ESS 203 - Glaciers and Global Change

Monday February 22, 2021.

Outline for today

- Today's highlights on Wednesday – *Justice Correa-West*
- Highlights from Friday – *Angela Gaither*

Today

- How ***far*** will a glacier retreat or advance after an abrupt climate shift?
- How ***long*** for a glacier to adjust after a climate change?
- Length response to an ongoing climate change?

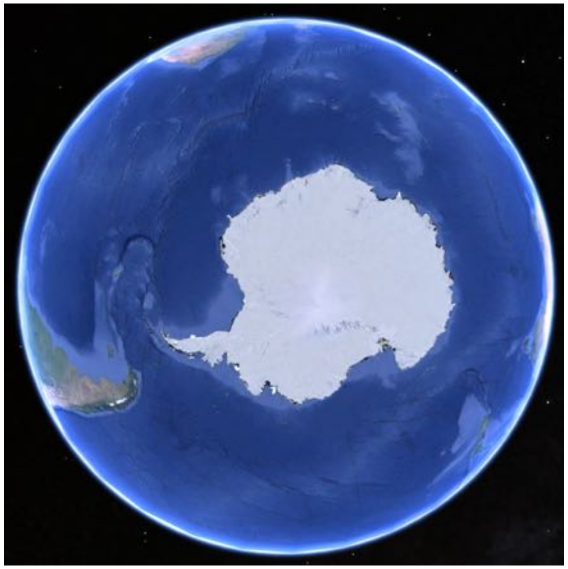
Mid-term #1 – the average was 22/30

Question #1 − Peer review

- *Nature* was the ***only*** peer-reviewed journal in the list.

Question #2 − Ice-Age ending

- Hudson Bay was ***not*** dry land in the Ice Age − it was covered with several km of ice.
- Those Utah lakes were ***no***t formed from melting glaciers, just from heavier rain than today.
- .The southern hemisphere was also very cold in the Ice Age, but there just was ***no land*** on which to start another ice sheet.



Question #3 Griselda's mission

- The water was not going to race straight across the polder as if it was confined in a channel; it would spread out, like water when you fill a bathtub.

If you didn't do as well as you hoped on Midterm #1, remember that each Mid-term is worth only 12.5% of the class grade.
For Mid-term #2, try the study questions ahead of time, and talk over your trial answers with classmates.

Mid-term #2, Wednesday March 3

Five study questions for Mid-term #2 are posted in Canvas.

- 3 of these will form the actual test.

Study sessions with classmates?

- Talking through the questions and trial answers with your classmates can be very valuable.
- Read the notes “Writing a test” on the TESTS page

  https://courses.washington.edu/ess203/TESTS/tests_index.shtml.

Studying Effectively

- To get good marks when questions require prose answers, you need to write answers that are understandable and convincing.
- Writing down an answer from a group discussion that you didn’t fully understand can be obvious to graders.
- I may be a bit less forgiving about fuzzy thinking and fuzzy ideas than in the first Midterm.
- So talk these questions through thoroughly with your classmates until you understand the issues.

HW 20 – Assignment for Wednesday

It's time to start reading some peer-reviewed papers. Please read the *Science* paper
Oerlemans, J. (1994) Quantifying Global Warming from the Retreat of Glaciers. *Science* 264(5156), pp. 243-245.

It is posted on the class web site (READINGS tab),
https://courses.washington.edu/ess203/RESOURCES/READING/reading_index.shtml
or under the Files tab on Canvas:
https://canvas.uw.edu/courses/1434502/files/folder/HomeWork?preview=73938535

In half to one page of prose, answer *The 3 Questions.*

- What is the question that the paper tries to address?
- What is the answer (according to the authors)?
- What points are still unclear to you?

In class we are currently looking at how changes in glacier size can give information about climate changes. This is what Oerlemans did.

Please have the Oerlemans *Science* paper (digital or hard copy) available during class on Wednesday, so that you can discuss it with your break-out Group partners.

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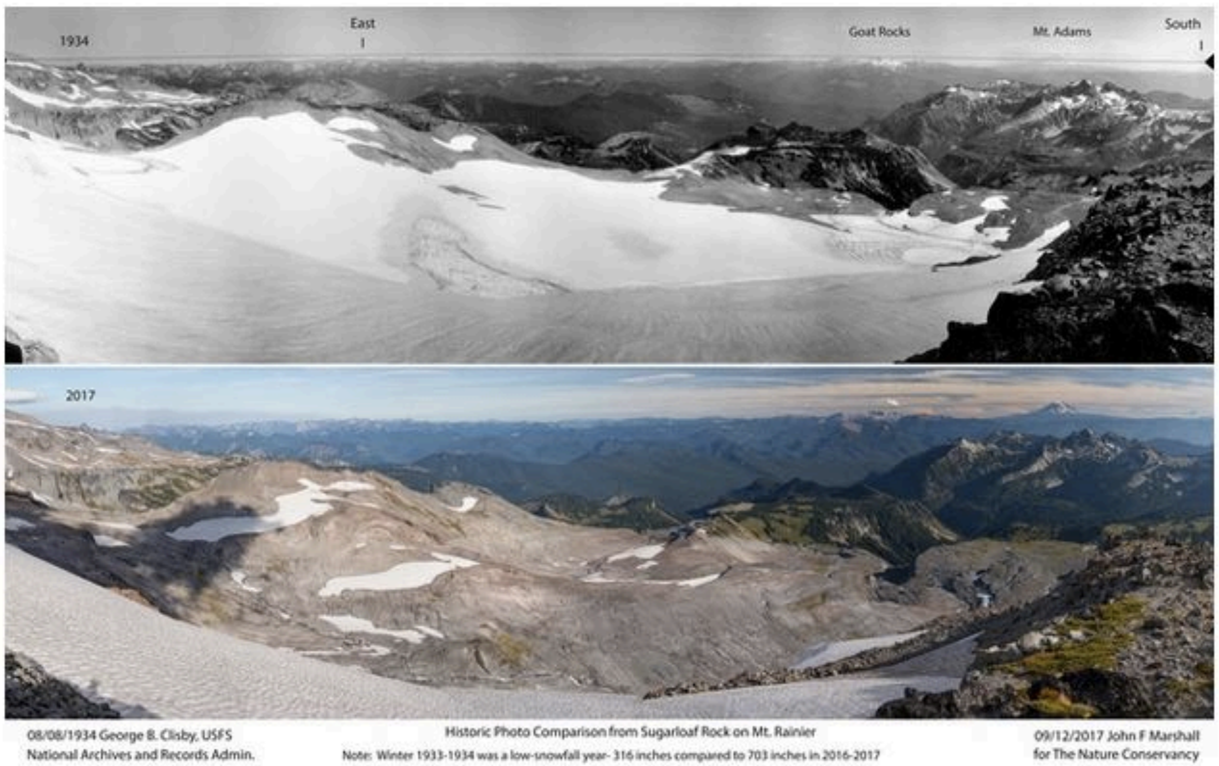
See how Mount Rainier glaciers have vanished over time, with this eye-opening photo project

Originally published February 21, 2018 at 6:00 am | *Updated February 21, 2018 at 4:59 pm*



The Seattle Times

front page
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Imagine Mount Rainier without its icy mantle

Nov. 15, 2019 at 12:01 pm | *Updated Nov. 19, 2019 at 10:52 am*

1 of 2 | *Mount Rainier continues to lose its icy cap to climate change. Since 1970, Mount Rainier's glaciers have lost 18% of their... (Jim Richardson / National Geographic)* **More**

By Jon Waterman

Nov. 15, 2019

Since 1970, Mount Rainier's glaciers have lost 18% of their volume. Over the last decade, these glaciers have been melting at six times the historic rate, causing damaging floods.

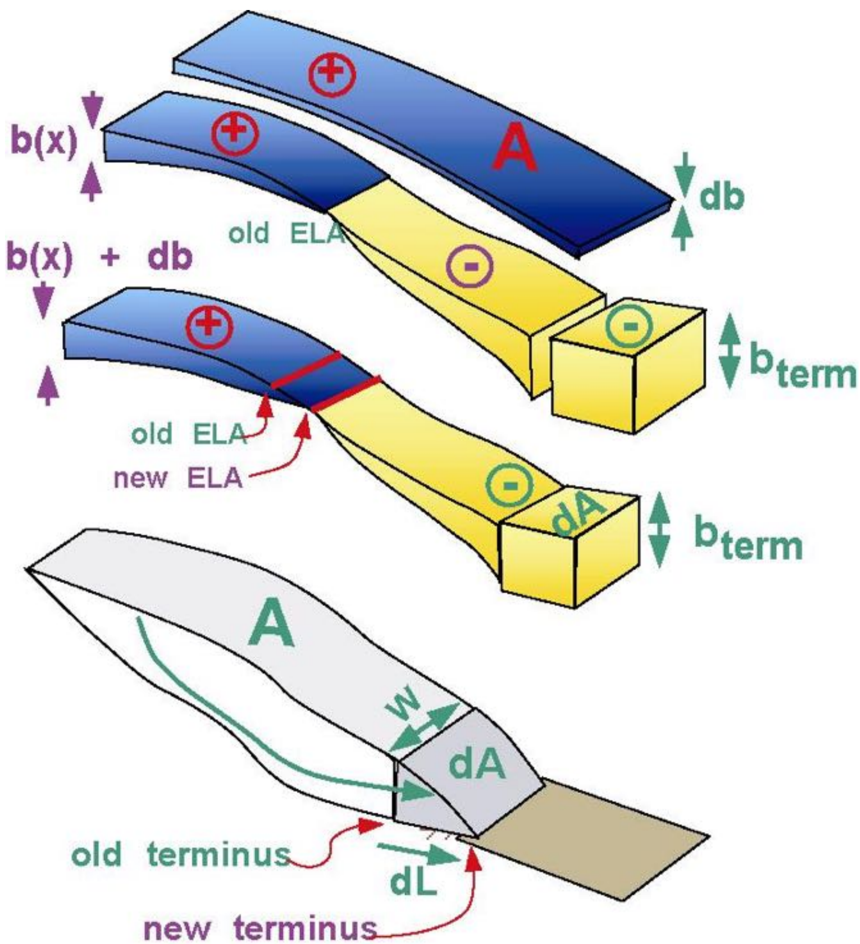
Imagine Mount Rainier without its icy mantle

Nov. 15, 2019

Across Puget Sound and above the rain forest of Olympic National Park, the mid-elevation glaciers are not as cold and protected as the high-altitude glaciers of Rainier. A 2009 inventory of ***Olympic National Park*** glaciers showed that ***over 27 years, 82 glaciers have disappeared.*** Fewer than 184 glaciers remain in the park, and diminishing melt water has caused the Quinault River to reach record lows.

Amid the most glacially populated region of the state, ***North Cascades National Park*** would appear to be enriched by its 312 glaciers. But ***over the last century, those icefields have thinned, and in many cases, disappeared to 44% of their former size***.

Length change after a sudden climate shift



$$dL = -\left(\frac{A \times db}{W_{term} \times b_{term}} \right)$$

dL is large when db is large.

- Glacier advances farther with bigger climate jump.

dL is large when A is large.

- Advances farther with bigger glacier area collecting additional snow that must be melted off.

dL is large when W_{term} is small.

- Advances farther when glacier can't spread sideways at terminus.

dL is large when b_{term} is small.

- Advances farther with less effective melting at terminus.

Asking the question the other way …

Do you think that we might be able to estimate the climate change "db" in the accumulation pattern by measuring the distance that a glacier terminus has moved? Remember …

$$A \times \mathrm{d}b = -\,\mathrm{d}A \times b_{\mathrm{term}}$$

Extra snow db added all over glacier area A

Extra ice melted off new area dA now covered by ice at the terminus, at rate $-b_{\mathrm{term}}$

You can ***measure***:

- Terminus ablation rate b_{term}
- Glacier area A
- New area covered $\mathrm{d}A = W_{\mathrm{term}} \times \mathrm{d}L$
  - Glacier width W_{term} at terminus
  - Glacier advance dL

What's left?

Only db, the climate change …

$$\mathrm{d}b = \frac{-\,\mathrm{d}A \times b_{\mathrm{term}}}{A}$$

$$\boxed{\mathrm{d}b = \frac{-\,\mathrm{d}L \times W_{\mathrm{term}} \times b_{\mathrm{term}}}{A}}$$

Where else can you use these ideas?

Why try to figure out these esoteric ideas anyway?

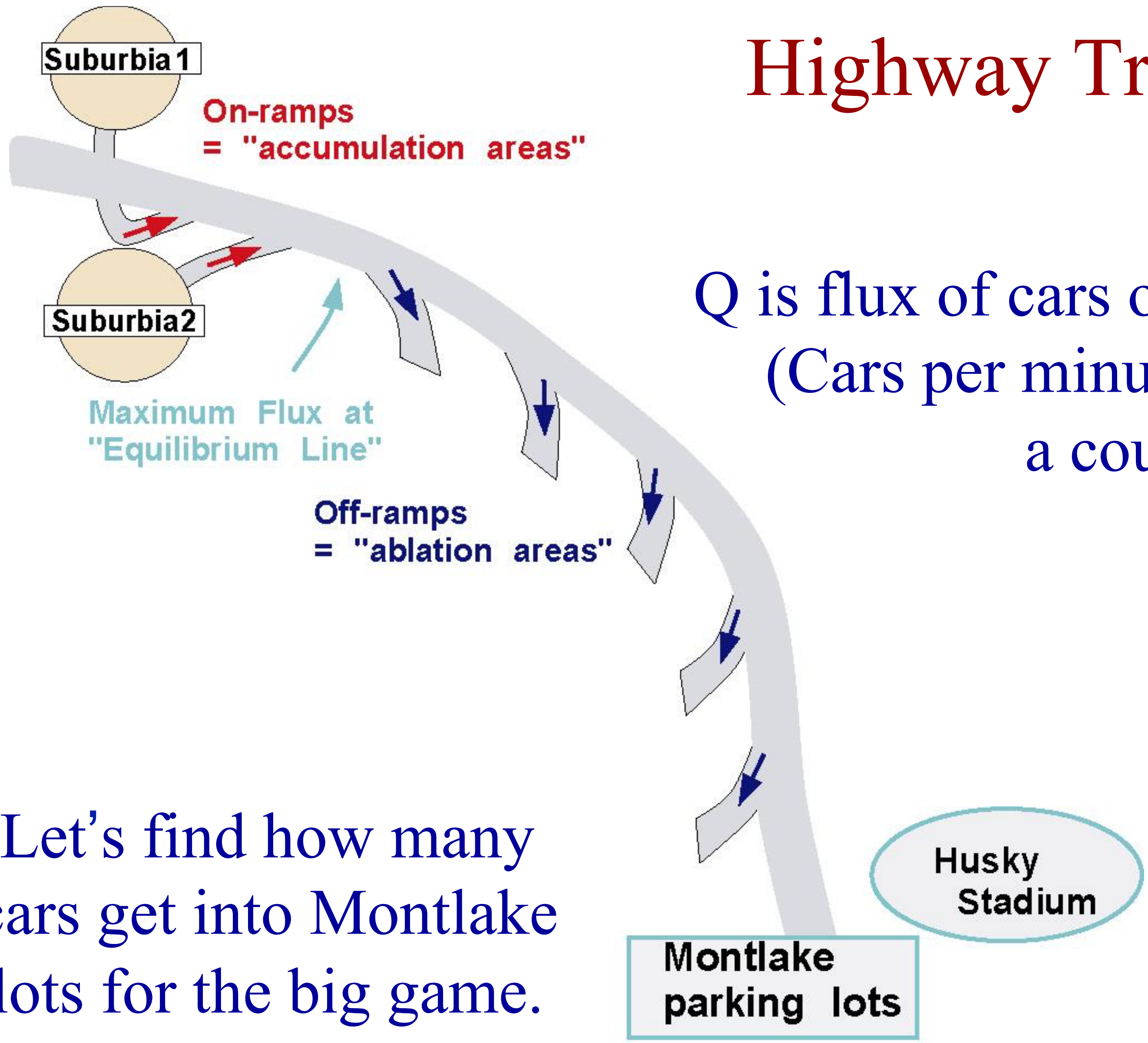
Here are some other examples that use the same ideas –

- Balancing your check book.

- Estimating freeway traffic.

- Can you think of others?
  - Stockroom inventory rotation
  - UW student enrollment

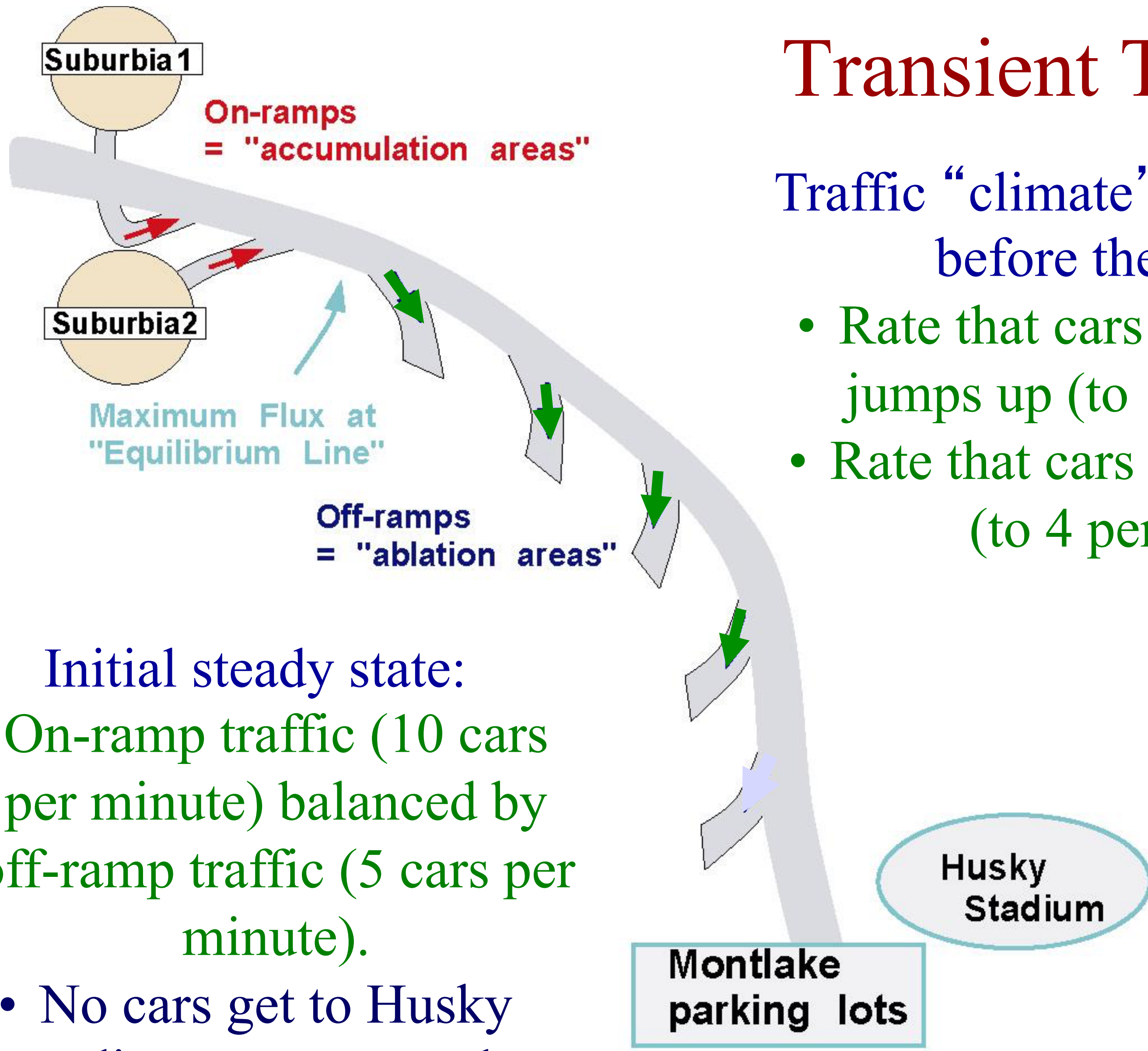
Highway Traffic



Q is flux of cars on the road (Cars per minute passing a counter).

Let's find how many cars get into Montlake lots for the big game.

Transient Traffic



Traffic "climate" changes 1 hour before the big game.

- Rate that cars leave Suburbia jumps up (to 11 per minute).
- Rate that cars take exits drops (to 4 per minute).

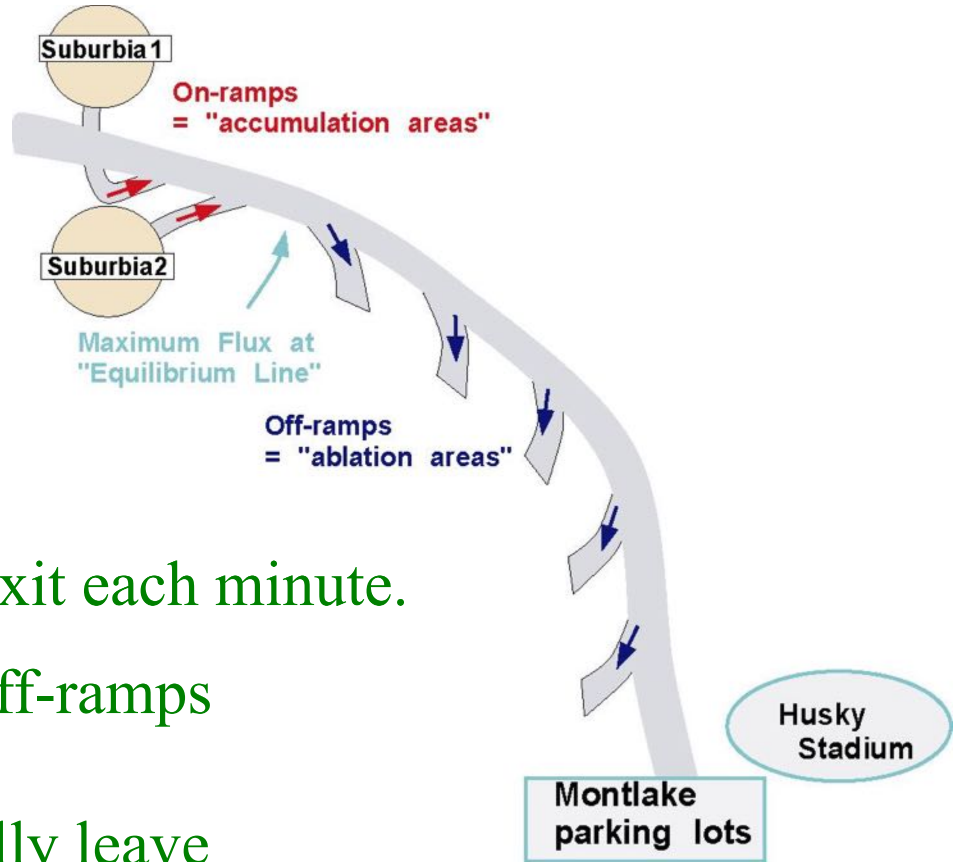
Initial steady state:

- On-ramp traffic (10 cars per minute) balanced by off-ramp traffic (5 cars per minute).
- No cars get to Husky stadium, or even to the next-nearest exit.

Filling up I-5

Increased accumulation rate:
db = one more car per minute now enters from each suburb.

Decreased ablation rate:
db = one fewer car taking each exit each minute.



A = number of on-ramps and off-ramps initially in use (6).

b_{term} = number of cars that initially leave I-5 at an off-ramp (-5).

Can we figure out whether any cars will now get to Montlake?

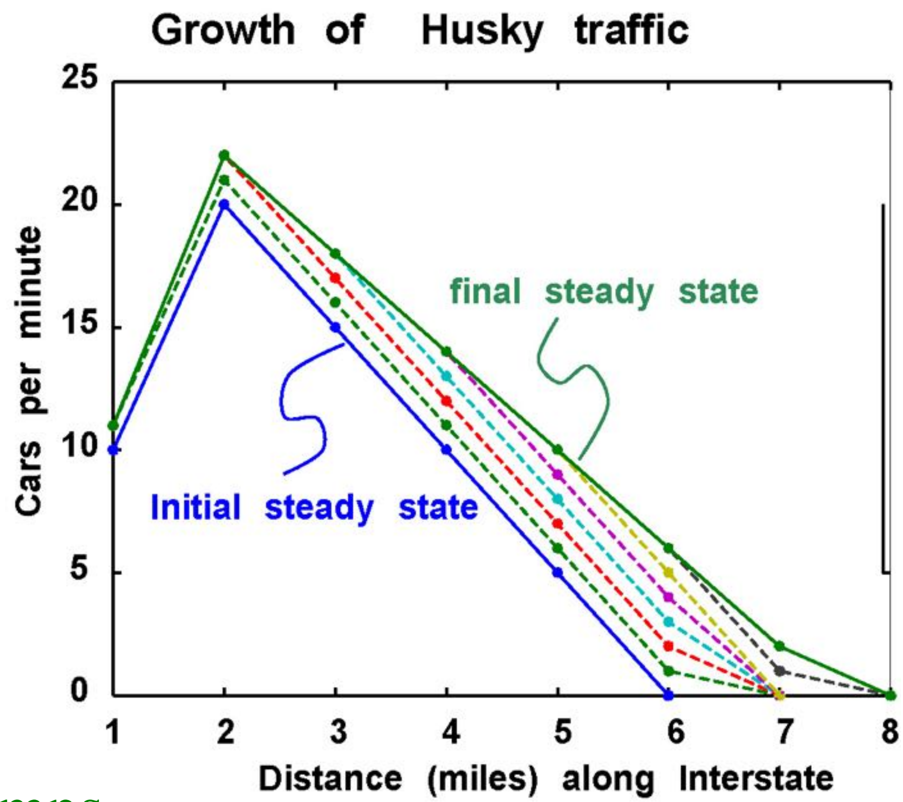
- dA = number of additional off-ramps that will see traffic.

Filling up I-5

$$-b_{\text{term}} \times dA = A \times db$$

Increased traffic climate:

- $db = 1$ car /minute at each ramp.
- b_{term} = number of cars that leave I-5 at each off-ramp initially (-5 cars/minute).
- dA = number of additional off-ramps that will see traffic.
- A = total number of on-ramps and off-ramps initially in use (6).



$$dA = \frac{A \times db}{-b_{\text{term}}} = \frac{6\,\text{ramps} \times 1\,{\text{car}}/{\text{min}}}{5\,{\text{car}}/{\text{min}}} = 1.2\,\text{ramps}$$

The riddle: So what year is it?

Must be 2020.

- No fans were going to see the Huskies, due to Covid-19… ☹

Could also have been 2008.

- Only a dribble of die-hard fans were still going to see the Huskies, after 14 straight losses … ☹
- But the average GPA of the players was up. ☺

We haven't mentioned dynamics lately …

So far, our thought experiment about glacier advances has been entirely kinematic.

But do ***forces*** and ***material properties of ice*** affect

- How far a glacier advances?
  (hmmm… didn't seem to matter …)

- How long does a glacier take to adjust to new steady climate?

Are you curious about that?

- OK. Let's do another thought experiment.

"Look at that Glacier Honey"

Suppose a whole team of tourists continually pour honey into a valley high on a mountain near Blue Glacier.

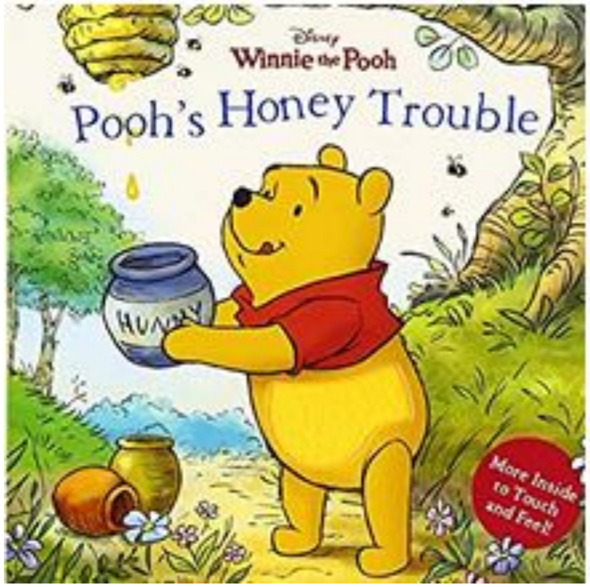
- Don't ask me why they do it.
- (My guess is that it is probably a funky ritual of some weird environmentalist cult.)

- The amount of honey that they pour each year equals the volume of ice that accumulates at the corresponding place in the accumulation area of Blue Glacier each year.

Honey Glacier kinematics

- As the honey flows down the hill, many hungry black bears (for which Olympic National Park is famous) lick at the honey.
- Each year, the hungry bears eat a volume of honey that equals the volume of ice melted in a year at the corresponding place on Blue Glacier.
- At some point far down the hillside, the honey is gone.
- The flux of honey (volume passing by in a year) at any cross-section on Honey Glacier is identical to the flux of ice at the corresponding point on Blue Glacier.

Curious Scientists ask Questions about Honey Glacier



- What constitutes accumulation?
- What constitutes the accumulation area?
- What constitutes ablation?
- What constitutes the ablation area?
- Where is the "terminus" of Honey Glacier, in relation to the terminus of Blue Glacier in the adjacent valley?
- Which "glacier" is thicker?
- Which "glacier" flows faster?
- Which glacier has larger flux (of ice or honey)?

https://docs.google.com/document/d/1gkhqg3kH775RjYke-bYOiYtS_ZYE8MuDSKlPGrNaWCE/edit#heading=h.5spg5w2dqiai

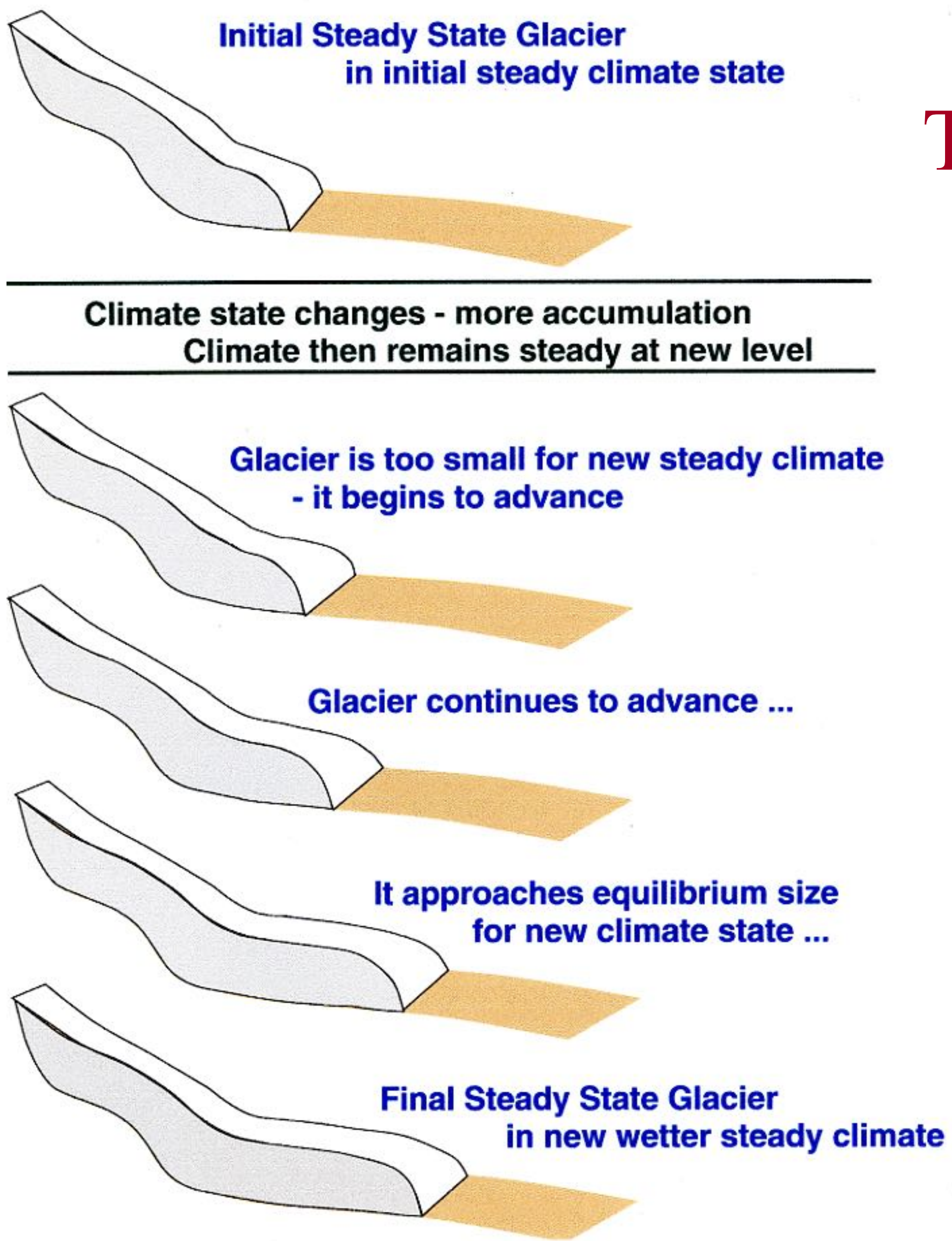
Honey Glacier Dynamics

The ***flux*** of honey (volume passing by in a year) at any point on Honey Glacier is identical to the ***flux*** of ice at the corresponding point on Blue Glacier.

But …

- Honey Glacier is much ***thinner*** than Blue Glacier.
- Honey Glacier flows much ***faster*** than Blue Glacier.

- The ***nature of the flowing material*** determines whether the flow is thin and fast, or thick and slow.
- The volume of material transported in the same.



The climate shifts

. . .

We figured out already how far the glacier will advance.

But how long does all this take?

How long does it take for a glacier to adjust to an abrupt climate change?

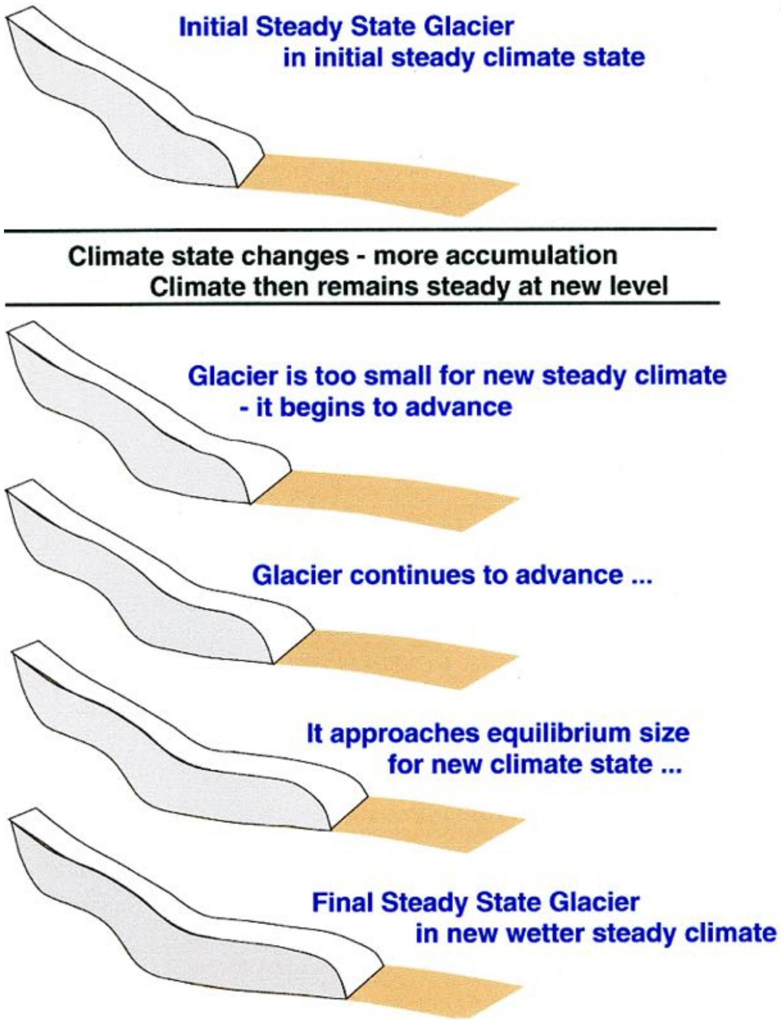
A glacier cannot adjust to a new size instantly when the climate changes abruptly.

It takes ***time*** for the glacier to ***collect enough additional ice*** to reach a bigger steady-state size if climate gets wetter or colder.

It takes ***time*** for a glacier to ***shed enough ice*** to reach a new, smaller steady-state size if climate warms up.

- Which glacier probably changes its volume the most, if its accumulation is increased, (e.g. by 10%), Blue Glacier or Honey Glacier?
- Which of these 2 glaciers probably adjusts faster to its new "climate"?

Sudden change to colder,wetter climate …



Glacier will advance to new steady-state length.

- ***How long*** will this take?

As before, we could run a complicated computer model with many boxes.

- Watch as each box grows.
- See how long until boxes (and glacier) stop growing.

But … is there a simpler way?

Where are the Thickness Changes the Greatest?

- Near the terminus

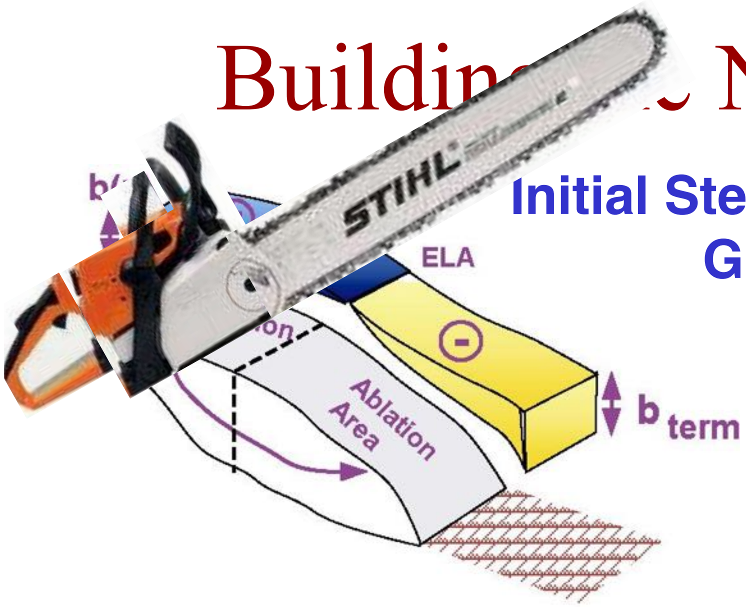
What Prevents Fast Adjustment?

- Glacier needs time to collect enough extra ice to fill its new size.
- How much extra ice does it need?

Pattullo Glacier, BC Coast Mountains

Post and LaChapelle, *Glacier Ice*

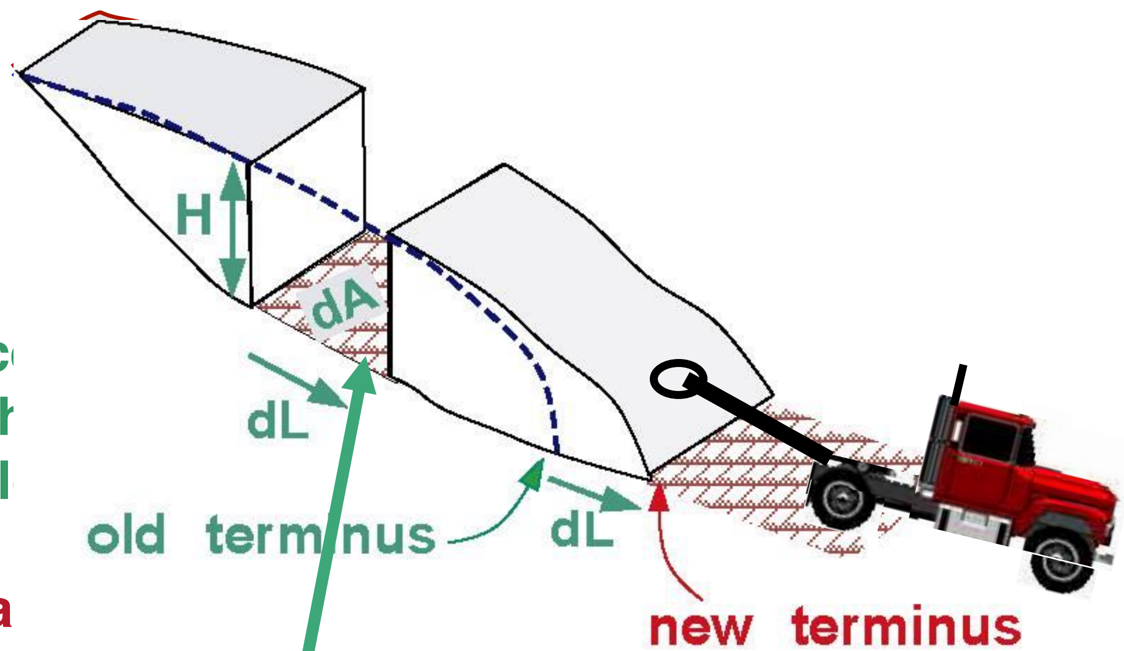
Buildin… New Steady-State Glacier



Initial Steady-State Glacier

Only a thought experiment

- Do not try this at home with your own glacier!



Glacier thickness changes most near terminus.

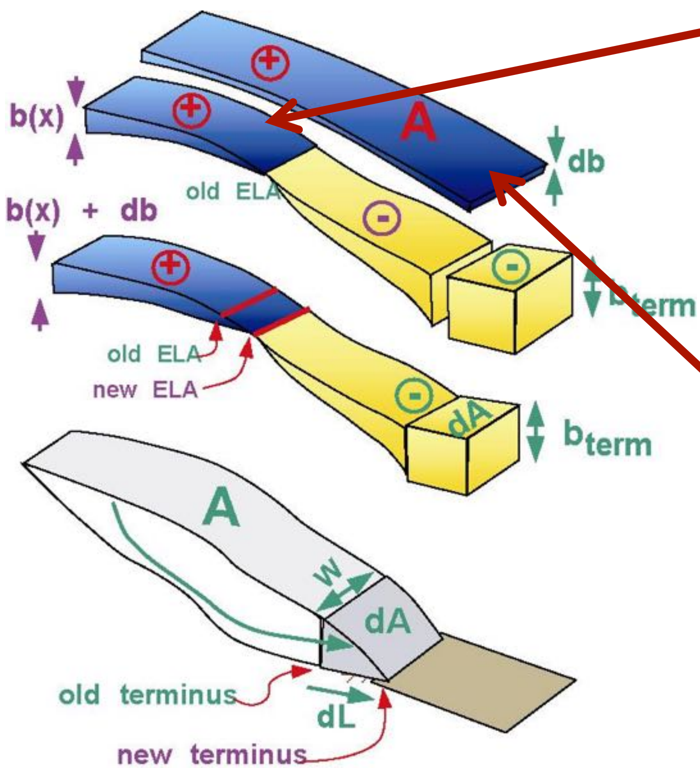
- **Imagine that we can slic through initial glacier with giant chain saw at the ol Equilibrium Line.**
- **Flying chips!! Stand clea**

- **Hitch up a giant tow truck, and slide lower portion down to new terminus.**
- **This opens up a gap with area dA.**

How can we fill the gap?

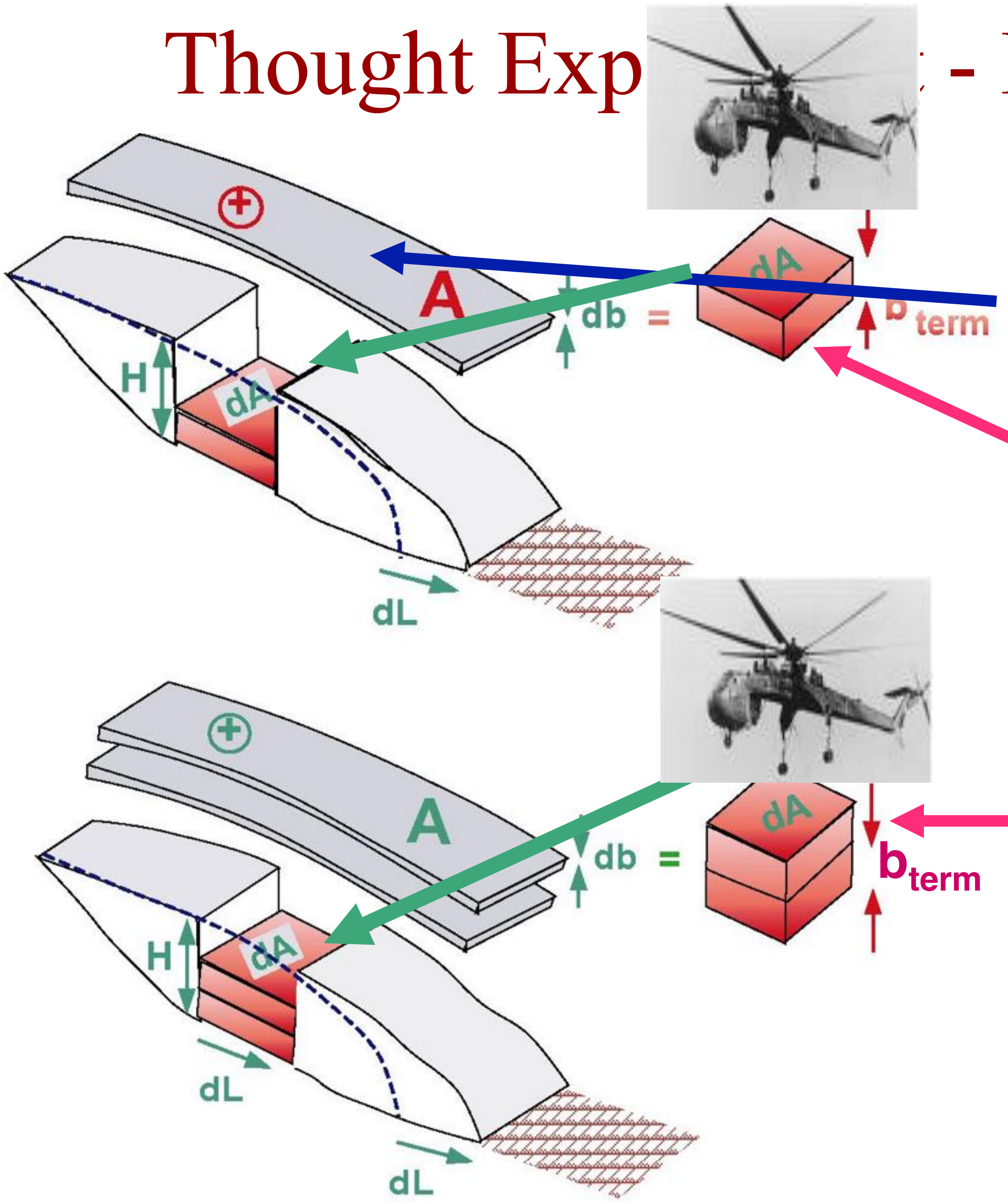
How long will it take to fill this Gap?

That depends on what sources of extra mass are available …



- All prior accumulation was needed to maintain initial steady state.
- The only extra available ice comes from the climate change represented by db

Thought Exp - Filling the Gap



In year 1, we can collect extra volume A×db

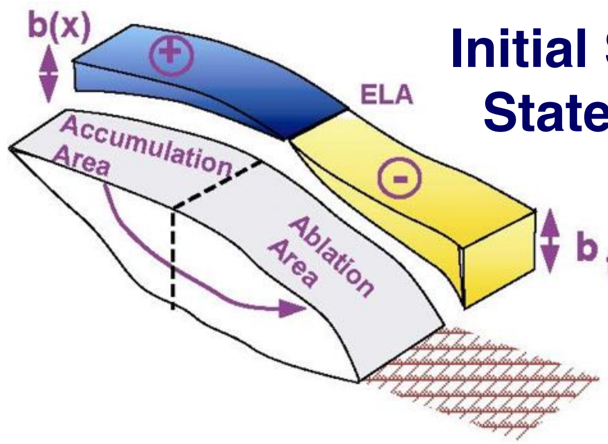
We know this is the same volume as $-b_{term} \times dA$

Using a gigantic helicopter, we can place this block in the gap. (It fits perfectly!)

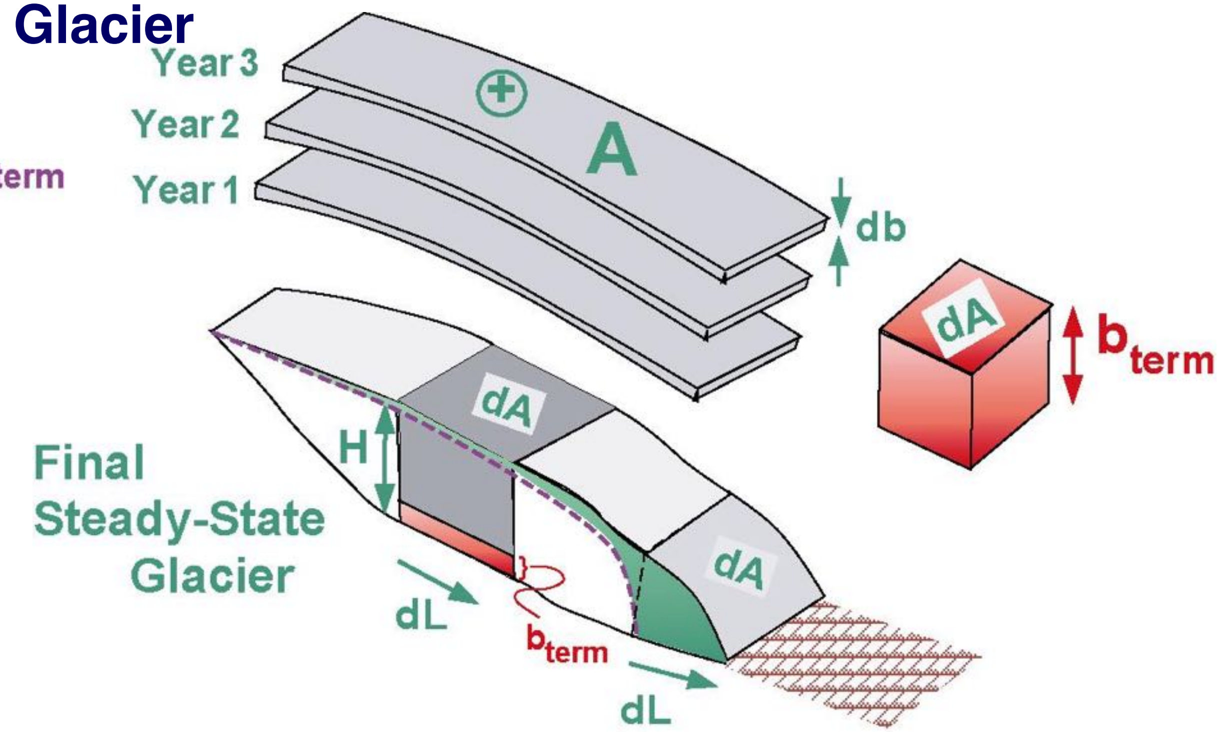
In year 2, we can collect a second block $-b_{term} \times dA$

Hiring the helicopter again the next year, we can drop this second block in the gap.

Time to Build up to New Steady-State Volume



Initial Steady-State Glacier

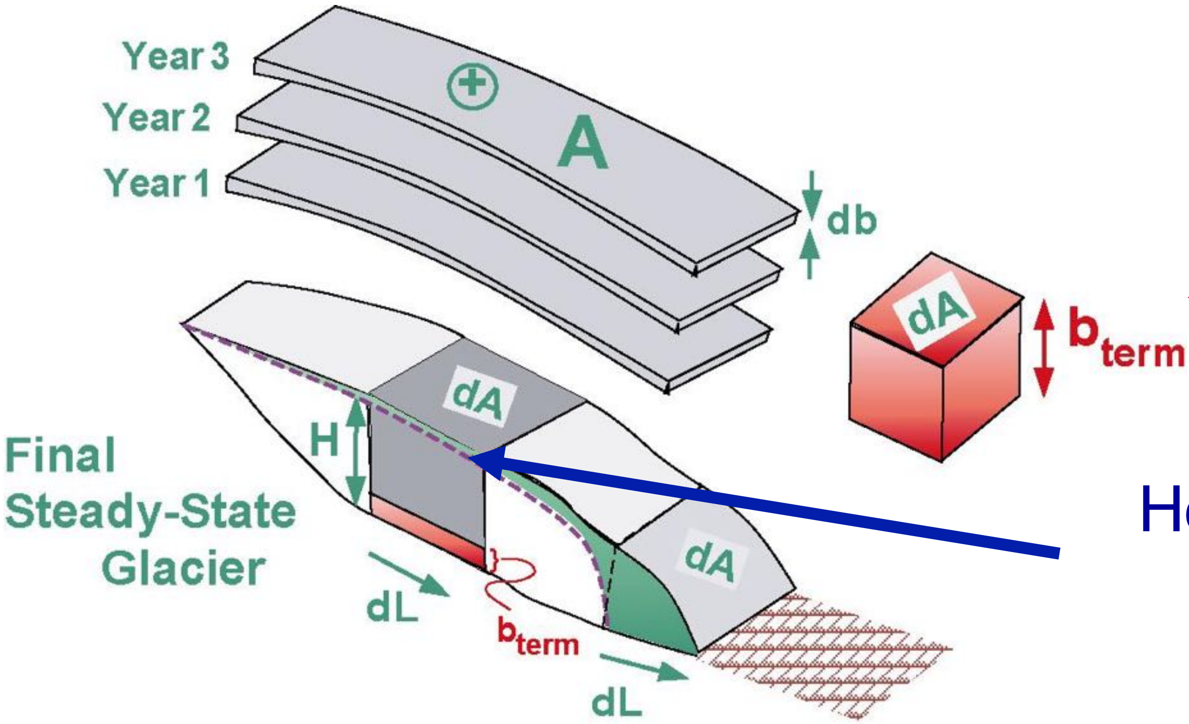


How many blocks with area dA and thickness b_{term} does it take to fill the gap?

$$\text{Time} = \frac{\text{Extra volume needed}}{\text{Volume of block added each year}}$$

$$= \frac{H \times dA}{A \times db} = \frac{H \times dA}{-dA \times b_{term}} = \frac{H}{-b_{term}}$$

Looked at another way …

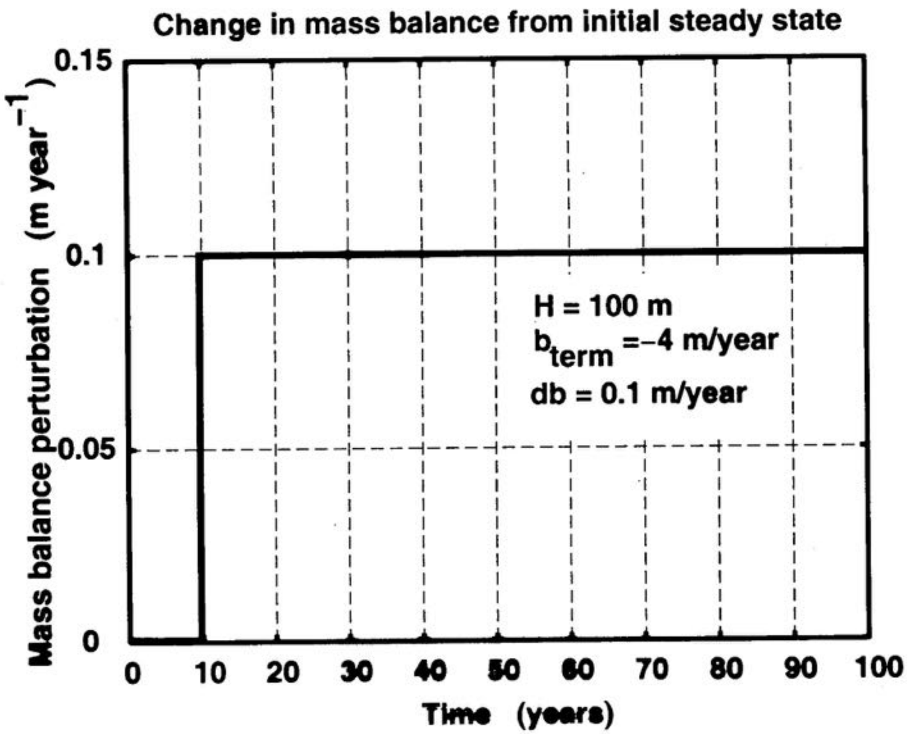


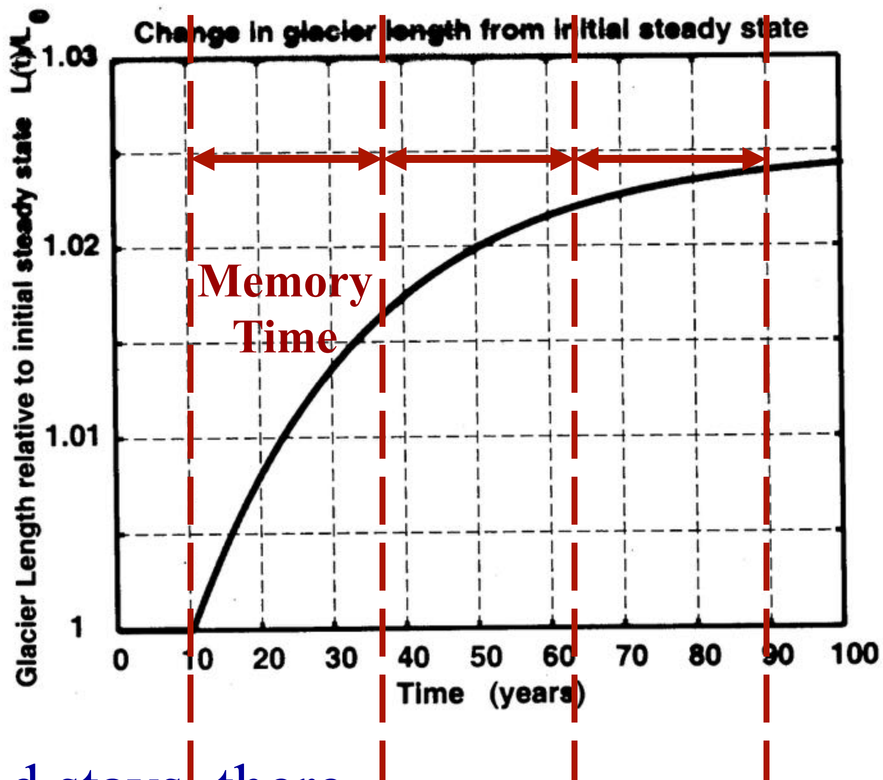
Every year we can raise the level in the gap by $-b_{term}$

How many years until the gap is filled?

$$\text{Number of years} = \frac{\text{Thickness needed}}{\text{Thickness added each year}} = \frac{H}{-b_{term}}$$

Length Response to Climate Shift



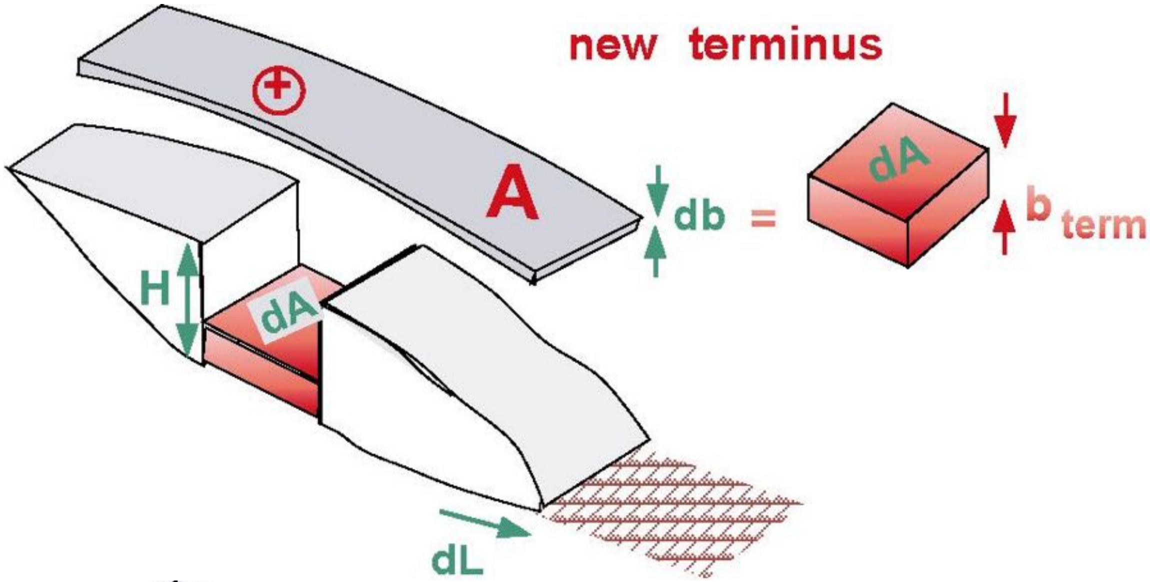


Climate jumps to a new state and stays there.

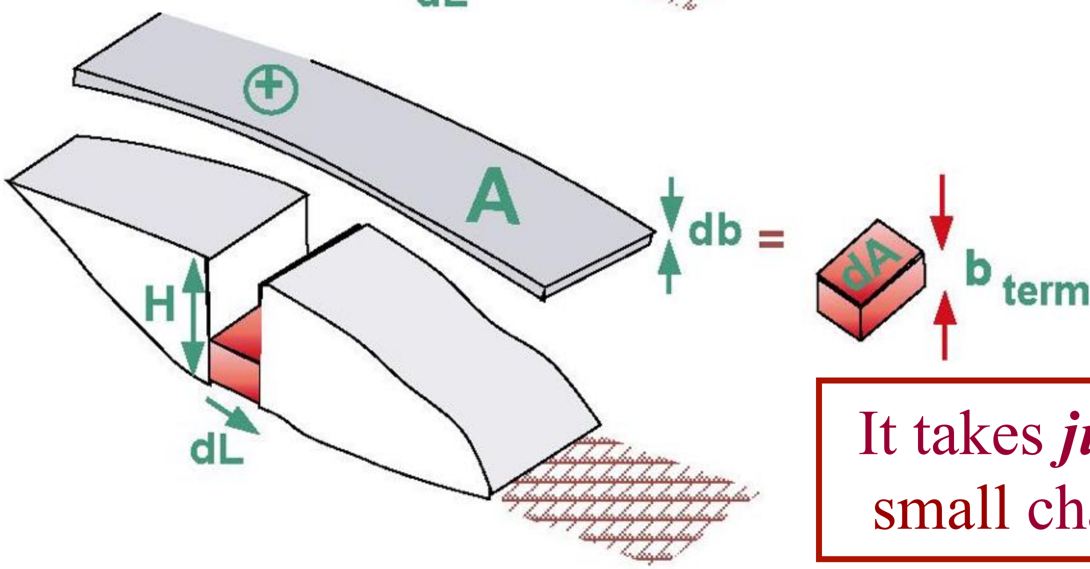
Terminus advances to new position.

- Memory Time (- H/b_{term}) is actually time needed to acquire about 2/3 of new ice needed to “fill” the new steady-state glacier.
  - In each successive time interval (- H/b_{term}), glacier acquires about 2/3 of the remaining ice that it needs.

Does size of Change "db" Affect Memory Time?



1 year after *large* climate shift, the extra ice collected would fill gap area dA to depth of $-b_{term}$

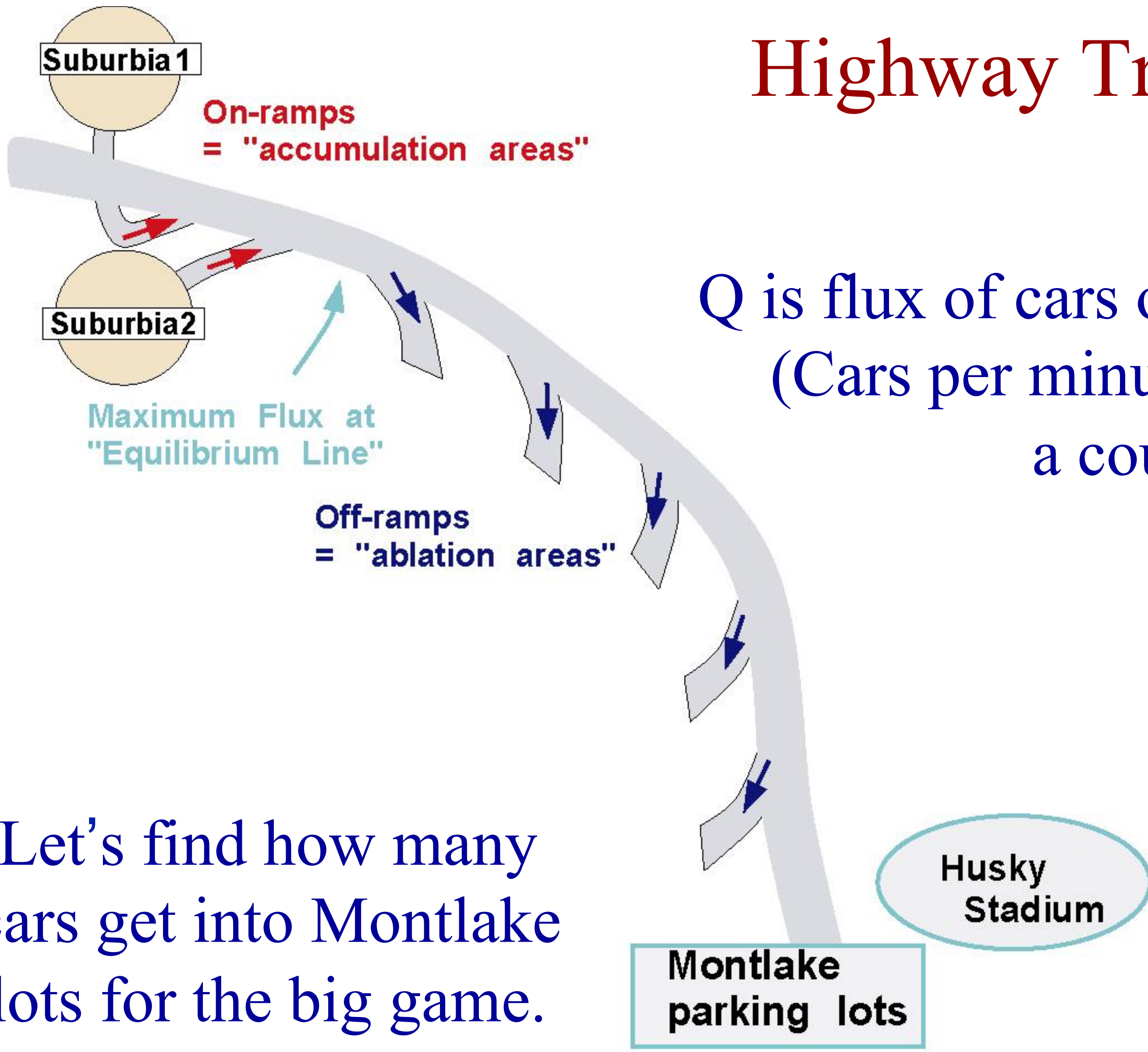


1 year after *small* climate shift, the extra ice collected would fill (smaller) gap area dA to depth of $-b_{term}$

It takes ***just as long*** to respond to a small change as to a large change.

(Only difference – in that time, glacier doesn't advance as far.)

Highway Traffic



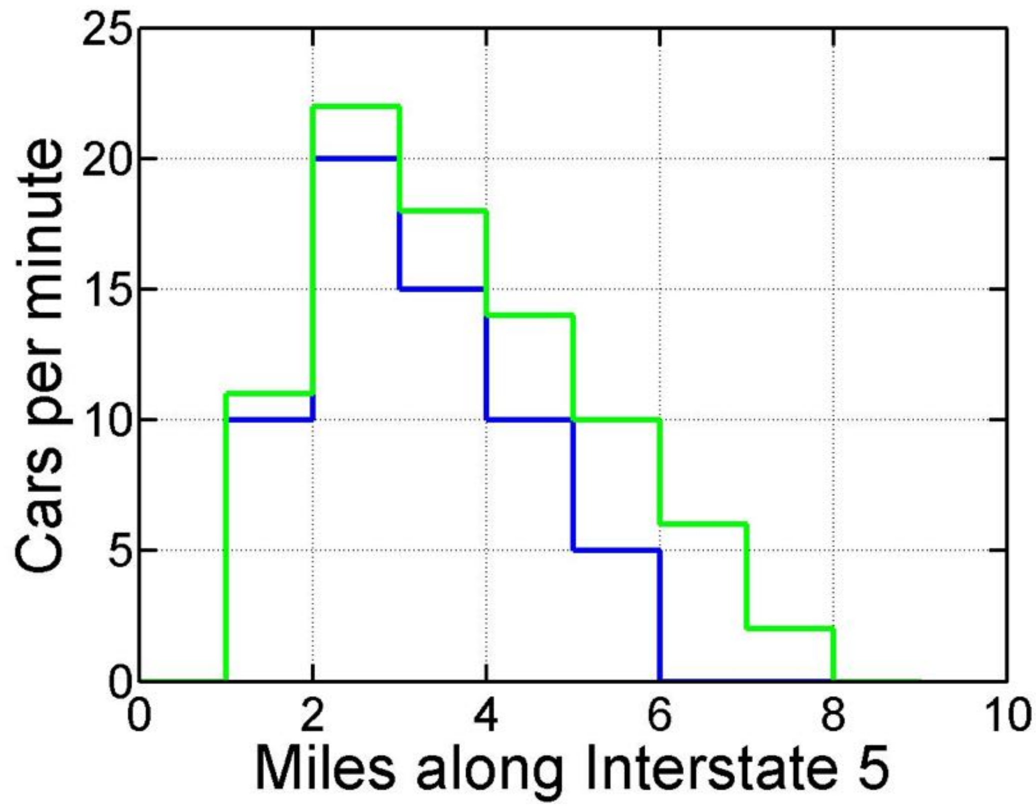
Q is flux of cars on the road (Cars per minute passing a counter).

Let's find how many cars get into Montlake lots for the big game.

Time to Fill up I-5

- b_{term} = number of cars that left I-5 at each off-ramp (-5 cars/minute) .

- H = cars per mile initially on the highway at "Equilibrium Line" (20 cars).

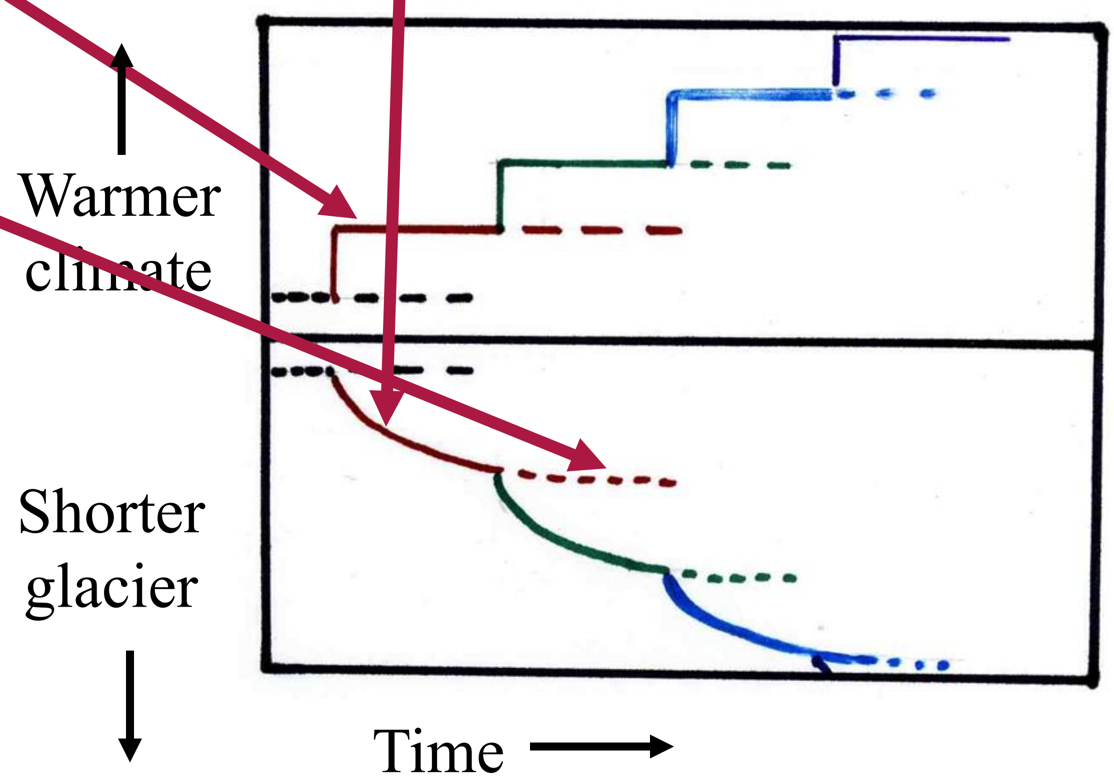


- We can figure out long it takes for cars to start reaching Husky Stadium.

$$\text{Time} = \frac{H}{-b_{term}} = \frac{20\,\text{cars}}{5\,\text{cars}/\text{minute}} = 4\,\text{minutes}$$

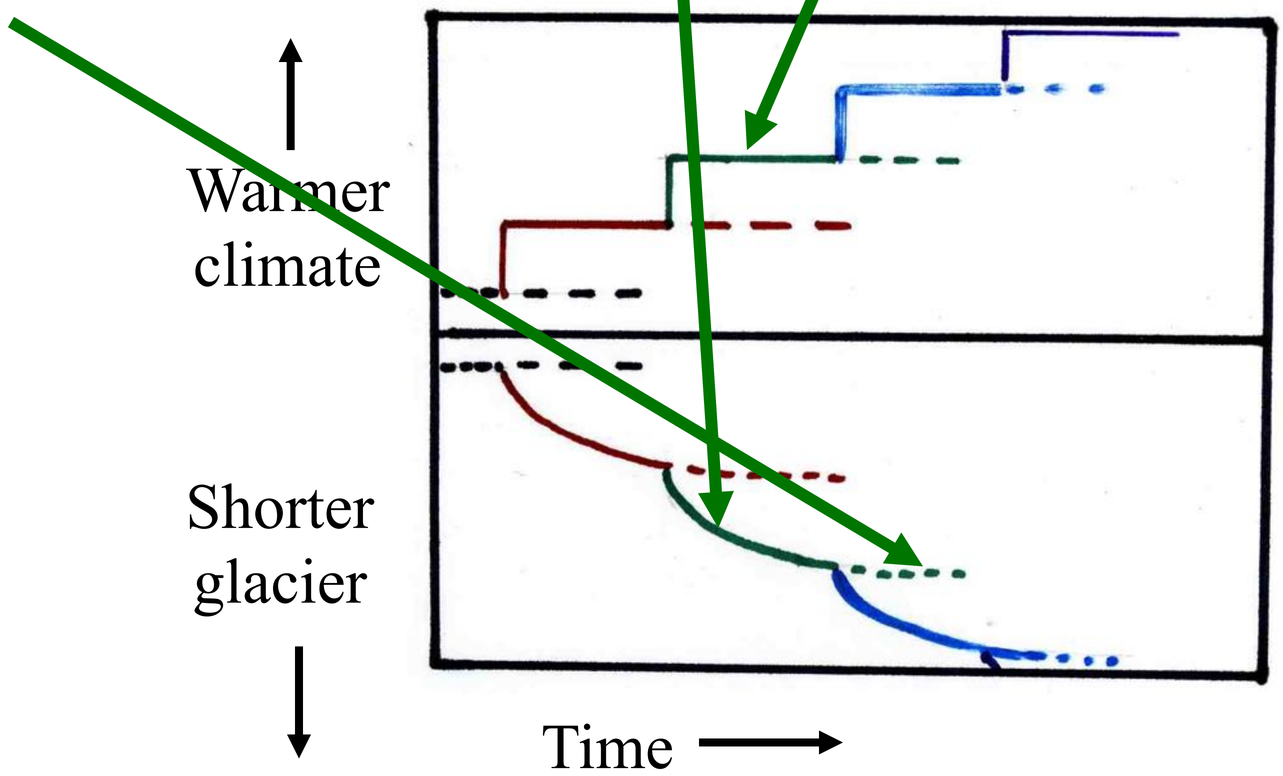
Superposition of Climate Changes

- The climate changes abruptly to a warmer and drier state.
  - glacier retreats, rapidly at first.
- Then slower and slower as it approaches its new reduced steady size.



Just as retreat slows down, climate changes again.

- Climate becomes even warmer and drier.
- This speeds up the retreat again.
- The retreat slows down, as the terminus approaches the new steady position for this latest climate.

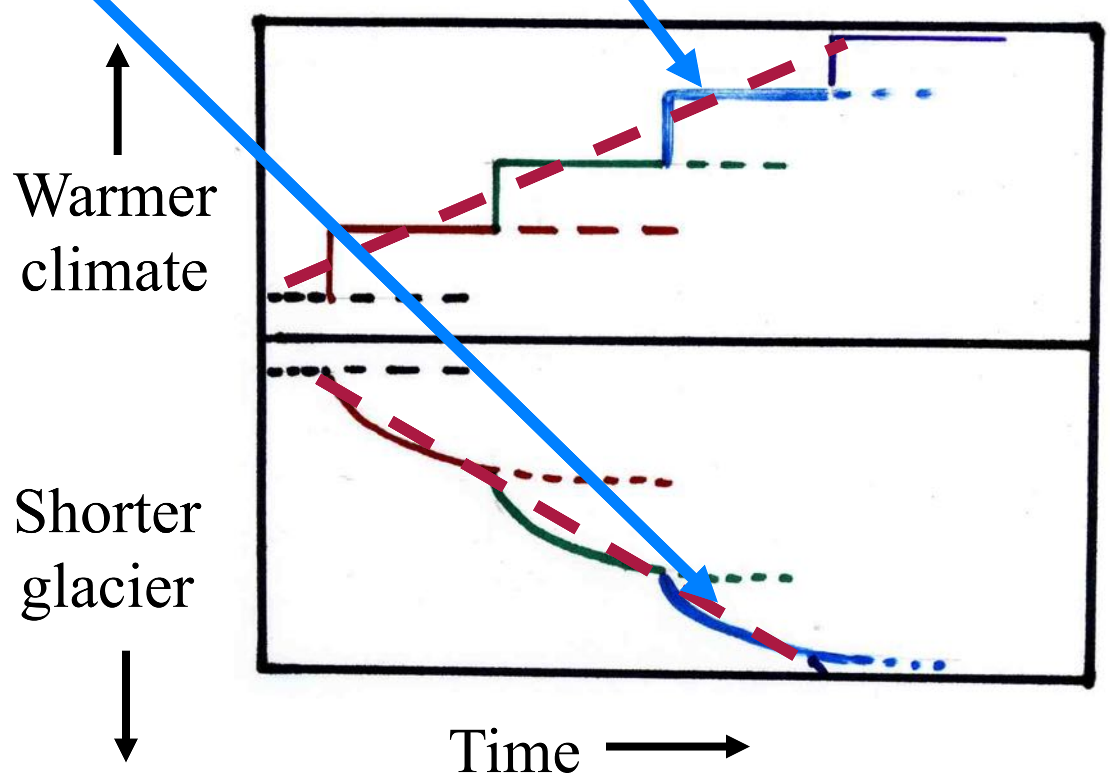


Climate Change Continues

- Yet again, the climate warms.
- The terminus retreats faster again.

What just happened?

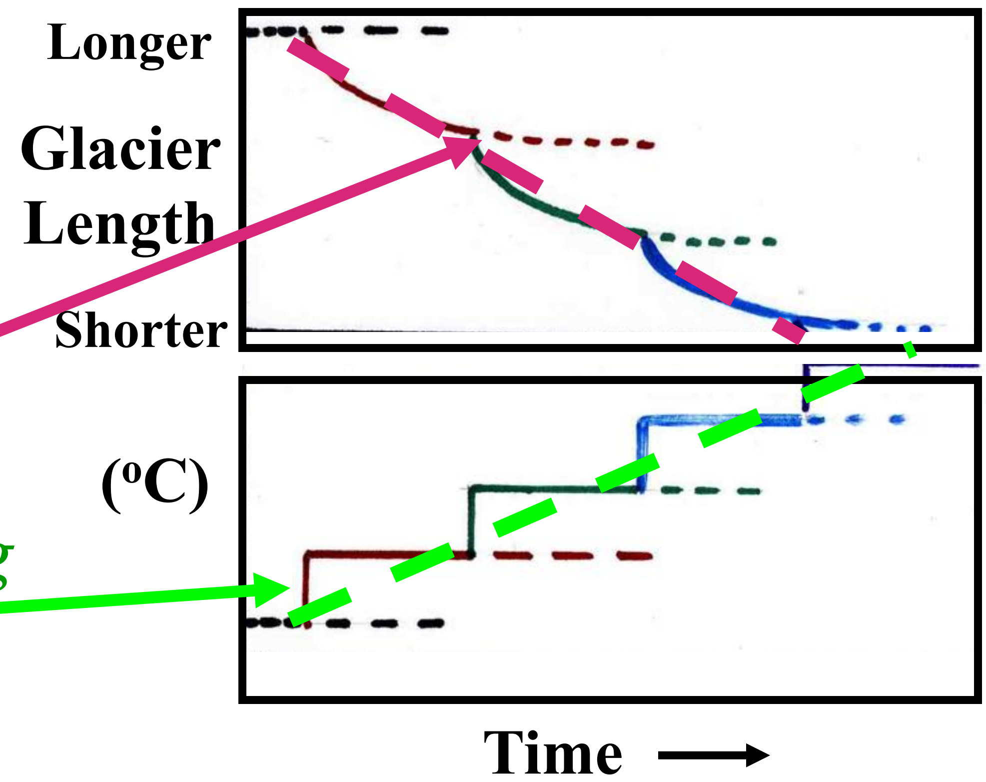
- We just used our knowledge of glacier response to a climate jump in order to estimate response to a continuous gradual change!



Superposition of Climate Changes

A constantly retreating glacier terminus may be a sign of a constantly warming climate.

(Anon.)



Curious Scientists predict glacier changes

Glacier	Length L	Terminus Width W_{term}	Thickness at ELA H	Terminus climate b_{term}	Climate change db
#1	2 km	0.2 km	100 m	-4 m/yr	-0.02 m/yr
#2	100 km	1 km	1000 m	-1 m/yr	-0.02 m/yr
#3	1000 km	20 km	3000 m	-0.5 m/yr	-0.02 m/yr

Each group, choose one glacier and estimate

- how far your glacier will advance
- The time scale for that advance to happen