Glaciology
EESCGU4220

Lecture 3: Accumulation zone processes

Mass balance (MB)

Specific mass balance

Surface facies

Accumulation

Measuring MB

Firn densification

Glaciology
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Lecture 3: Accumulation zone processes

Mass balance

Specific mass balance

Surface facies

Accumulation

Measuring MB

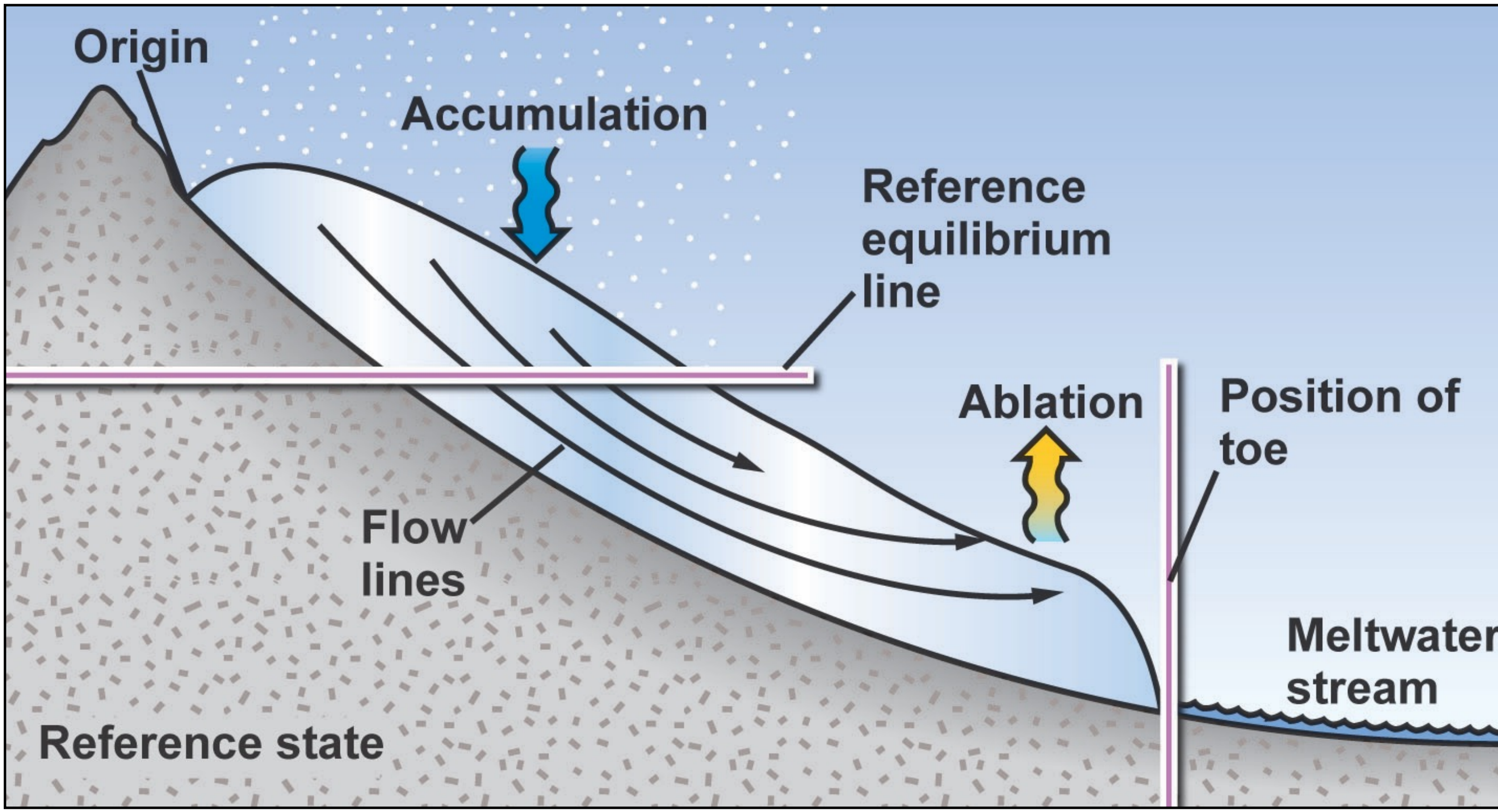
Firn densification

Start recording!

Discuss office hours.

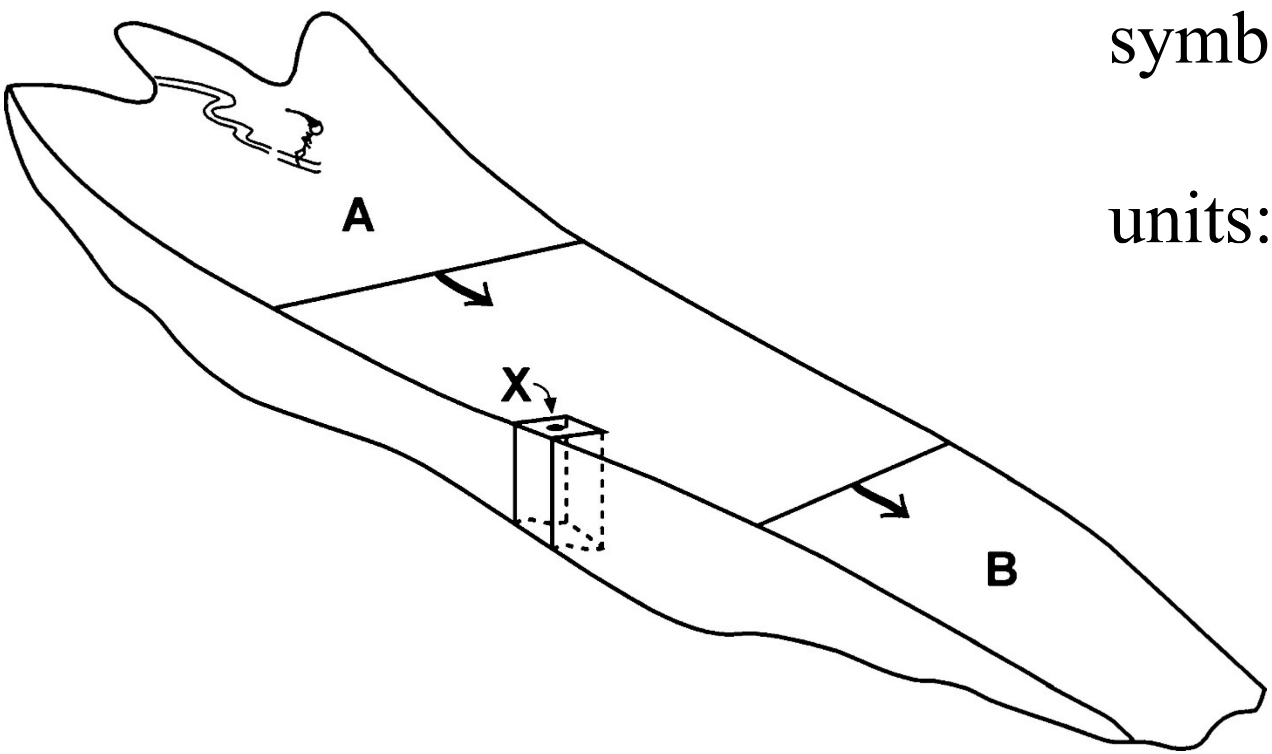
Mass balance

Mass balance = total mass gain – total mass loss



Specific mass balance

Change in mass per unit area



symbol: b

units: kg m^{-2}

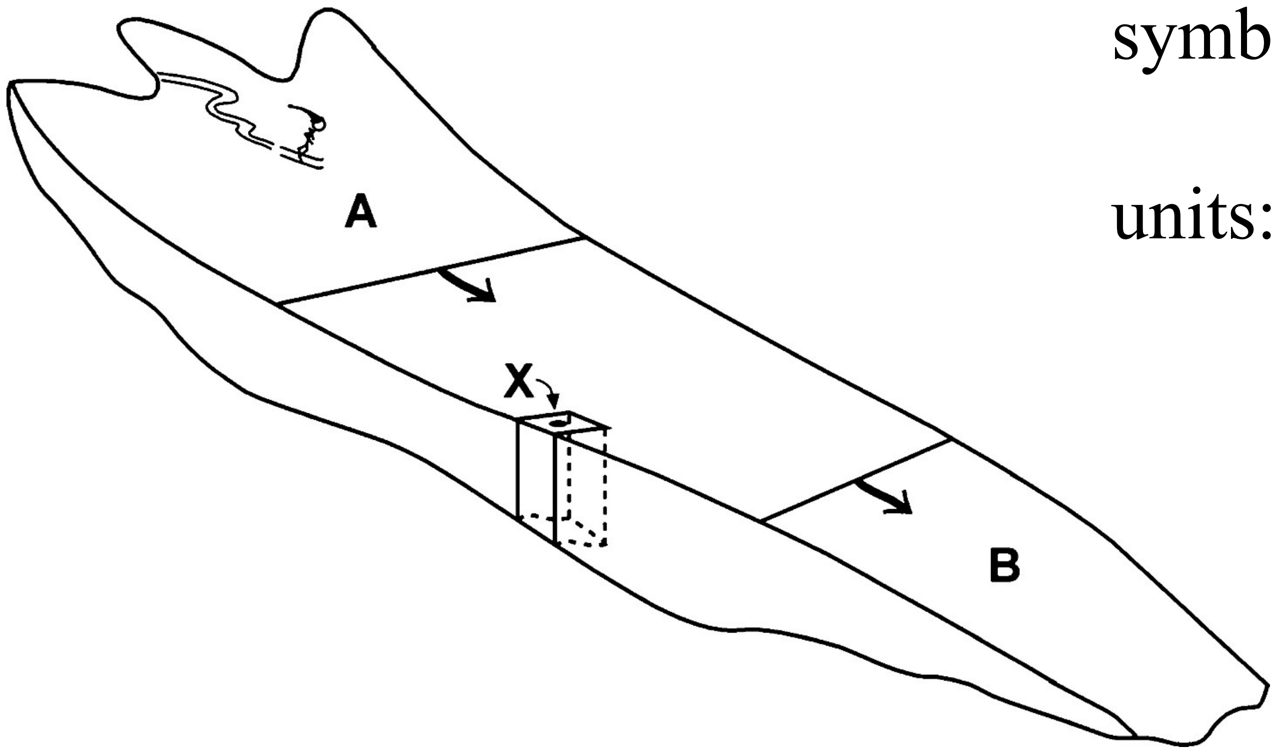
Cuffey and Paterson (2010)

Specific mass balance

Change in mass per unit area

Includes surface, englacial and basal components.

(not ice flow)



symbol: b

units: kg m^{-2}

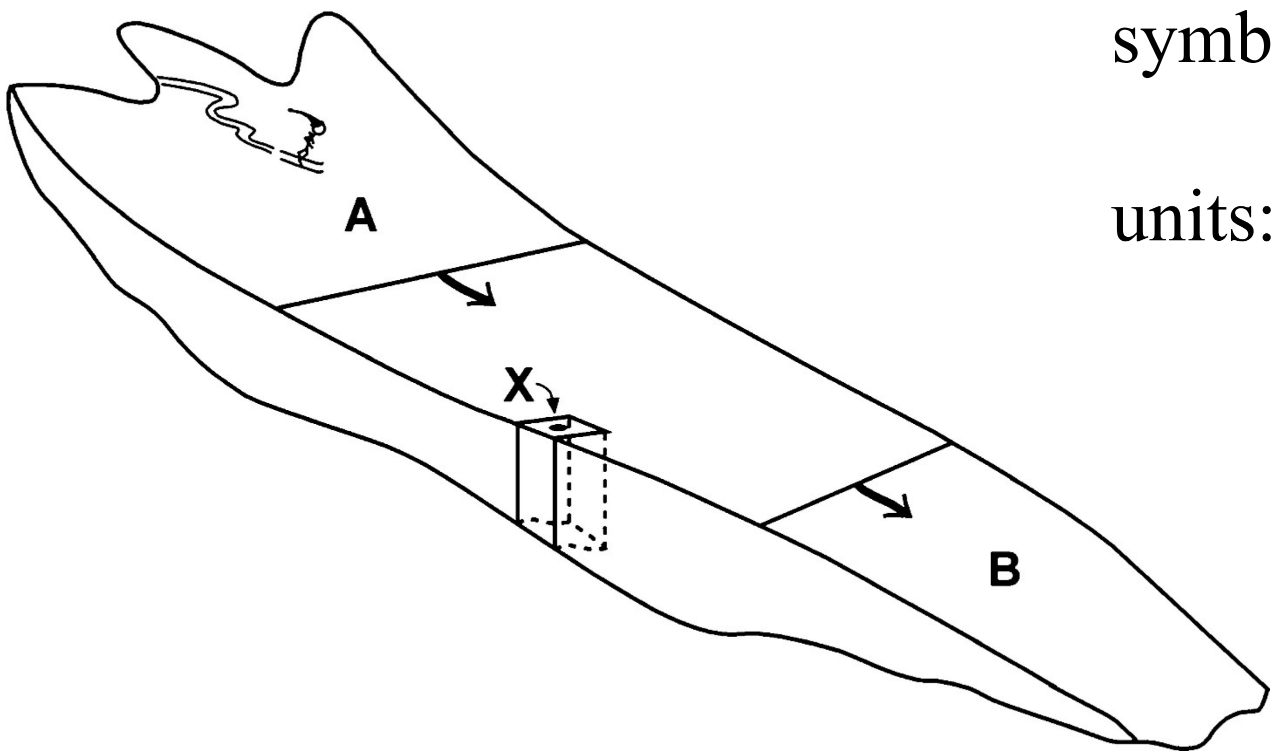
Cuffey and Paterson (2010)

Specific mass balance rate

Change in mass per unit area per unit time

Includes surface, englacial and basal components.

(not ice flow)



symbol: $\dot{b}$

units: kg m^{-2} a^{-1}

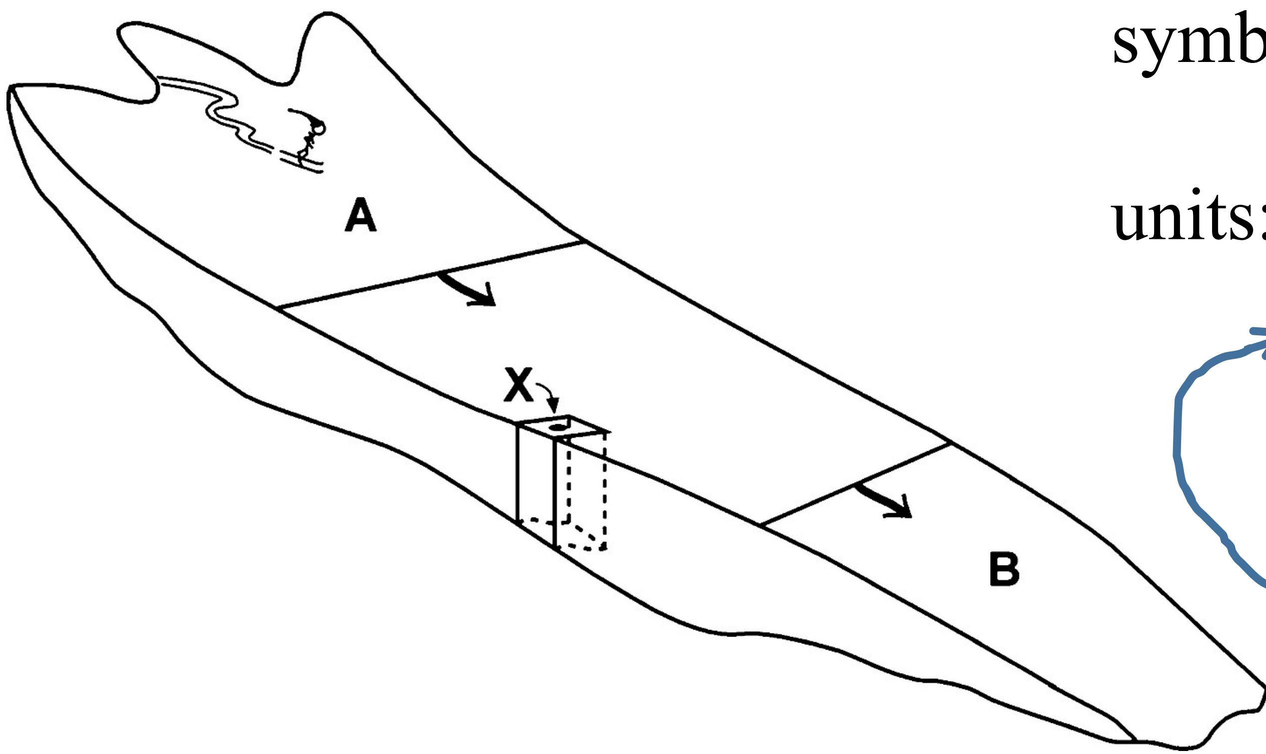
Cuffey and Paterson (2010)

Specific mass balance rate

Change in mass per unit area per unit time

Includes surface, englacial and basal components.

(not ice flow)



symbol: $\dot{b}$

units: kg m^{-2} a^{-1}

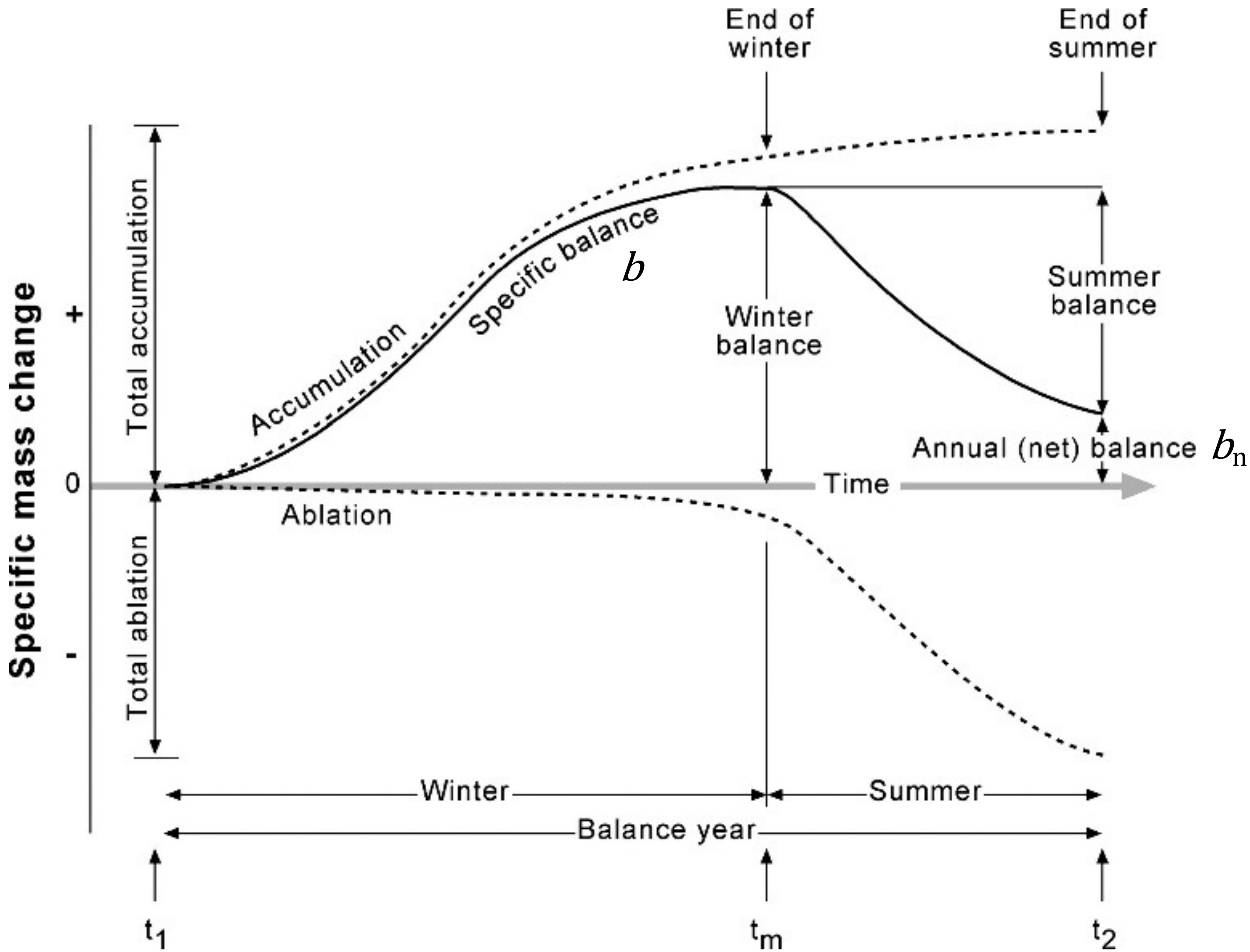
m a^{-1}

m w.e. a^{-1}

This is “ice-equivalent” used in ice-sheet modelling.

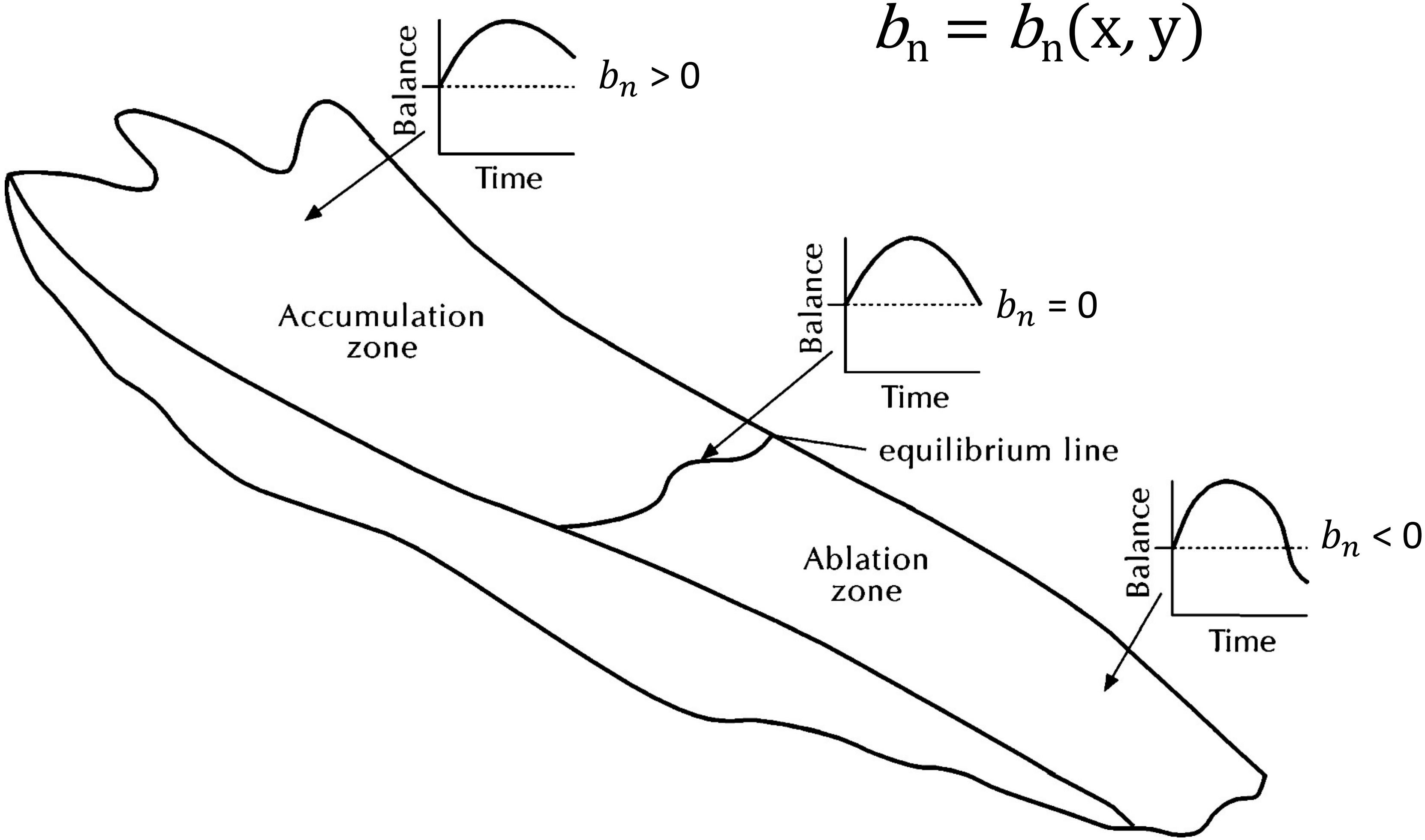
Cuffey and Paterson (2010)

Annual or net specific balance, b_n



Spatially-varying net specific balance

$$b_\mathrm{n} = b_\mathrm{n}(\mathrm{x}, \mathrm{y})$$



Cuffey and Paterson (2010)

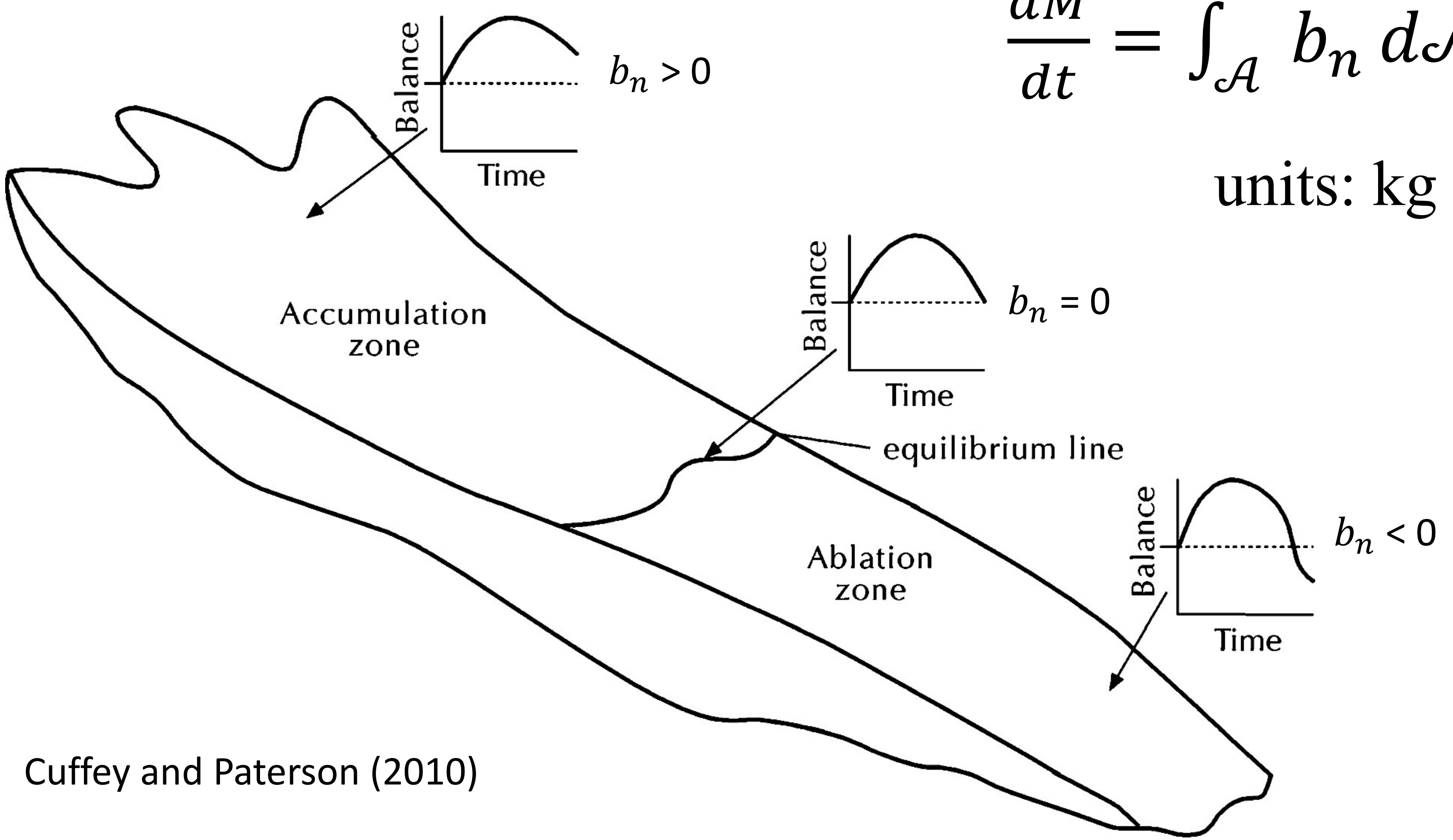
Glacier balance

Change in total mass of the glacier, M, per unit time

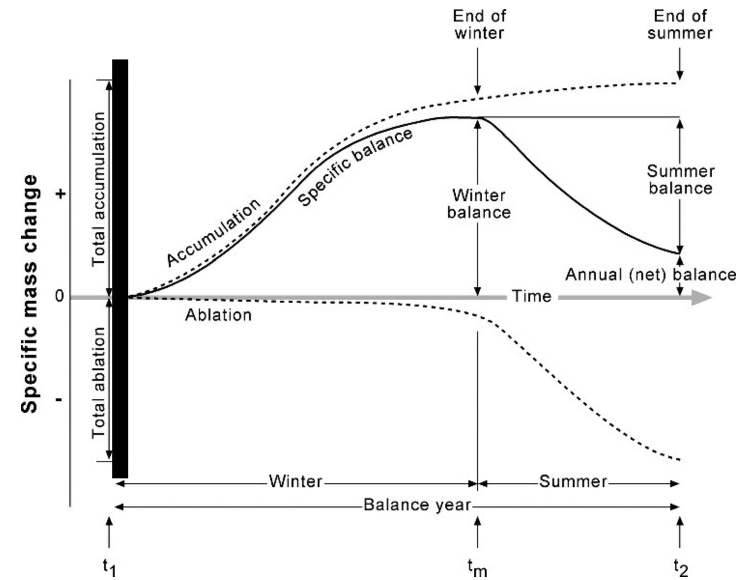
integrate specific balance

$$\frac{dM}{dt} = \int_{\mathcal{A}} b_n \, d\mathcal{A}$$

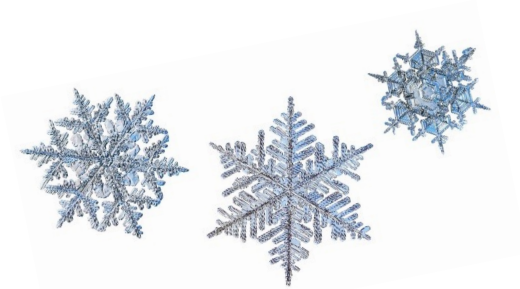
units: kg a^{-1}

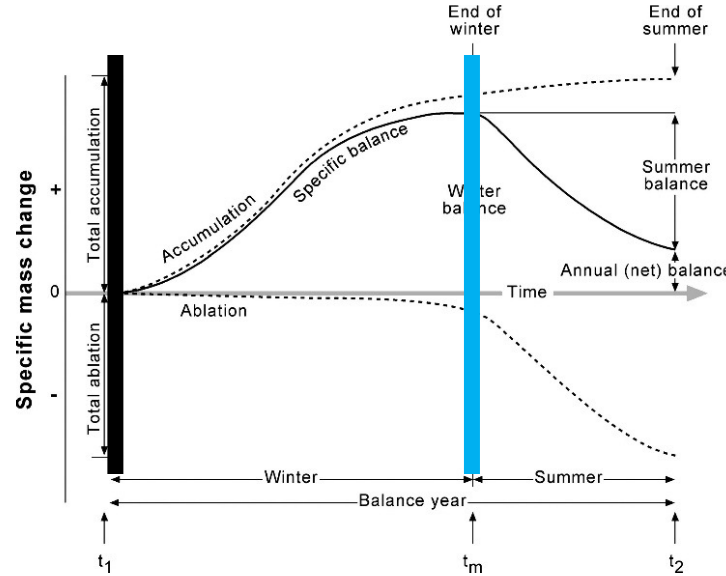


Cuffey and Paterson (2010)



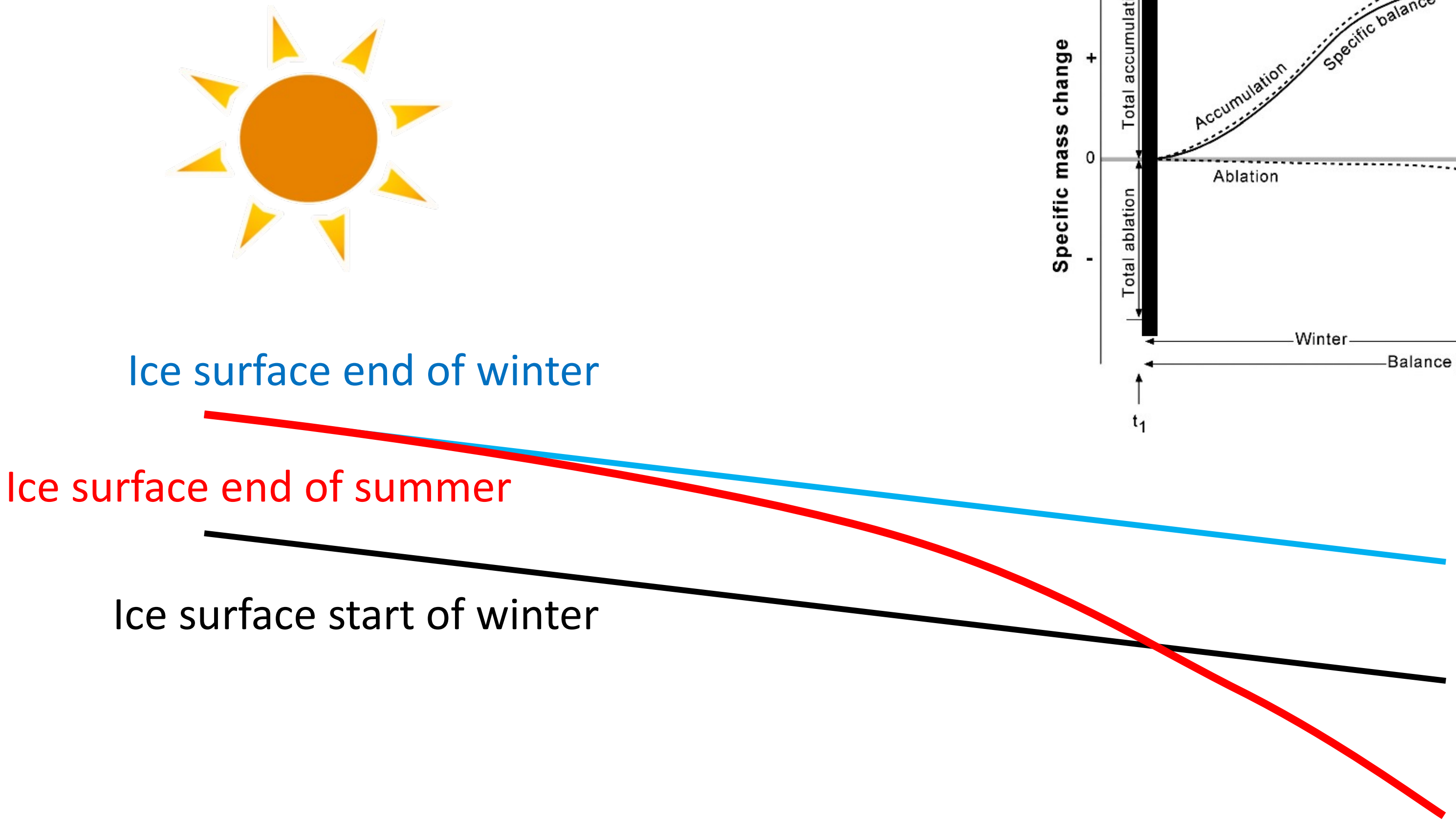
Ice surface start of winter



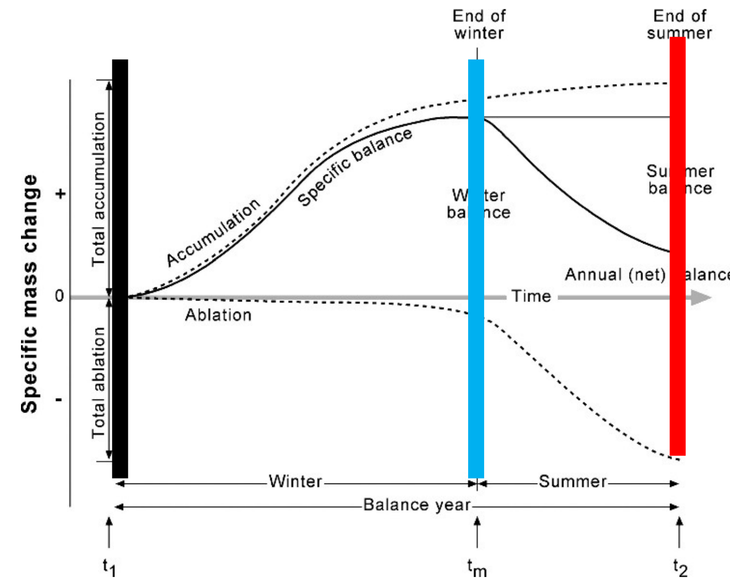


Ice surface end of winter

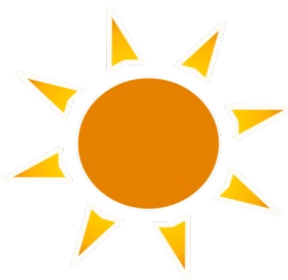
Ice surface start of winter

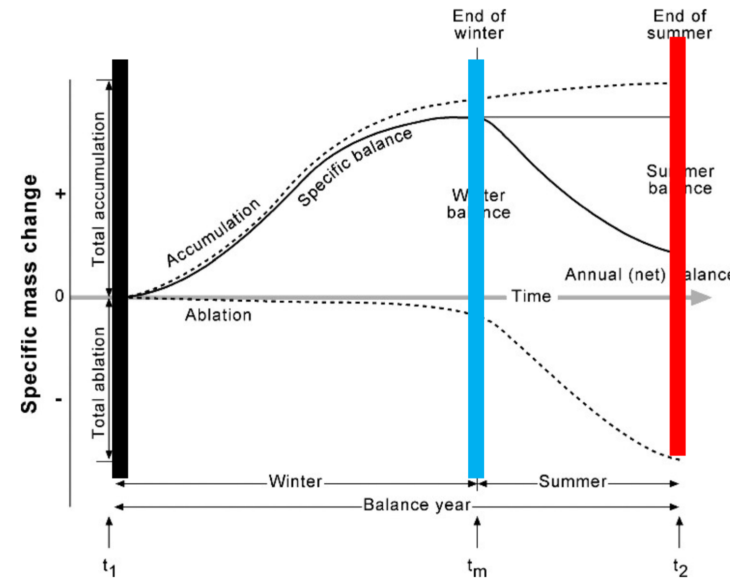


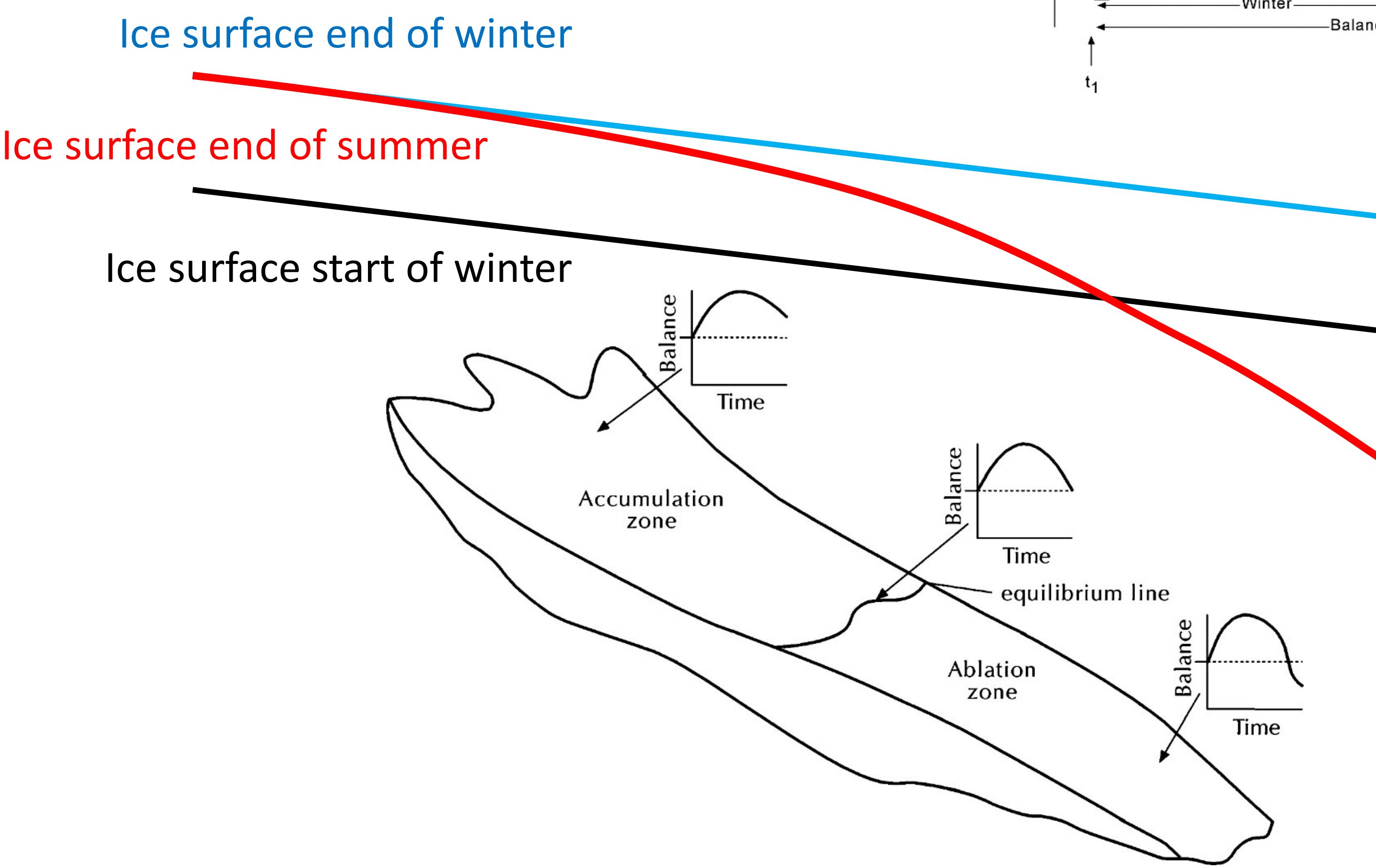
Ice surface end of winter
Ice surface end of summer
Ice surface start of winter



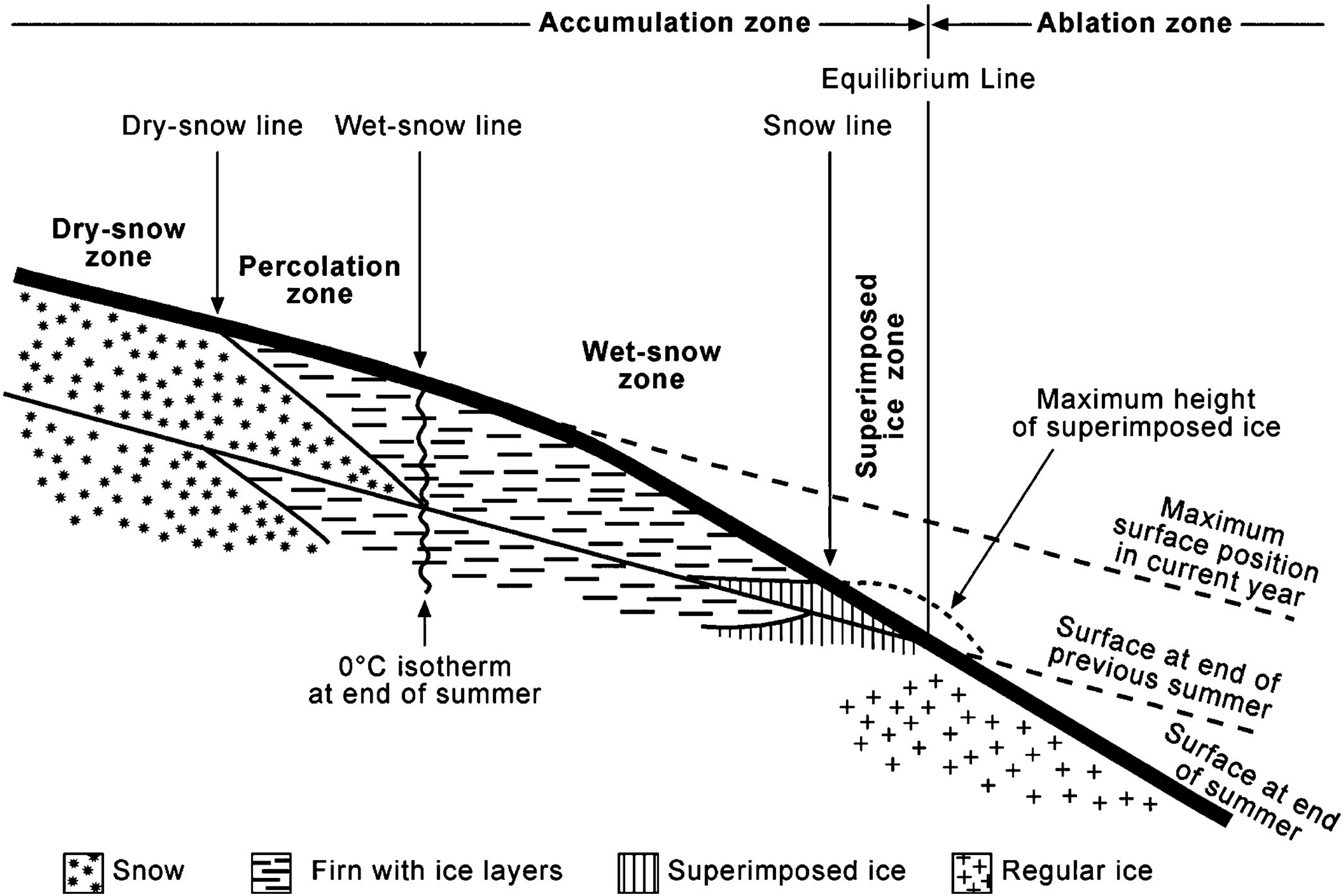
End of winter
End of summer
Specific mass change
+
0
-
Total accumulation
Total ablation
Accumulation
Specific balance
Ablation
Time
Winter
Summer
Balance year
t_1
t_m
t_2



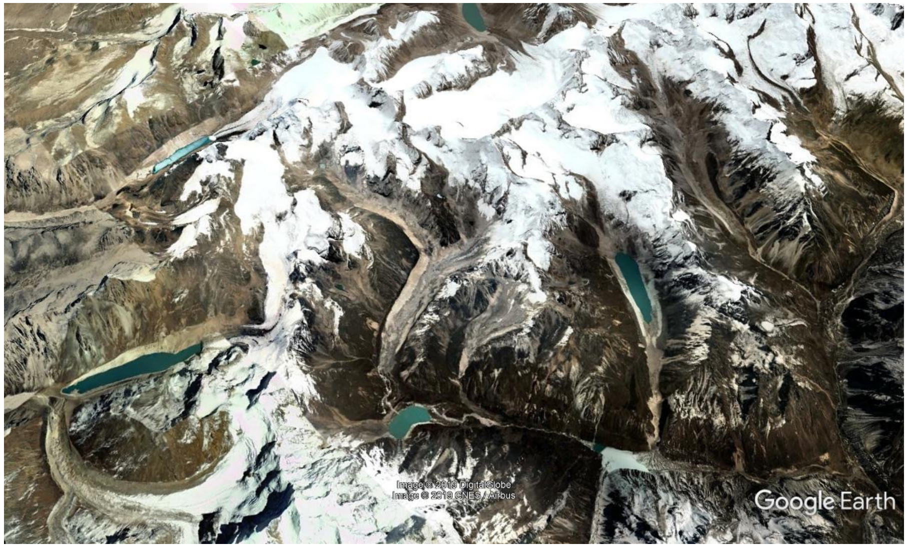

End of winter
End of summer
Specific mass change
+
0
-
Total accumulation
Total ablation
Accumulation
Specific balance
Ablation
Winter balance
Summer balance
Annual (net) balance
Time
Winter
Summer
Balance year
t_1
t_m
t_2

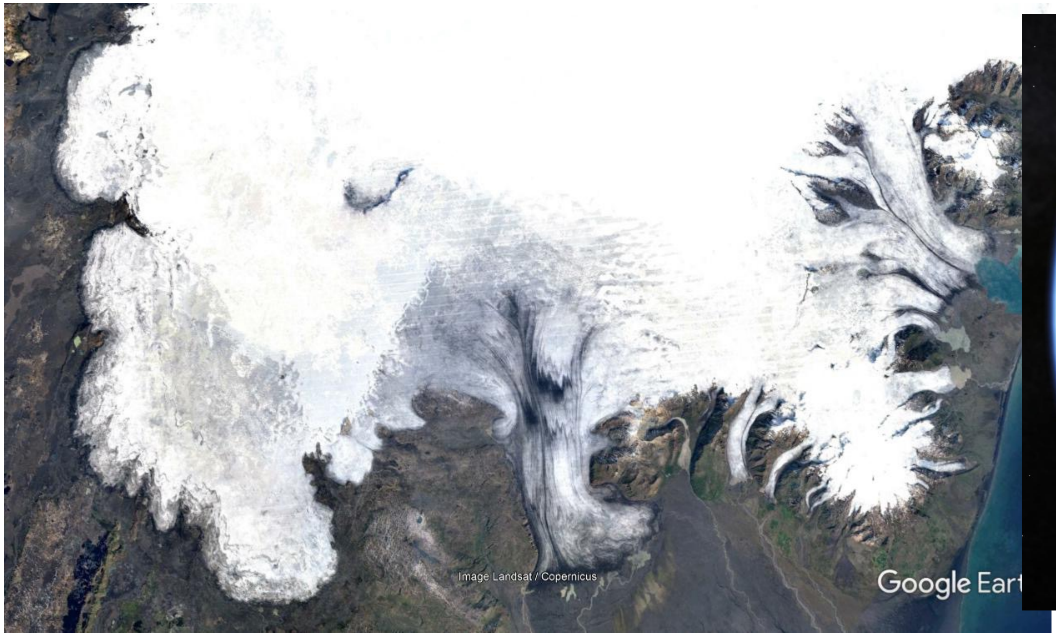

Ice surface end of winter
Ice surface end of summer
Ice surface start of winter
Balance
Time
Accumulation zone
equilibrium line
Ablation zone

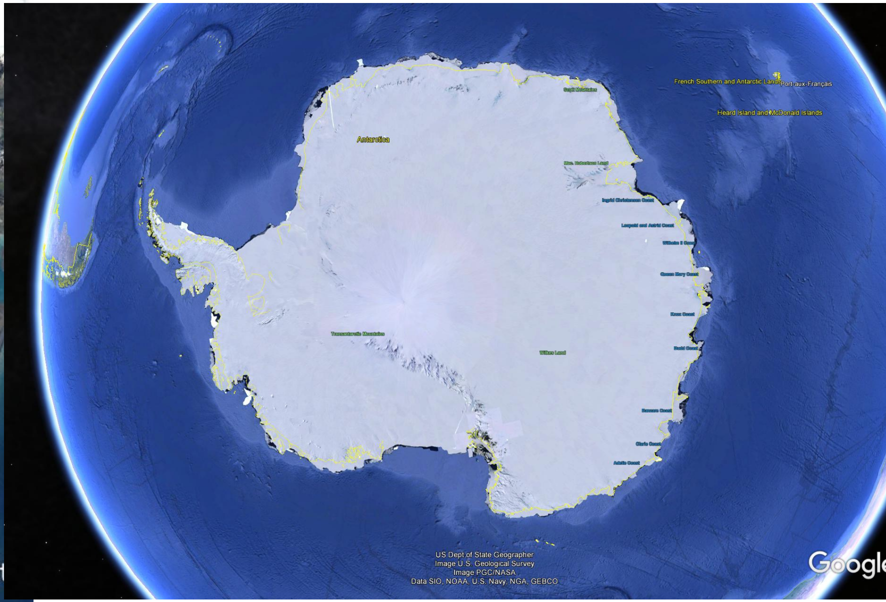
Surface facies



Accumulation zones from space





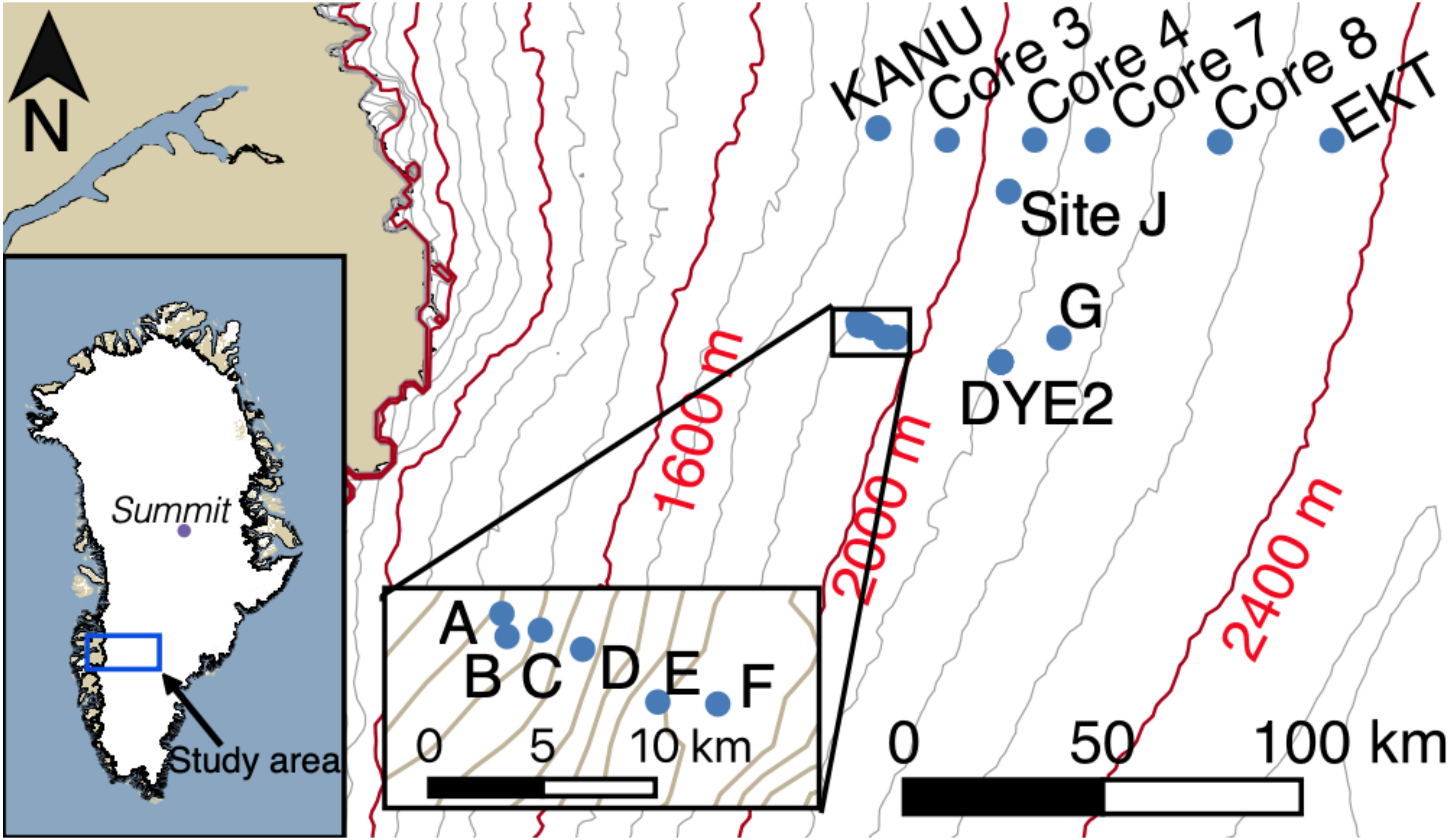


Accumulation processes

- Snow fall (dominates almost everywhere)
- Basal freezing

Greenland’s percolation zone


ZARGES

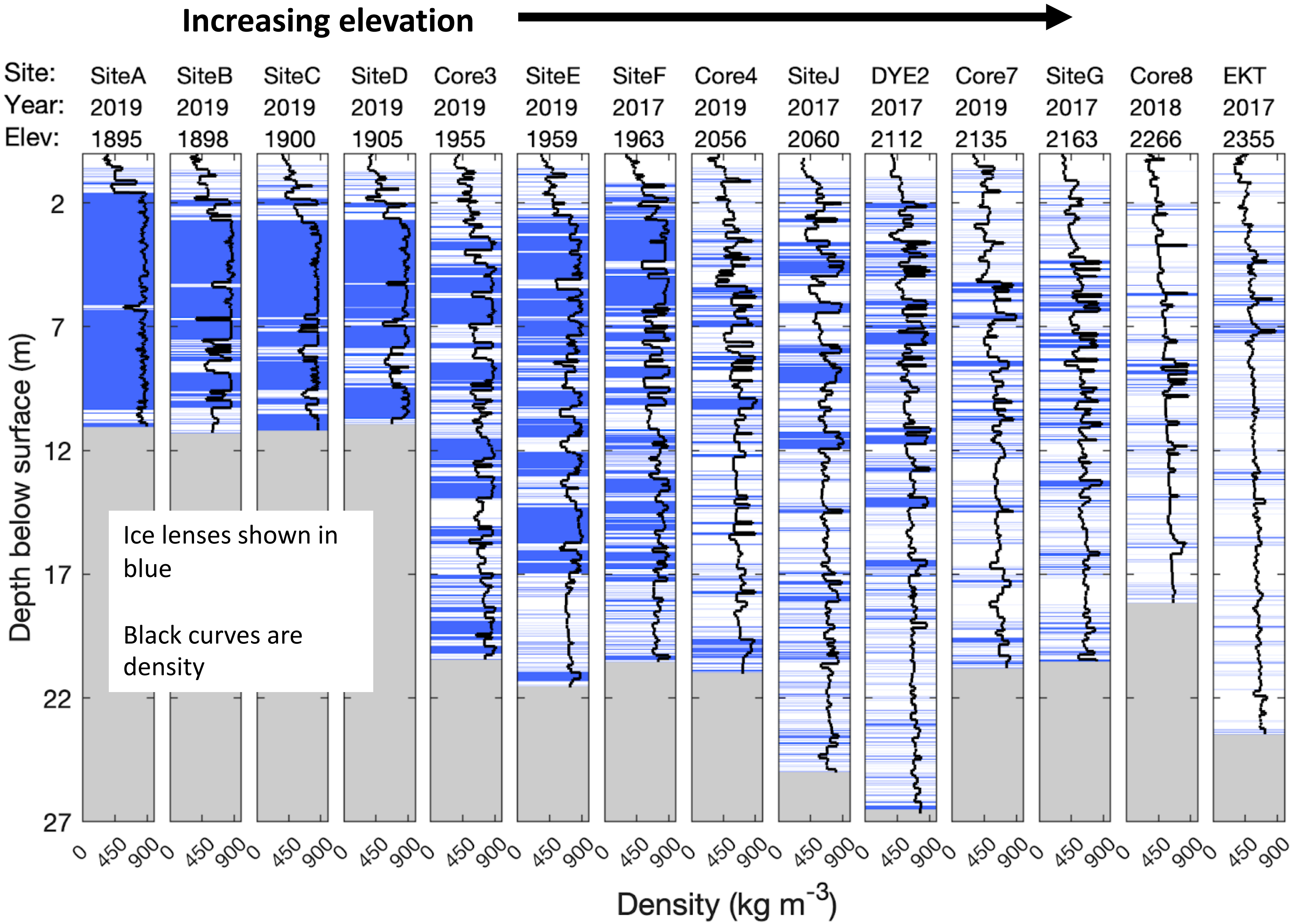


Rennermalm et al., in prep

Photo: Regine Hock

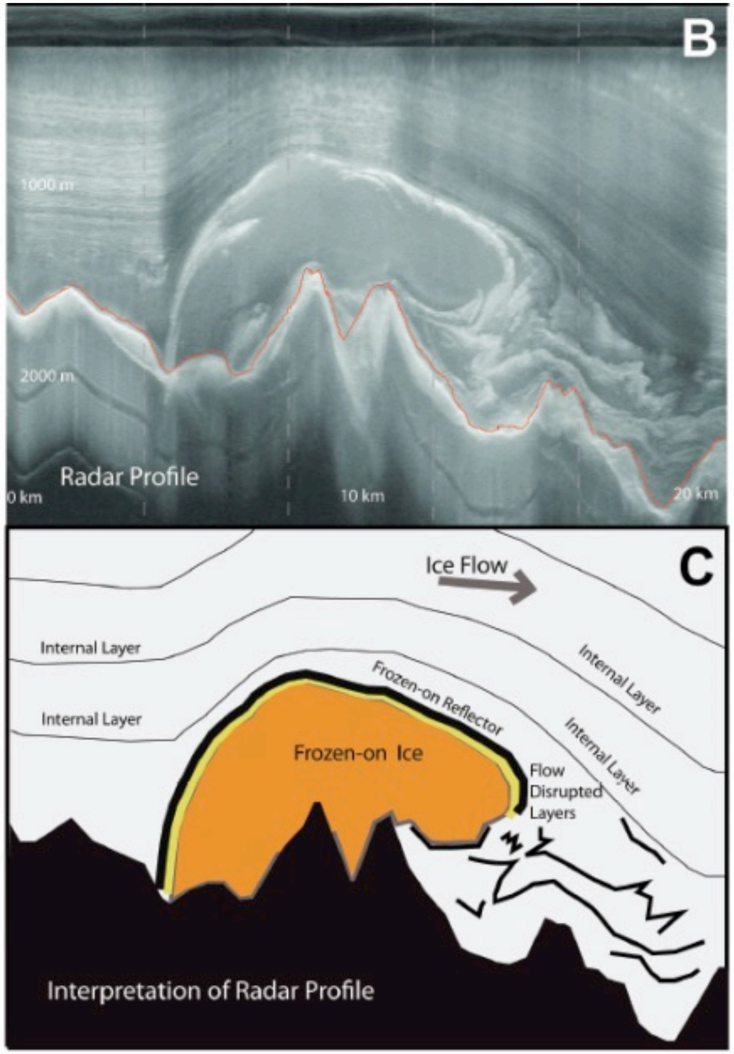

Ice lens

Increasing elevation

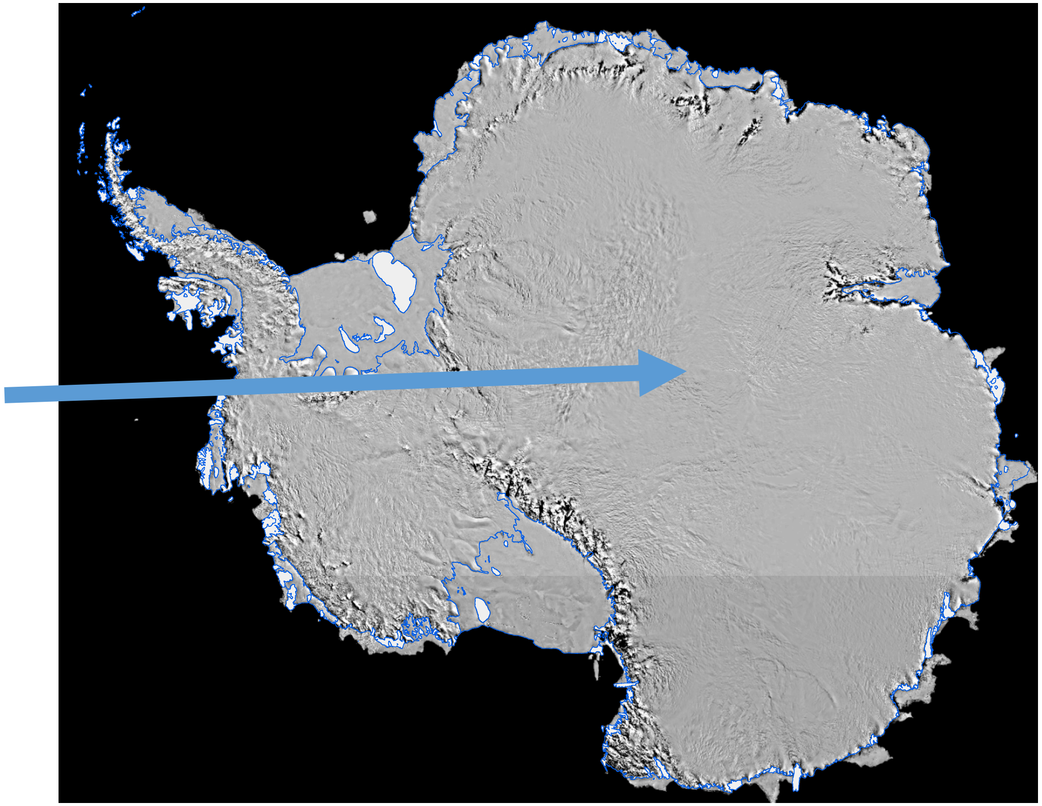


Rennermalm et al., 2022

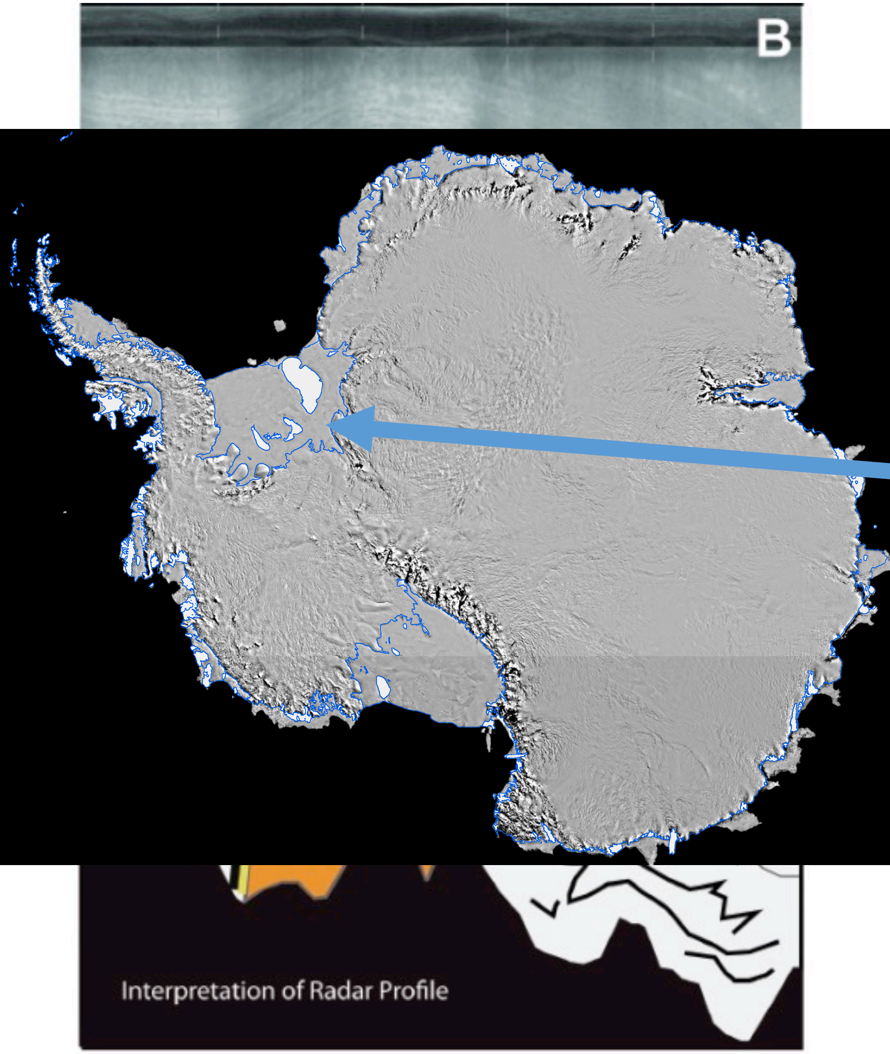
Basal freeze-on on ice shelves and on grounded ice



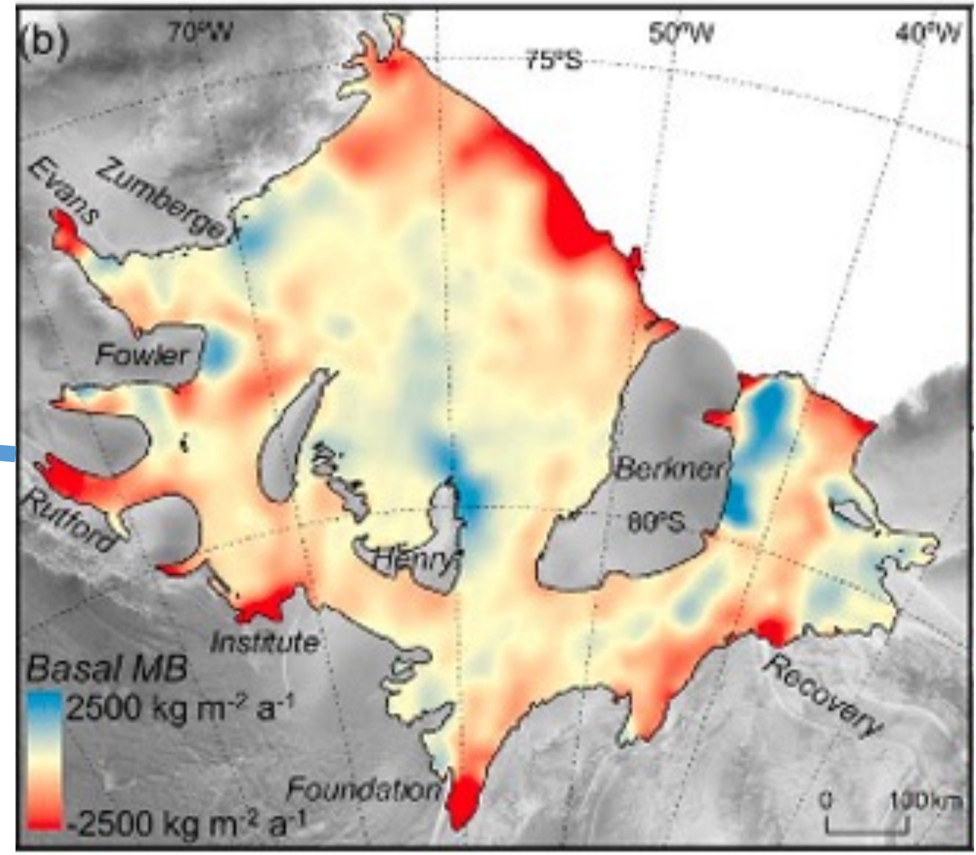
Bell et al. (2011)



Basal freeze-on on ice shelves and on grounded ice



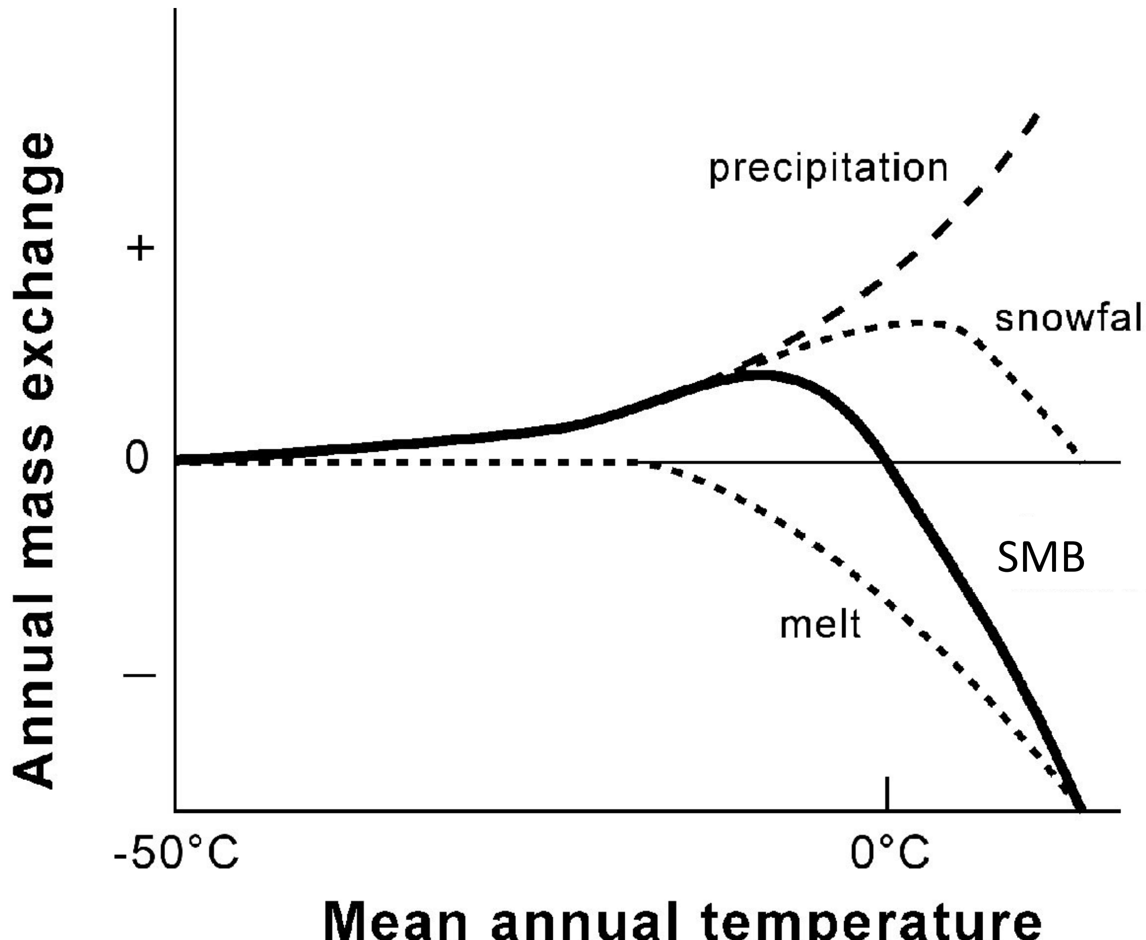
Bell et al. (2011)



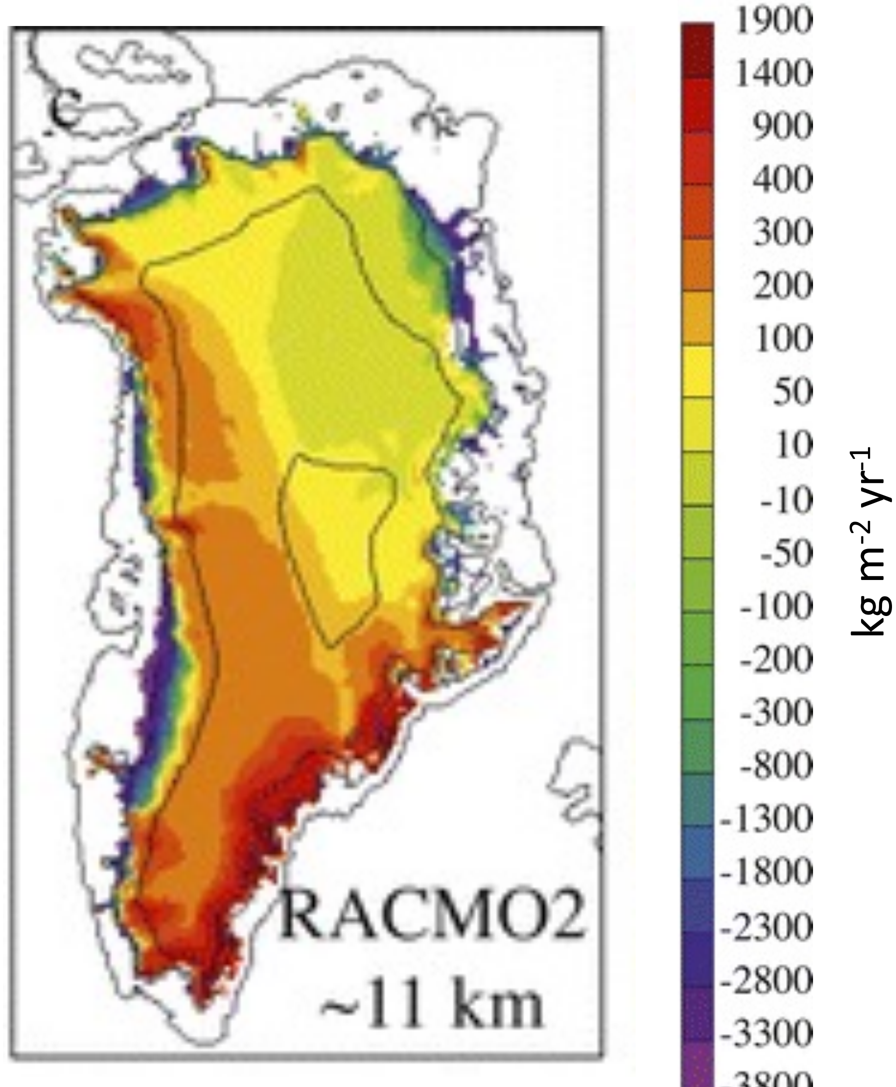
Moholdt et al. (2014)

Surface mass balance (SMB) often dominates mass balance (MB)

- Temperature is the primary control on SMB



Long-term SMB of Greenland



Vizcaíno et al. (2014)

2 minute break

Firn

-- snow that has survived on the surface of a glacier for a full melt season.

Snow starts out low density and increases in density over time until it becomes ice.

Firn densification

Q: Why is it important to understand it?

Q: What controls densification?

Maximum pressure in a snowball?

Roll over image to zoom in

CAMRY

Camry Digital Hand Dynamometer Grip Strength Measurement Meter Auto Capturing Hand Grip Power 200 Lbs / 90 Kgs

192 customer reviews | 24 answered questions

Amazon's Choice for "dynamometer"

Price: $29.99 & **FREE Shipping**. Details

In Stock.

Want it Monday, Jan. 22? Order within **10 hrs 27 mins** and choose **Standard Shipping** at checkout. Details

Sold by Travel Inspira and Fulfilled by Amazon. Gift-wrap available.

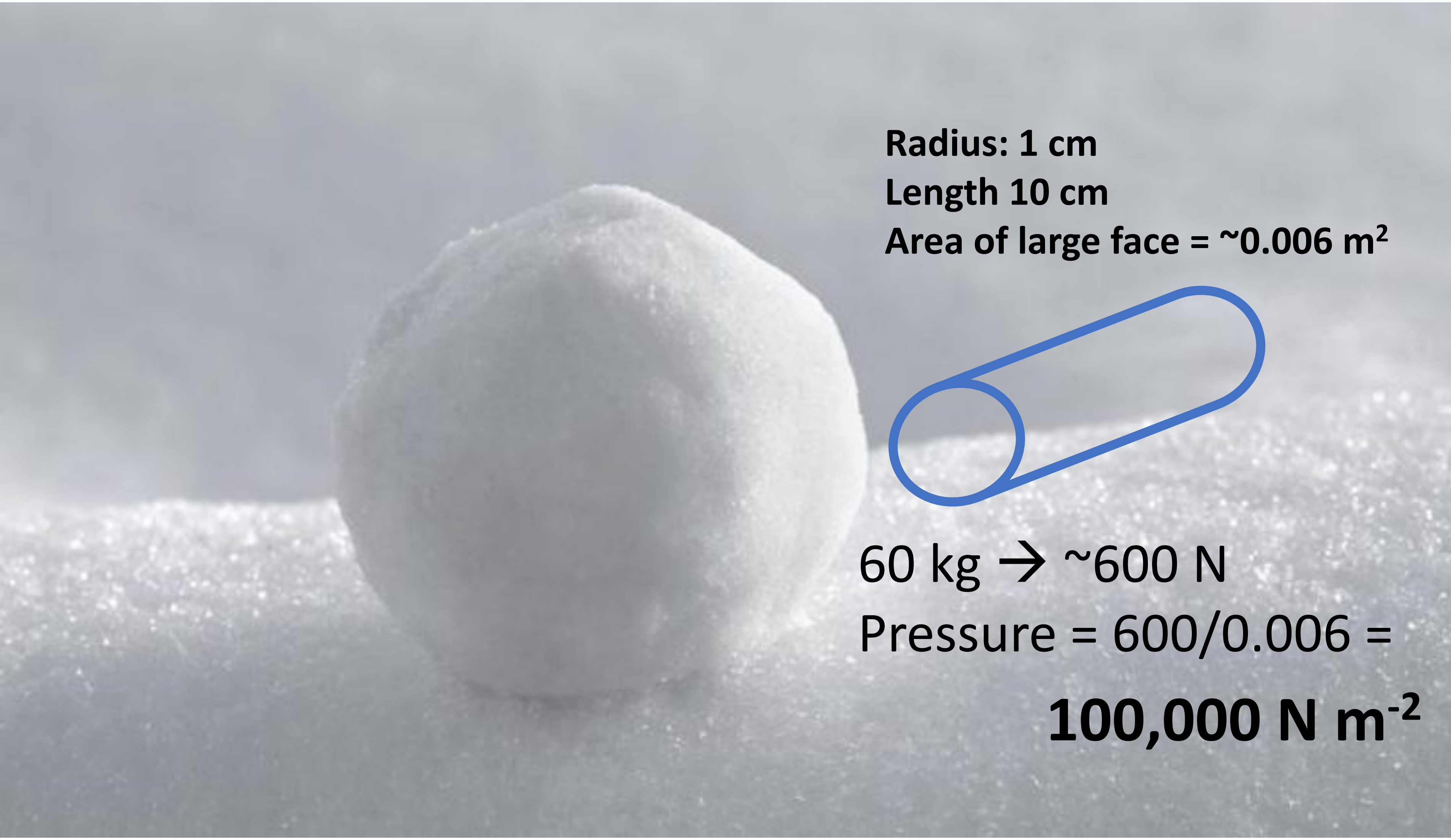
- ACCURACY - Equipped with high precision strain gauge sensor, the hand dynamometer gives you accurate momentary digital reading of gripping power. Measuring Capacity: 198lbs / 90kgs; Division: 0.2lbs / 0.1kgs
- USER FRIENDLY - Squeeze the hand dynamometer with maximum isometric effort for at least 5 seconds. After testing, the LCD will automatically display the maximum grip value and a grip value status bar showing the status of “weak”, “normal” or “strong” according to age and gender preset for each test.
- MEMORY RECORD - The device can store data for up to 19 definable users, and their records can be recalled anytime when needed; Moreover, the incremental increase or decrease from the last record will be automatically shown for comparison after each test.
- Adjustability - Turn the adjustable gear to get an ideal grasp according to the size of hands. It is good fit for both big hand and small hand.
- EASY TO READ - Large LCD screen shows all measurements clearly on the same screen. Displayed measurements include: user code, age, gender, grip value in pound or kg and grip status. Engineered for home, sports and clinical use. 2* AAA batteries included; 5-year product warranty.

Used & new (2) from $29.99 & FREE shipping. Details

Maximum pressure in a snowball?

AGE	Weak	Normal	Strong
10–11	< 12.6	12.6–22.4	> 22.4
12–13	< 19.4	19.4–31.2	> 31.2
14–15	< 28.5	28.5–44.3	> 44.3
16–17	< 32.6	32.6–52.4	> 52.4
18–19	< 35.7	35.7–55.5	> 55.5
20–24	< 36.8	36.8–56.6	> 56.6
25–29	< 37.7	37.7–57.5	> 57.5
30–34	< 36.0	36.0–55.8	> 55.8
35–39	< 35.8	35.8–55.6	> 55.6
40–44	< 35.5	35.5–55.3	> 55.3
45–49	< 34.7	34.7–54.5	> 54.5
50–54	< 32.9	32.9–50.7	> 50.7
55–59	< 30.7	30.7–48.5	> 48.5
60–64	< 30.2	30.2–48.0	> 48.0
65–69	< 28.2	28.2–44.0	> 44.0
70–99	< 21.3	21.3–35.1	> 35.1

Typical grip strength: 30-60 kg



50,000 - 100,000 N m^{-2}

50 - 100 kPa

Overburden pressure

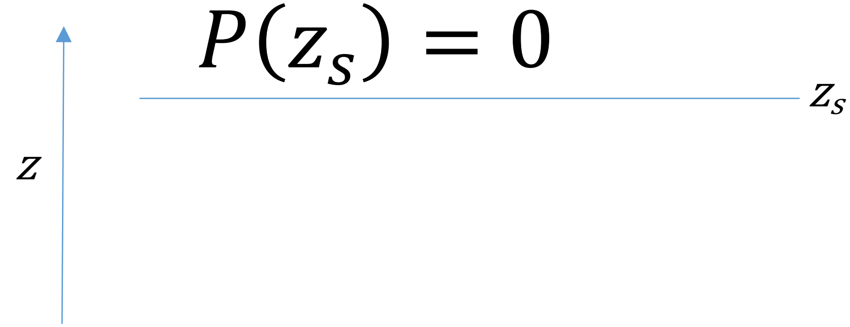
We want an equation for how pressure P varies with depth z

Overburden pressure

We want an equation for how pressure *P* varies with depth *z*

$$\frac{dP}{dz} = -\rho(z)g$$

$$P(z_s) = 0$$



Overburden pressure

We want an equation for how pressure *P* varies with depth *z*

$$\frac{dP}{dz} = -\rho(z)g$$

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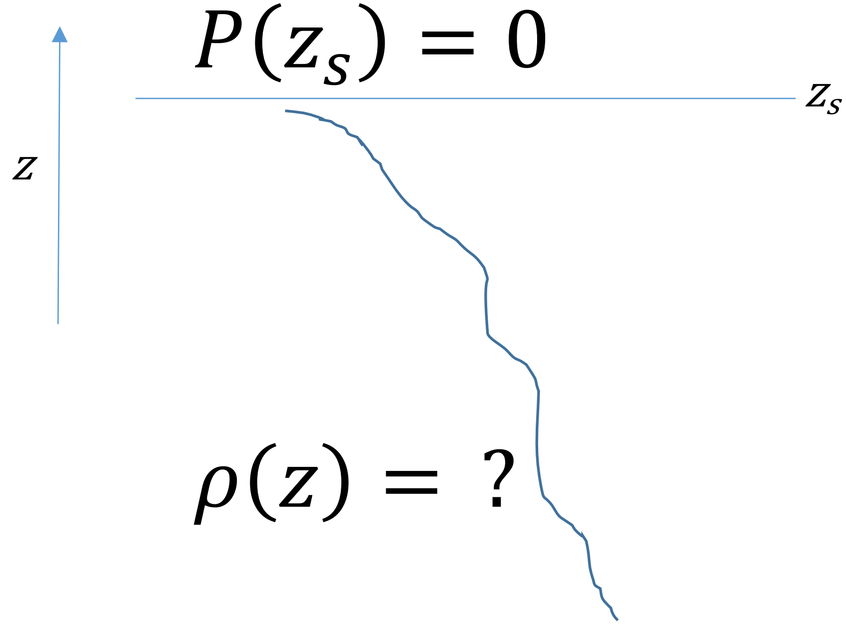


$$\rho(z) = \ ?$$

Measured firn density profiles

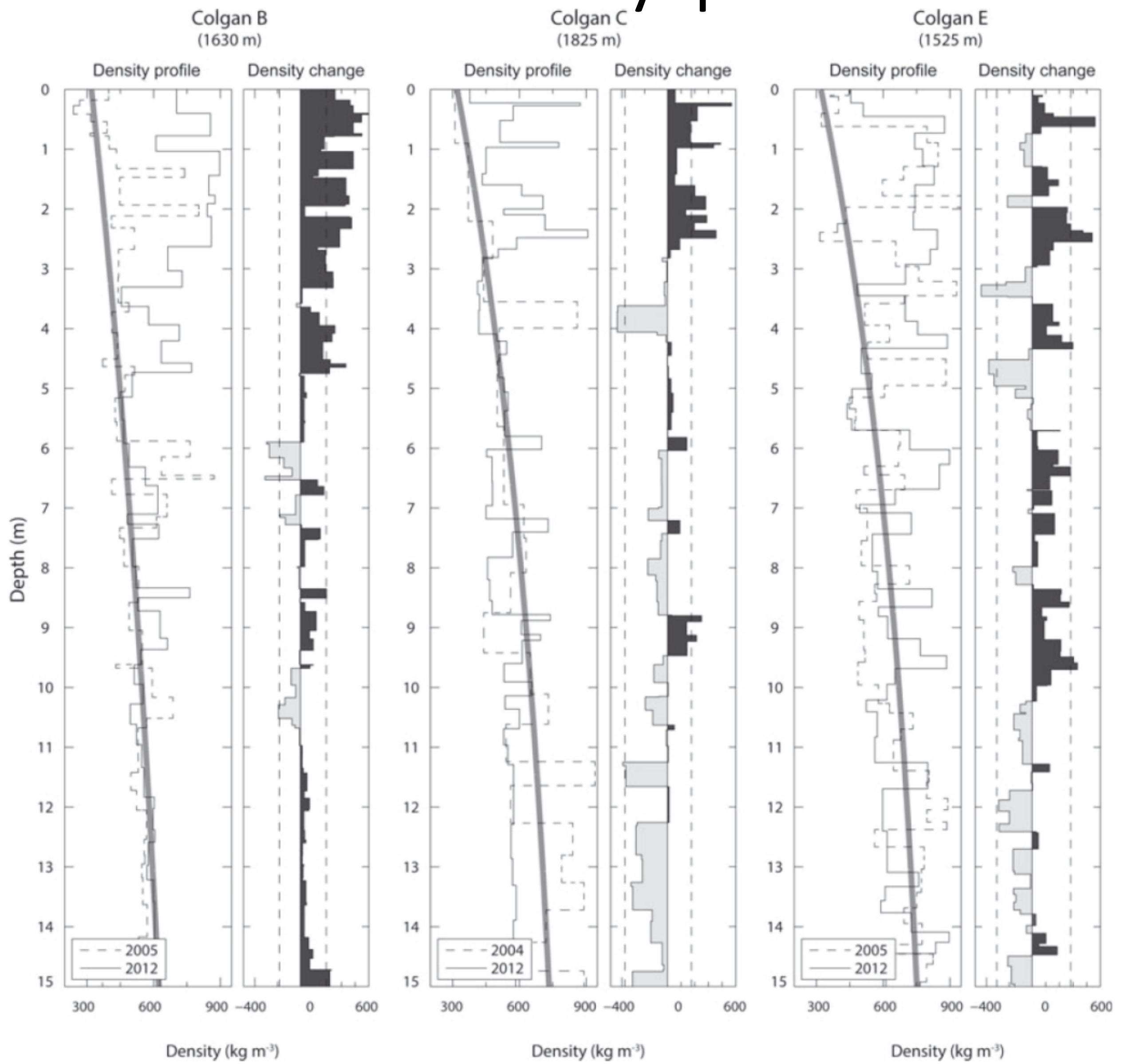


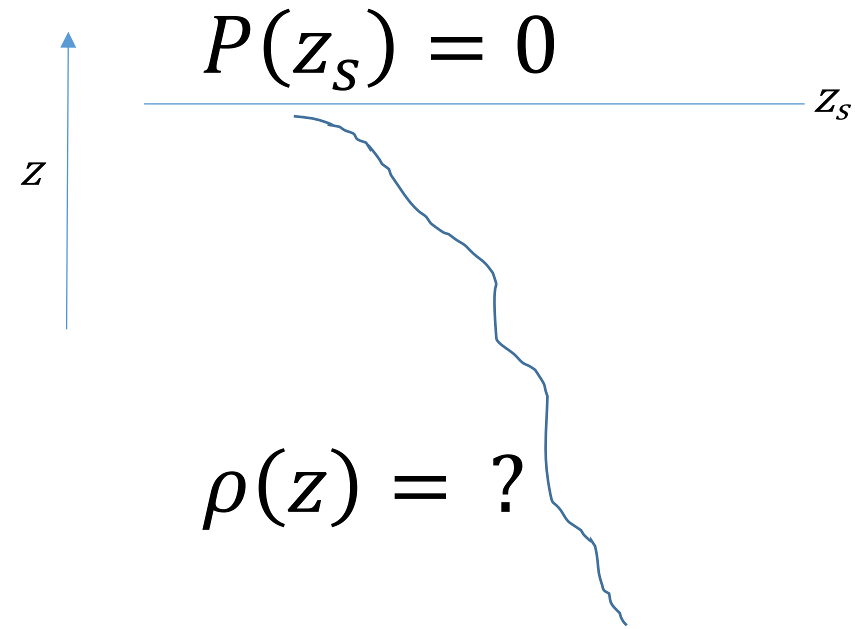
Fig. 5. Measured and empirically derived (thick gray line) firn density profiles for Colgan B, C and E sites. The firn density change is the 2012 firn density less the 2004/05 firn density. The dashed lines represent ±2 standard deviations from the mean change of the bottom 10 m.

Bezeau et al. (2013)

Overburden pressure

We want an equation for how pressure *P* varies with depth *z*

$$\frac{dP}{dz} = -\rho(z)g$$

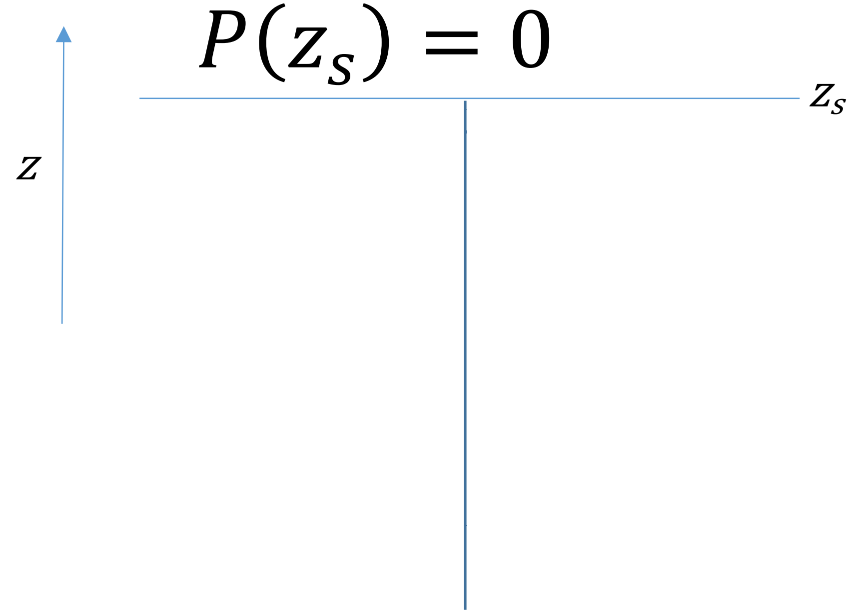


Overburden pressure

We want an equation for how pressure *P* varies with depth *z*

$$\frac{dP}{dz} = -\rho(z)g$$

$$P(z_s) = 0$$

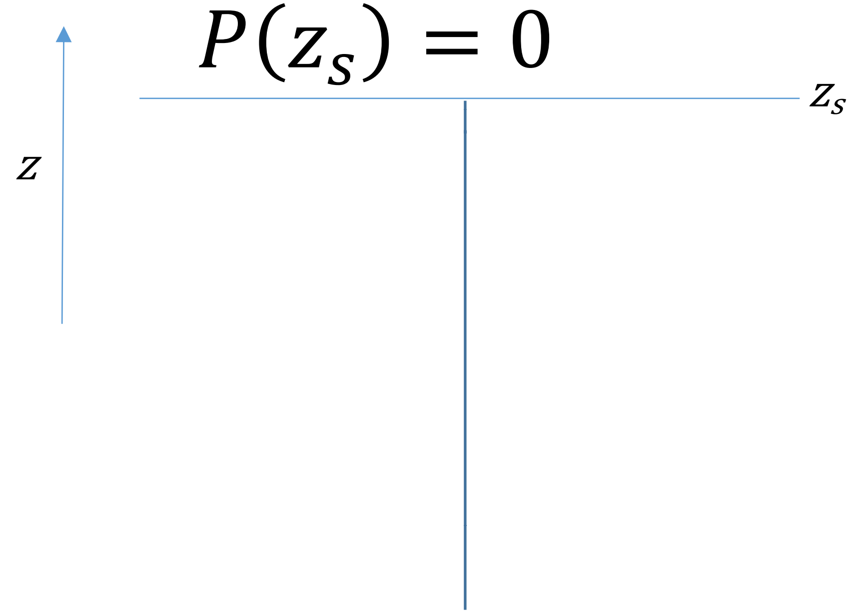


$$\rho(z) = 500\ \mathrm{kg\ m^{-3}}$$

Overburden pressure

We want an equation for how pressure *P* varies with depth *z*

$$P(z_s) = 0$$



$$P(z) = g\rho(z_s - z)$$

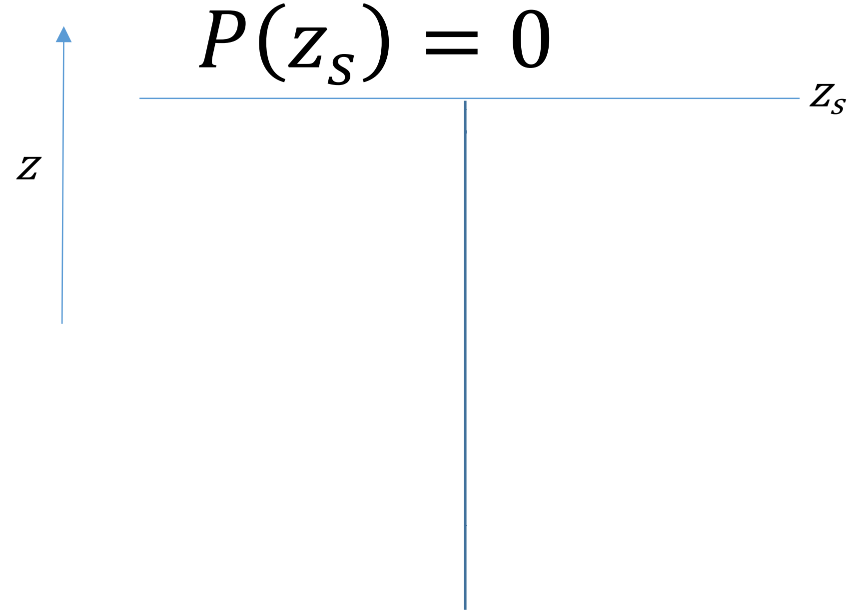
$$\rho(z) = 500\ \mathrm{kg\ m^{-3}}$$

Overburden pressure

We want an equation for how pressure *P* varies with depth *z*

$$\frac{P}{g\rho} = (z_s - z)$$

$$P(z_s) = 0$$



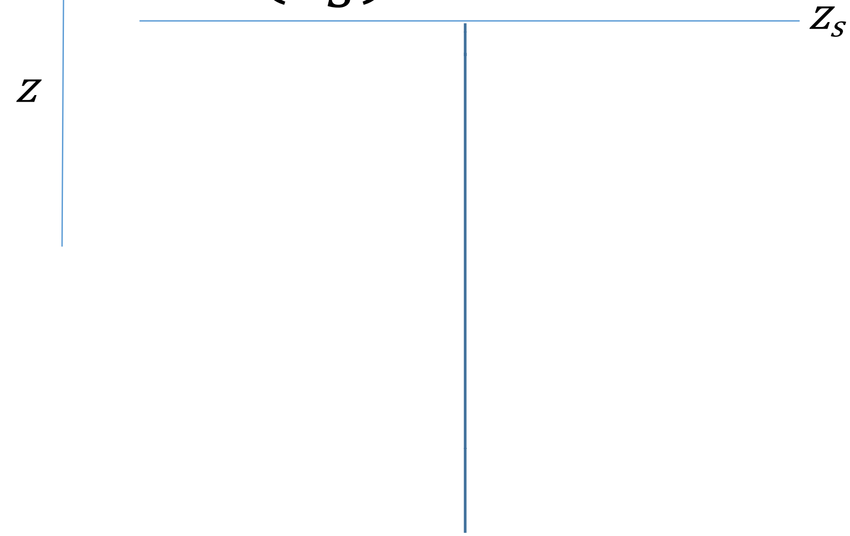
$$\rho(z) = 500\ \mathrm{kg\ m^{-3}}$$

Overburden pressure

We want an equation for how pressure *P* varies with depth *z*

We can exert as much pressure with our hand as 10 - 20 m of firn!

$$P(z_s) = 0$$



$$\rho(z) = 500 \text{ kg m}^{-3}$$

Firn densification processes

Its complicated!

Settling

movement of grains relative to each outer
increases density up to ~550 kg m^{-3}

Sublimation

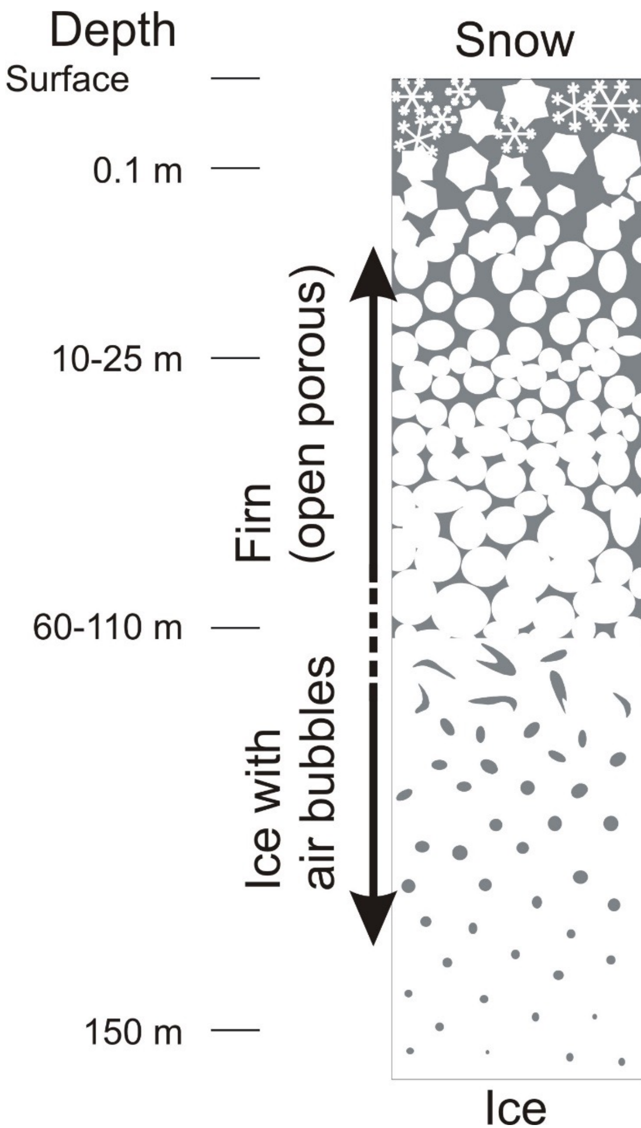
>550 kg m^{-3},
movement of molecules to ‘necks’ of grains due to vapour-pressure gradients in pores.

Deformation of grains

Through diffusion creep
(more details next week)

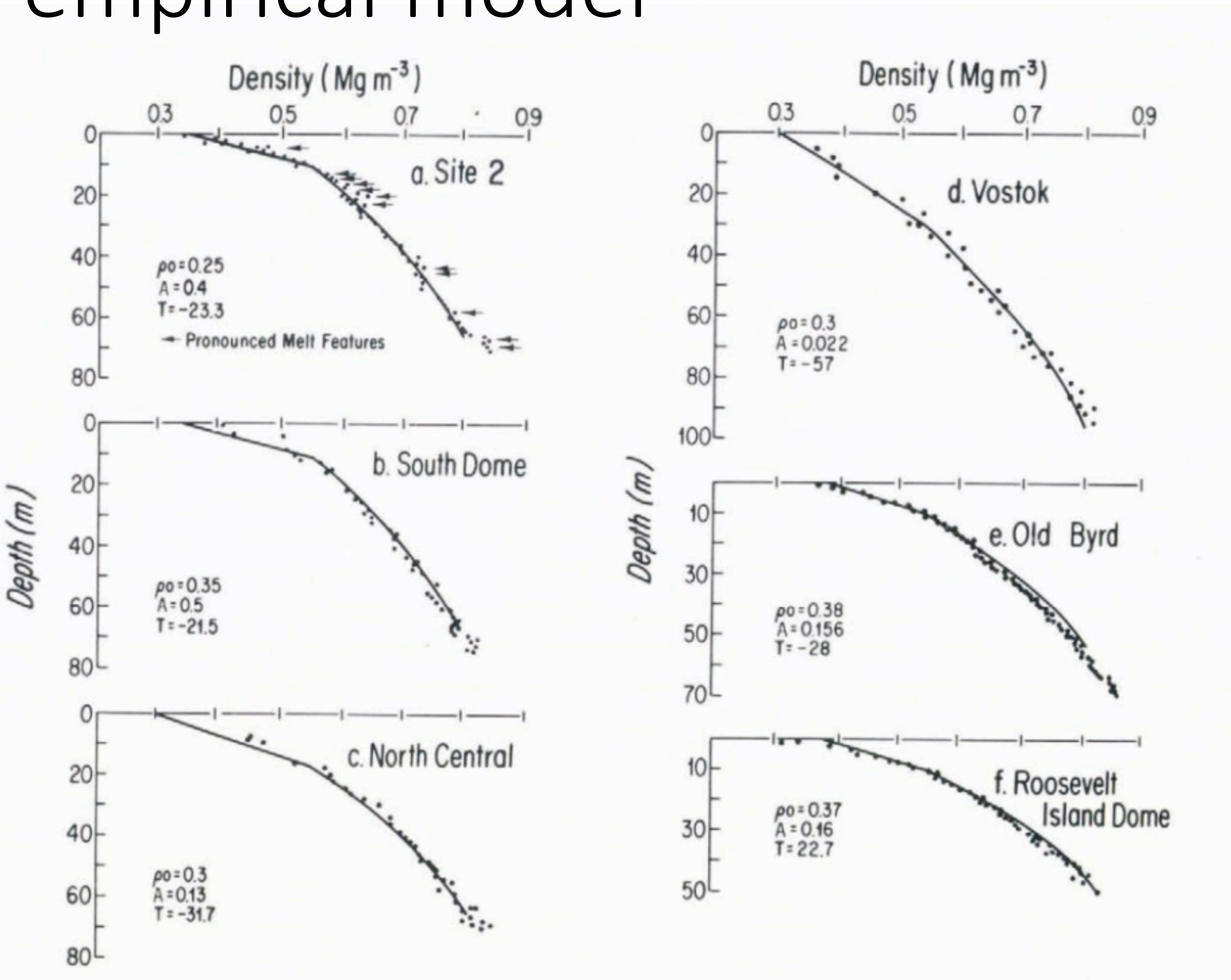
At ~830 kg m^{-3} pores “close off” and firn becomes ice.

Compression of air in bubbles allows ice density to reach ~917 kg m^{-3}.



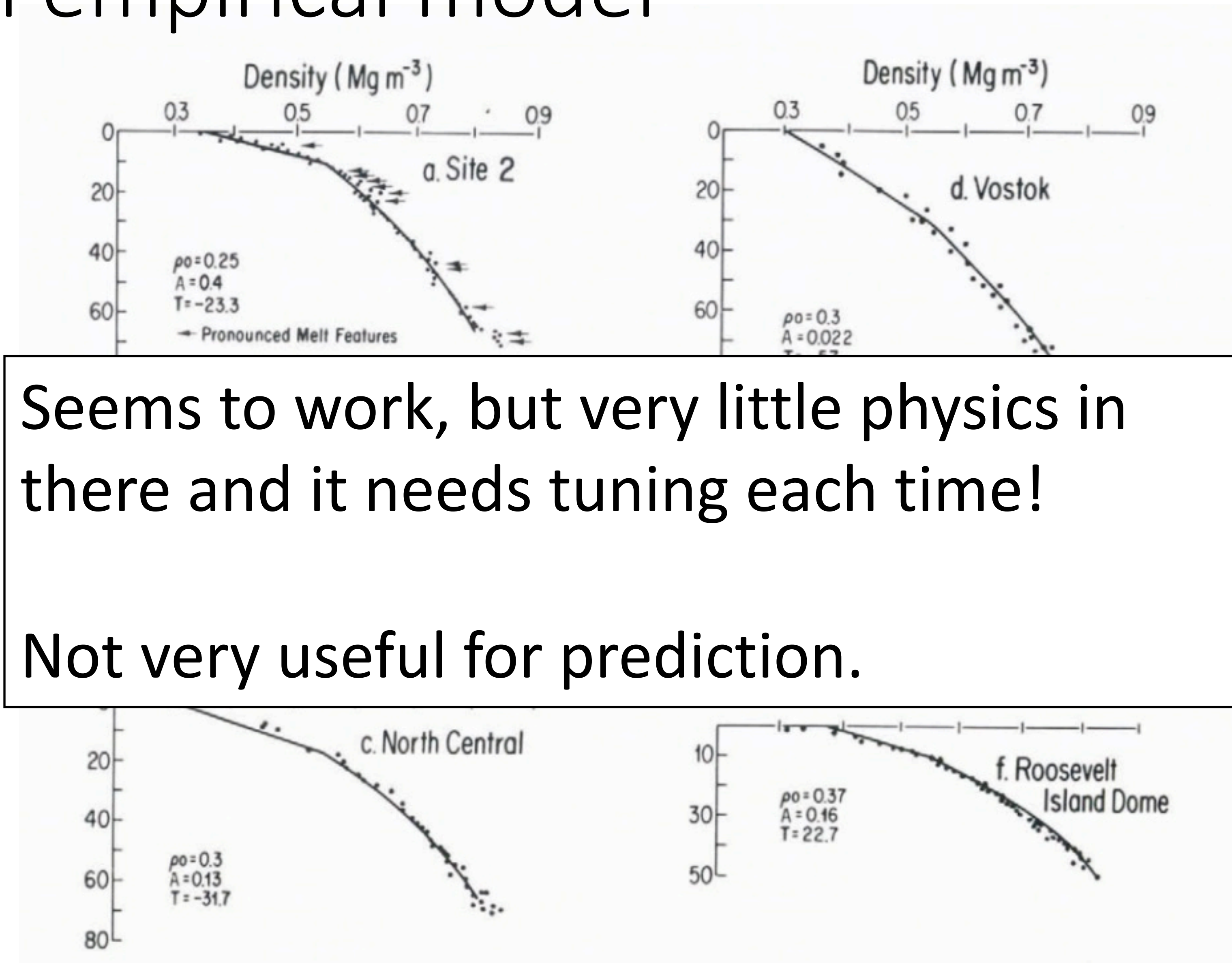
University of Copenhagen, Center for Ice and Climate

An empirical model



Herron and Langway (1980)

An empirical model



Seems to work, but very little physics in there and it needs tuning each time!

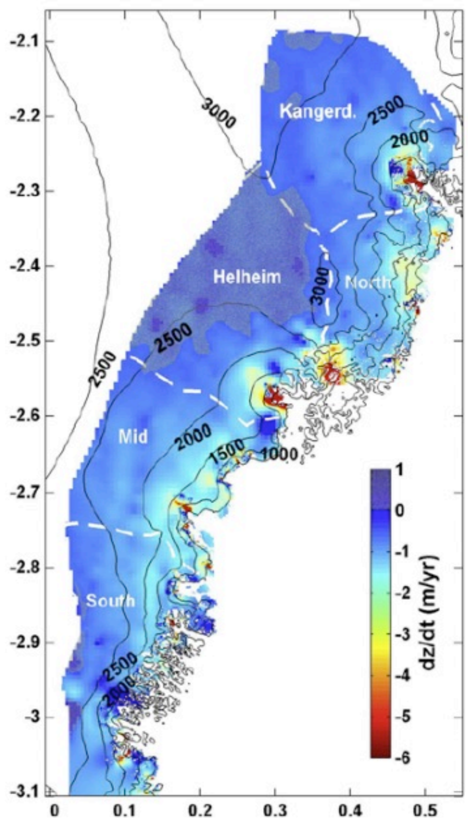
Not very useful for prediction.

Herron and Langway (1980)

Why is getting this right important?

1. Geodetic mass balance

Howat et al. (2008)



2. Ice core paleo-climate records

Ice cores preserve old ice and old air.

The ice is older than the air by an amount that depends on firn densification rates.

Summary:

- Specific mass balance is the balance between accumulation (mostly snow fall) and ablation (mostly melting) at one point on a glacier.
- We characterize glacier surfaces in terms of several glacier 'facies', related to how much melting happens.
- Firn densification is complex, but important.

On Tuesday:

- Our first practical session
- Watch the python videos I sent
- Be prepared to be writing code in class time

References

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