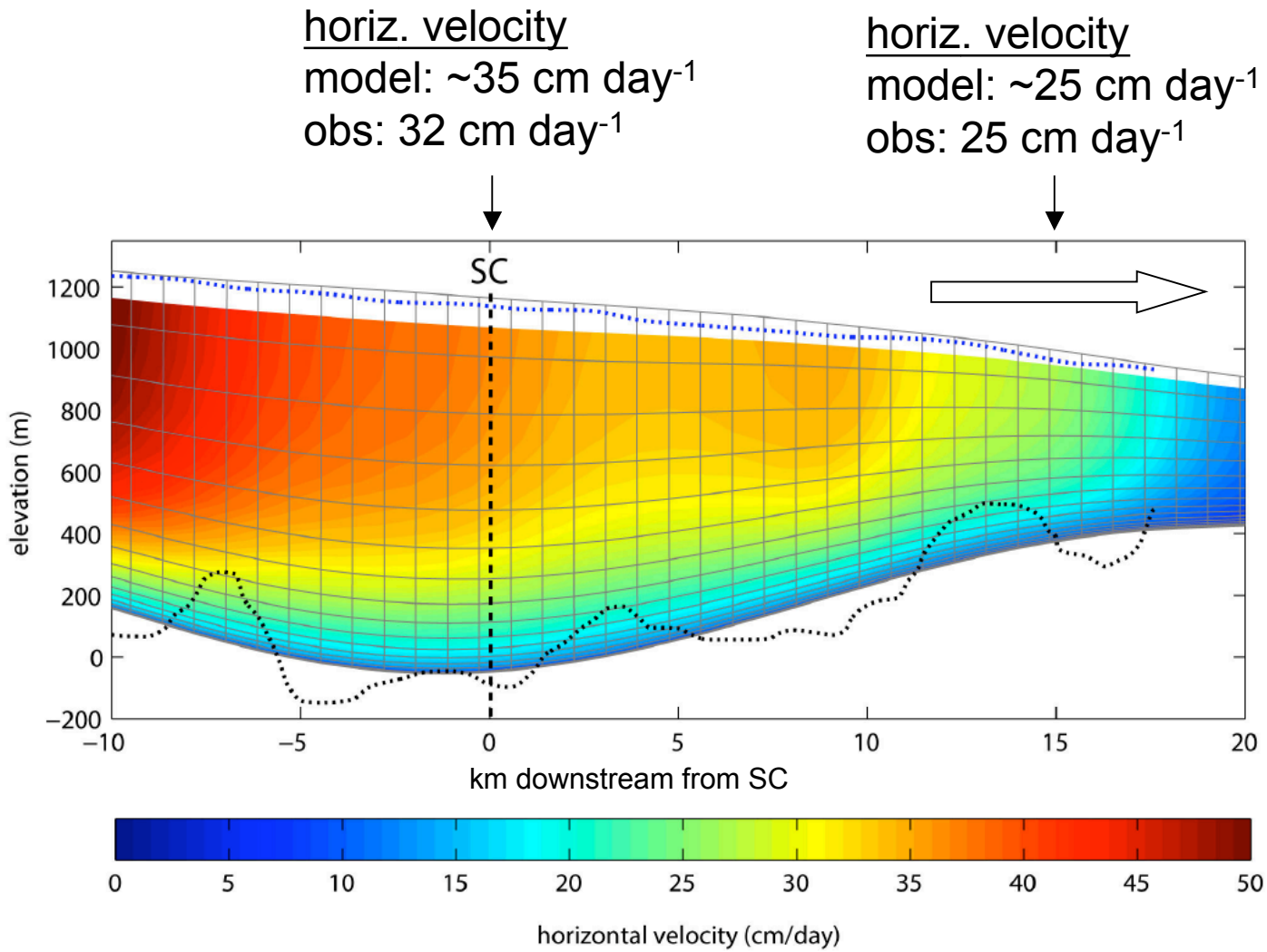
[1]Price and others (in review)

Flow Modeling

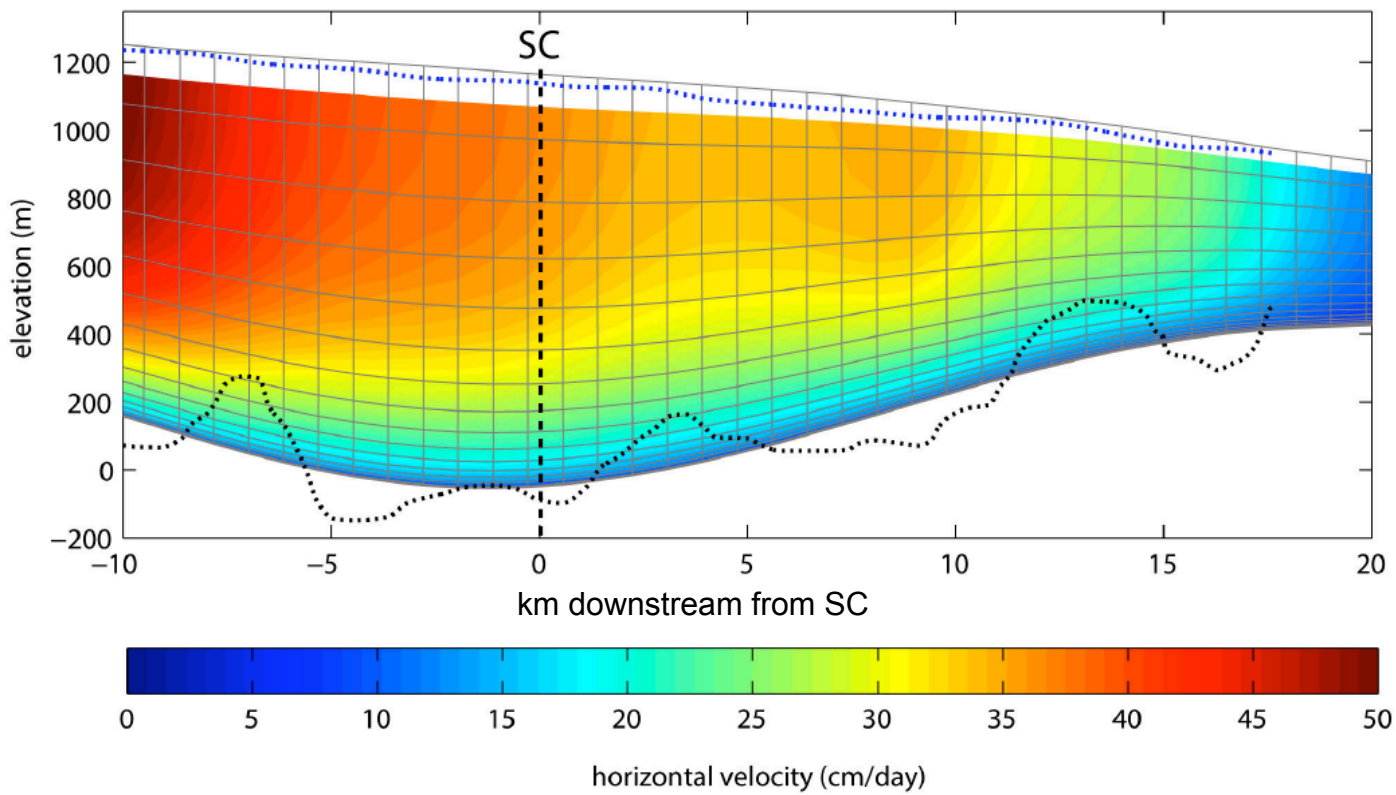
Simplifying assumptions:

**a thawed, sliding bed is assumed in both cases


20km
SC
GPS1
GPS2

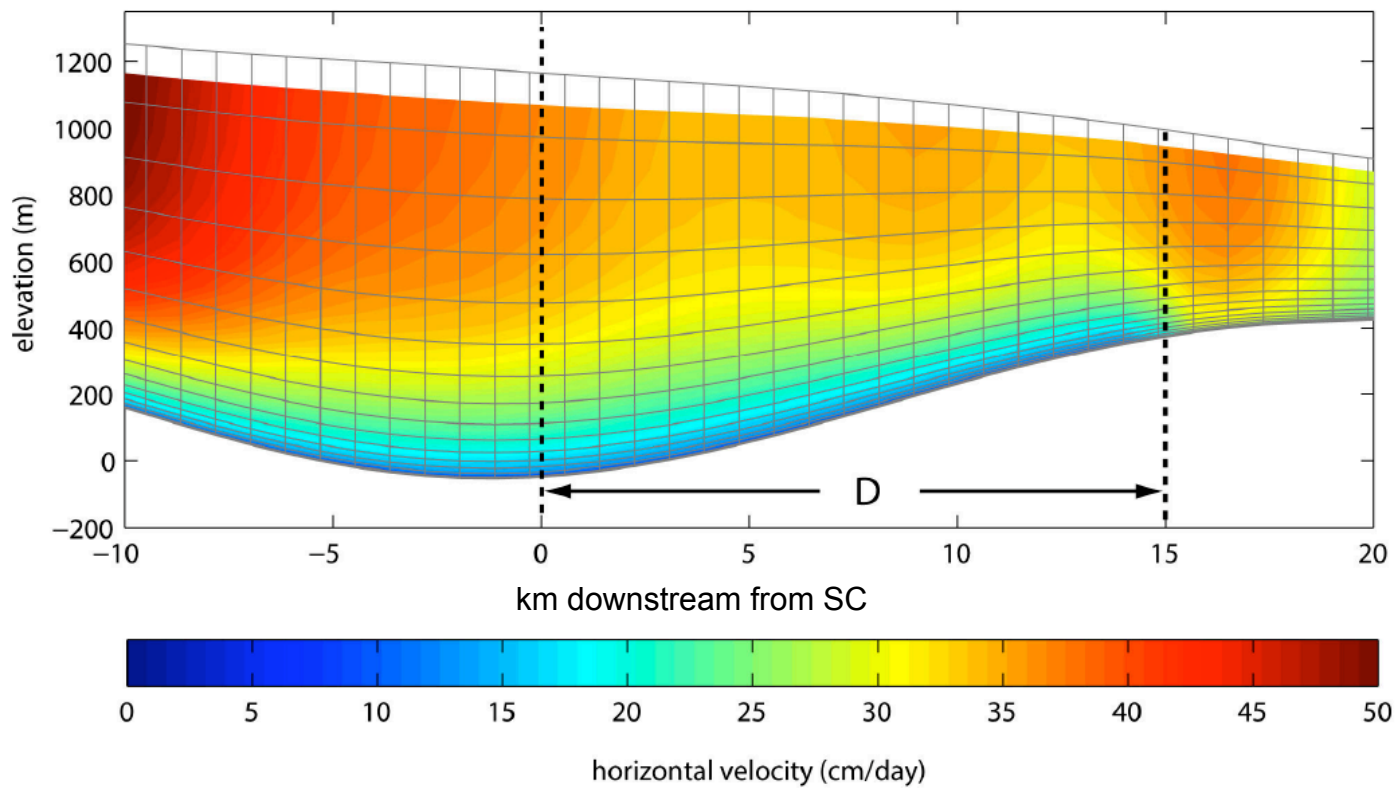


Initial, steady-state for isothermal model



… to simulate an increase in basal lubrication and sliding initiated from 15km downstream of SC to the margin, soften the basal layers there …

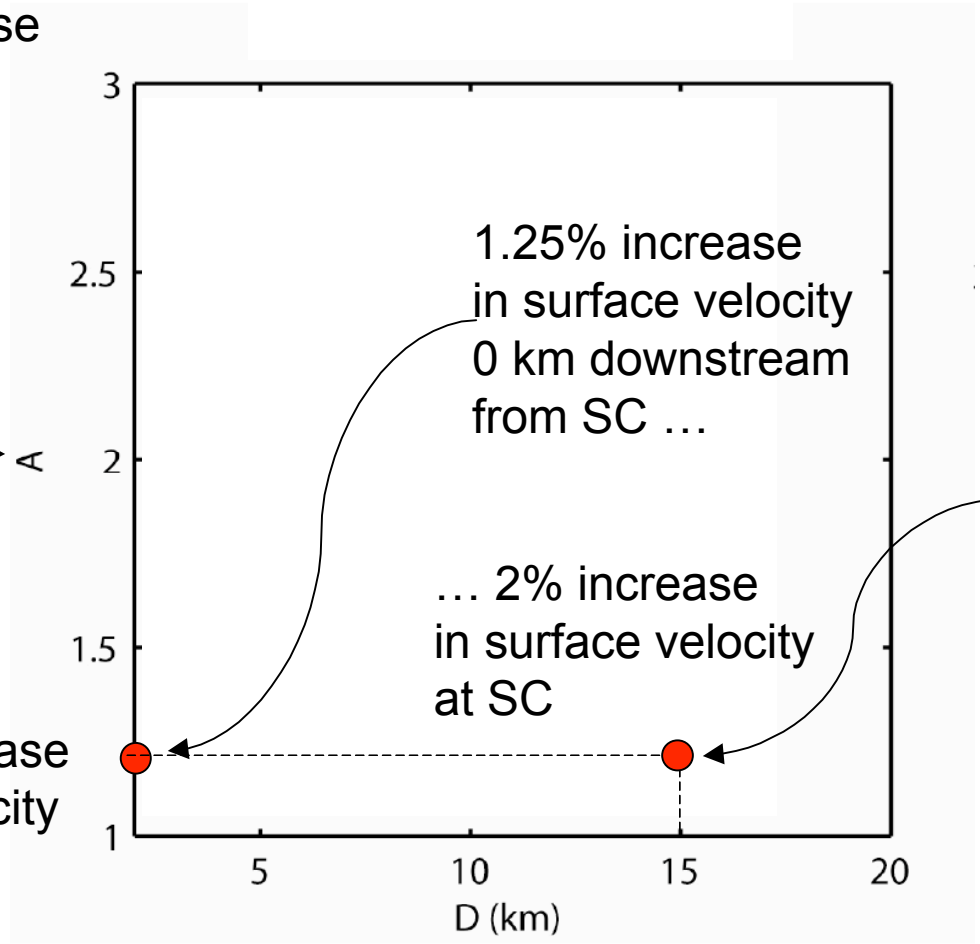
… increase in surface velocity D km downstream is ~25% (U_s/U_0=1.25 = A)
… increase in surface velocity at SC is ~2%



We want to compile results for many model runs in which we systematically vary the length scale, “D”, and “A”, the magnitude of the acceleration at D (through Δsliding)

Plotting the results in D-A parameter space

A: fractional increase in velocity, U/U_0, at location D km from SC



1.25% increase in surface velocity 0 km downstream from SC …

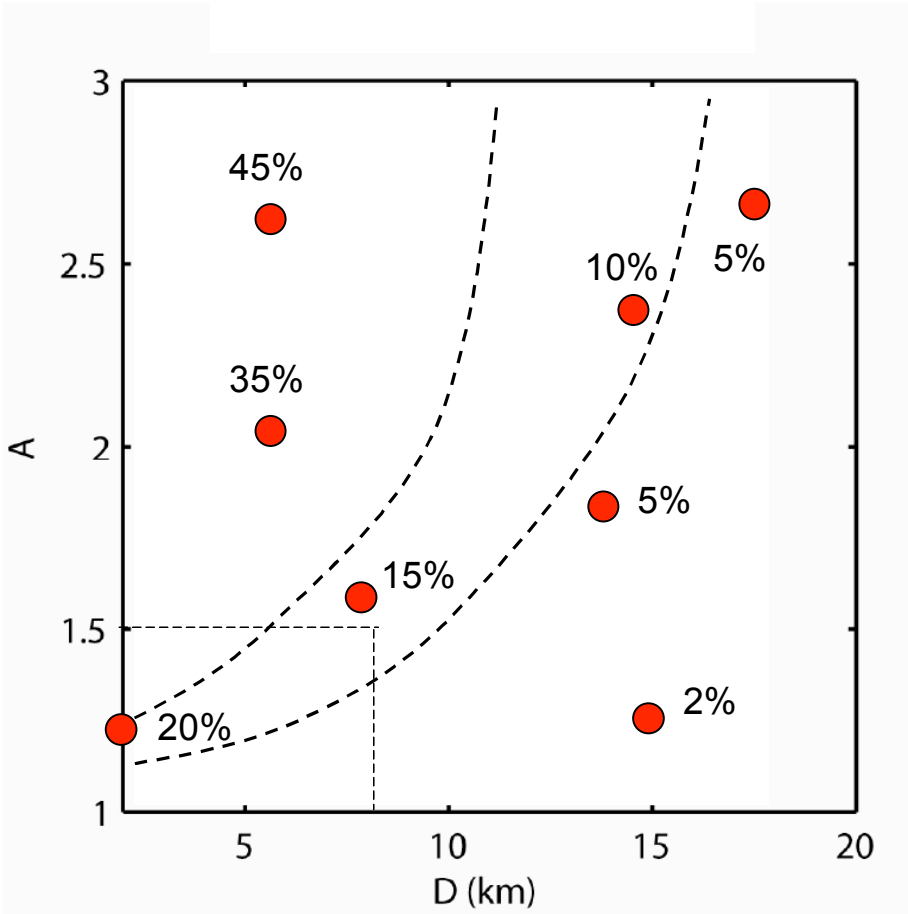
… 2% increase in surface velocity at SC

25% increase in surface velocity 15 km downstream from SC …

… 1.25% increase in surface velocity at SC

D: distance in km downstream from SC acceleration is initiated

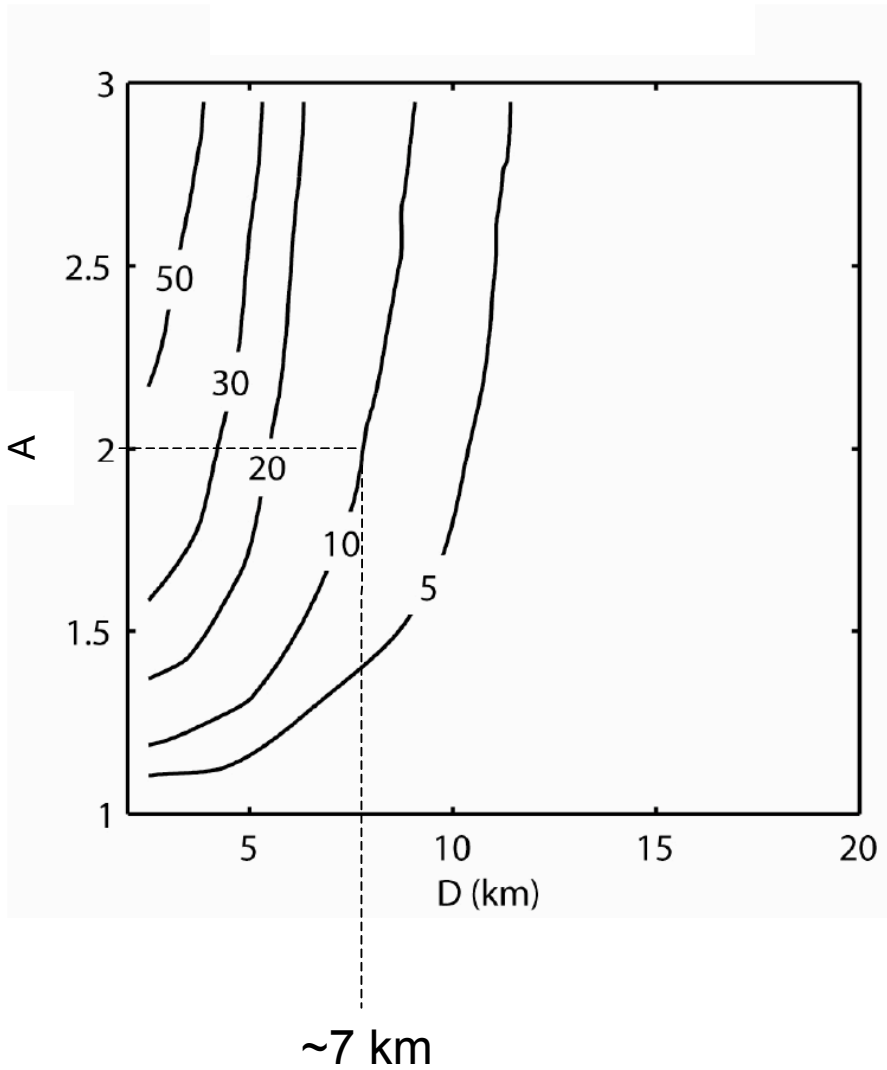
Plotting the results in D-A parameter space



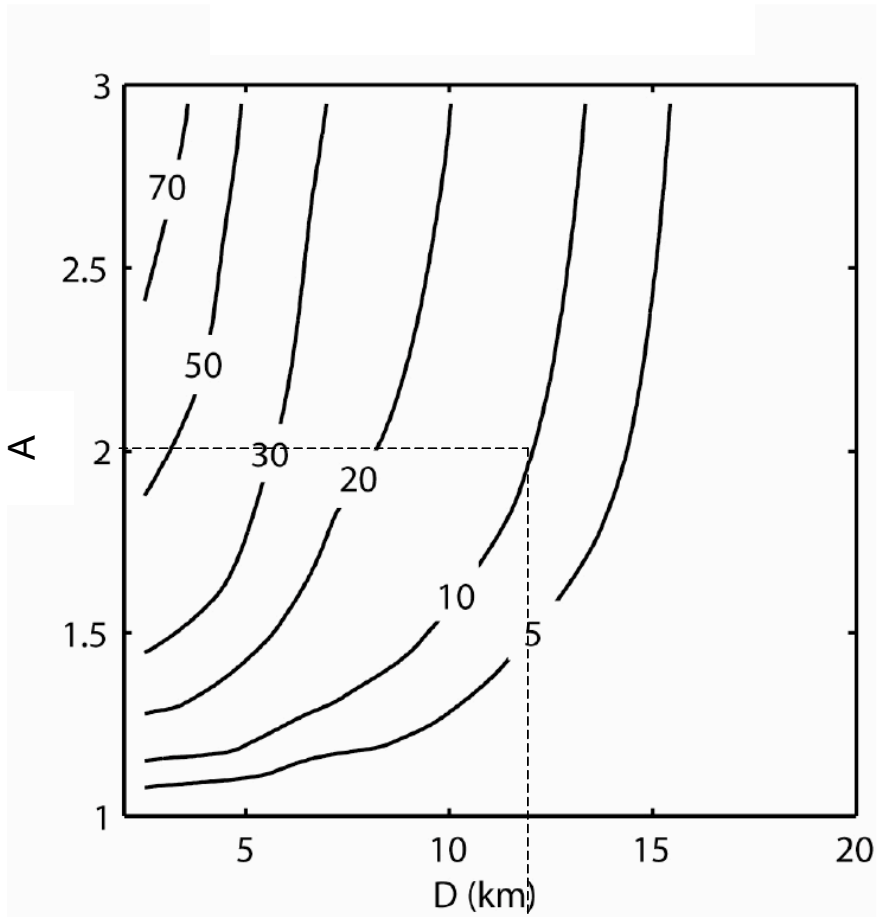
… dashed lines, contours of 10-20% acceleration at SC, enclose region for which the Zwally et. al observations are satisfied by the model …

Here, for example, an acceleration of 1.5x initiated at ~ 7 km downstream from SC will satisfy the observations at SC

Isothermal model, $U_{bed} / U_{sfc} = 0.3$



polythermal model, $U_{bed} / U_{sfc} = 0.8$



**From model, we conclude that 2x acceleration initiated 7-12 km downstream from SC could be responsible for the accelerations observed at SC **

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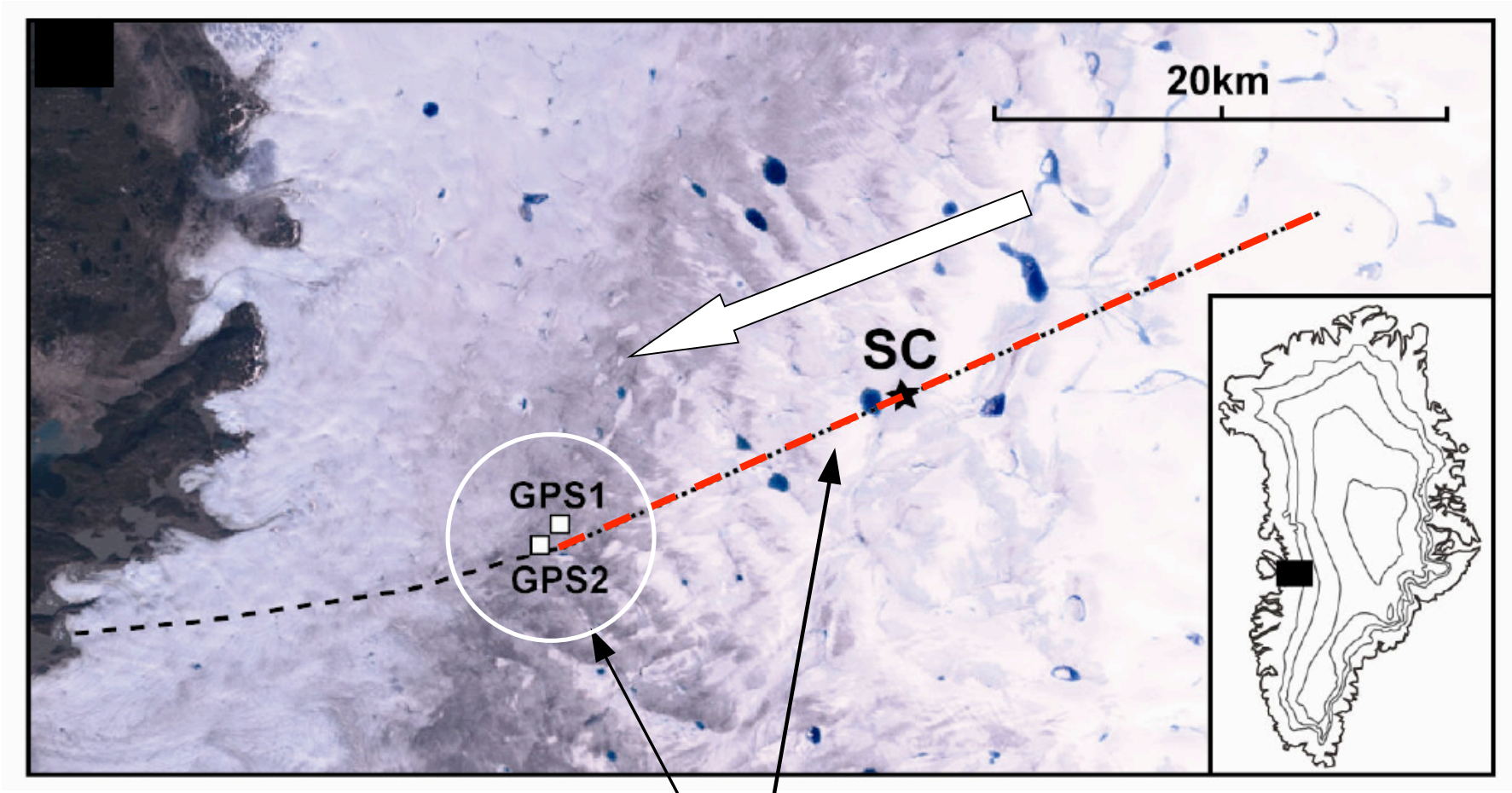
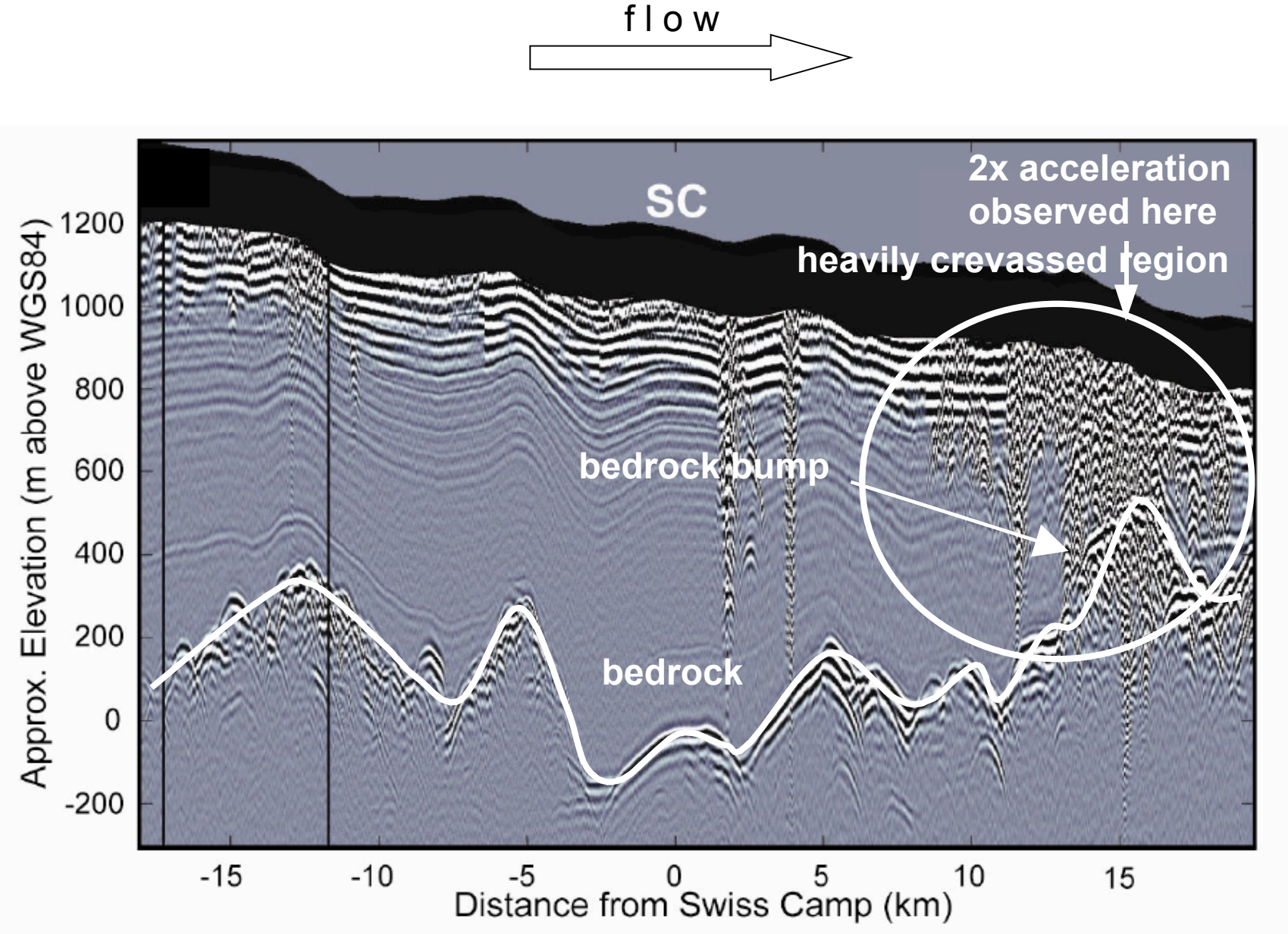
field camp, central Greenland



~2x, seasonal velocity acceleration observed here,
Radio-Echo Sounding (RES) profile line
in summer of 2006 (Rumrill and others, 2006)


flow
SC
2x acceleration
observed here
heavily crevassed region
bedrock bump
bedrock
Approx. Elevation (m above WGS84)
1200
1000
800
600
400
200
0
-200
-15
-10
-5
0
5
10
15
Distance from Swiss Camp (km)

Interpretation from observations and modeling

Who cares? What did we show here?

Summary and Conclusions

- seasonal accelerations observed along the flank of the GIS can be explained by larger magnitude accelerations initiated from downstream
- additional glaciological factors also favour the region downstream, nearer to the margin, as being the location at which accelerations are initiated
- as the “source” for the accelerations gets closer to the margin and farther from the ice sheet interior, flow dynamics and other glaciological characteristics become more “glacier like” and less “ice sheet like”
- as the “source” for the accelerations gets closer to the margin and farther from the ice sheet interior, the implications of the Zwally et. al (2002) observations become somewhat less exciting w.r.t. the ice sheet’s response to a warming climate

sunset, Ilulisat, Western Greenland

Summary and Conclusions

- This work suggests taking greater caution when interpreting observations of change before using those observations to make predictions about future changes.

- Other recent work[1], which reports on deceleration and thickening of GIS outlet glaciers after dramatic acceleration, thinning, and retreat, also suggest caution.

- Does this mean that we (the authors of this work) believe that the GIS is not in "danger" in the face of future climate warming, or that recent observations of change are not important to understand?

- We are only now starting to understand that ice sheet marginal regions behave similar to other smaller, temperate bodies of ice[2], and this realization will have significant implications for how ice sheets respond to future climate forcing

[1]Howat and others (2007), [2]Truffer and Fahnestock (2007)

sunset, central Greenland