Bed topography controls response time of Greenland outlet glacier mass loss

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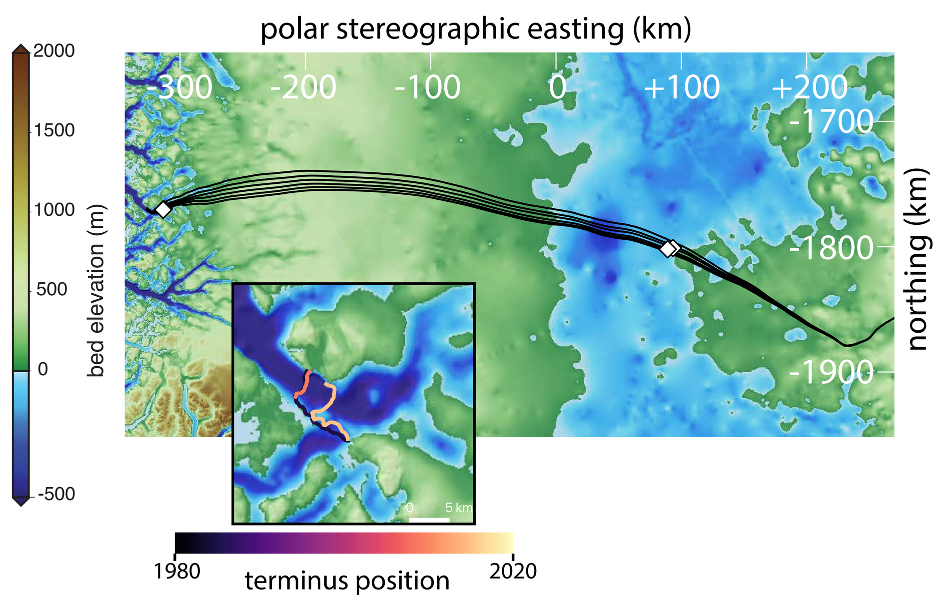
NASA POSTDOCTORAL PROGRAM

Take-home messages

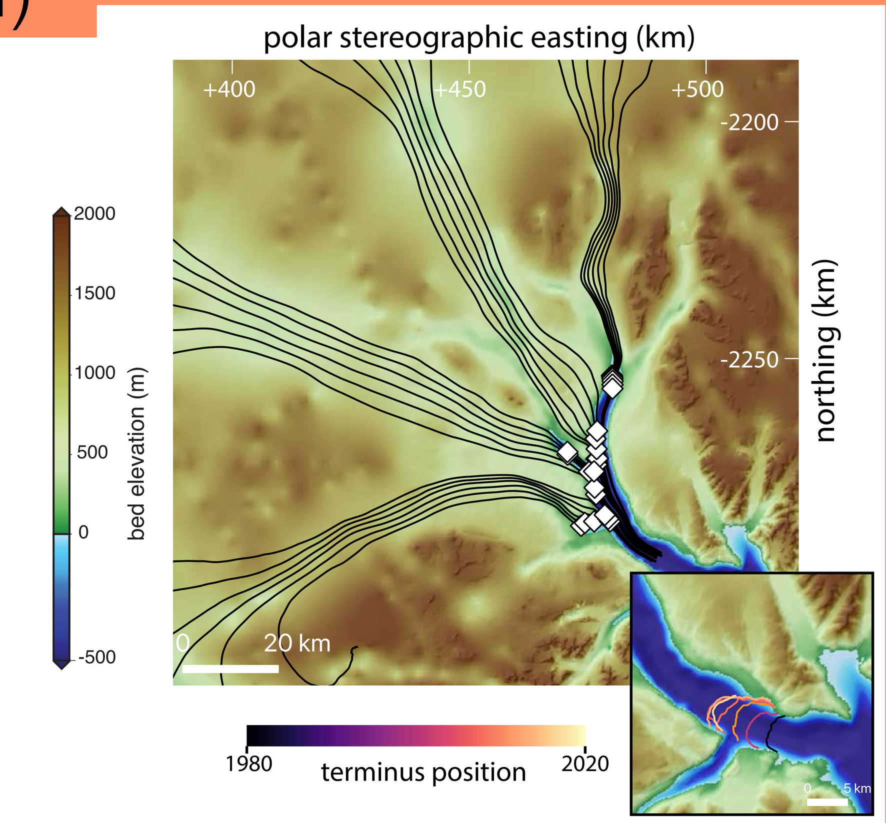
1. Outlet glaciers with gentle bed topography allow terminus-initiated thinning to diffuse far inland and respond slower.
2. Outlet glaciers with mountainous bed topography limit spatial extent of terminus-initiated thinning and respond faster.
3. Refining the timing of sea-level rise over next 100 years from GrIS requires modeling response of each individual outlet glacier.

Spatial extent of thinning in response to terminus retreat

Kakivfaat Sermiat (KAK)



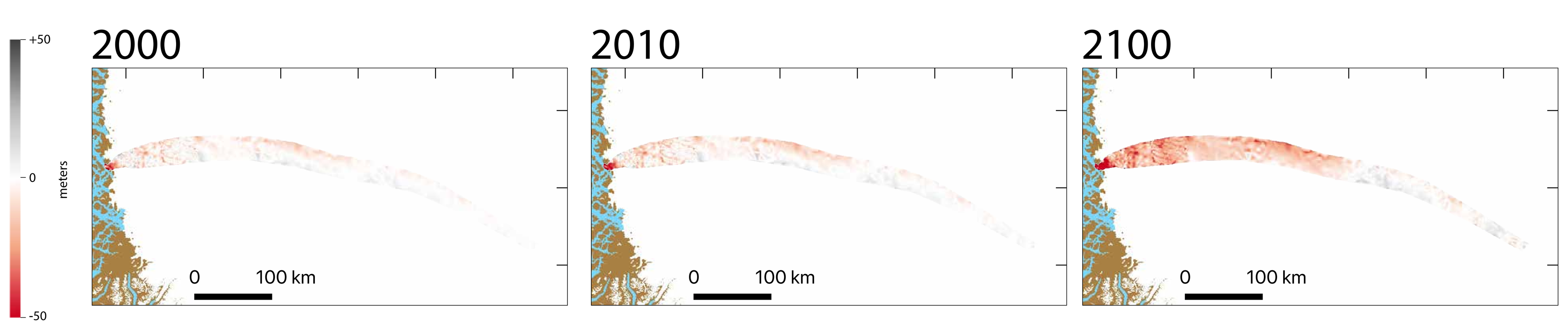
Kangerlussuaq Gletscher (KLG)



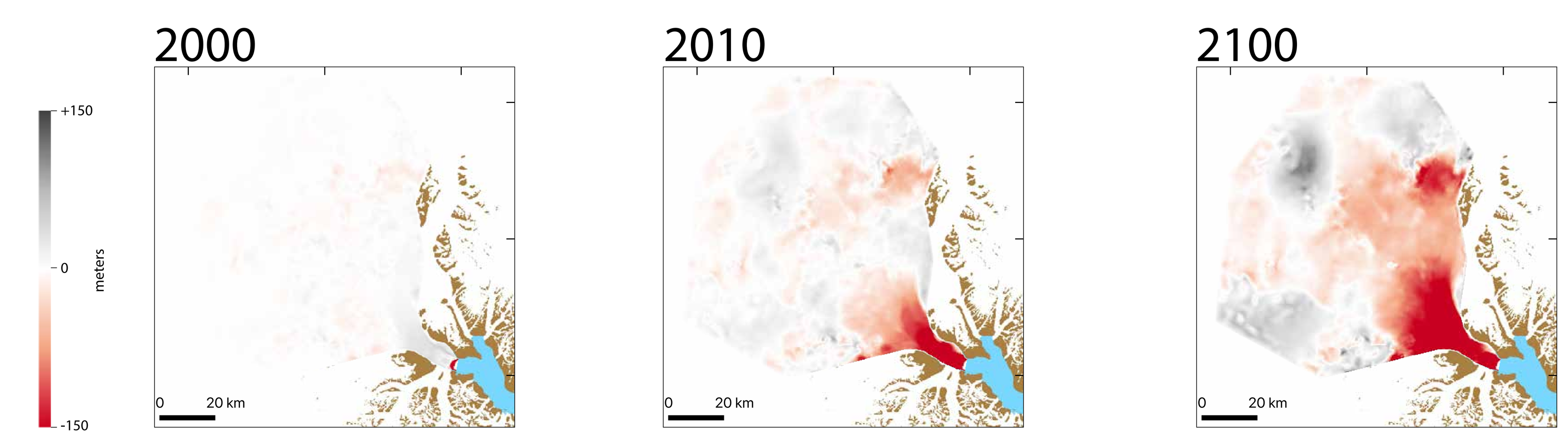
gentle (typical of northwest)	bed topography	mountainous (typical of east)
scattered, some far inland ◇	geometric thinning limits*	clustered, at heads of troughs ◇
low (3 km³/yr)	ice discharge	high (13 km³/yr)
100s of km inland	spatial extent of thinning	limited to 35 km of terminus
slower	response time	faster

How did we do the modeling?
We used the Ice Sheet System Model (ISSM)
1. Initialize glacier with pre-retreat geometry/velocity (SSA physics)
2. Force glacier to retreat (level-set method)
3. Allow glacier to respond to retreat until year 2100

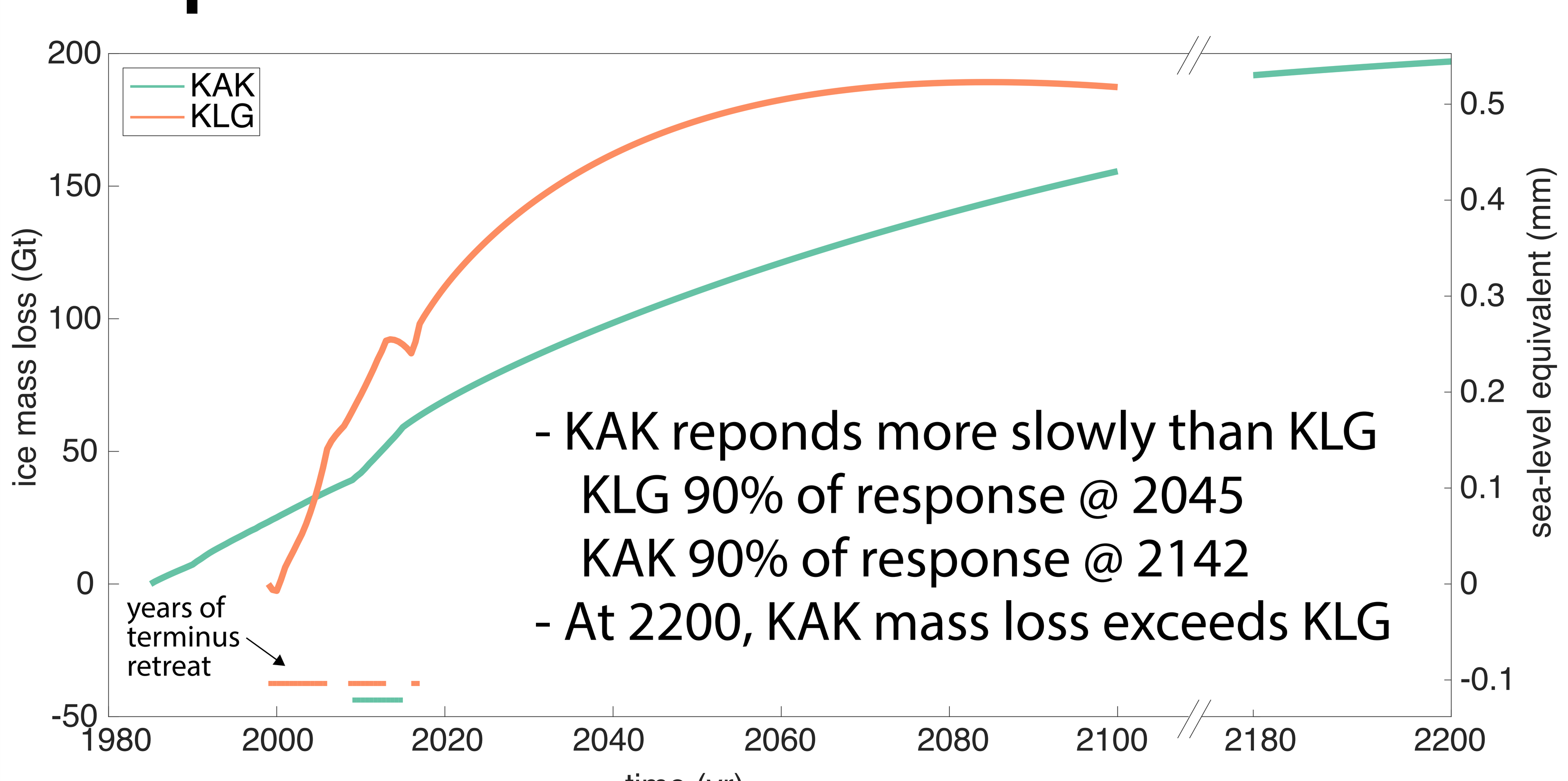
After retreat, modeled dynamic thinning extends 100s of km inland.



After retreat, modeled dynamic thinning is limited to 35 km from terminus.



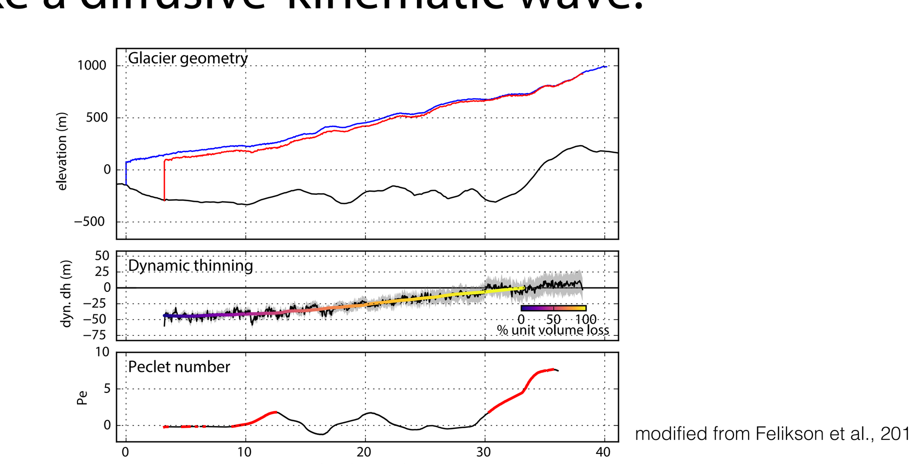
Response time of mass loss



*Using Peclet number (Pe) to predict thinning

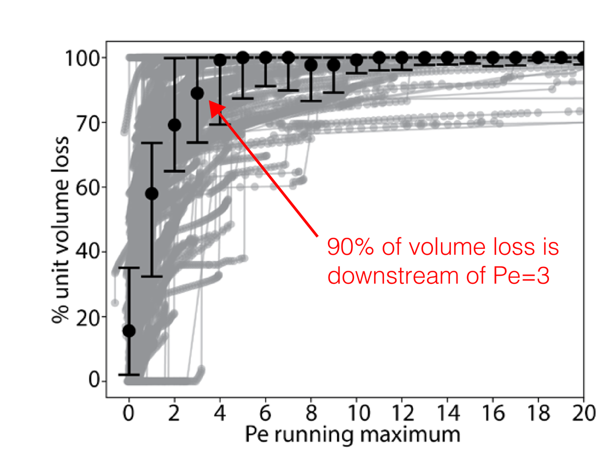
Simple metric, based on geometry, to predict how far inland thinning can spread from terminus.

(1) After terminus retreat, thinning behaves like a diffusive-kinematic wave:



$$\text{Peclet number} = \frac{\text{downglacier advection}}{\text{upglacier diffusion}}$$

(2) By comparing Pe to measured dynamic thinning ...

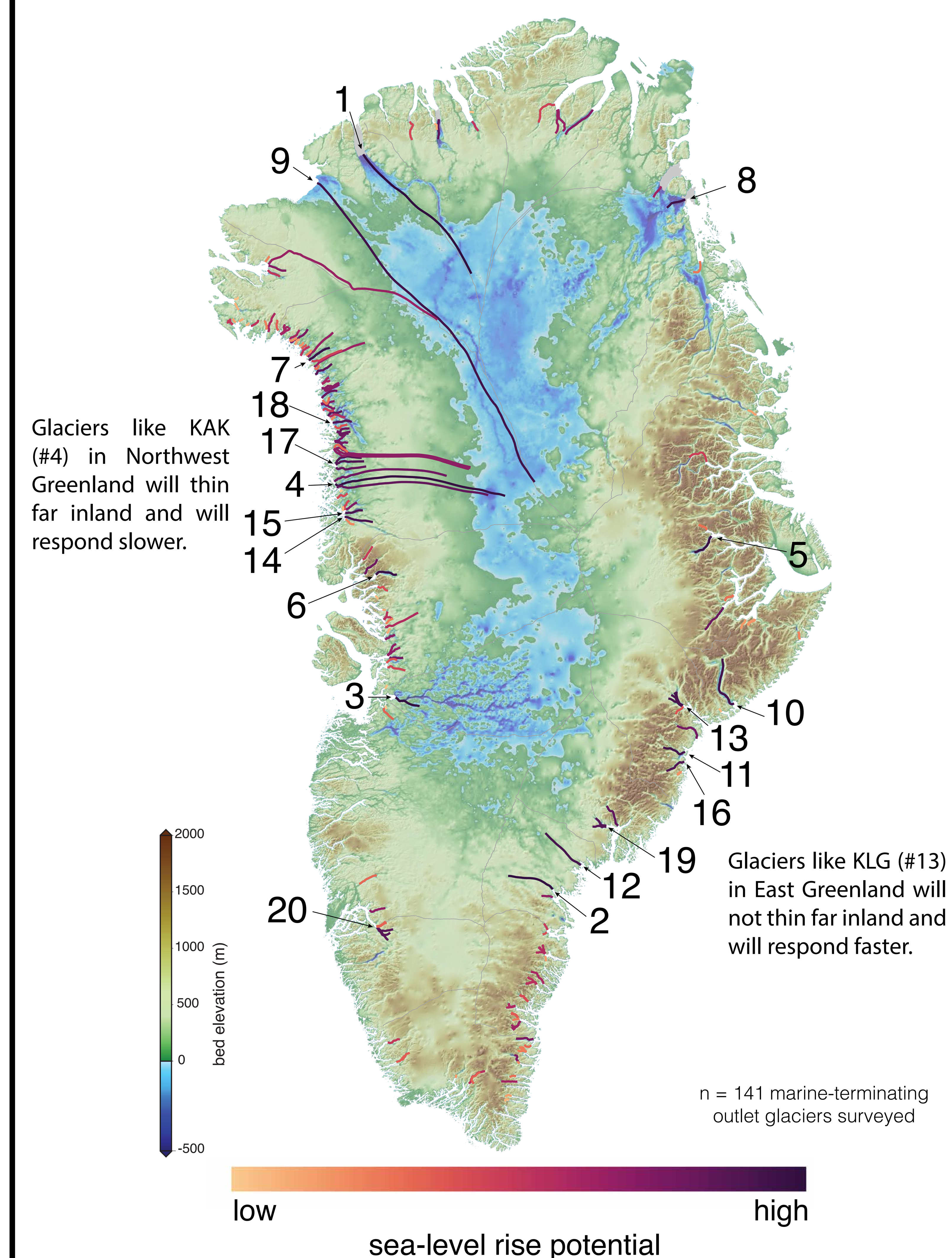


... we find that thinning diffuses upstream until Pe=3 (Felikson et al., 2017).

Sea-level rise potential

If perturbed, glaciers will thin from terminus to length of drawn flowlines.

Glaciers ranked by potential contribution to sea-level rise (method below) with top 20 highest potential contributors numbered.



Method

1. Find Pe=3 predicted inland thinning limits for flowlines surveyed across glacier flow
2. **Glacier-wide thinning limit:** maximum distance to Pe=3 thinning limits minus 1 std. dev. of distances to all across-flow Pe=3 thinning limits
3. **Sea-level rise potential:** rank glaciers separately by (1) glacier-wide thinning limits and (2) rank glaciers by ice flux. Then, rank by the average of (1) and (2).

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References.
Felikson, D., Bartholomaus, T.C., Catania, G.A., Korsgaard, N.J., Kjær, K.H., Morlighem, M., Noël, B., van Den Broeke, M., Stearns, L.A., Shroyer, E.L. and Sutherland, D.A., 2017. Inland thinning on the Greenland ice sheet controlled by outlet glacier geometry. *Nature Geoscience, 10*(5), p.366.

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