ESS 203 - Glaciers and Global Change

Friday February 26, 2021.

Outline for the day

- Today's highlights on Monday – *Simon Dawson*
- Last Wednesday's highlights – *Alex Kissel*

Oerlemans (1996) on glaciers and 20th C *global* warming

- Comparison with thermometers

Roe et al. (2016) update, more data, new methods

- results also show *local* warming virtually everywhere.

Mid-term #2 on Wednesday

Talking through the study questions is very helpful to success.

- I suggest setting up study sessions with your term-project group.
- If you know a classmate in another term-project group, set up study sessions combining both term-project groups.

HW 22 – due Monday March 1

Please read Chapter 6, *Defrosting Earth* (pages 89-114) in text *Frozen Earth*.

- In a page or less, outline several unique features of surficial geology in eastern Washington, Idaho, and Montana, and why those features pointed to huge floods.
- In a few sentences, describe why you think J. Harlan Bretz was unable for so many years to convince his peers about the reality of the huge glacial outburst floods.

Optional question –

- Which language created the word *jökulhlaup*, and how do the native-speakers pronounce it? ☺

Oerlemans (1994)

Comparison of glaciers with thermometers as a way to measure global warming

Thermometer Networks

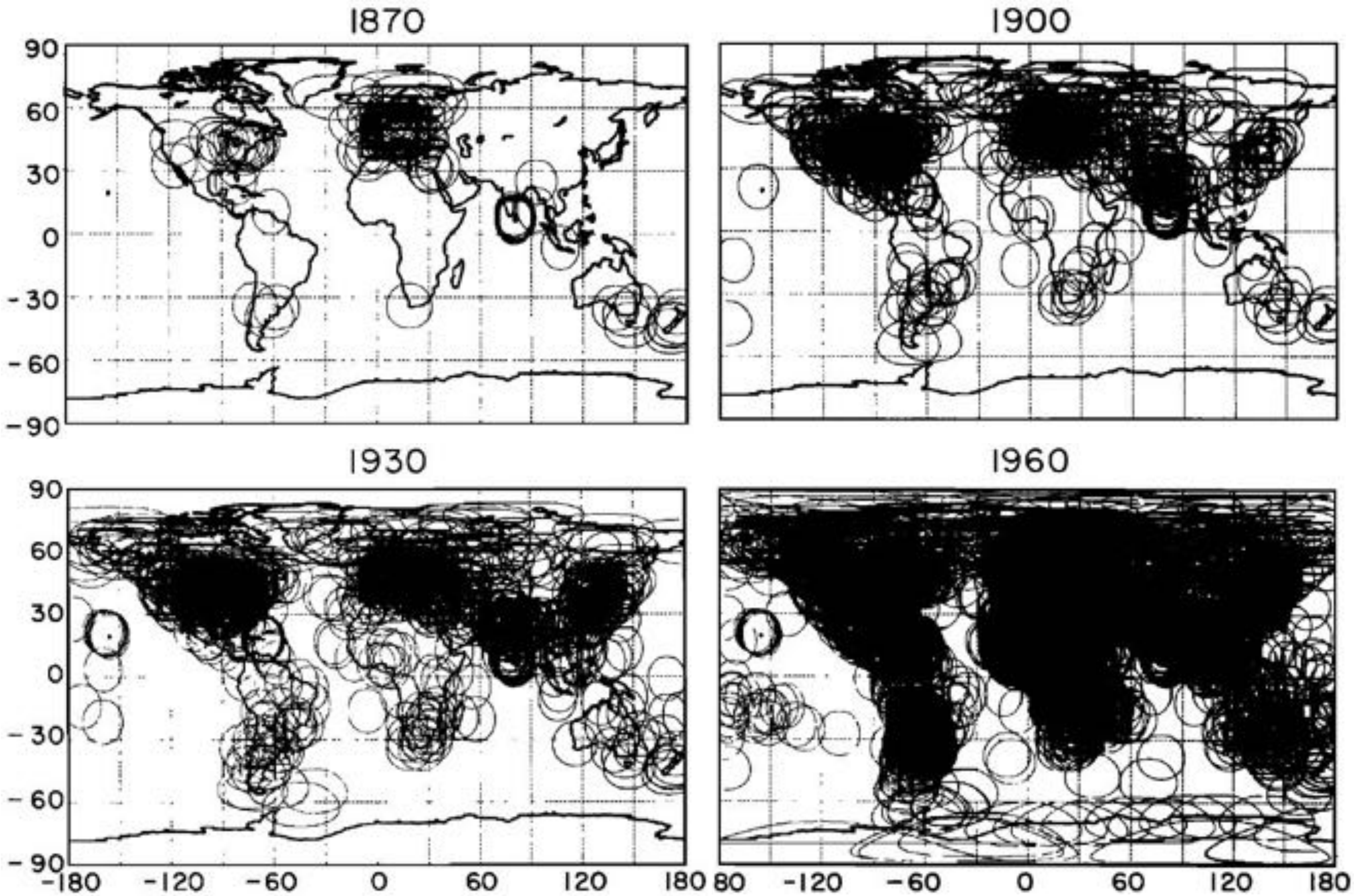
Isn't it simpler to just measure global warming with some thermometers?

Hansen and Lebedeff did exactly that in 1987.

- They collected tens or hundreds of thousands of air temperature measurements from weather stations all over the world.
- They then averaged all those measurements year by year to infer a global temperature rise.

Thermometer Networks

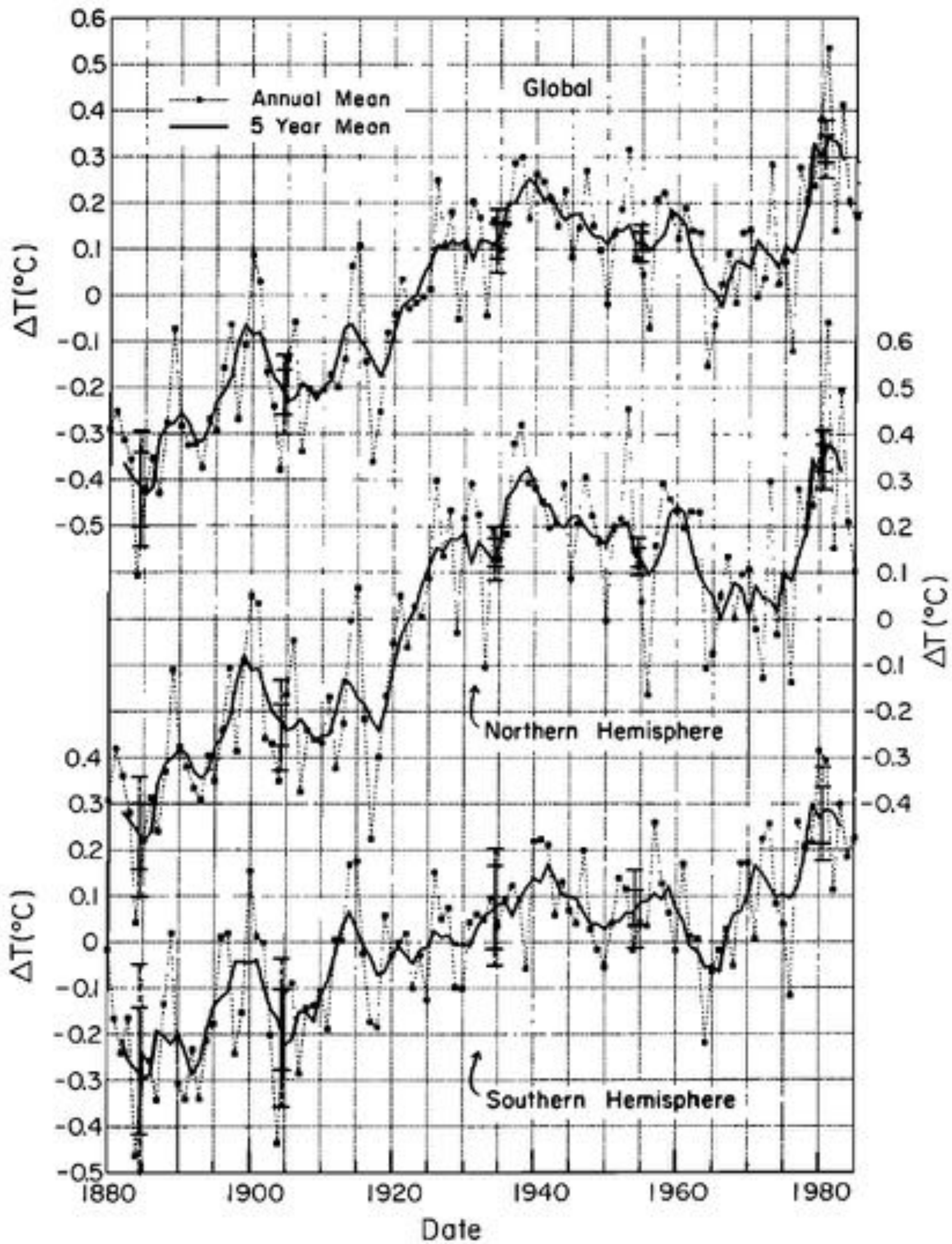
Each circle with radius 1000 km represents ***one*** thermometer



Hansen and Lebedeff 1987. *JGR* 92. 13,345.

Temperature Rising

Hansen and Lebedeff (1987) found a warming trend in both hemispheres of about 0.53^{o}C over 100 years.



Hansen and Lebedeff 1987. JGR 92. 13,345.

Advantages of thermometer method

- It is a direct measurement of the thing we are trying to find, i.e. increase of global temperature.
  (How about the glacier method?)

- It can have very high temporal resolution, i.e. it can potentially detect rapid changes in temperature.
  (How about the glacier method?)

- It can be used where there are no glaciers.
  (But glaciers can be used where there were no thermometers)

Disadvantages of thermometer method

We are looking for a signal that is less than 1 degree.

- How accurately do you think most thermometers were calibrated 100 years ago?
- How frequently were temperatures measured?
- Could hot/cold periods be missed during the day or night?
- Could time of warmest temperatures during the day have changed over a century (e.g. with land-use changes?
- Is a single thermometer representative of a larger area, e.g. a watershed, or a valley (or a circle 2000 km across)?

Disadvantages of thermometer method

A thermometer measures its ***own*** temperature, but we need to know the temperature in the air.

- For example, is sunlight shining on a thermometer?

So thermometer is inside a box to shade it.

- Can that box heat up like an oven?

Urban Heat Islands. Microclimate at a weather station may have warmed over 20th century because of environmental changes such as paving, construction, change of vegetation.

- How can we remove these effects from the records?

Comparison of 2 methods

- Glaciers already average effects over big areas, and they never "sleep", i.e. any warm or cold period will affect their mass balance.
- Terminus-position measurements 100 years ago were probably as accurate as modern measurements.
- Glaciers were not affected by nearby urbanization to the same ***degree*** (no pun intended).
- So the glacier-retreat study and the thermometer study are essentially independent ways to answer the same question.

The fact that both methods give comparable answers strengthens our confidence in both methods.

What's the message?

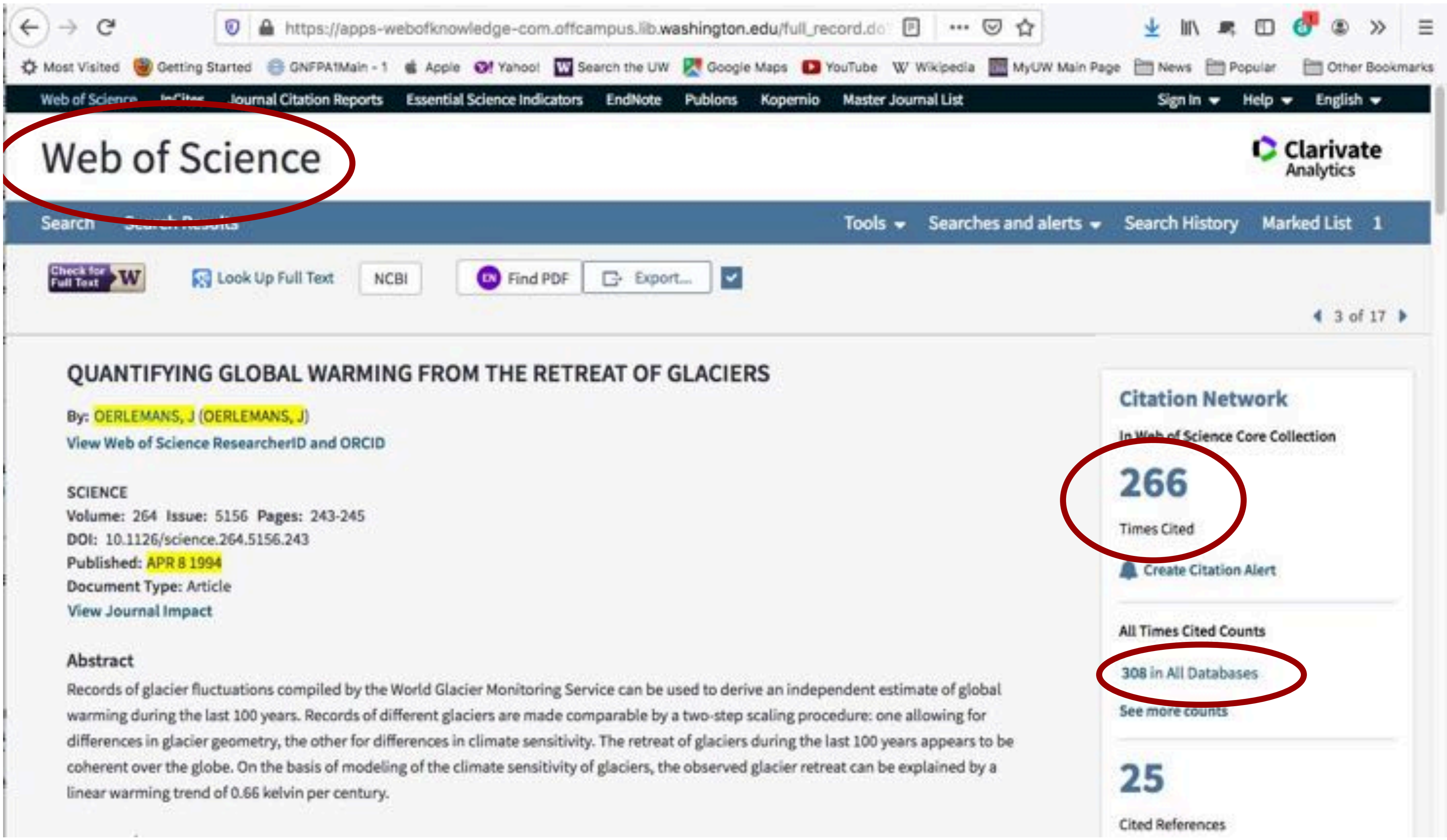
Several different methods of investigation point to global warming of nearly 1°C during the twentieth century.

- Retreating glaciers are one of these methods.

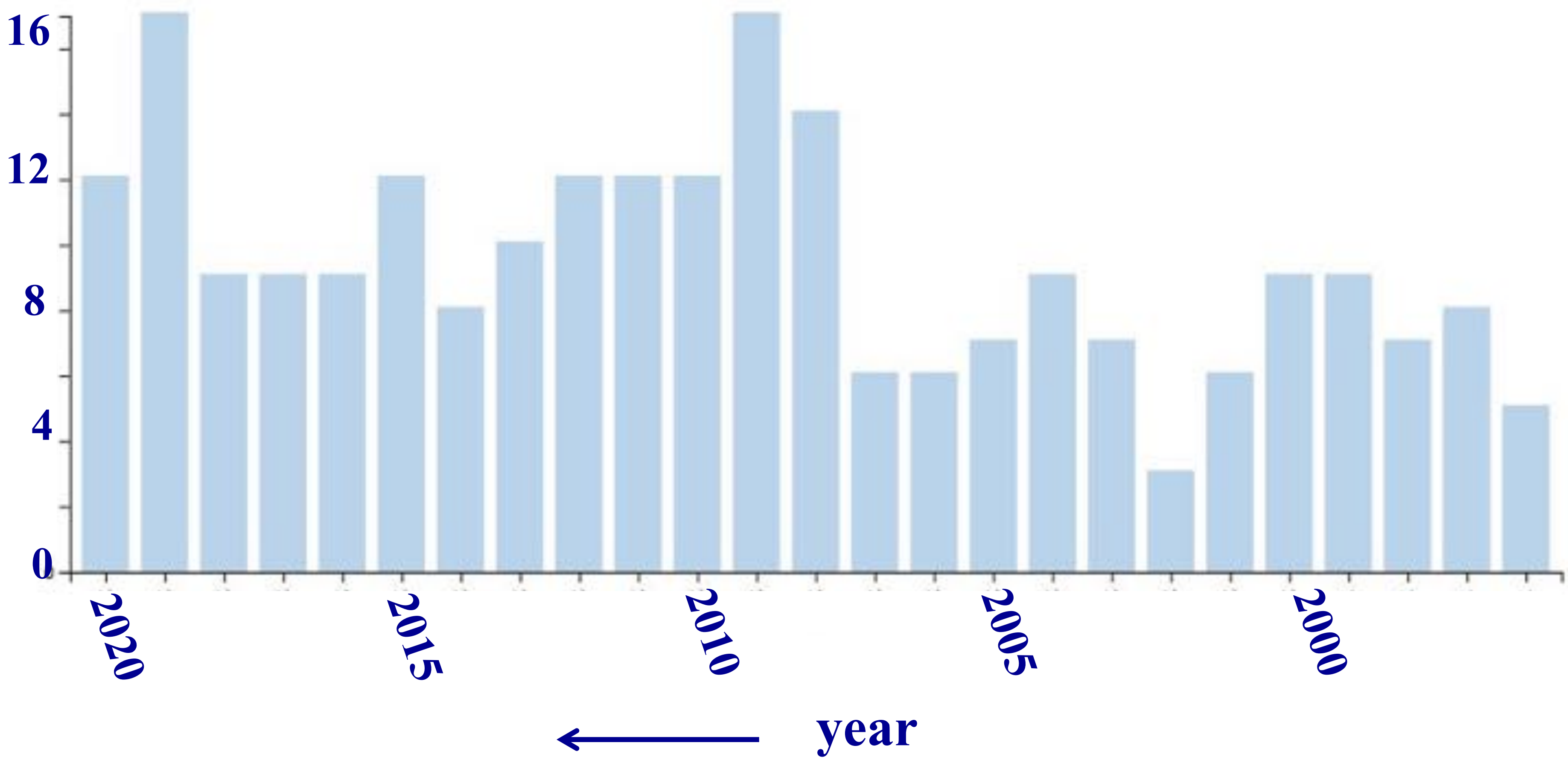
The paper by Oerlemans is over two decades old.

- Do other scientists still agree with him?
- How would you check?
- A literature search in a data base … how?

Have people used these results, or improved on them since 1994?



Citations by year since 1996

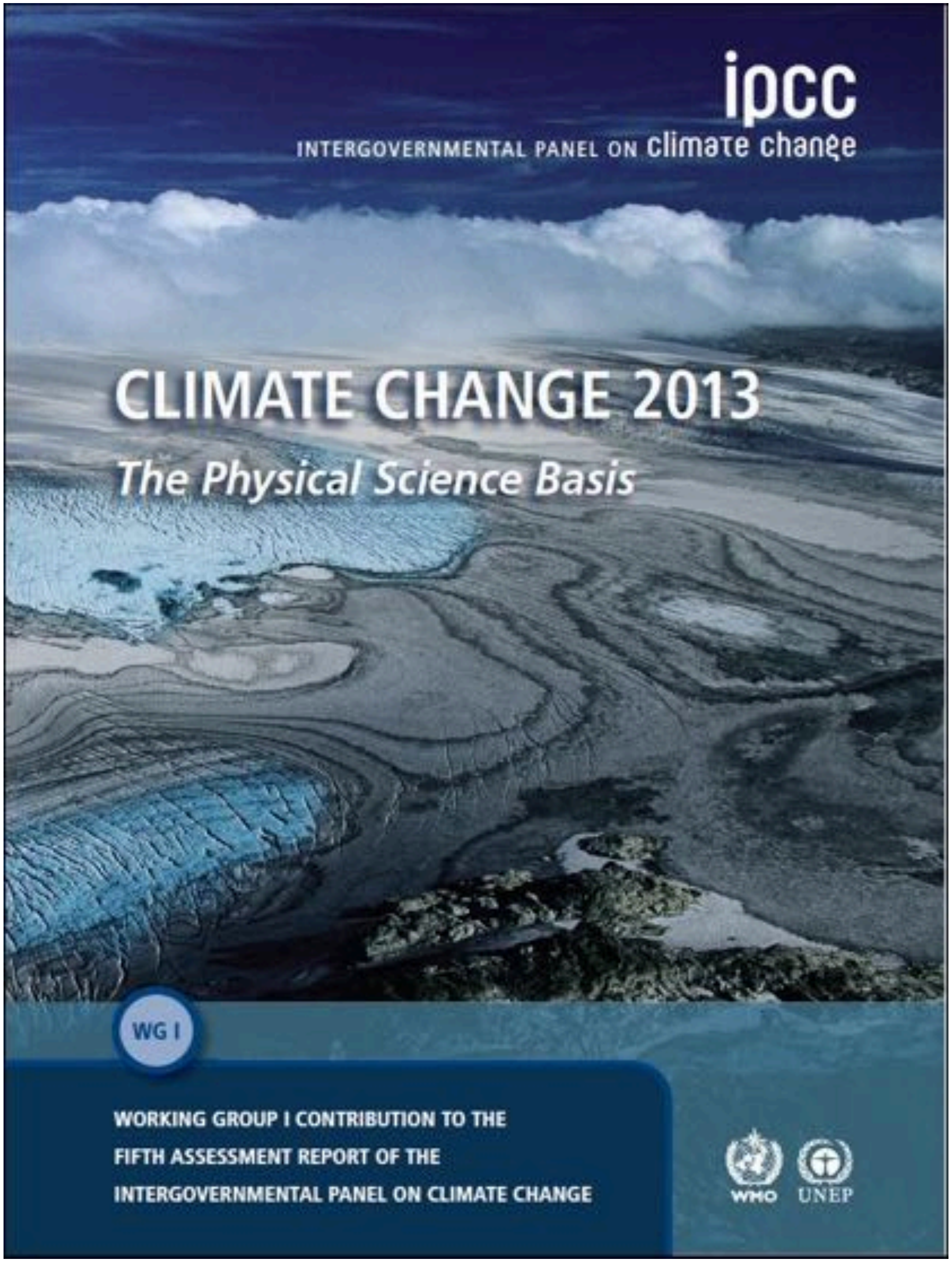


This paper has staying power …

Intergovernmental Panel on Climate Change

What does the IPCC say about global warming?

www.ipcc.ch



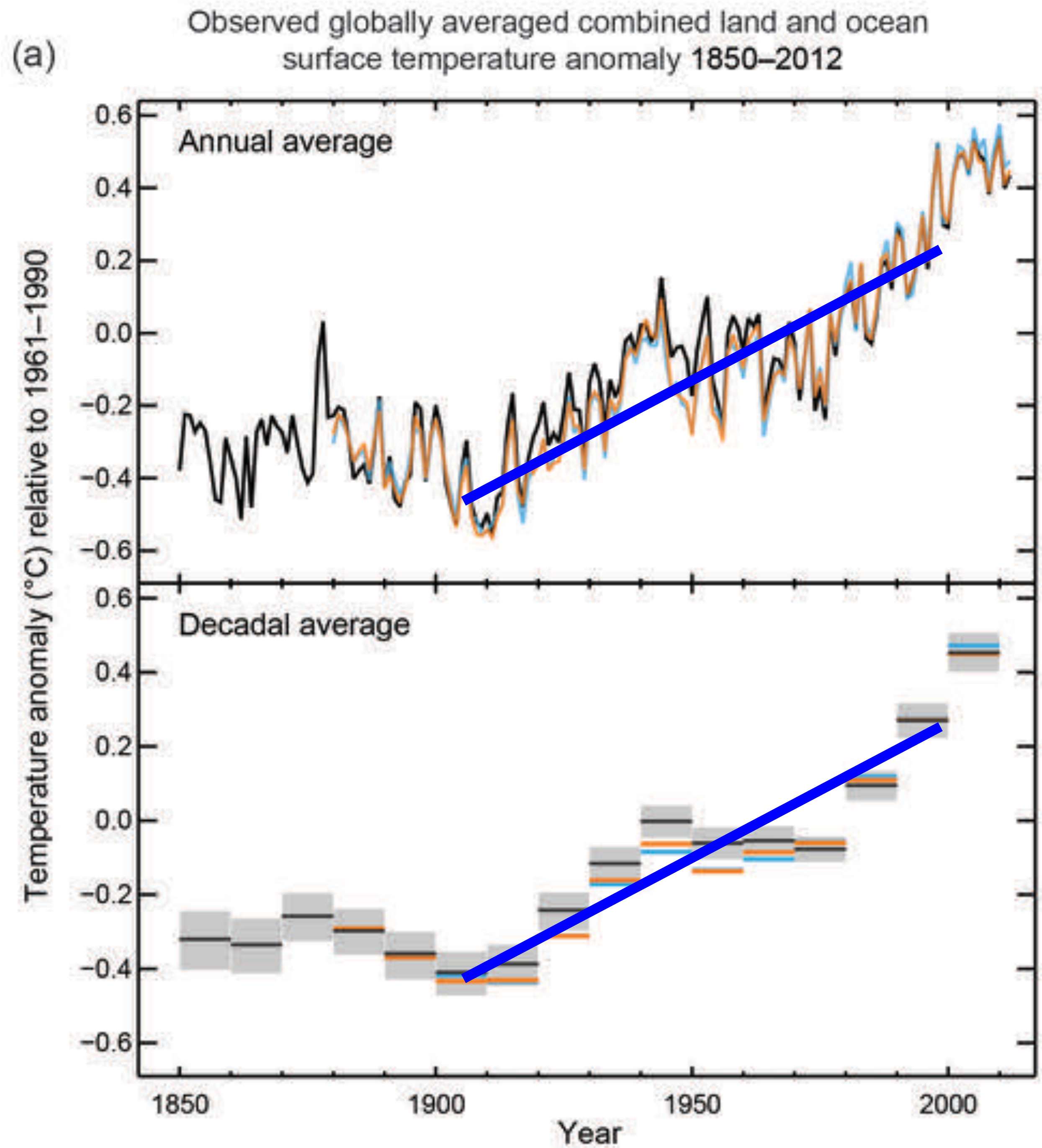
IPCC 2013

Figure SPM.1: Observed annual and decadal global mean surface temperature anomalies from 1850 to 2012.

I added the blue line showing the Oerlemans result

- 0.66°C/Century

www.ipcc.ch



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2013

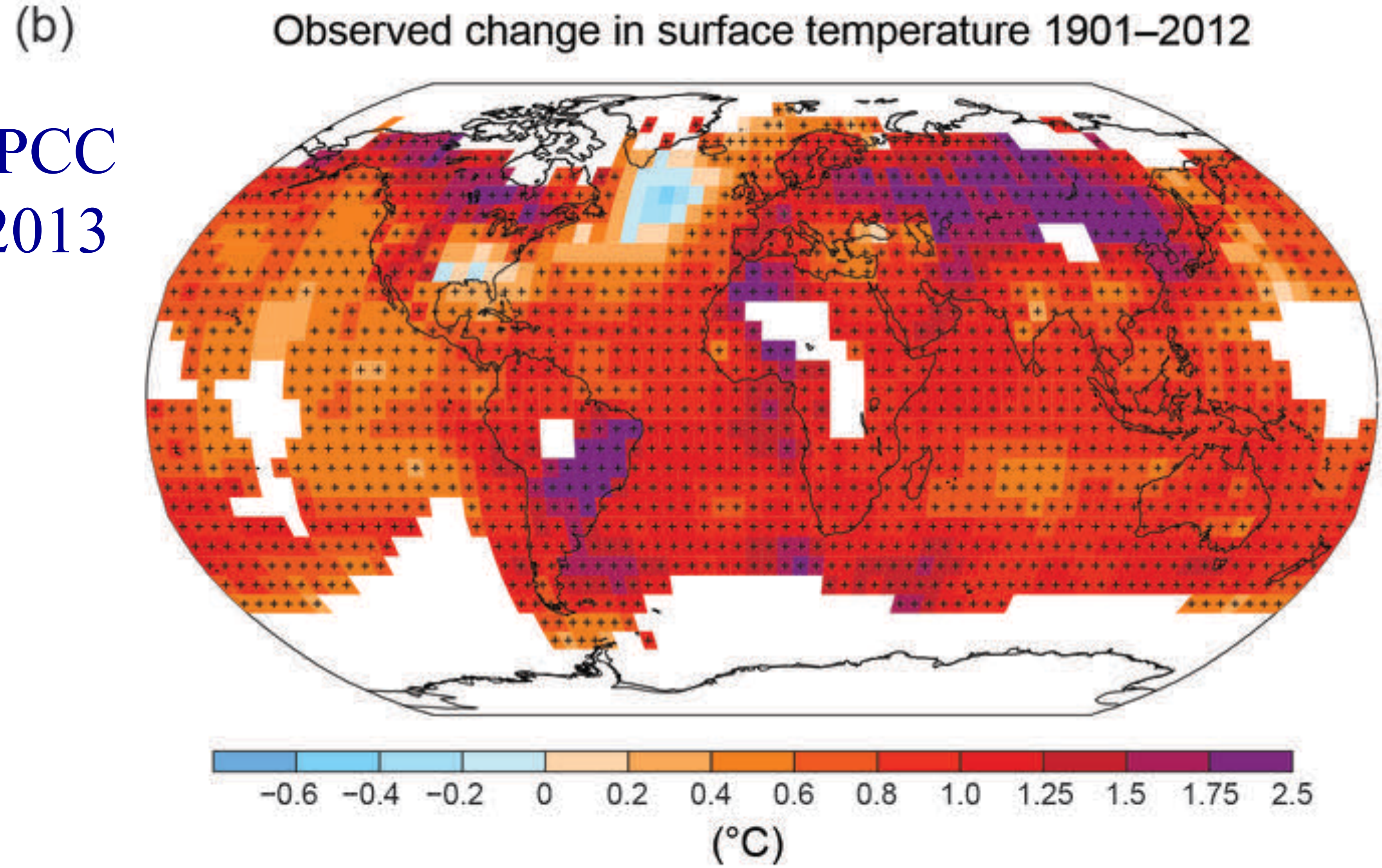

Figure SPM.1: Map of the observed surface temperature changes from 1901 to 2012.

www.ipcc.ch

What’s the next step?

Oerlemans needed to aggregate *all* glacier-retreat histories to extract a signal of *global* warming.

- Can we also learn something about *regional* warming trends from *individual* glaciers?
- Then we could also aggregate the *regional* trends to get *global* warming as well …

nature geoscience

ARTICLES

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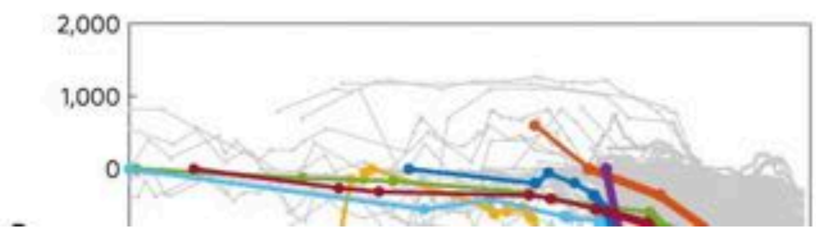
Centennial glacier retreat as categorical evidence of regional climate change

Gerard H. Roe[1]*, Marcia B. Baker[1] and Florian Herla[2]

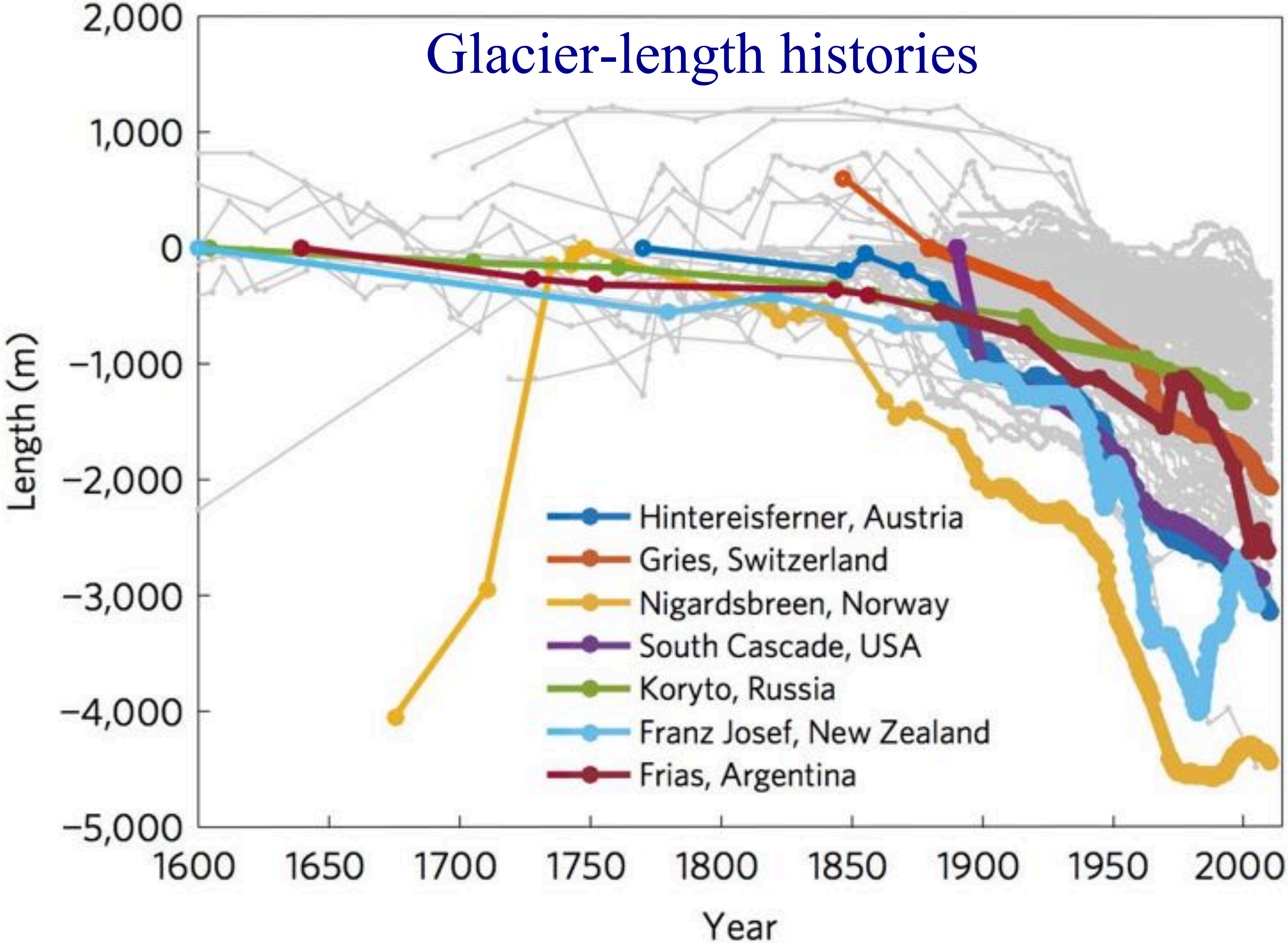
The near-global retreat of glaciers over the last century provides some of the most iconic imagery for communicating the reality of anthropogenic climate change to the public. Surprisingly, however, there has not been a quantitative foundation for attributing the retreats to climate change, except in the global aggregate. This gap, between public perception and scientific basis, is due to uncertainties in numerical modelling and the short length of glacier mass-balance records. Here we present a method for assessing individual glacier change based on the signal-to-noise ratio, a robust metric that is insensitive to uncertainties in glacier dynamics. Using only meteorological and glacier observations, and the characteristic decadal response time of glaciers, we demonstrate that observed retreats of individual glaciers represent some of the highest signal-to-noise ratios of climate change yet documented. Therefore, in many places, the centennial-scale retreat of the local glaciers does indeed constitute categorical evidence of climate change.

Alpine glaciers are consequential and captivating elements of the Earth system that feature prominently in the lives of nearby communities[1]. The nature of glacier motion was a research challenge for nineteenth-century physicists[2,3], and the late Holocene history of glacier margins has been a primary target of modern palaeoclimate science[4]. Consequently, the century-



1. Dept of Earth and Space Sciences, University of Washington, Seattle

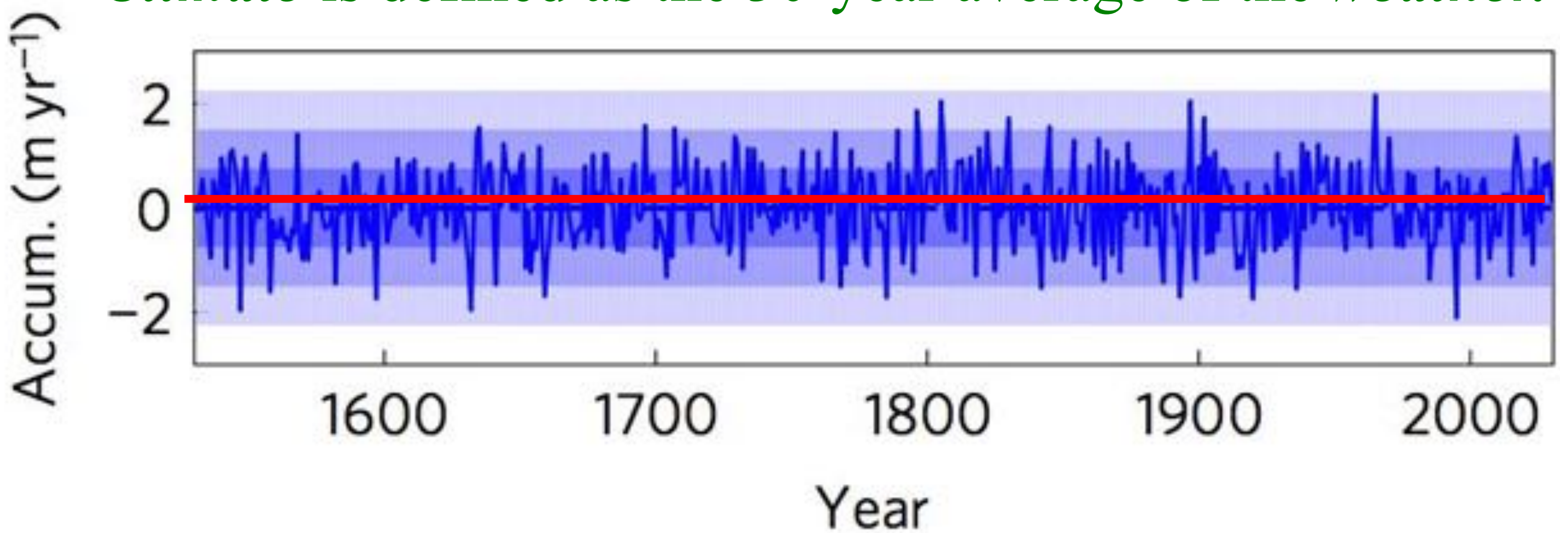
Glacier-length histories



How *steady* are glaciers in a steady-state climate?

After a glacier has come into balance with a steady-state climate, does its terminus always stay at the same position?

- ***Climate*** is defined as the 30-year average of the ***weather.***



- Blue curve is annual ***weather*** (accumulation on a glacier)
- Red line is the corresponding constant ***climate***.

Or stated another way –

- Climate is what you expect.
- Weather is what you get.

Curious Scientists flip a coin

Heads = +1   Tails = -1

Your group members will flip 50 coins and record:

Sequence of flips	e.g.		H	T	T	T	H	T	…
Value of each flip (+/-1)			1	-1	-1	-1	1	-1	…
Running total		0	1	0	-1	-2	-1	-2	…

e.g. here's Ed's result for one trial with 10 flips

Flips	-	T,	H,	H,	T,	H,	H,	H,	H,	T, T
Values		-1	1	1	-1	1	1	1	1	-1 -1
Running total	0,	-1,	0,	1,	0,	1,	2,	3,	4,	3, 2

- How far does your running total get from zero?
- Now sketch your running total.

https://docs.google.com/document/d/16IjpP3k_3uYt7T7PBwiUWF1C7IrUdjMCYovXtNyisSI/edit

Curious Scientists flip a coin

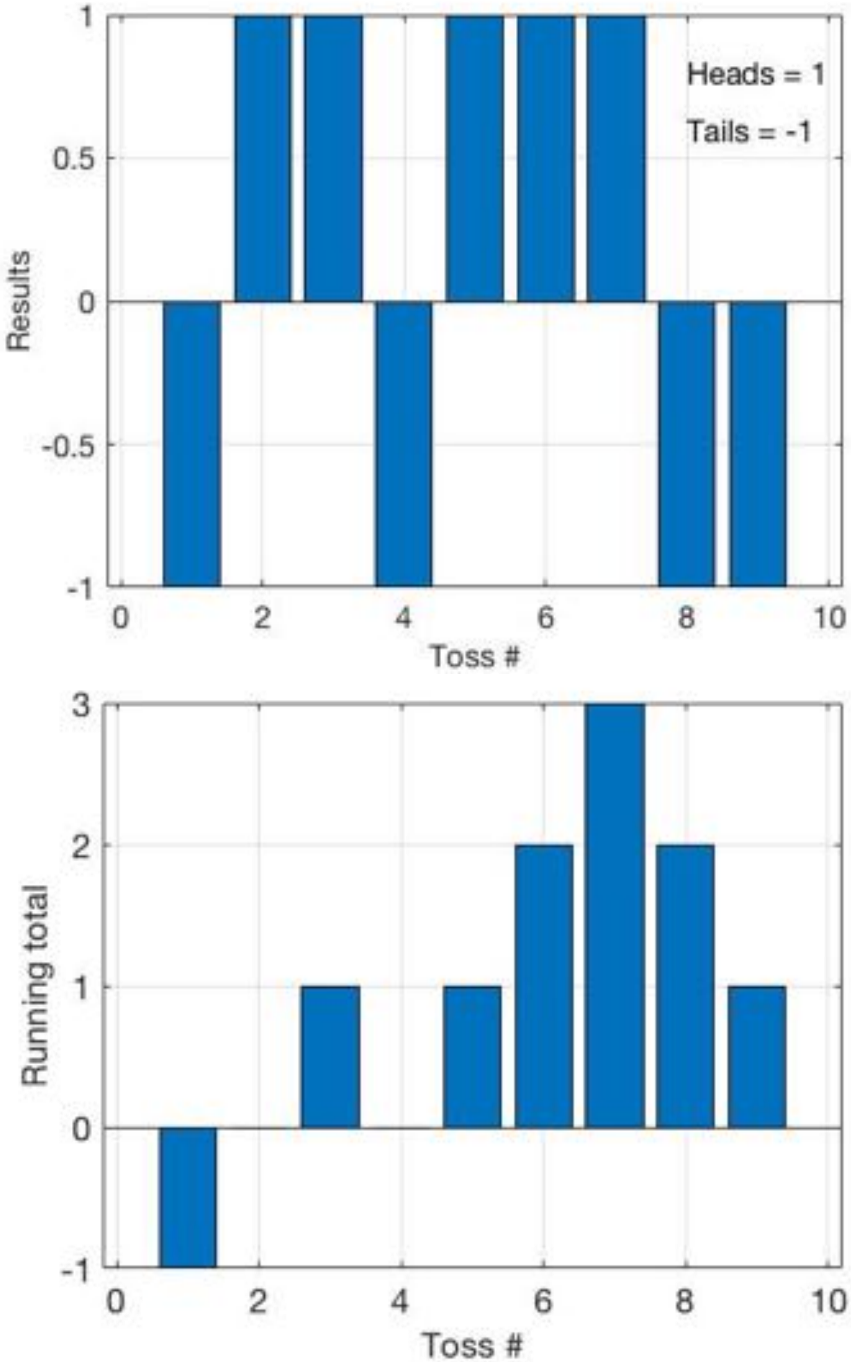
What you almost certainly *didn't* get was

Flips	- H, T, H, T, H, T, H, T, H, T …
Values	1 -1 1 -1 1 -1 1 -1 1 -1 …
Running total	0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0 …

Because that's not random.

- Flipping a coin -
Ed's Example after 10 tosses

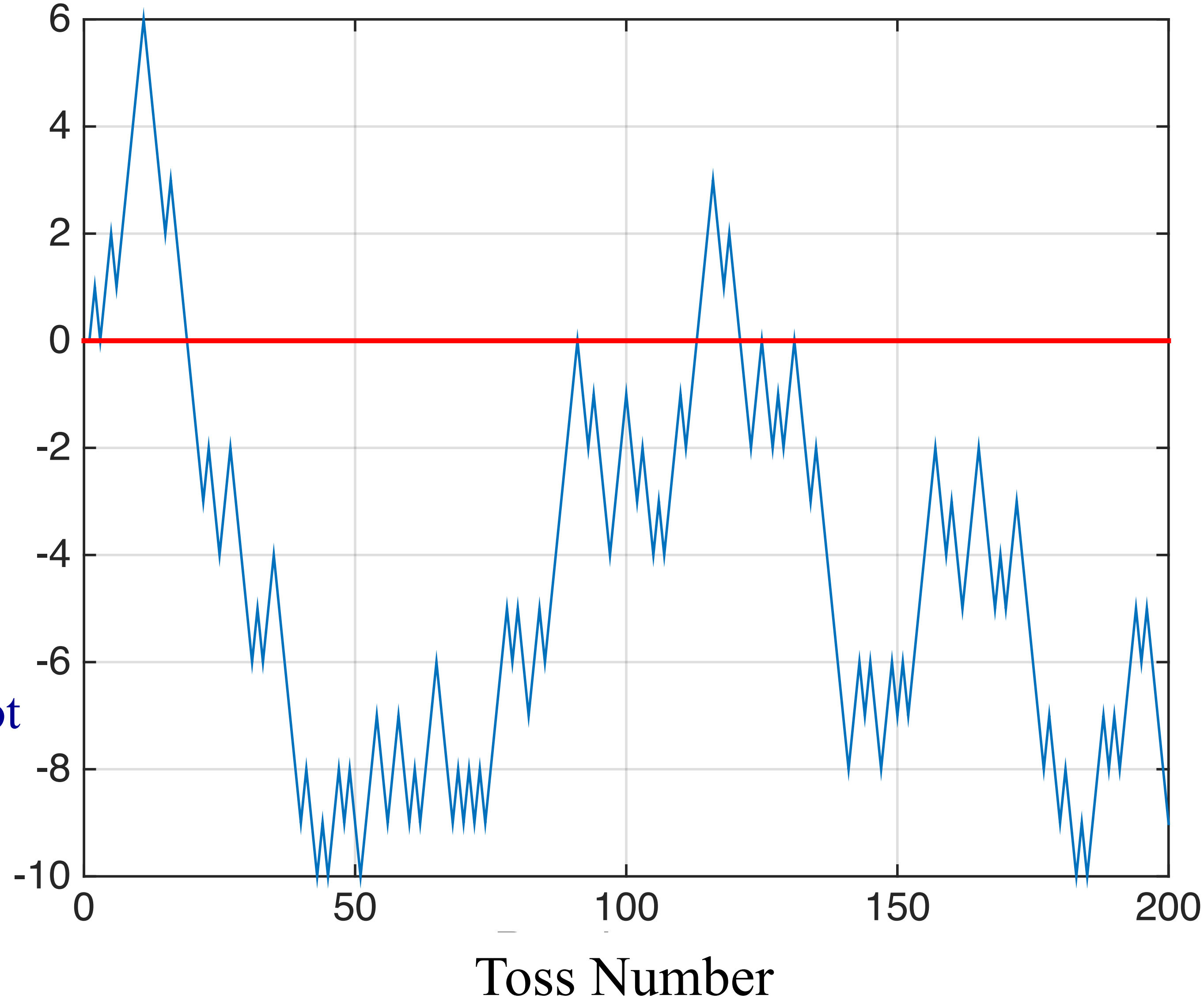
The running total can range far from the long-term average, which is zero.



Example - 200 coin flips

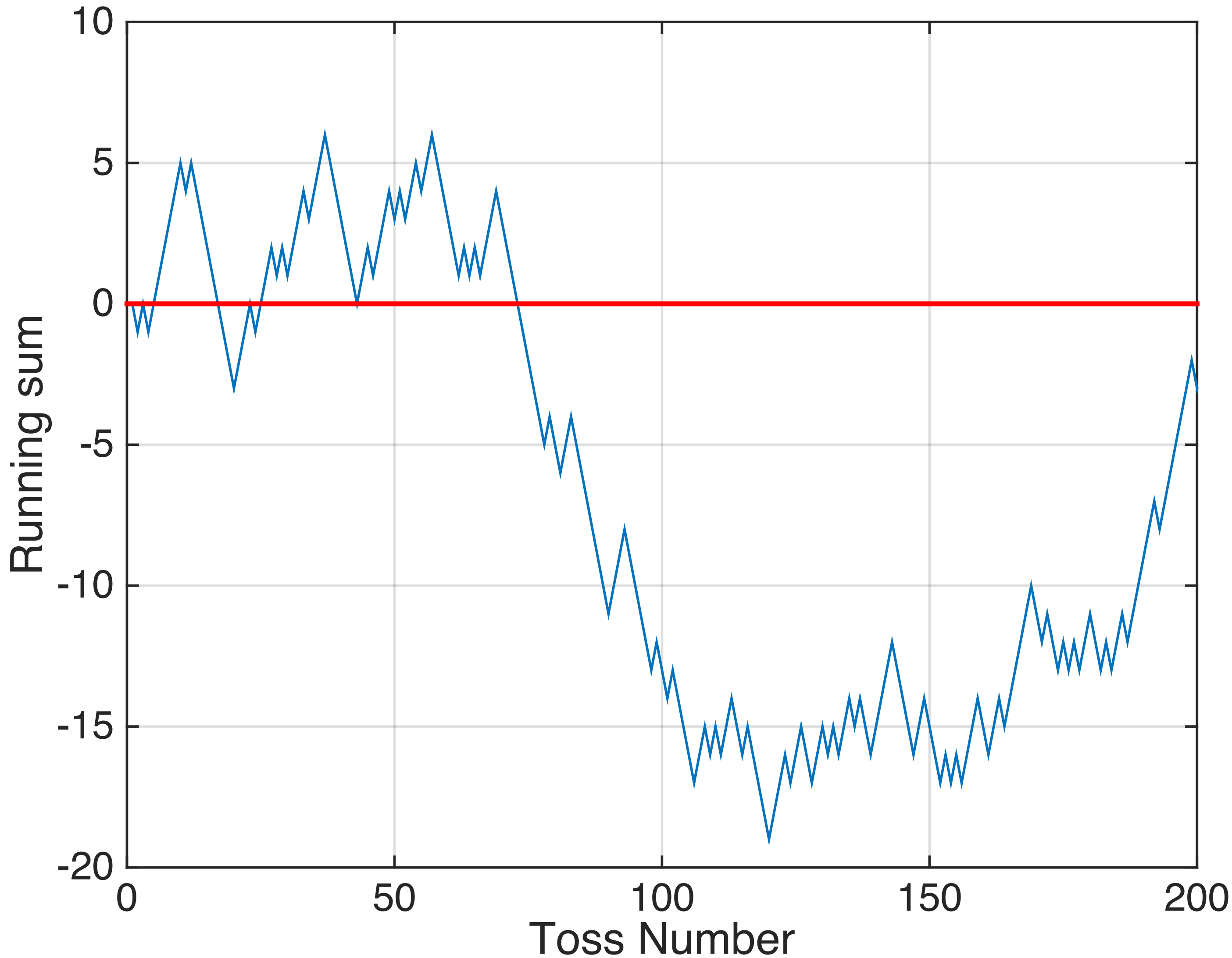
- After 200 flips, end value (-9) isn't far from zero.
- Average is also close to zero (-9/200 = -0.045)

- Interim values can get large (-10)
- Average after 50 tosses deviates a lot from zero (10/50 = 0.2). But it recovers later.



Another Example - 200 coin flips

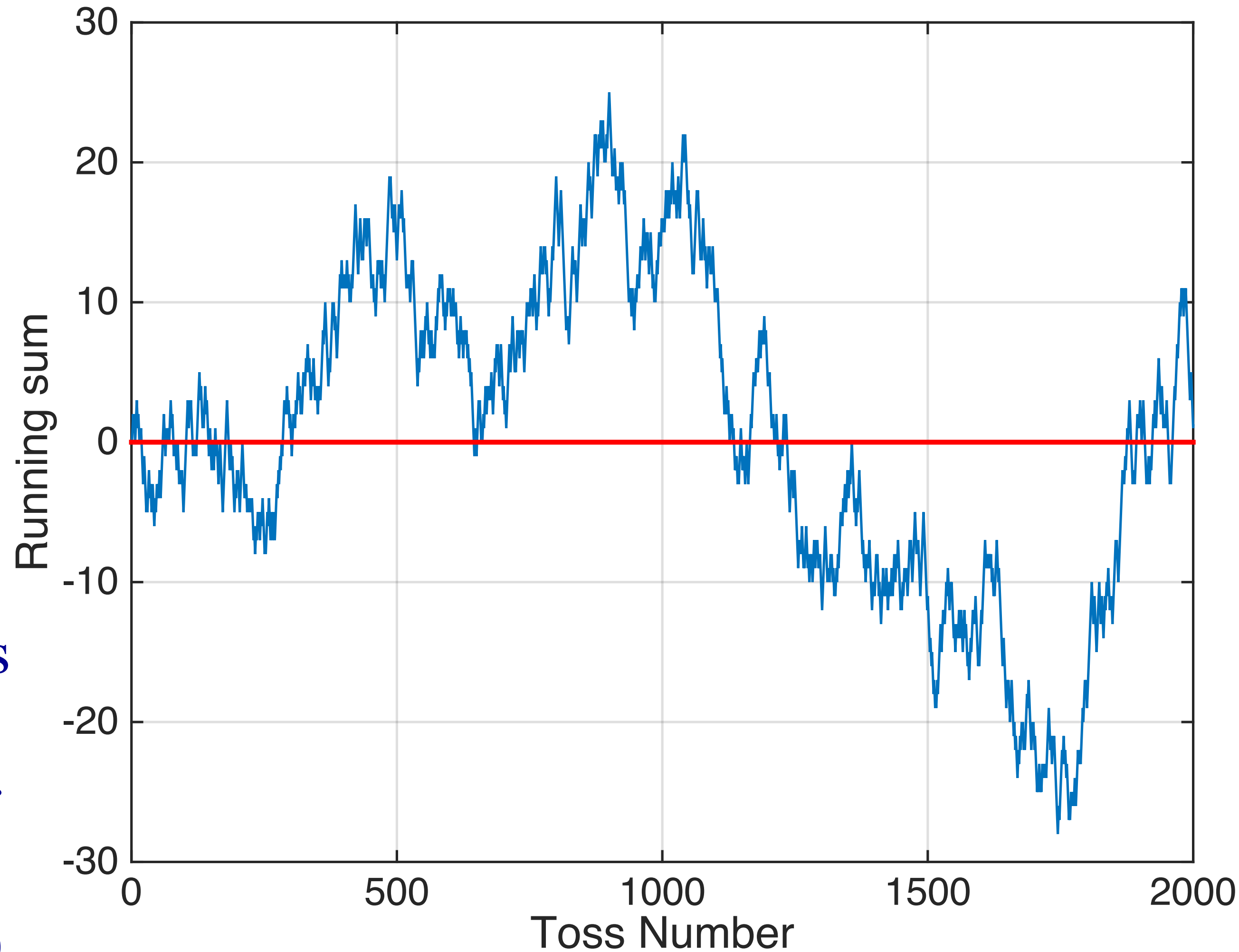
- End value (-3) is close to zero.
- Average is also close to zero (-3/200 = 0.015)



- Interim value can be large (-18)
- Average at 120 tosses deviates a lot from zero (18/120 = 0.15). But it recovers later.

Example - 2000 coin flips

End value isn't far from zero. Average (4/2000 = 0.002)



Big interim values (28), but average even then isn't far from zero (28/1750 = 0.016)

A glacier integrates mass balance (snowfall and melting) through time

Year-to-year fluctuations of snowfall and melting may be random and unbiased (like coin flips).

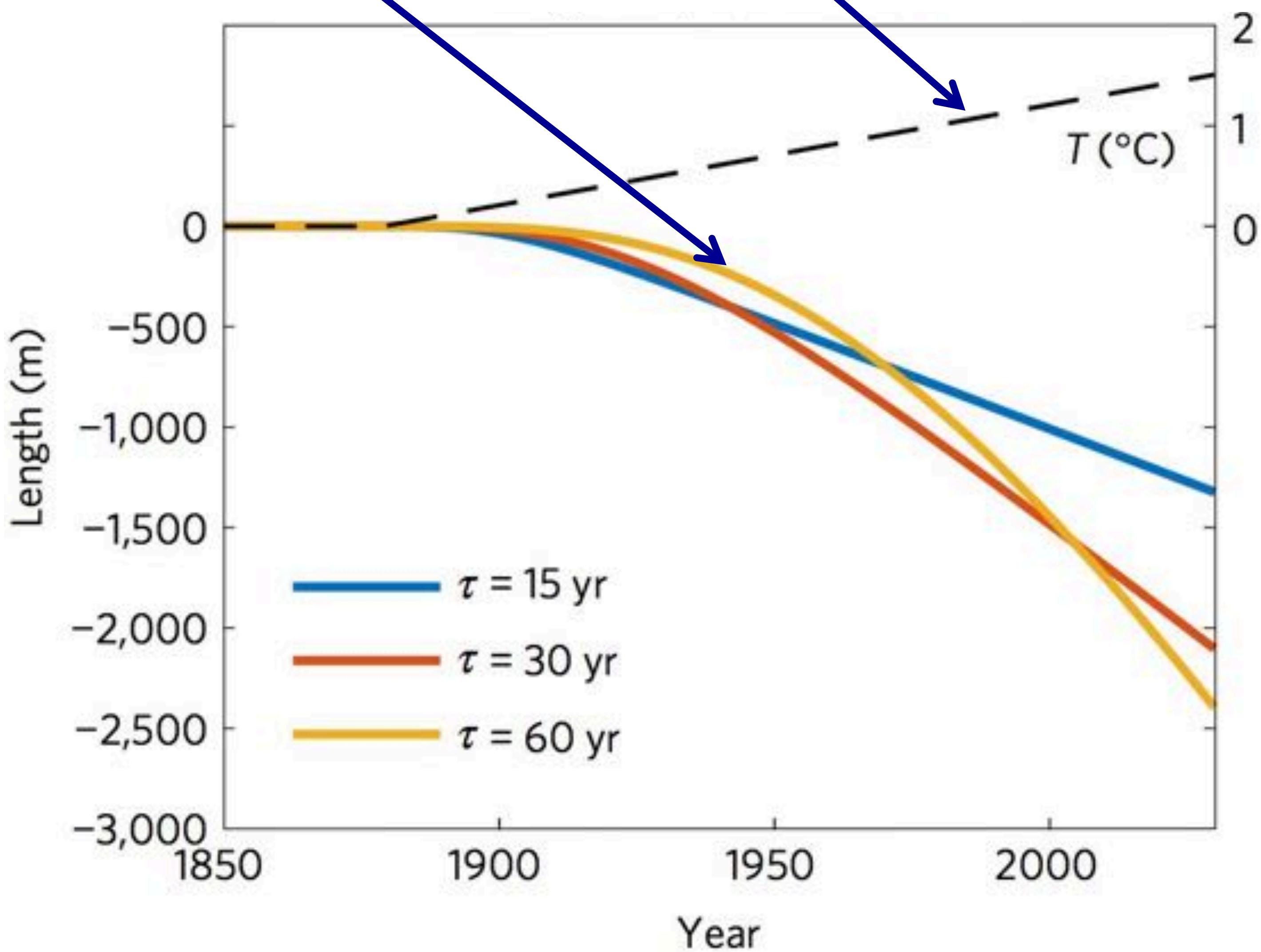
- However, there can be “runs” of positive-balance years, or negative-balance years.
- A run of positive years will make a glacier advance.
- A run of negative years will make a glacier retreat.

- How can we tell whether a change in glacier length is due to climate change, or to a run of non-average weather years?

Length response to temperature trend signal

3 models with different characteristic times

$\tau = -H/b_{term}$



All retreat steadily after a time τ

Signal to Noise

Signal-to-noise ratio "*s*" is a nondimensional number that tells us whether a linear-trend *signal* will be visible in the presence of *noise* after a time t_0.

- Random mass-balance fluctuations σ_b due to weather are the *noise* in a constant climate with mass balance b.

- If a glacier retreat rate has a large signal-to-noise ratio s_L, we can figure that the terminus change ΔL is *not* due to random weather variability.

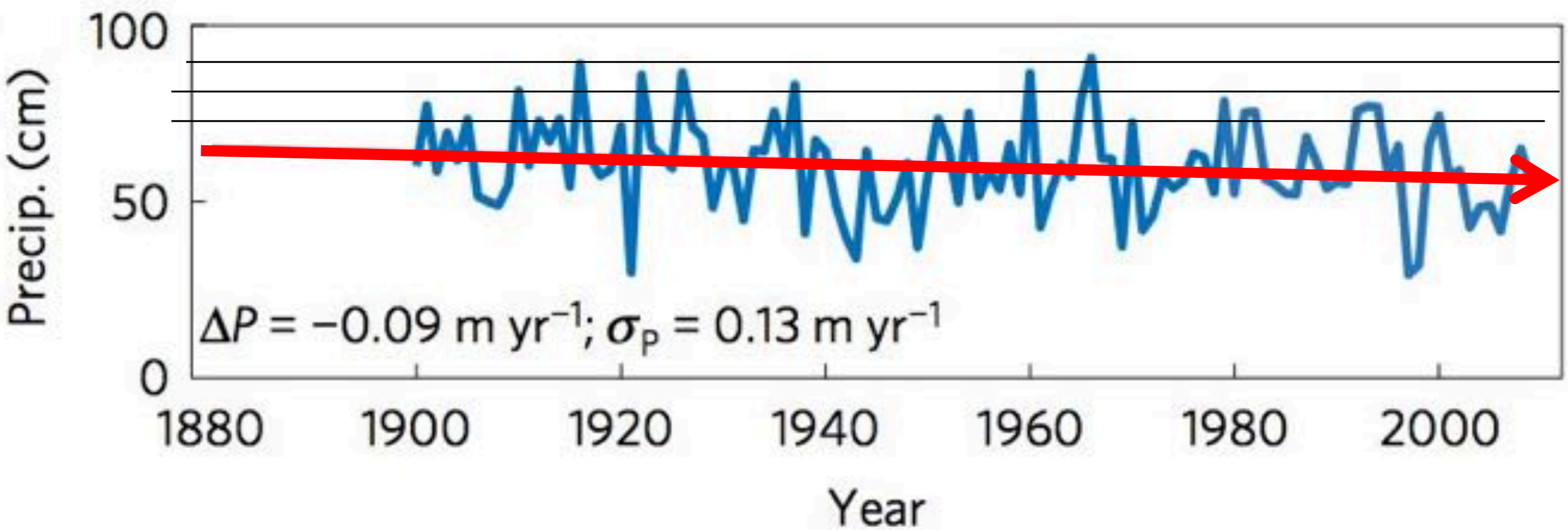
Signal to Noise

Nondimensional signal-to-noise ratio "s_b" tells us whether a signal (e.g. a trend) will be visible in the presence of super-imposed random noise due to random inter-annual weather.

- Here is a synthetic mass-balance record $b(t)$ with a linear trend from 60 cm/yr to 50 cm/yr over the 20th century

$$\frac{\Delta b}{t_0} = \frac{10\ \text{cm/yr}}{100\ \text{yr}} = \frac{1\ \text{mm/yr}}{1\ \text{yr}}$$

and random noise σ_b super-imposed.



Signal to Noise

Suppose the climate (mass balance) has a linear trend $\Delta b/t_0$ over time t_0.

• That's the climate signal.

Natural random year-to-year fluctuations are superimposed

• That's the noise σ_b.

• Their ratio is climate (mass balance) signal-to-noise s_b.

$$s_b = \left({}^{\Delta b}\!/\!_{t_0} \right) \Big/ \sigma_b$$

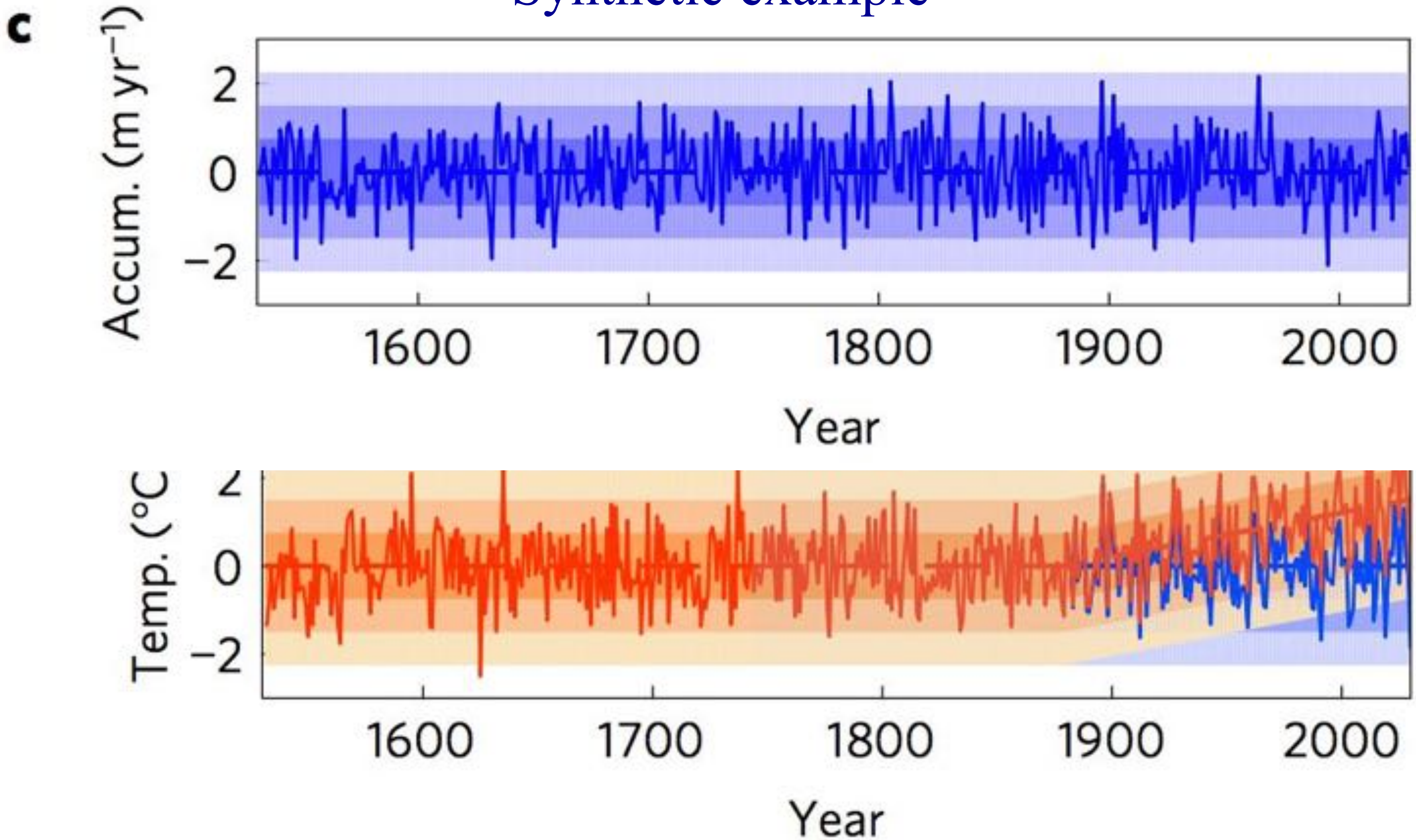
Signal to Noise

Because a glacier integrates weather variations (like the running total of coin flips), the signal-to-noise ratio s_L of glacier length amplifies weather signal-to-noise s_b.

$$s_L = \gamma\left(t_0, \tau\right) \times s_b$$

- $\gamma(t_0, \tau)$ is the amplification factor for a glacier with characteristic time τ and a climate trend that persists for time duration t_0.

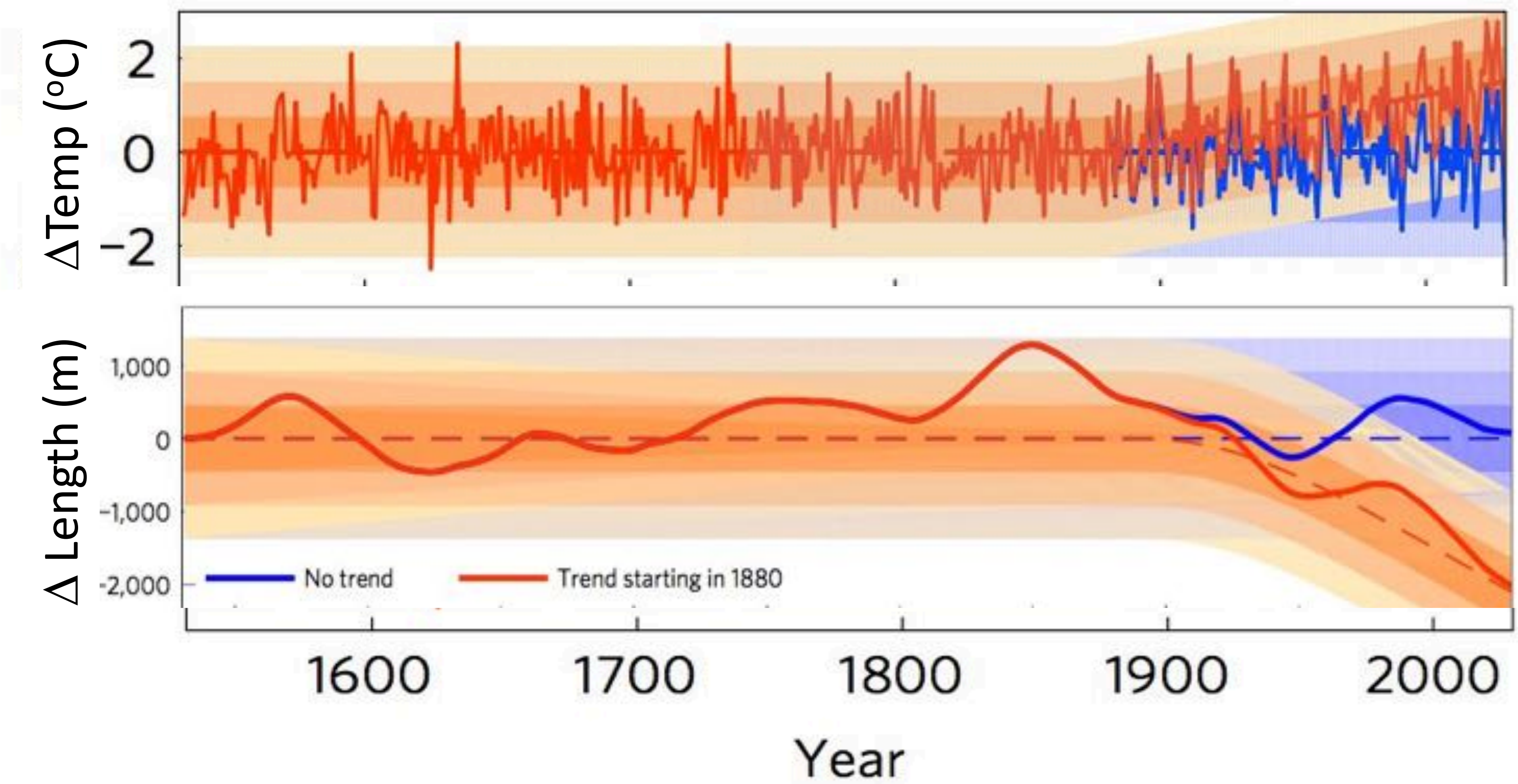
Synthetic example



Colored bands show 1, 2, 3 σ probabilities.

- 99.7% of all annual weather values will fall inside the 3 σ band.

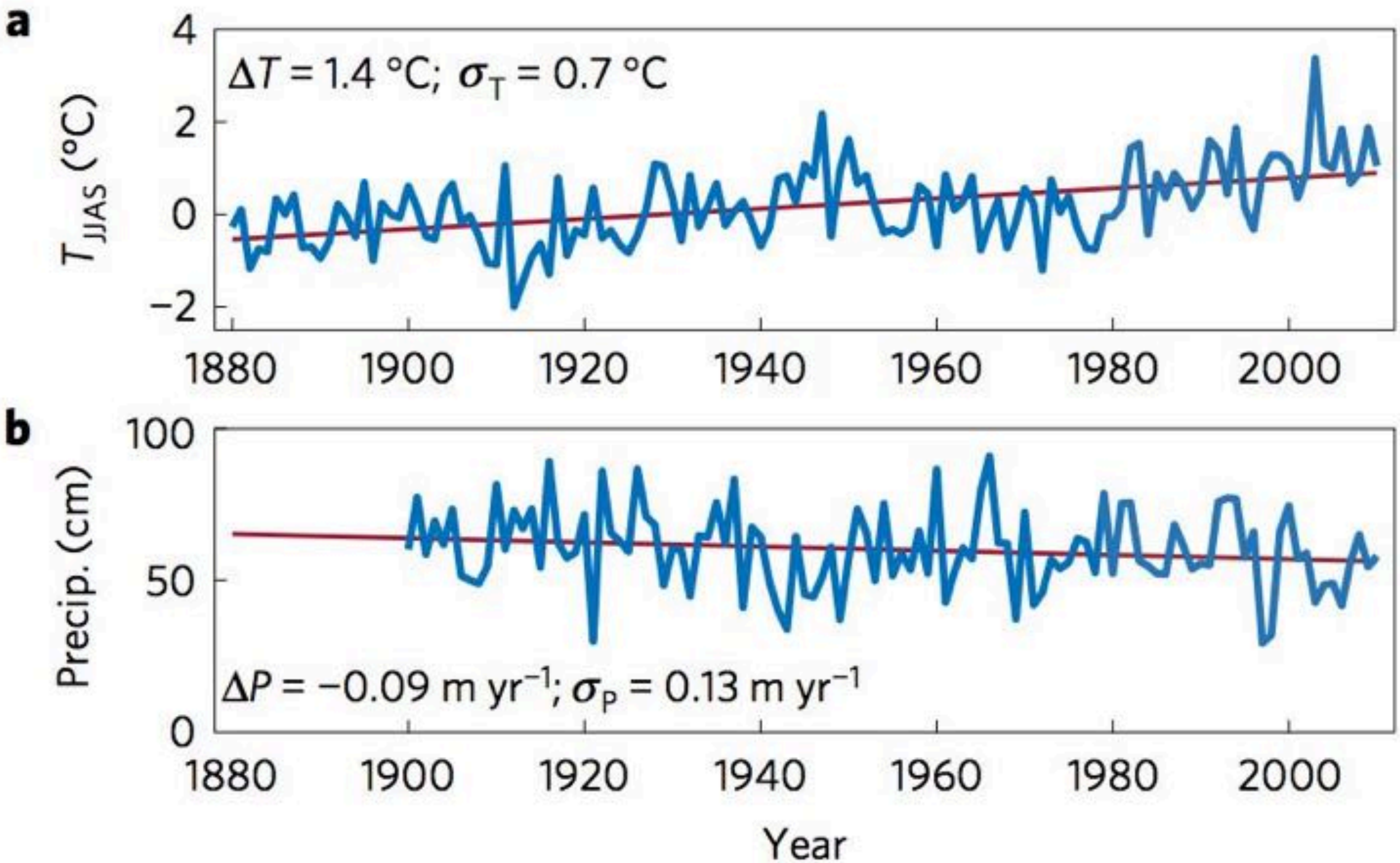
Glacier Response to warming trend – blue = steady T, red = warming trend

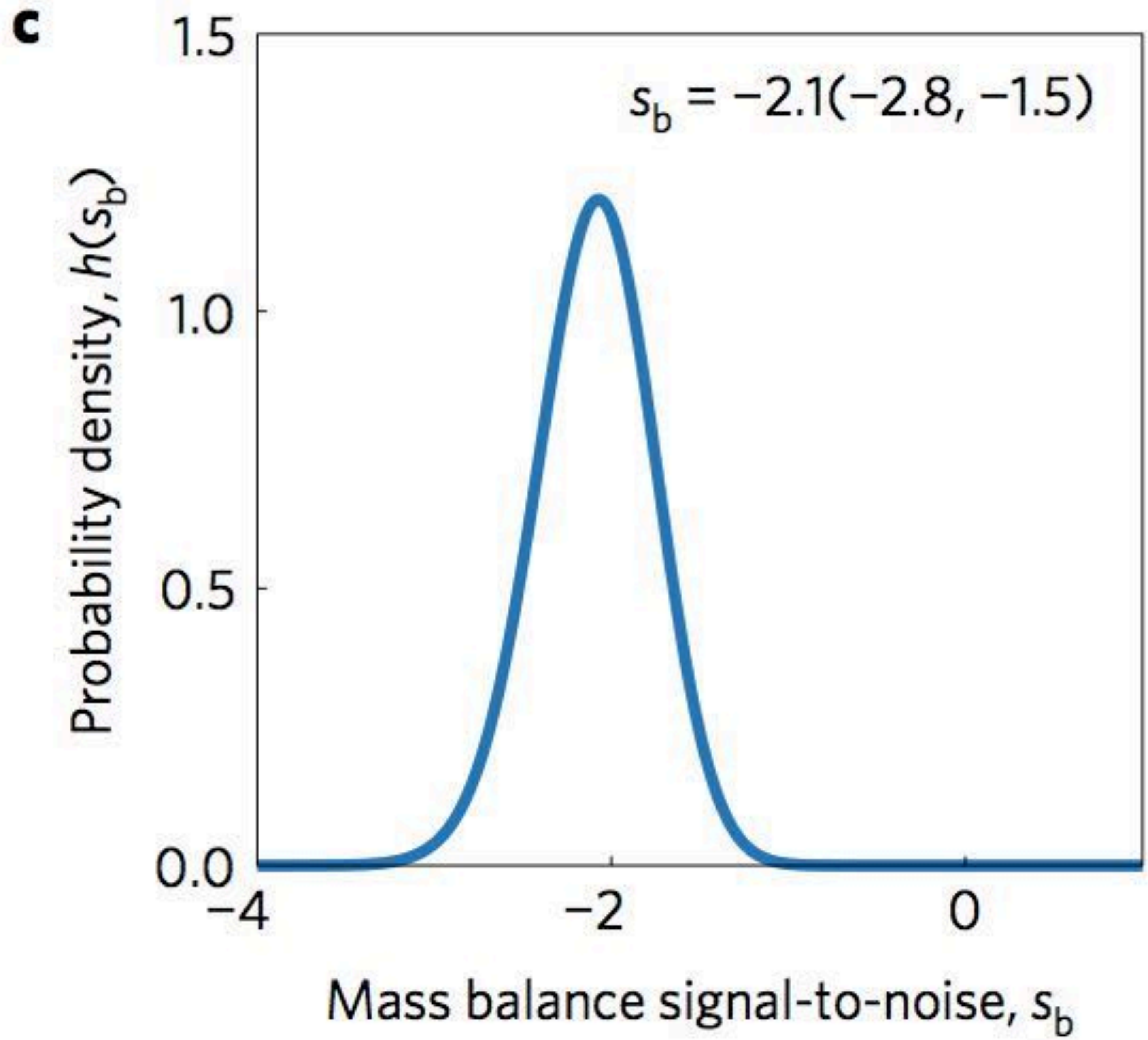


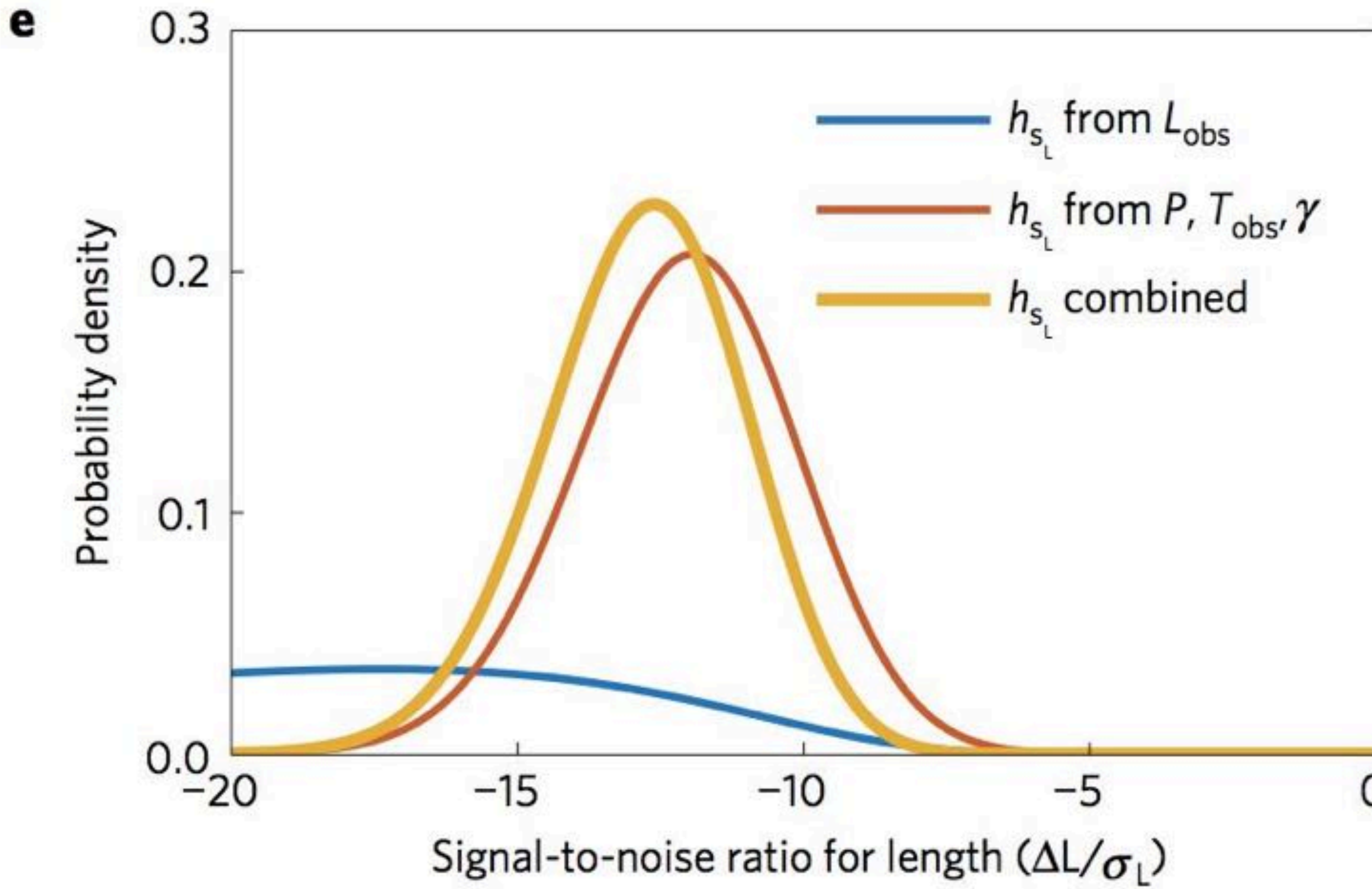
Colored bands show 1, 2, 3 σ probabilities.

- 99.7% of all glacier-length values will fall inside the 3 σ band.

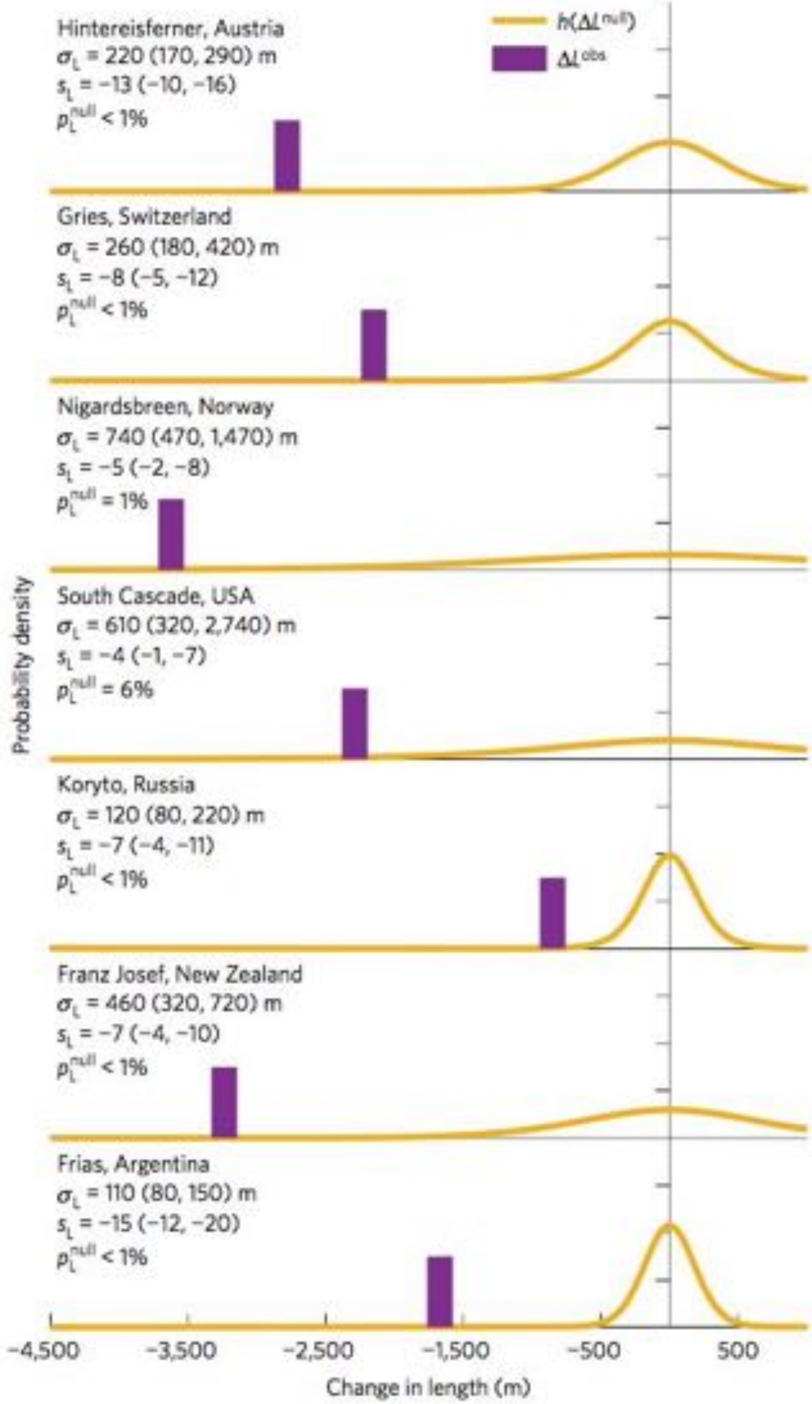
Hintereisfirner, AustrianAlps




c
1.5
1.0
0.5
0.0
−4
−2
0
$s_b = -2.1(-2.8, -1.5)$
Probability density, $h(s_b)$
Mass balance signal-to-noise, s_b



e
0.3
0.2
0.1
0.0
Probability density
−20
−15
−10
−5
0
Signal-to-noise ratio for length ($\Delta L/\sigma_L$)
h_{s_L} from L_{obs}
h_{s_L} from P, T_{obs}, γ
h_{s_L} combined



$h(\Delta L^{null})$
ΔL^{obs}
Hintereisferner, Austria
σ_L = 220 (170, 290) m
s_L = −13 (−10, −16)
p_L^{null} < 1%
Gries, Switzerland
σ_L = 260 (180, 420) m
s_L = −8 (−5, −12)
p_L^{null} < 1%
Nigardsbreen, Norway
σ_L = 740 (470, 1,470) m
s_L = −5 (−2, −8)
p_L^{null} = 1%
South Cascade, USA
σ_L = 610 (320, 2,740) m
s_L = −4 (−1, −7)
p_L^{null} = 6%
Koryto, Russia
σ_L = 120 (80, 220) m
s_L = −7 (−4, −11)
p_L^{null} < 1%
Franz Josef, New Zealand
σ_L = 460 (320, 720) m
s_L = −7 (−4, −10)
p_L^{null} < 1%
Frias, Argentina
σ_L = 110 (80, 150) m
s_L = −15 (−12, −20)
p_L^{null} < 1%
Probability density
−4,500
−3,500
−2,500
−1,500
−500
500
Change in length (m)

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Centennial glacier retreat as categorical evidence of regional climate change

By: Roe, GH (Roe, Gerard H.)[1]; Baker, MB (Baker, Marcia B.)[1]; Herla, F (Herla, Florian)[2]

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Abstract

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Keywords

KeyWords Plus: MASS-BALANCE; ICE-AGE; VARIABILITY; FLUCTUATIONS

Author Information

Reprint Address:
University of Washington University of Washington Seattle Univ Washington, Dept Earth & Space Sci, Seattle, WA 98195 USA.
Corresponding Address: Roe, GH (corresponding author)

\+ Univ Washington, Dept Earth & Space Sci, Seattle, WA 98195 USA.

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SCIENCE (1994)

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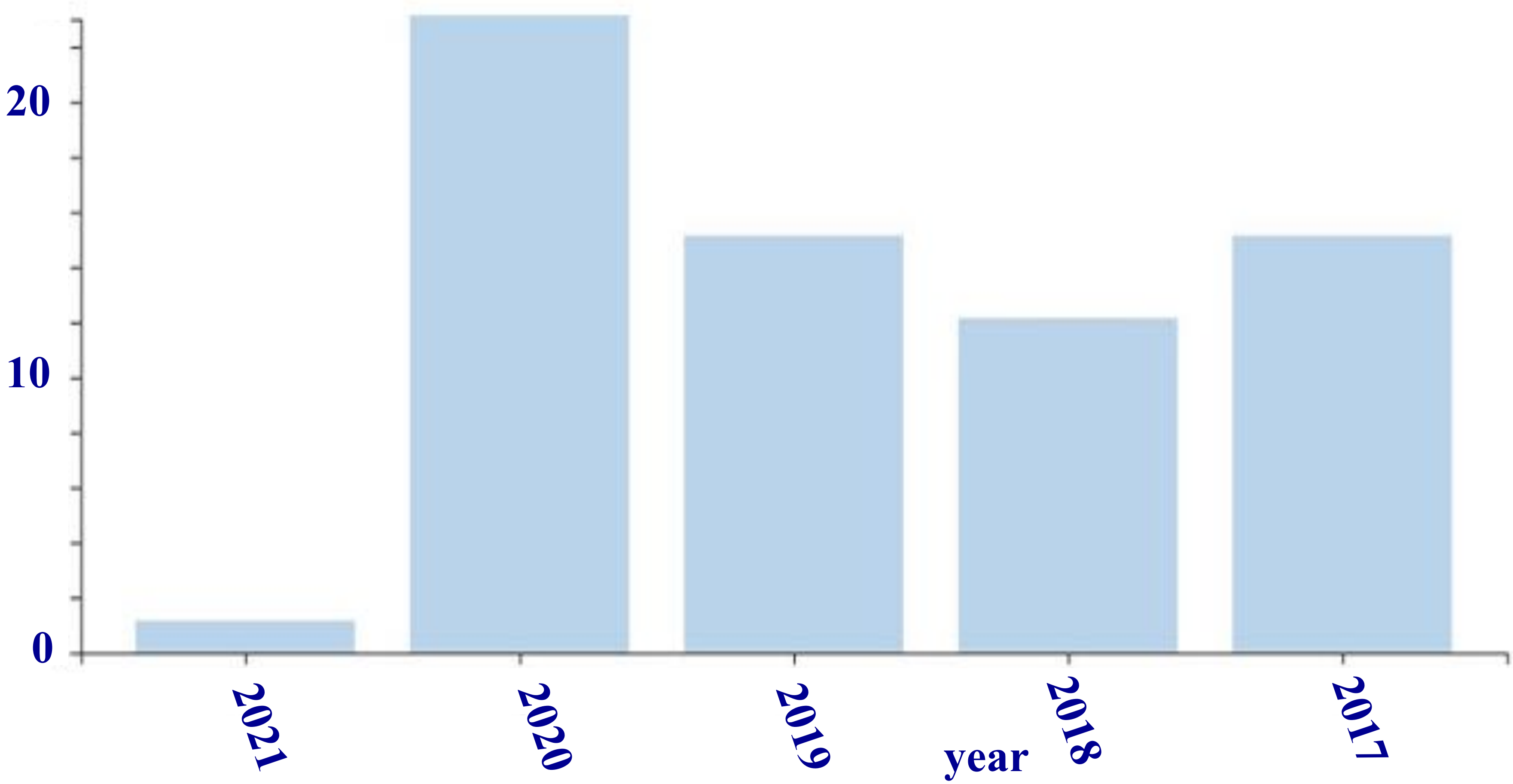

This paper has ben cited early and often …

- It is becoming a classic.