The failure of fracture mechanics: (or can we predict when melt lakes will drain?)

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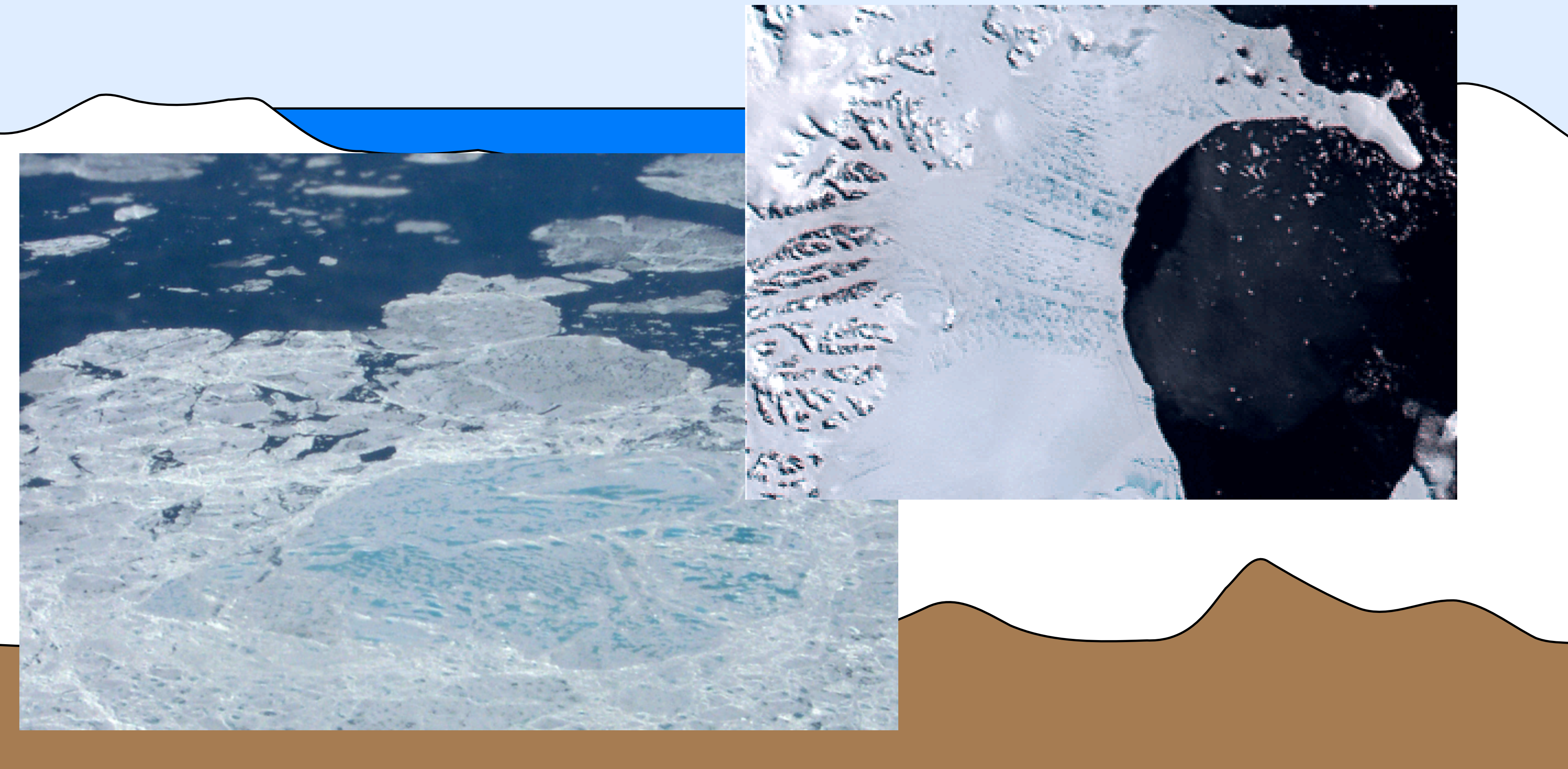


Outline

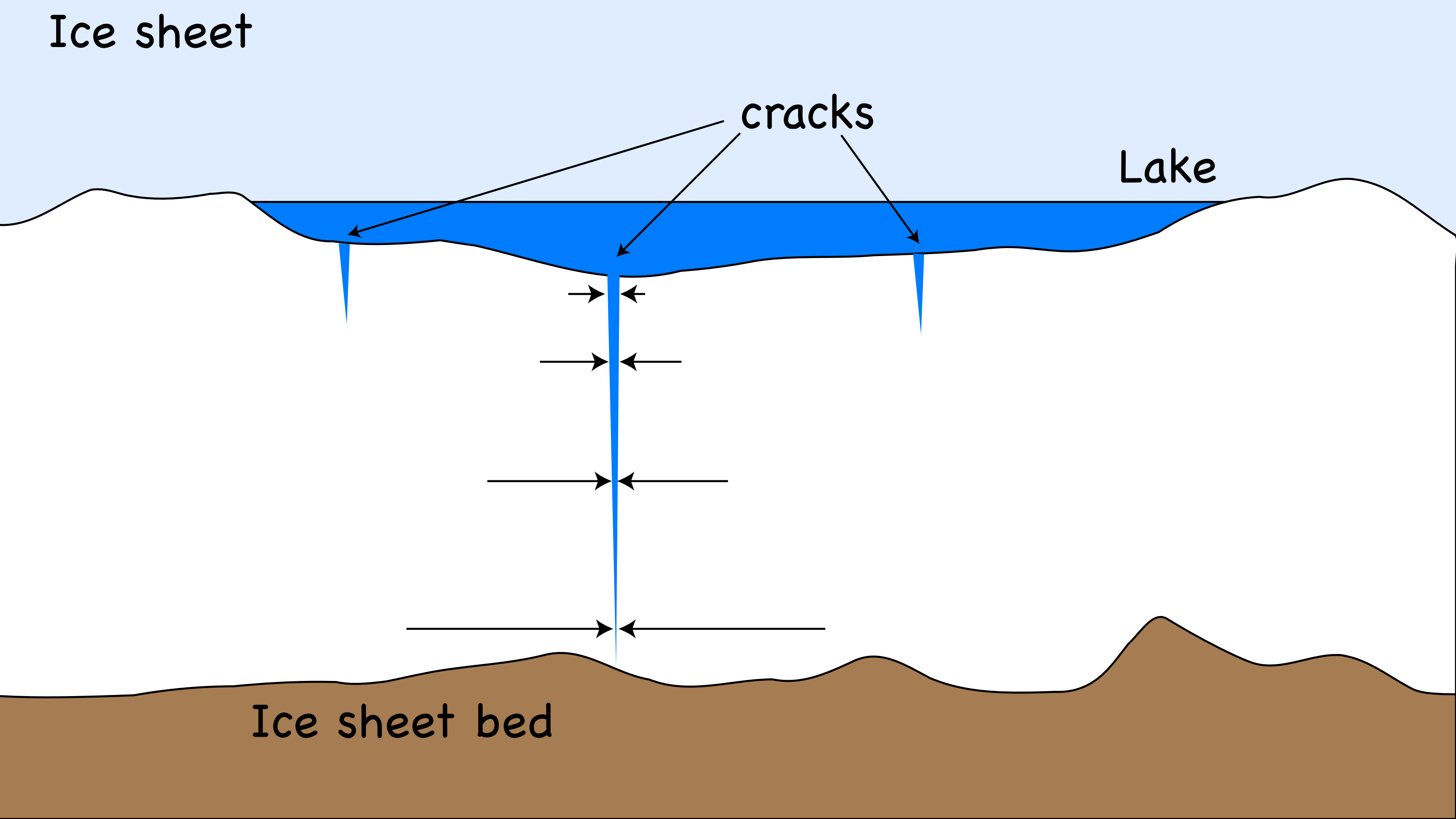
Question:
What factors control melt pond size distribution

(1) Surface energy balance of the ice sheet/shelf

(2) Topography of the ice sheet/shelf surface

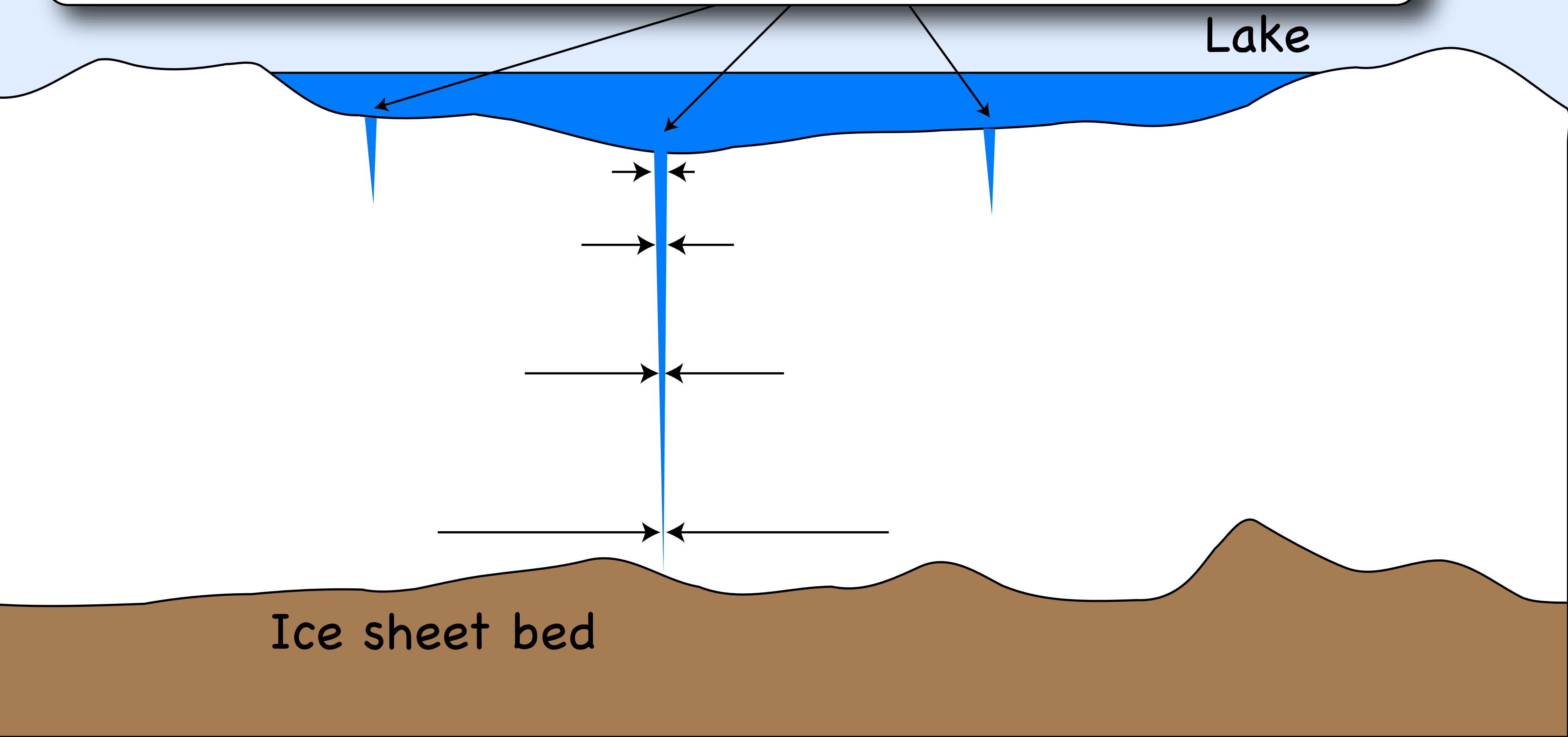
(3) Melt lake drainage

Traditional picture



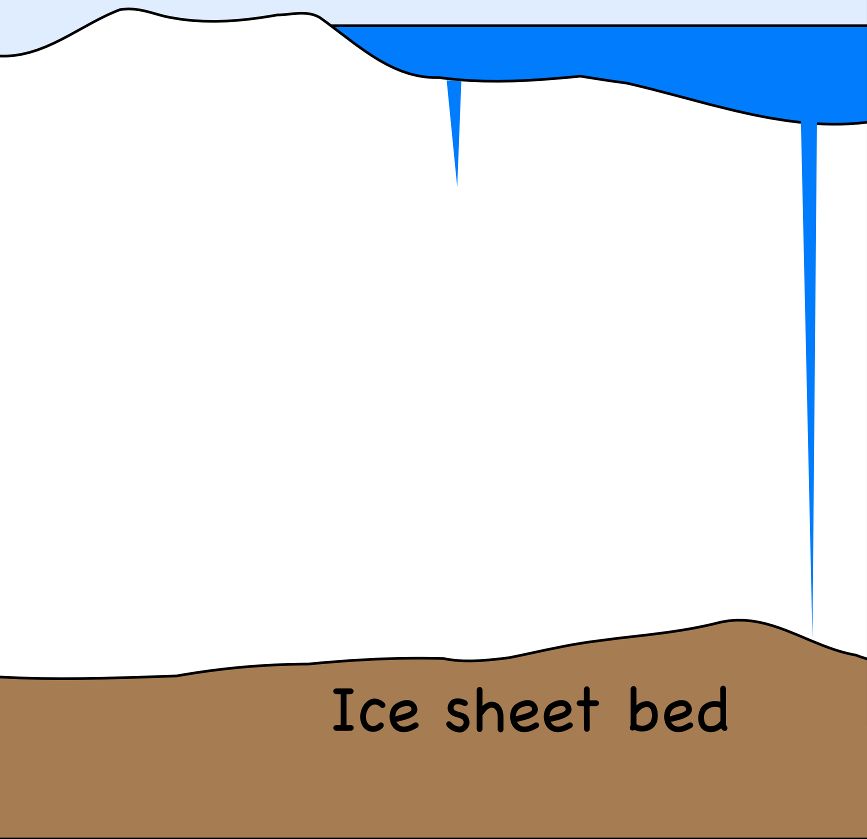
Traditional picture

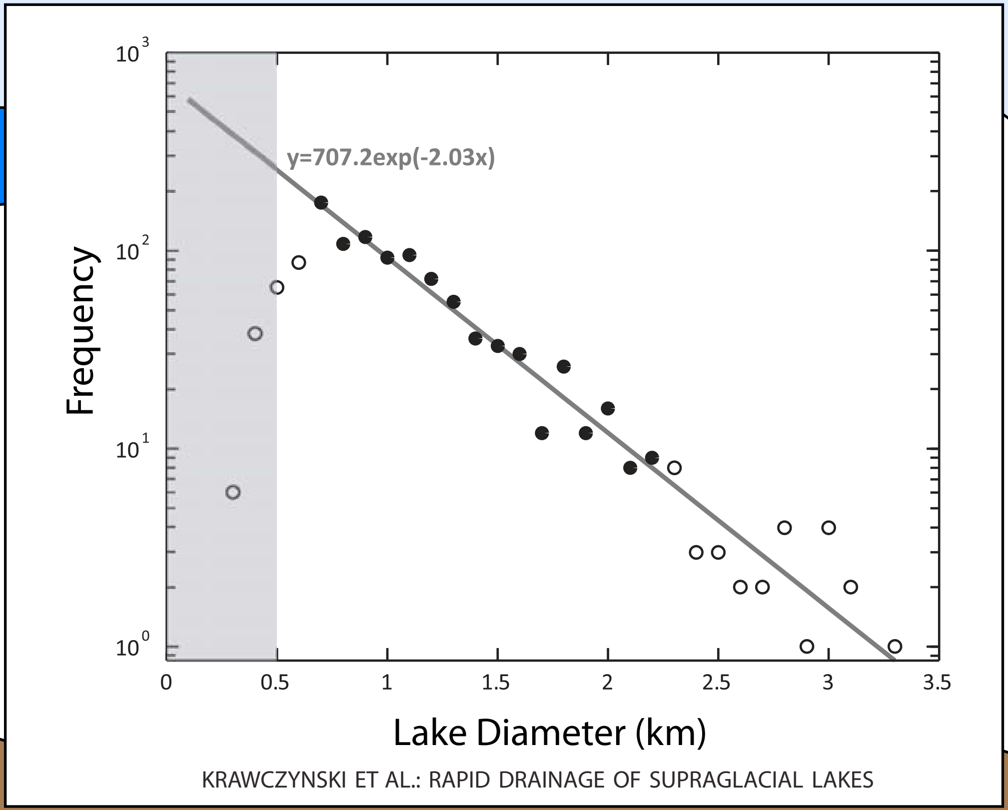
Large cracks filled with water will propagate to the ice sheet bed



Is water the limiting factor?

Most lakes have more than enough water to drain to bed (Krawcynski and others, 2009)





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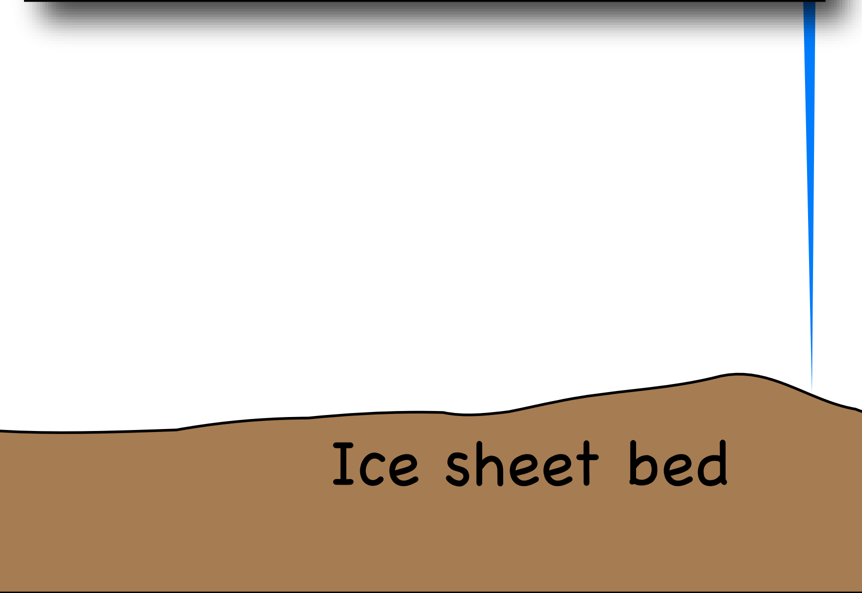
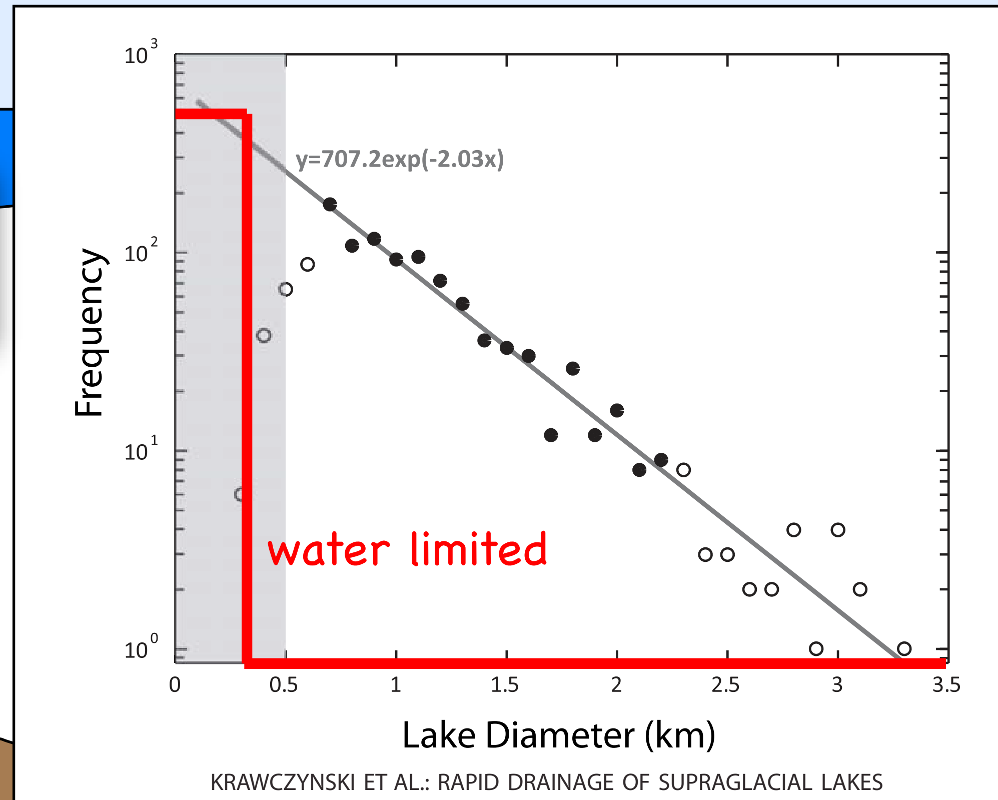
Water is not the limiting factor





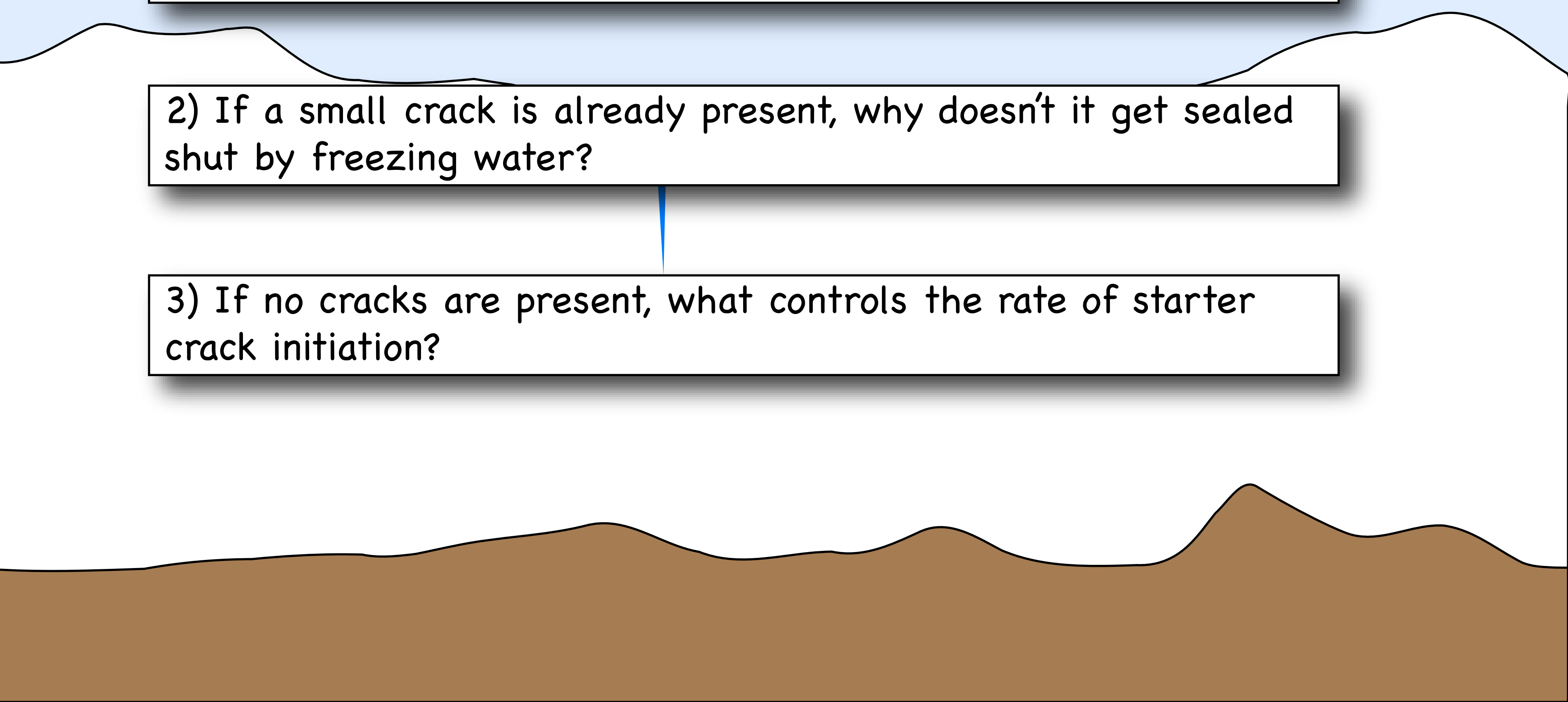
Problems with the traditional picture

Why don't melt lakes/ponds draing?

1) If a large crack is present, why doesn't it propagate as soon as it is filled?

2) If a small crack is already present, why doesn't it get sealed shut by freezing water?

3) If no cracks are present, what controls the rate of starter crack initiation?



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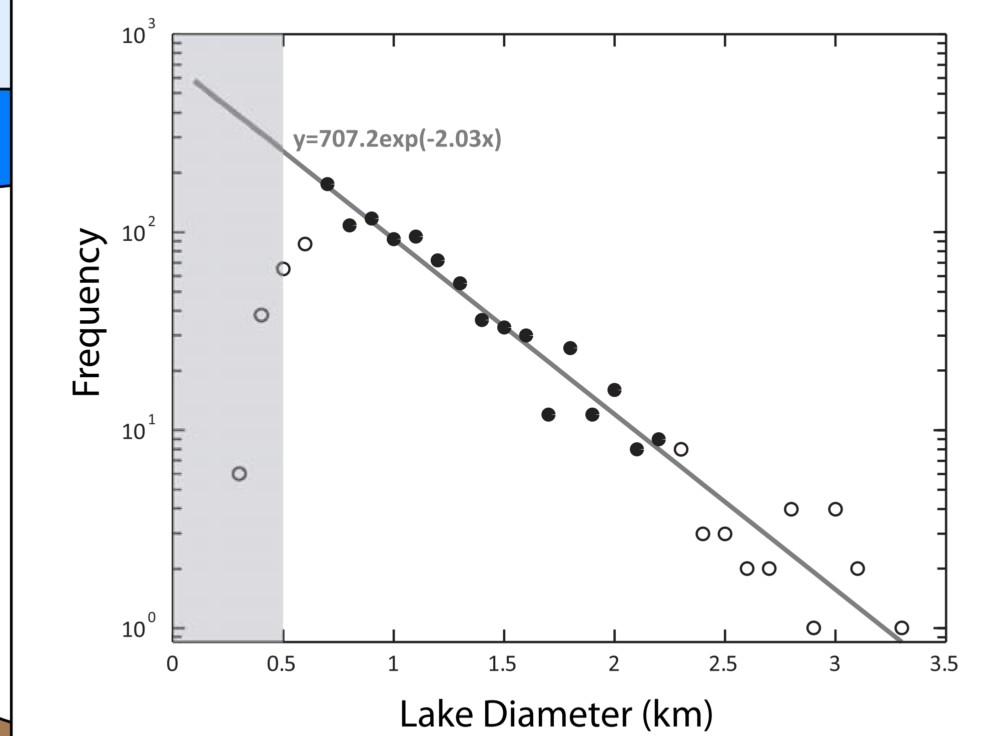
Size-frequency distribution of lakes is exponential

This is what I'm going to try to explain



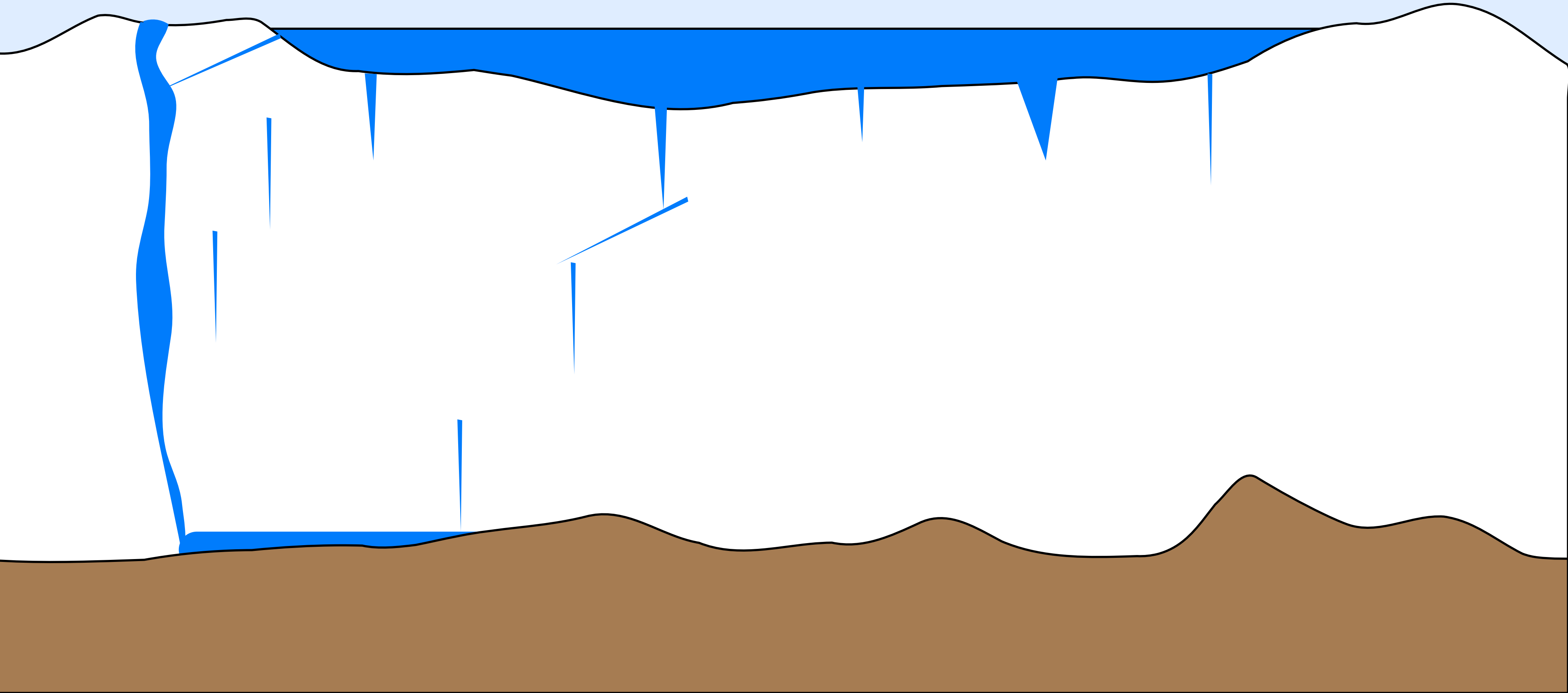
KRAWCZYNSKI ET AL.: RAPID DRAINAGE OF SUPRAGLACIAL LAKES

Ice sheet bed

A more nuanced picture

Pre-existing englacial hydrology/fracture network to connect to (moulines, fractures, channels, etc.)

Probability that a fracture intersects the englacial fracture network



Approach

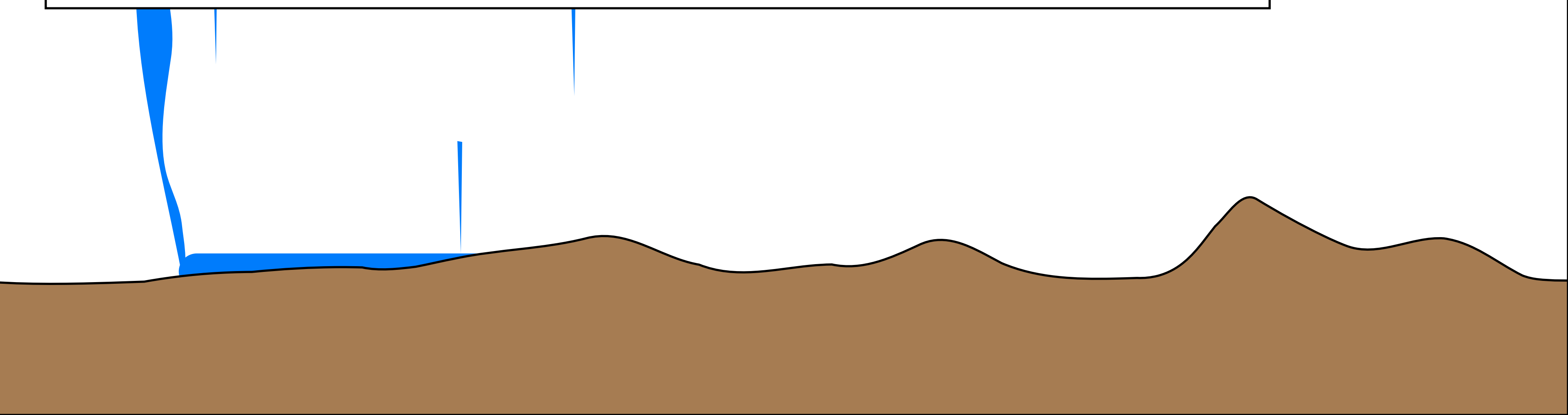
Assume:

(1) Probability of connecting to existing drainage network is $P(\tau,\phi)$:

τ = instananeous applied stress;

ϕ = “damage” or fracture density

(2) Probablity of failure initation at any point on the ice is statistically independent of failure initiation elsewhere



Approach

Assume:

(1) Probability of connecting to existing drainage network is $P(\tau,\phi)$:

τ = instananeous applied stress; history dependent

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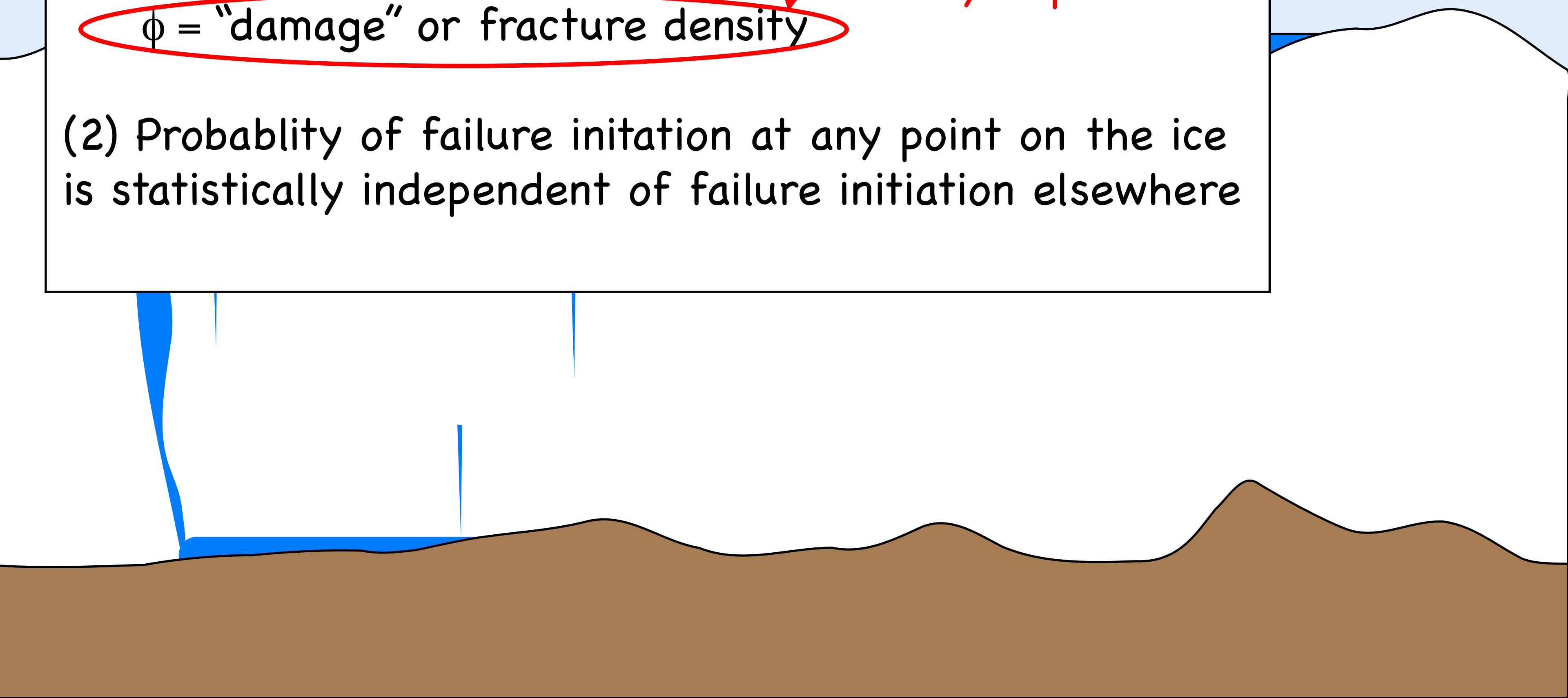

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$$P = 1 - \exp(-\varphi dA)$$

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Probability that a lake survives to grow to size A is exponential (and independent of φ)

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If stress, damage are ≈ constant over the lake area

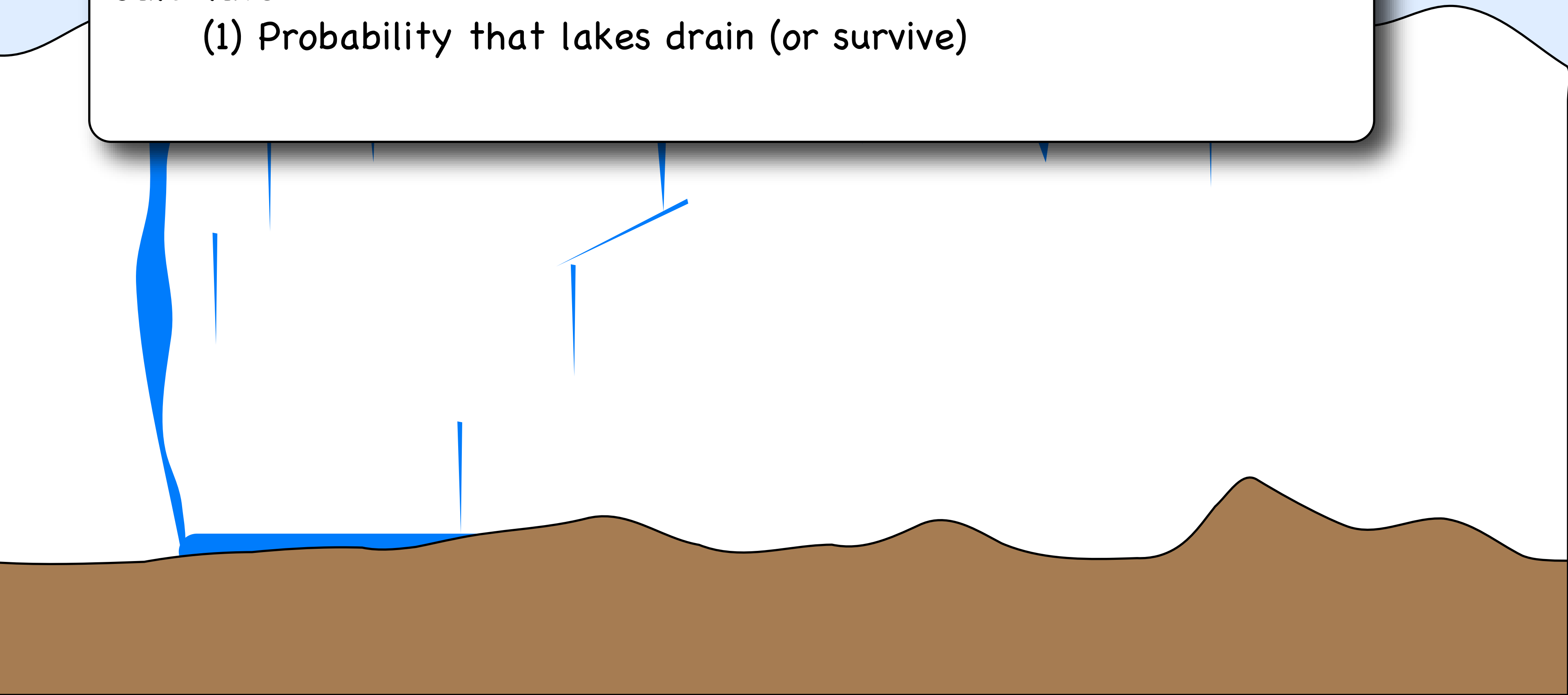
A random experiment . . .

Assume:

(1) A spatially uniform initial distribution of lakes
(2) Initial distribution of lake sizes are uniformly distributed

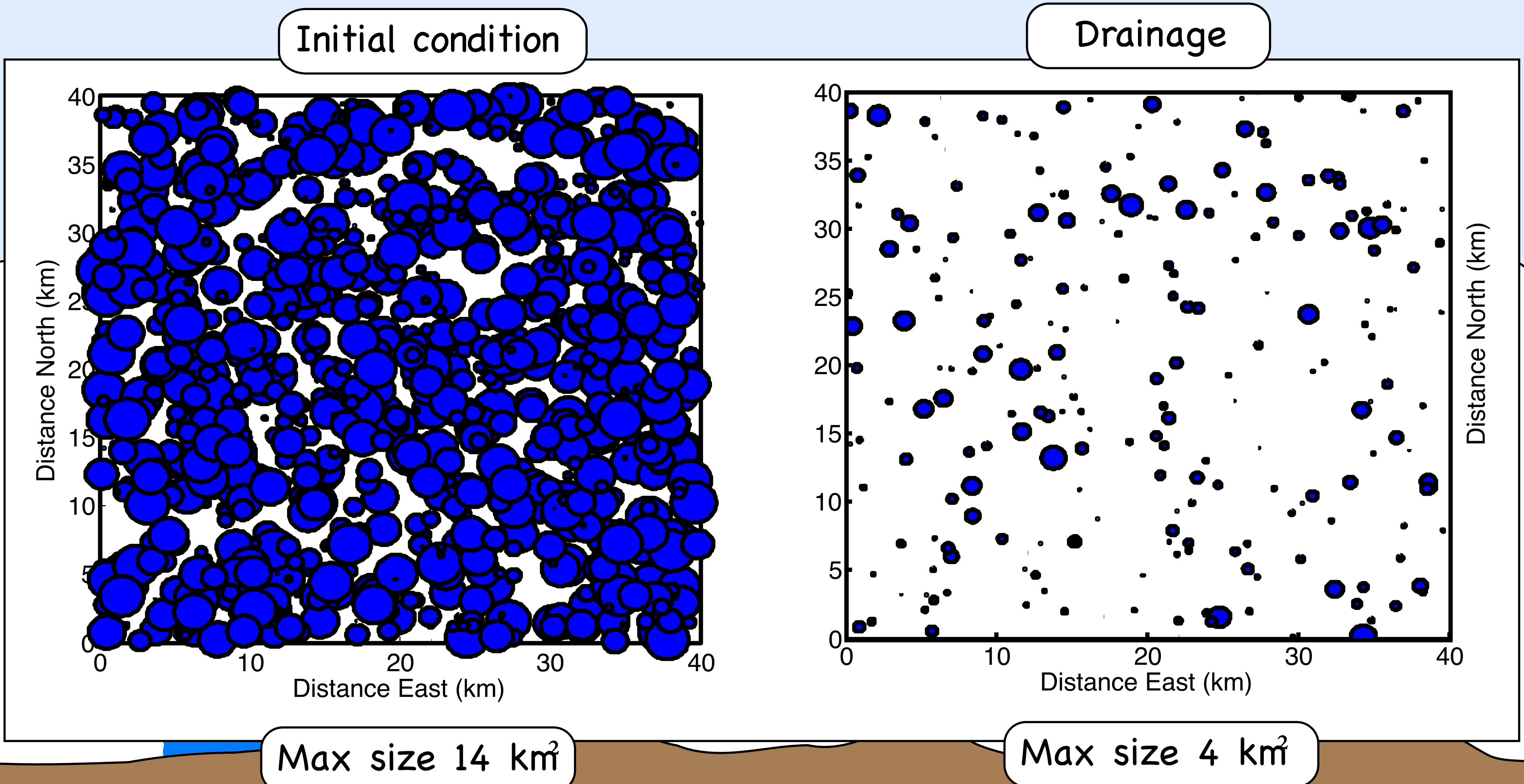
Calculate:

(1) Probability that lakes drain (or survive)



A random experiment . . .

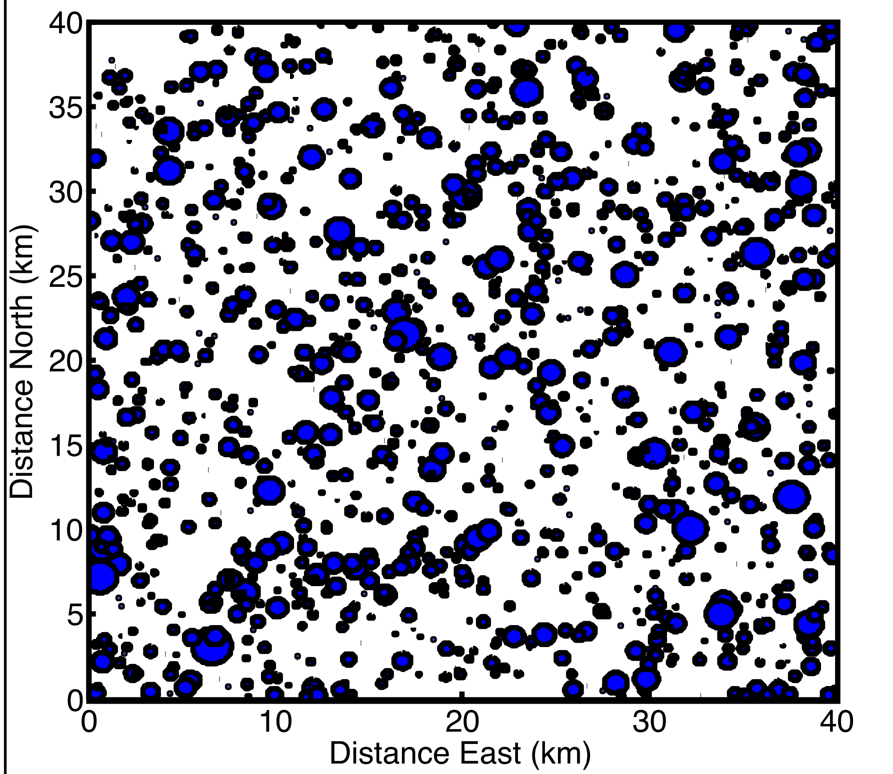
Uniform distribution of melt lakes



Effect of increasing surface melt

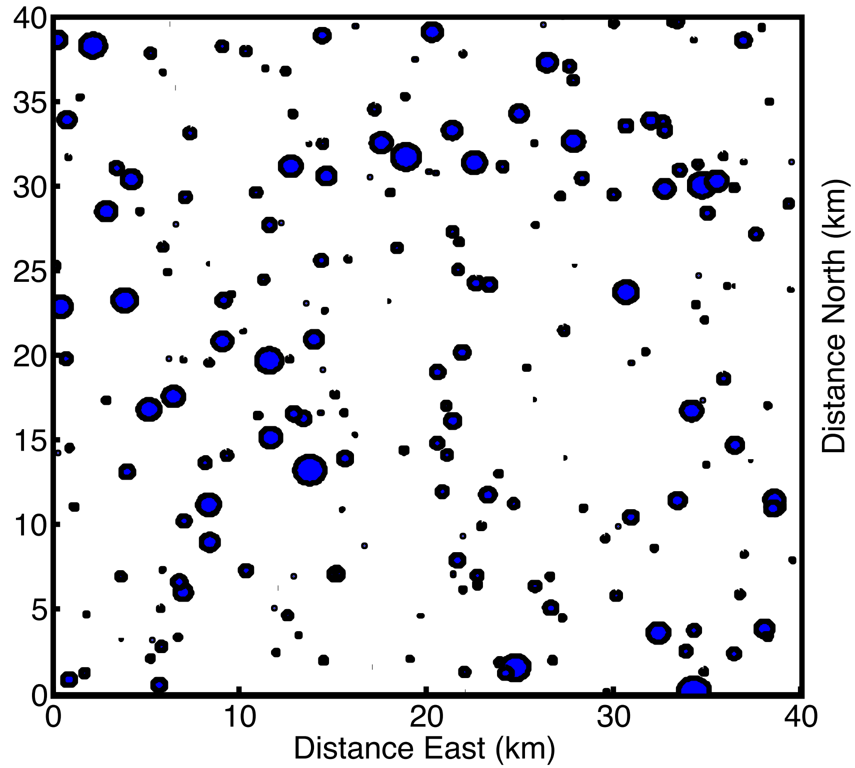
Uniform distribution of melt lakes

Double Surface Melt



Max size 7 km²

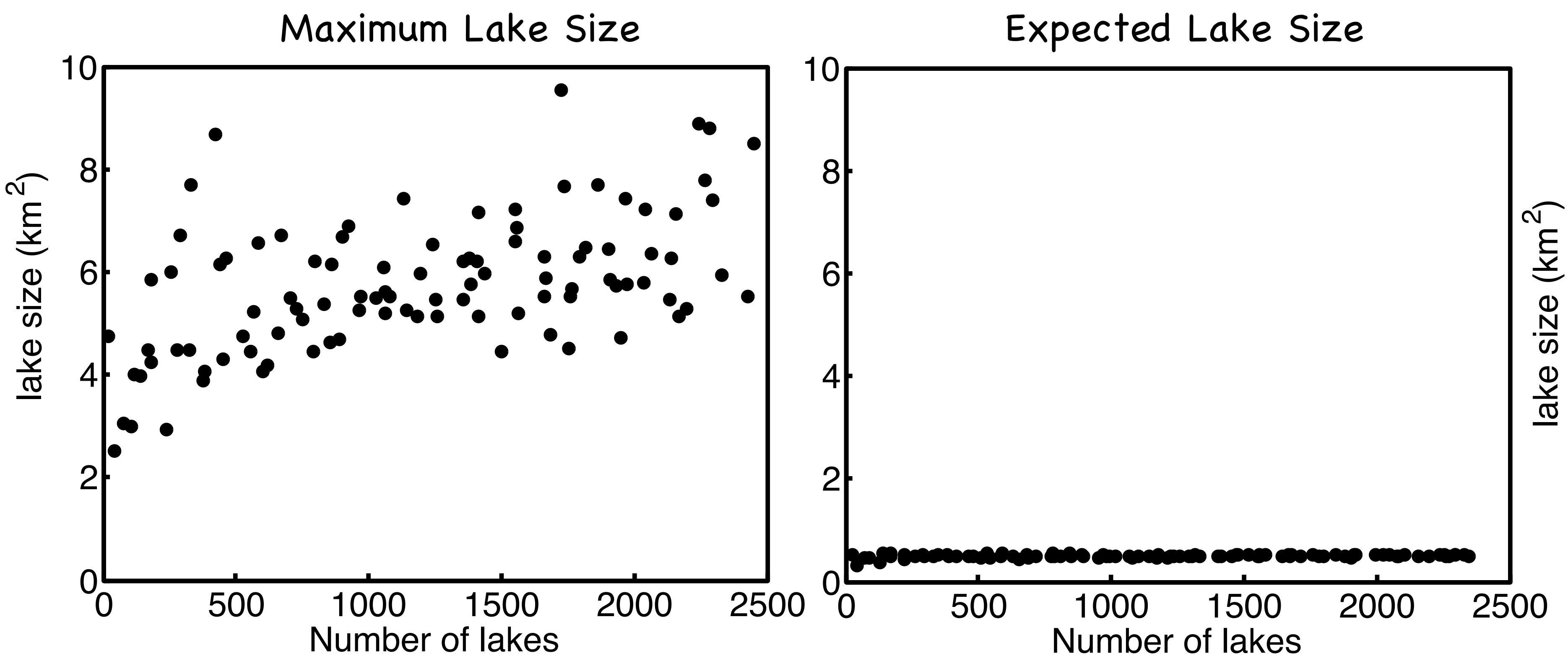
Drainage



Max size 4 km²

Effect of increasing surface melt

Uniform distribution of melt lakes



Conclusions

Need to invoke additional physics/hypothesis to apply LEFM to melt lake drainage

Amount of surface melt may not be the limiting factor that determines when a melt lake drains

Some caution is in order in applying/interpreting LEFM to ice sheets/shelves

Probabilistic models may be useful in making deterministic predictions