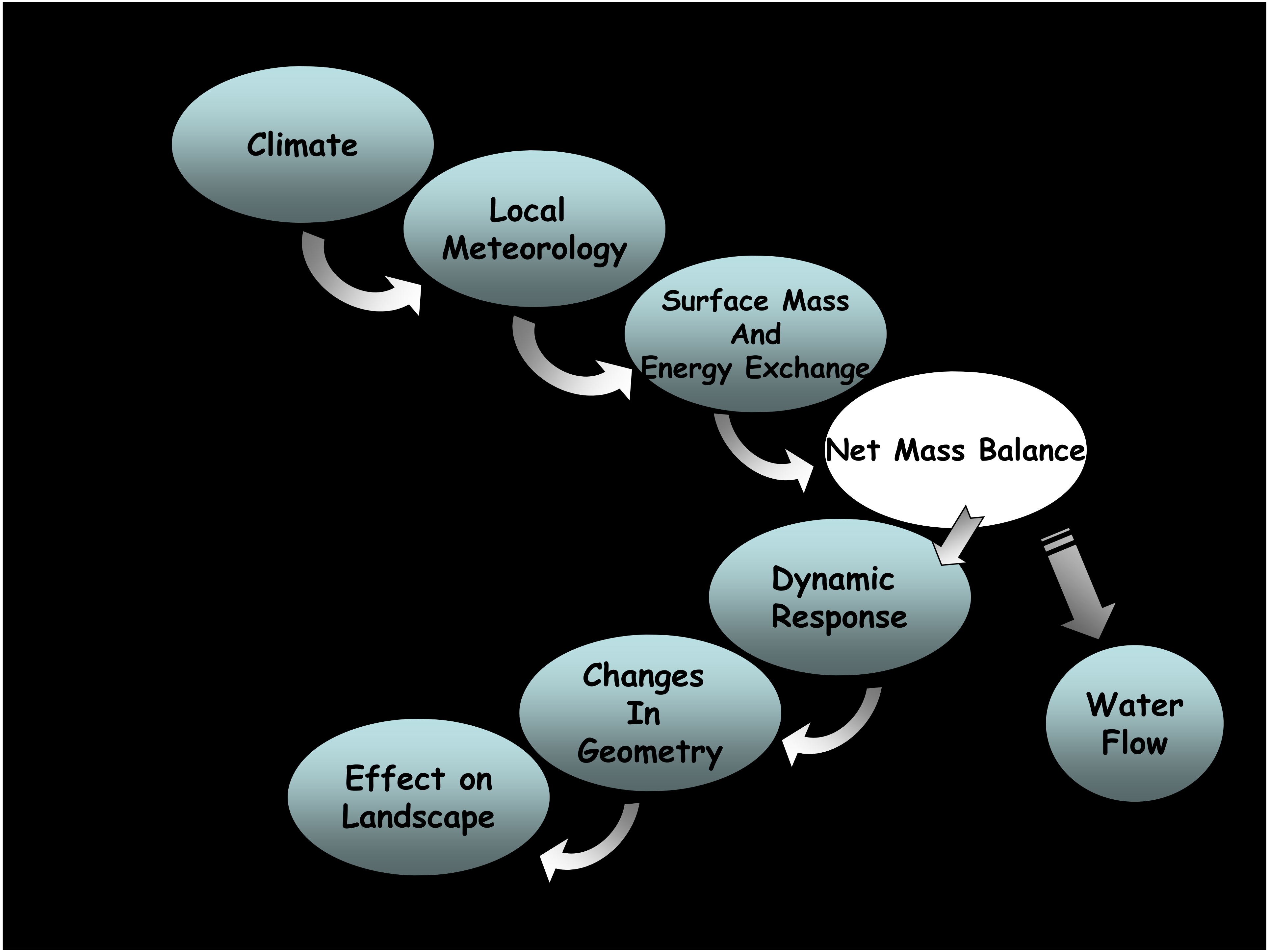
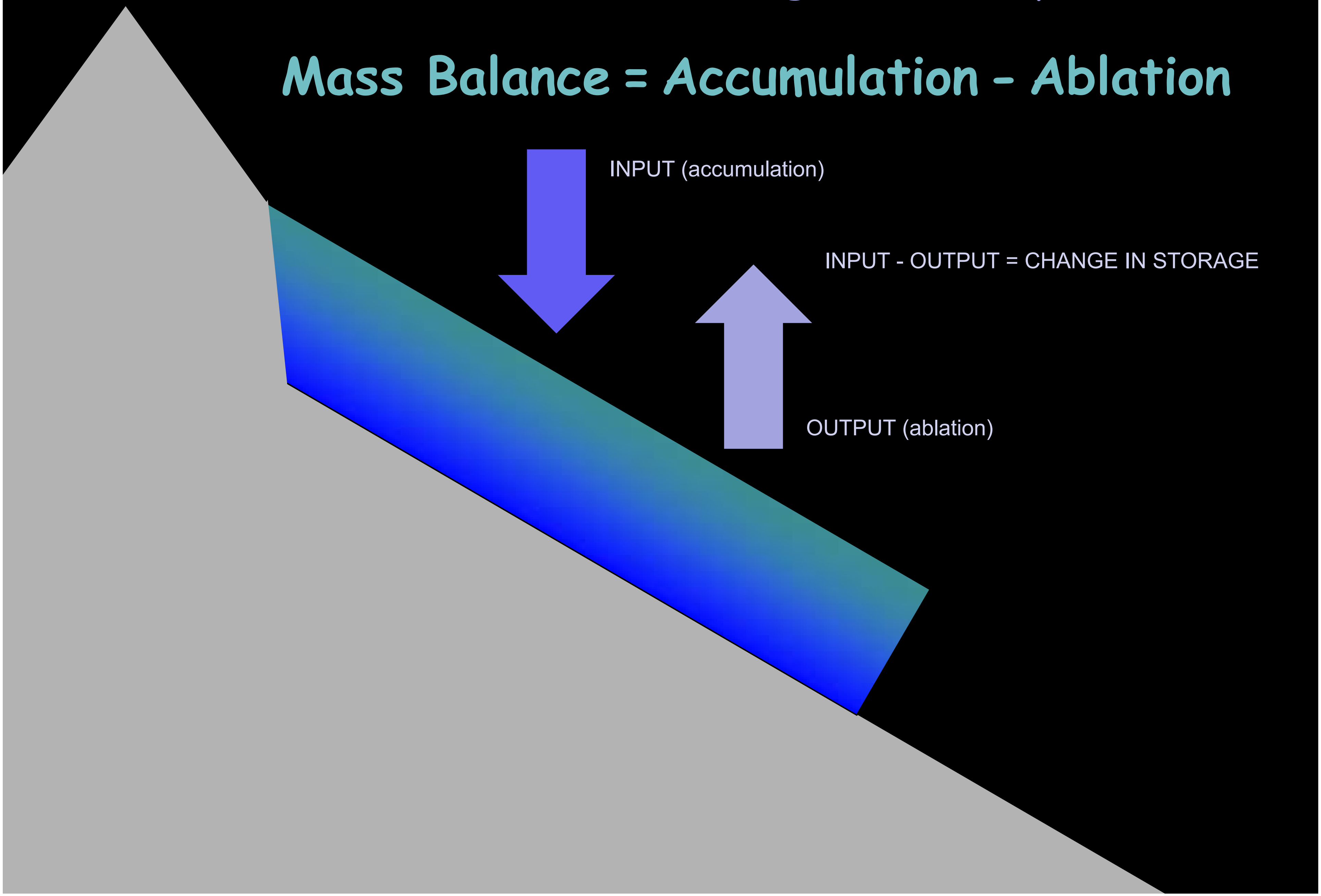
# Glacier Mass Balance


Climate
Local Meteorology
Surface Mass And Energy Exchange
Net Mass Balance
Dynamic Response
Water Flow
Changes In Geometry
Effect on Landscape

Mass conservation for a glacier is expressed as,

**Mass Balance = Accumulation - Ablation**



Mass Conservation for a glacier is expressed as,

**Mass Balance = Accumulation - Ablation**

Note that we also talk about accumulation/ablation seasons, and accumulation/ablation zones.

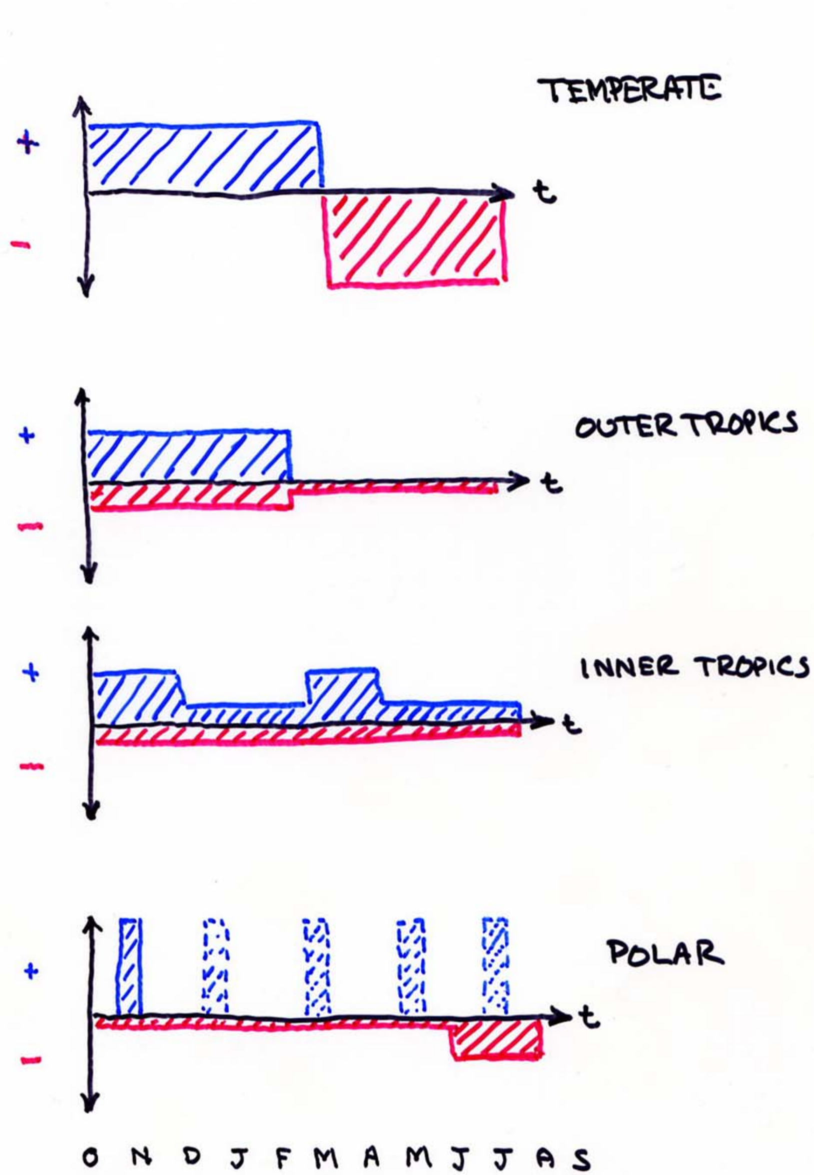
Regarding SEASONS.....

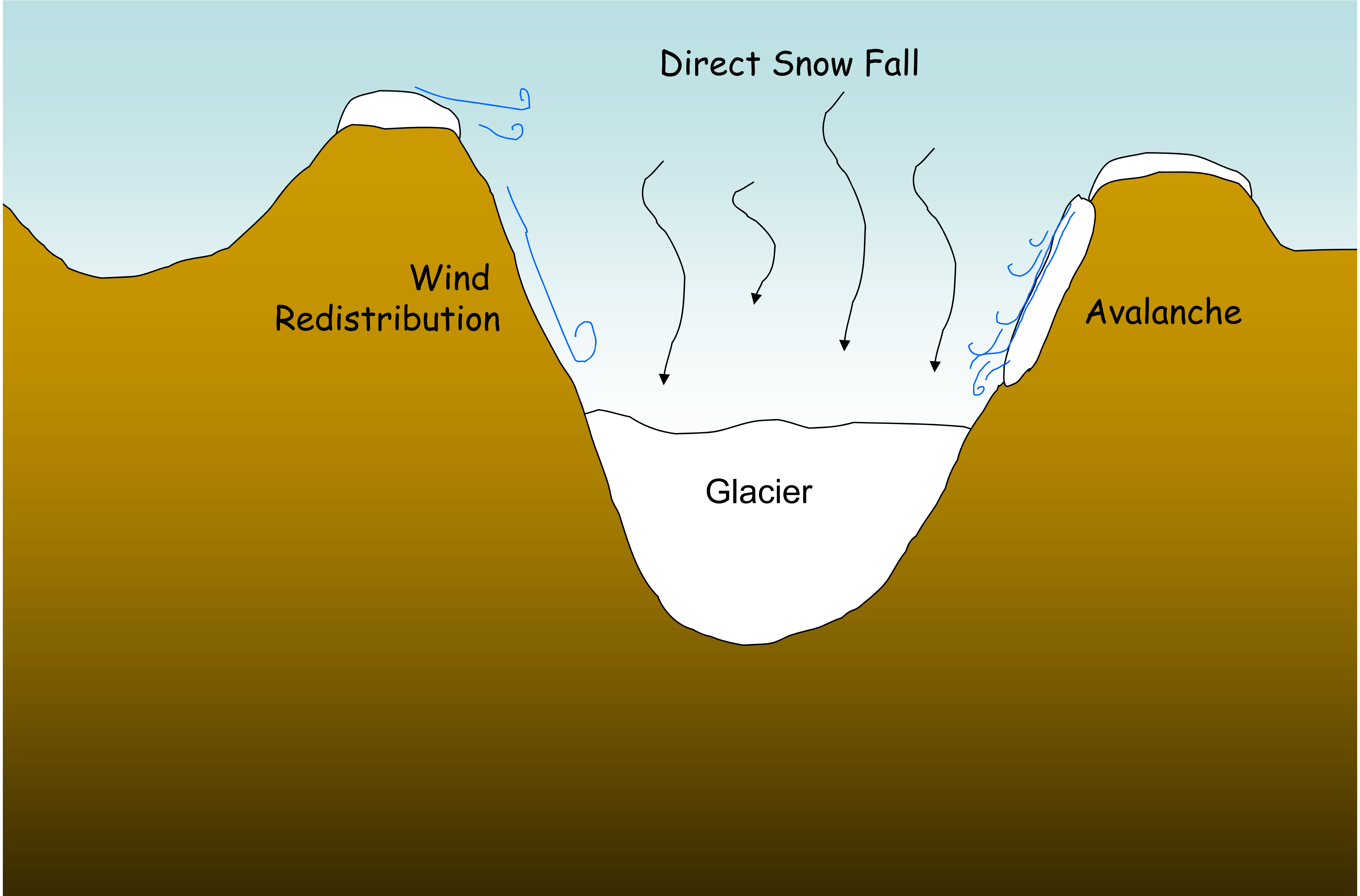
ablation season = winter

accumulation season = summer

# Mass Balance Regimes

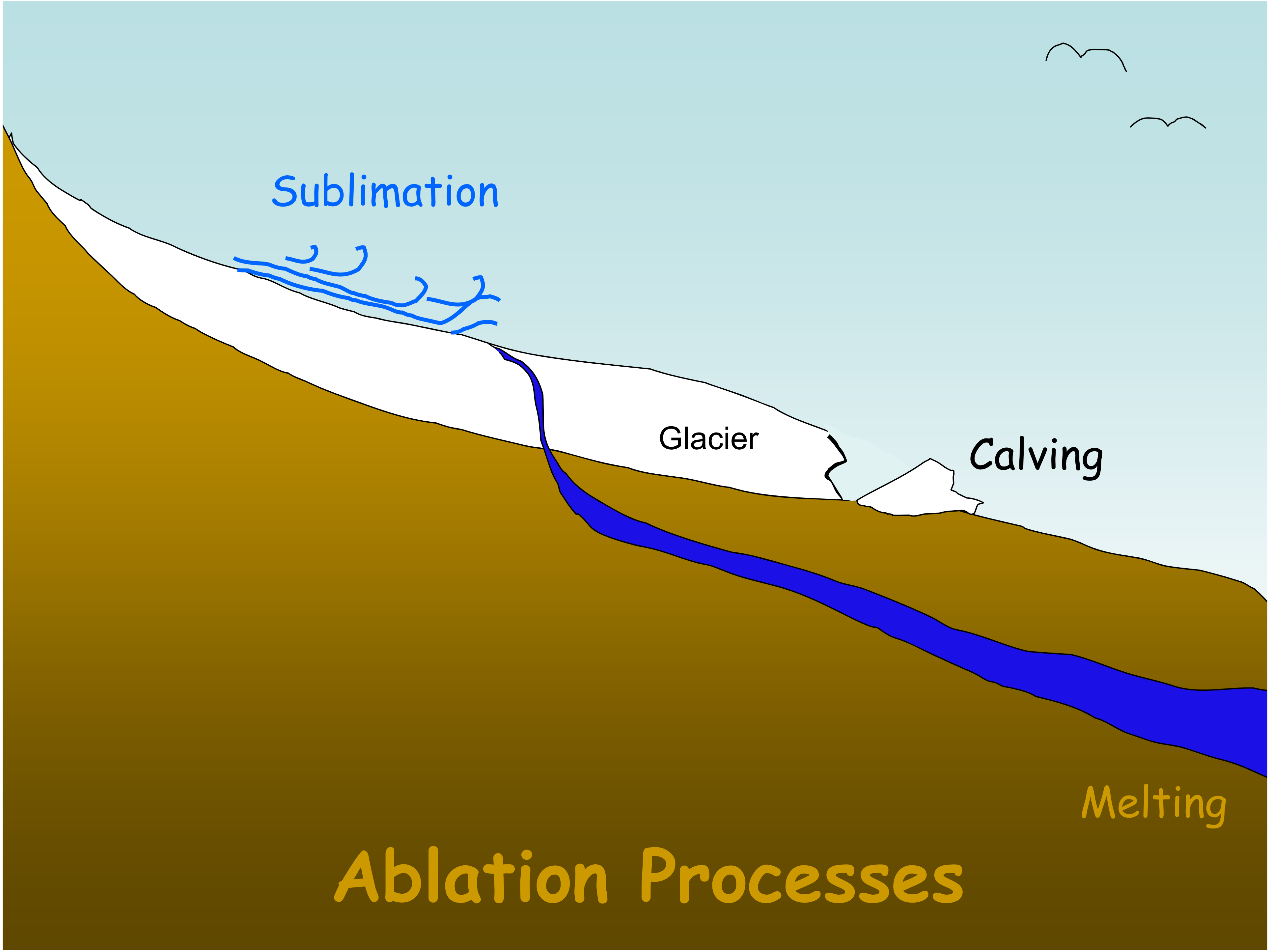
Not all climates conform
to the winter – accumulation,
summer – ablation season
Format.






# Snow Accumulation Processes

Weissmies (4023 m) Swiss Alps, Jurg Alean


Sublimation
Glacier
Calving
Melting
Ablation Processes

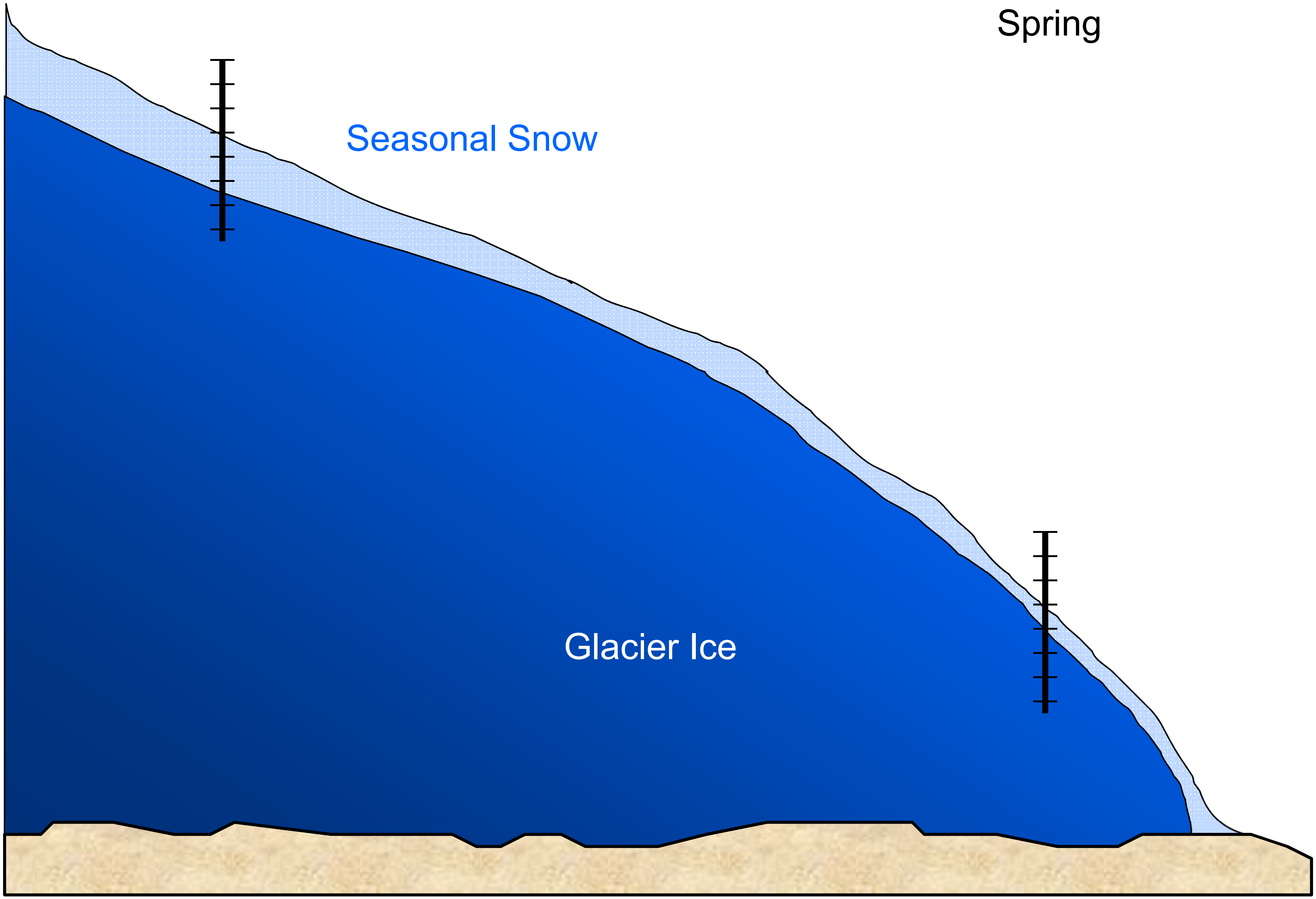
## Accumulation Zone
at higher elevations

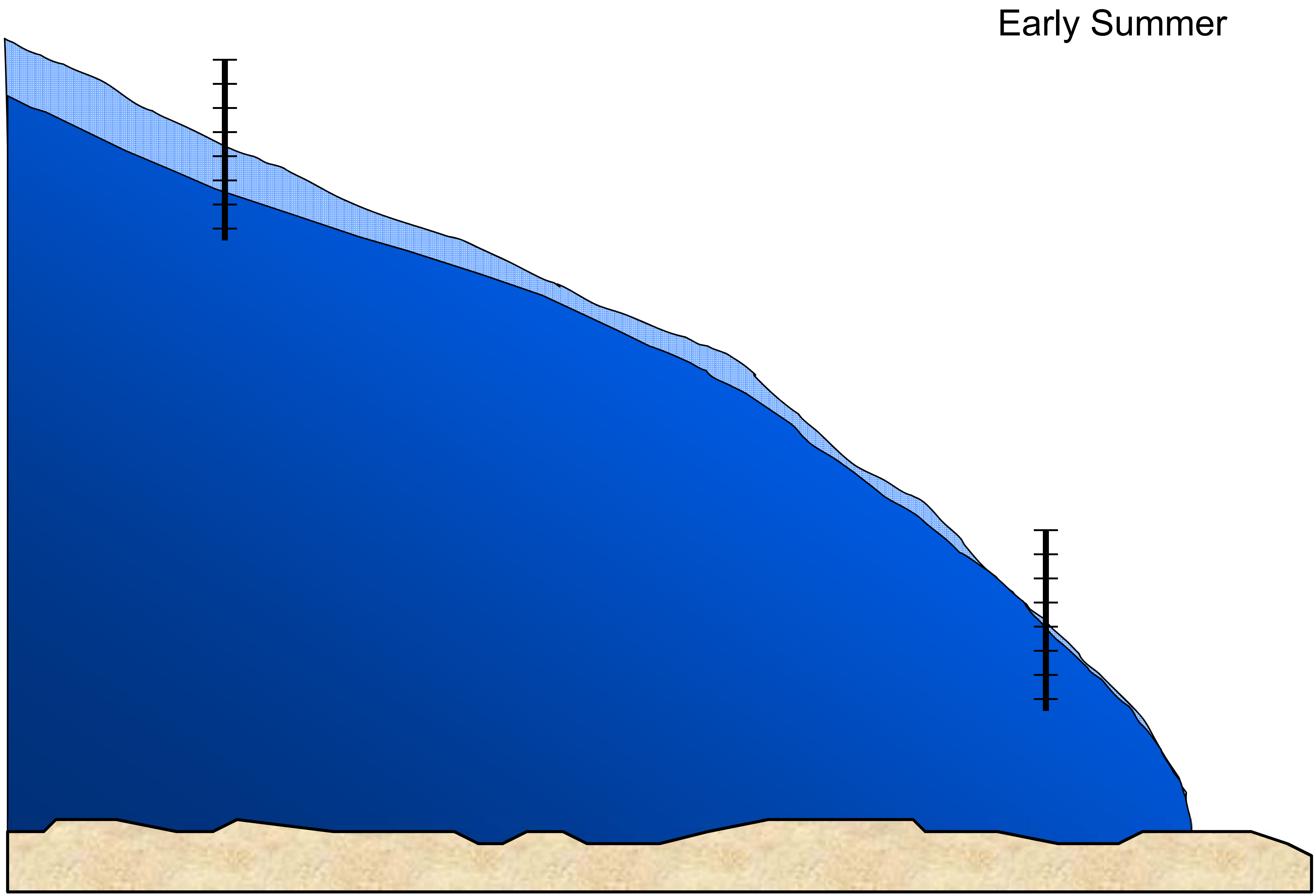
## Ablation Zone
at lower elevations

What about this situation?

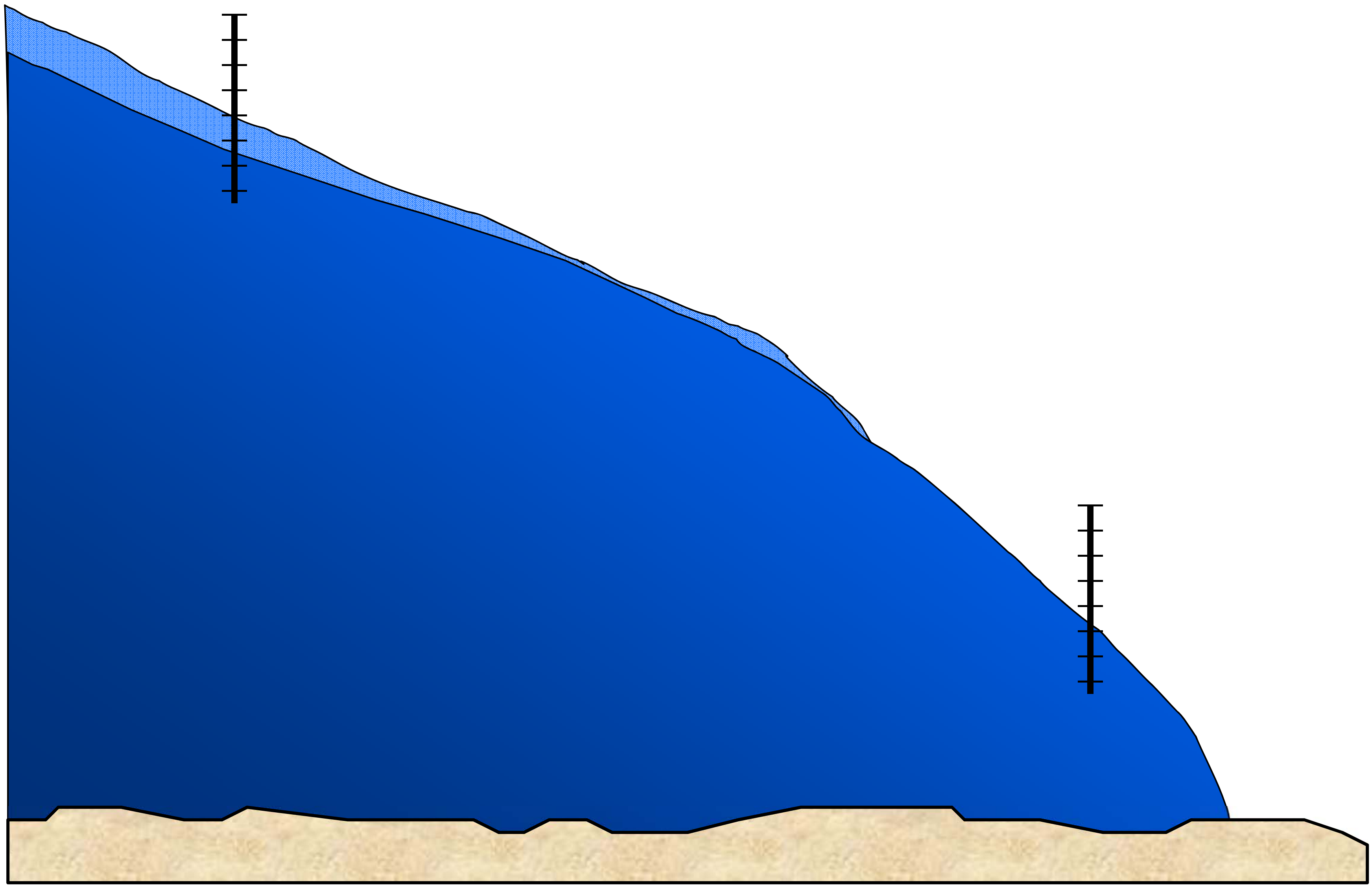
James Ross Island,
Antarctic Peninsula
Mike Hambrey

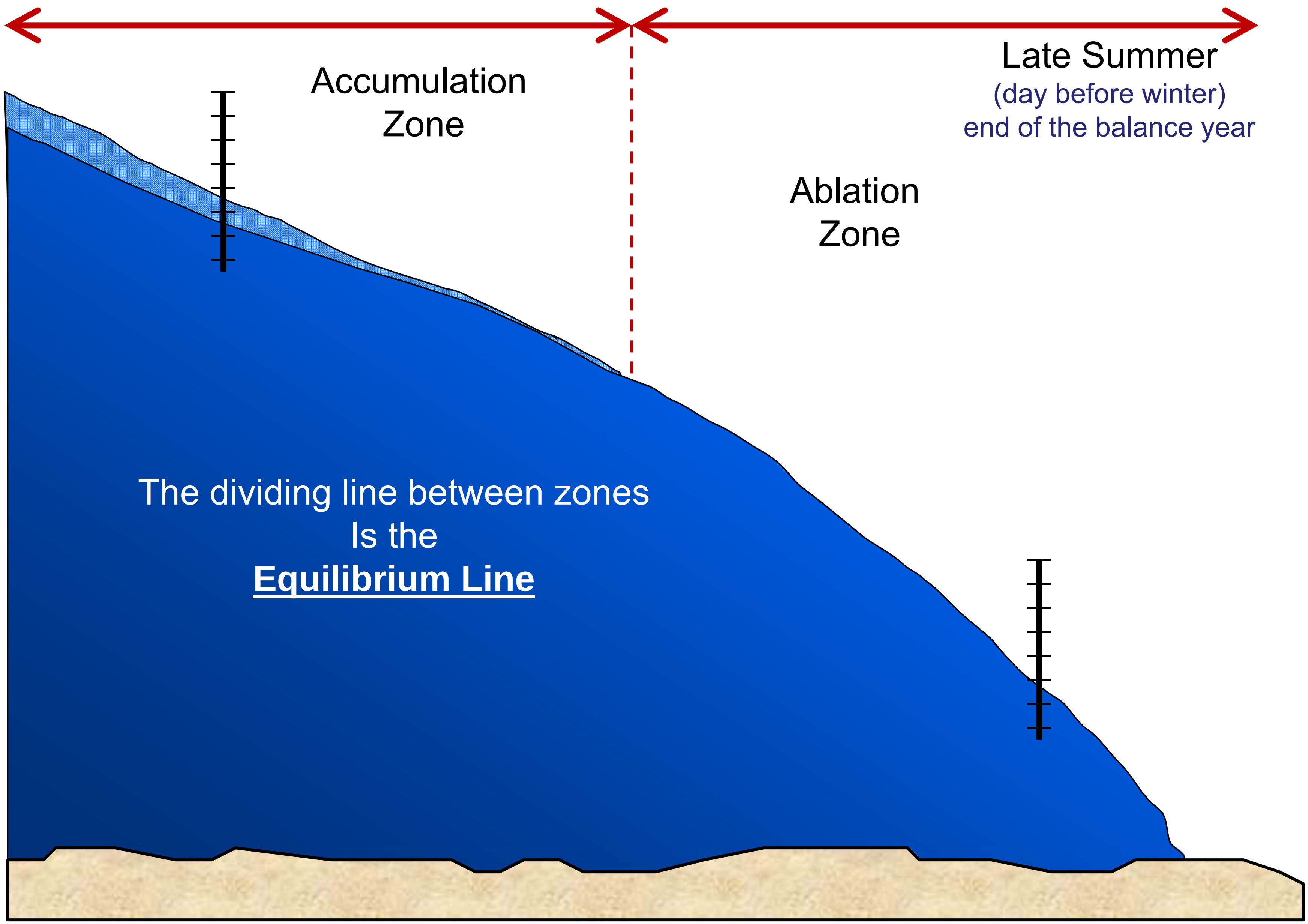
# Migration of the Snow Line




Early Summer

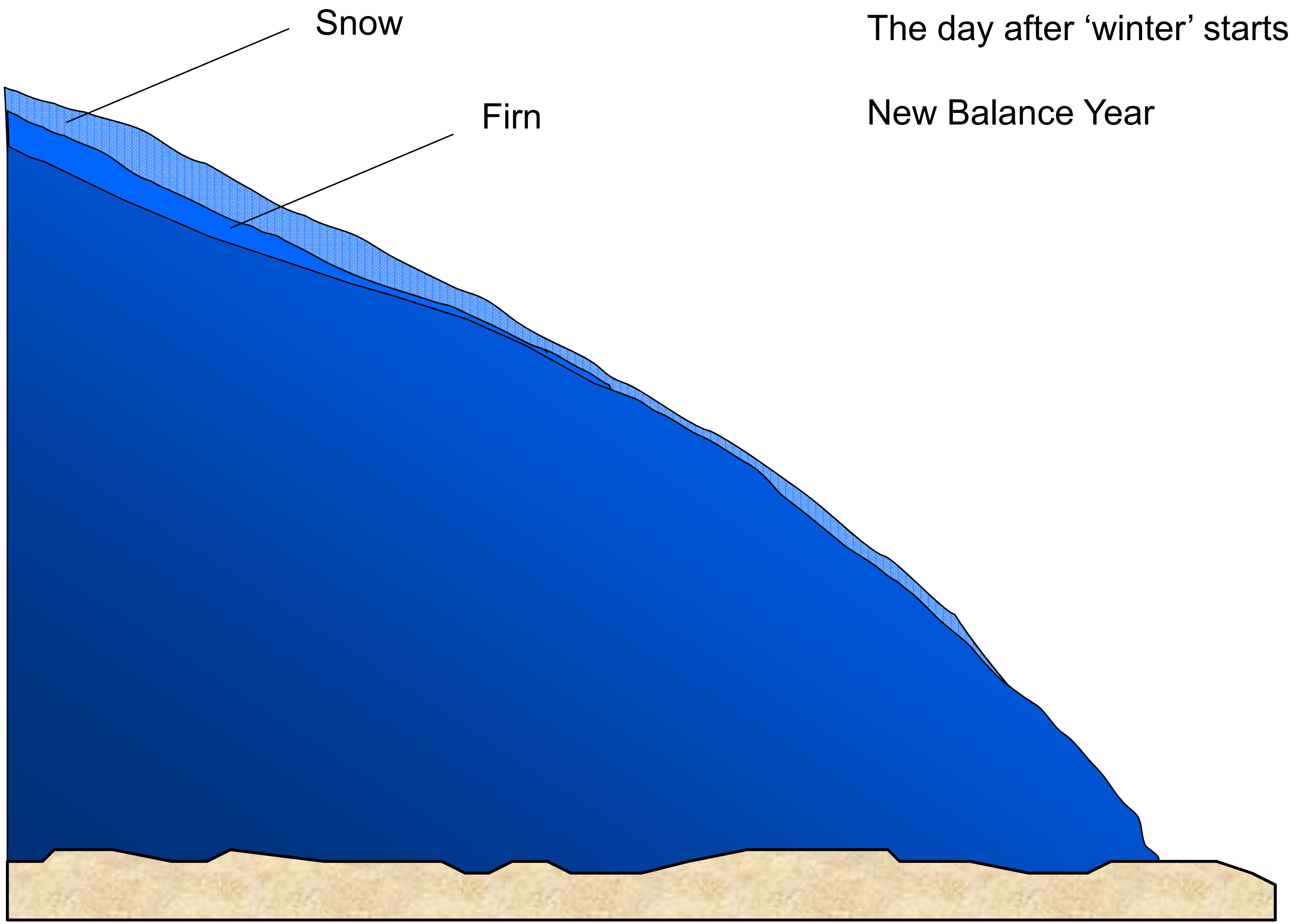
Mid Summer




Accumulation
Zone
Late Summer
(day before winter)
end of the balance year
Ablation
Zone
The dividing line between zones
Is the
Equilibrium Line

The day after ‘winter’ starts

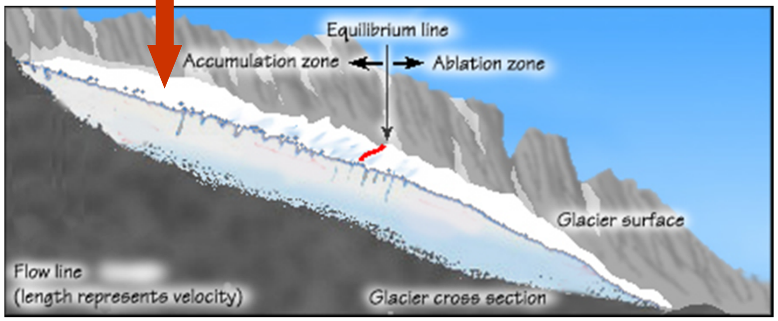
New Balance Year

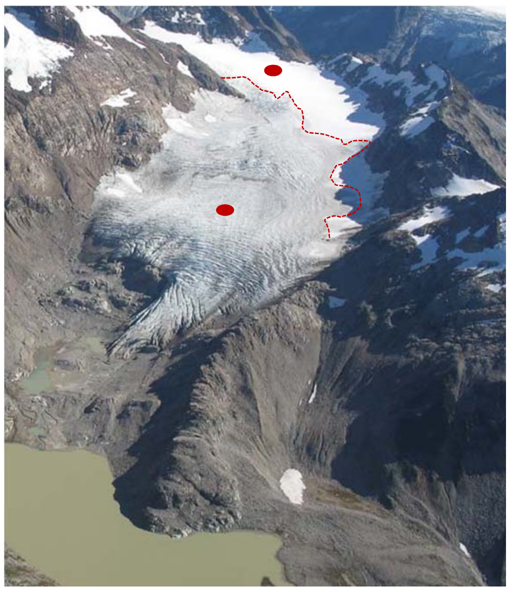


USGS 1955

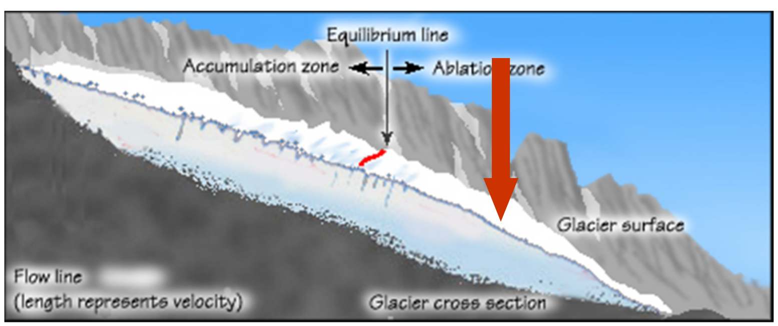
USGS 1960

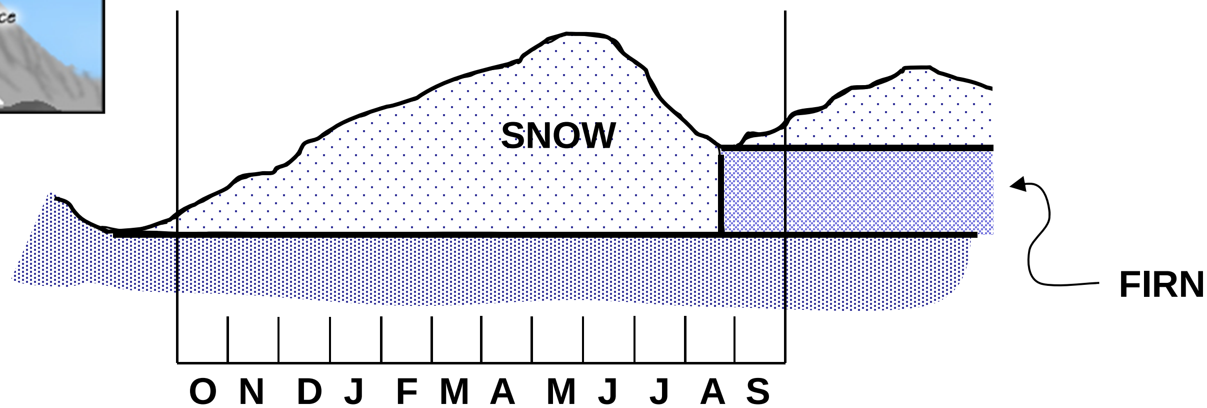
# Annual Cycle in the Accumulation and Ablation Zones

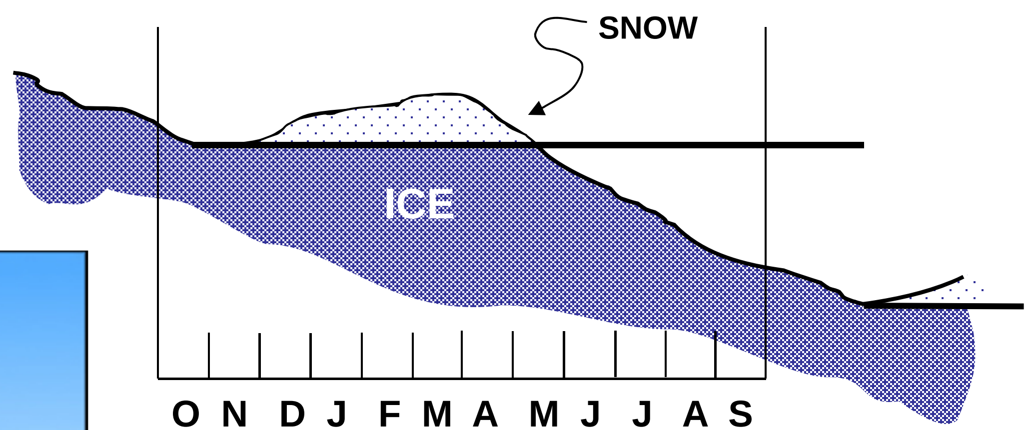


South Cascade Glacier
2004, John Scurlock



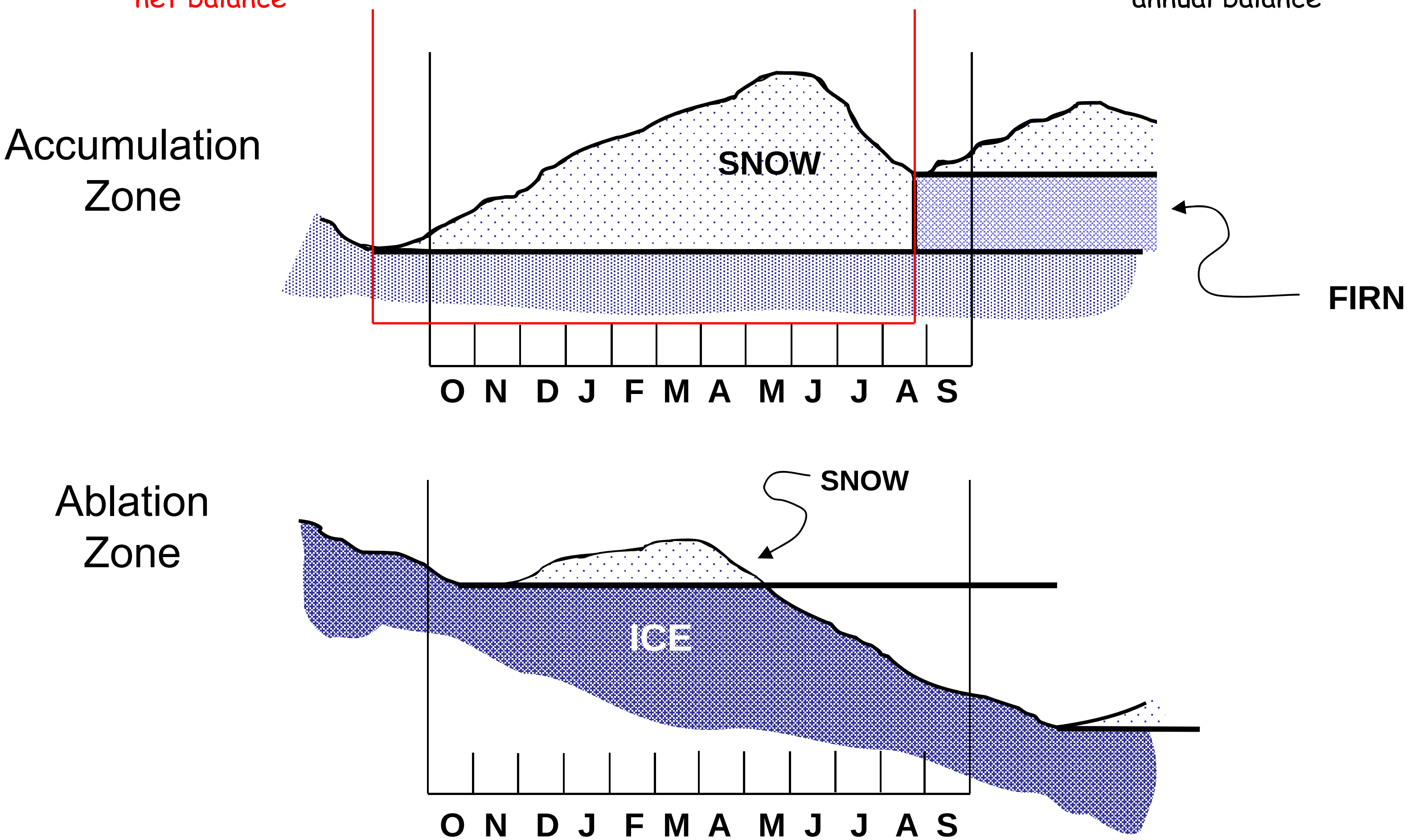



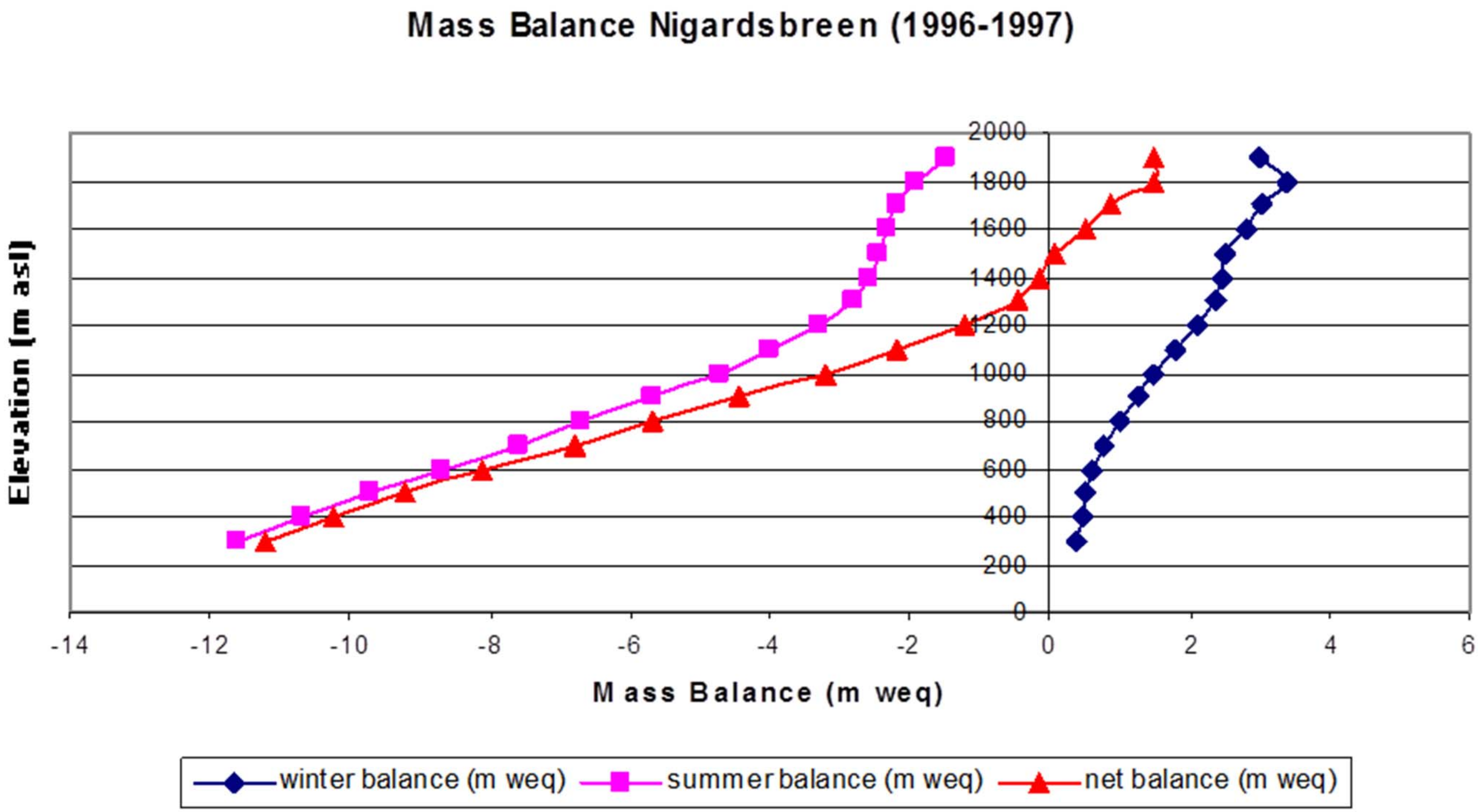
“Natural” Year
$b_n$

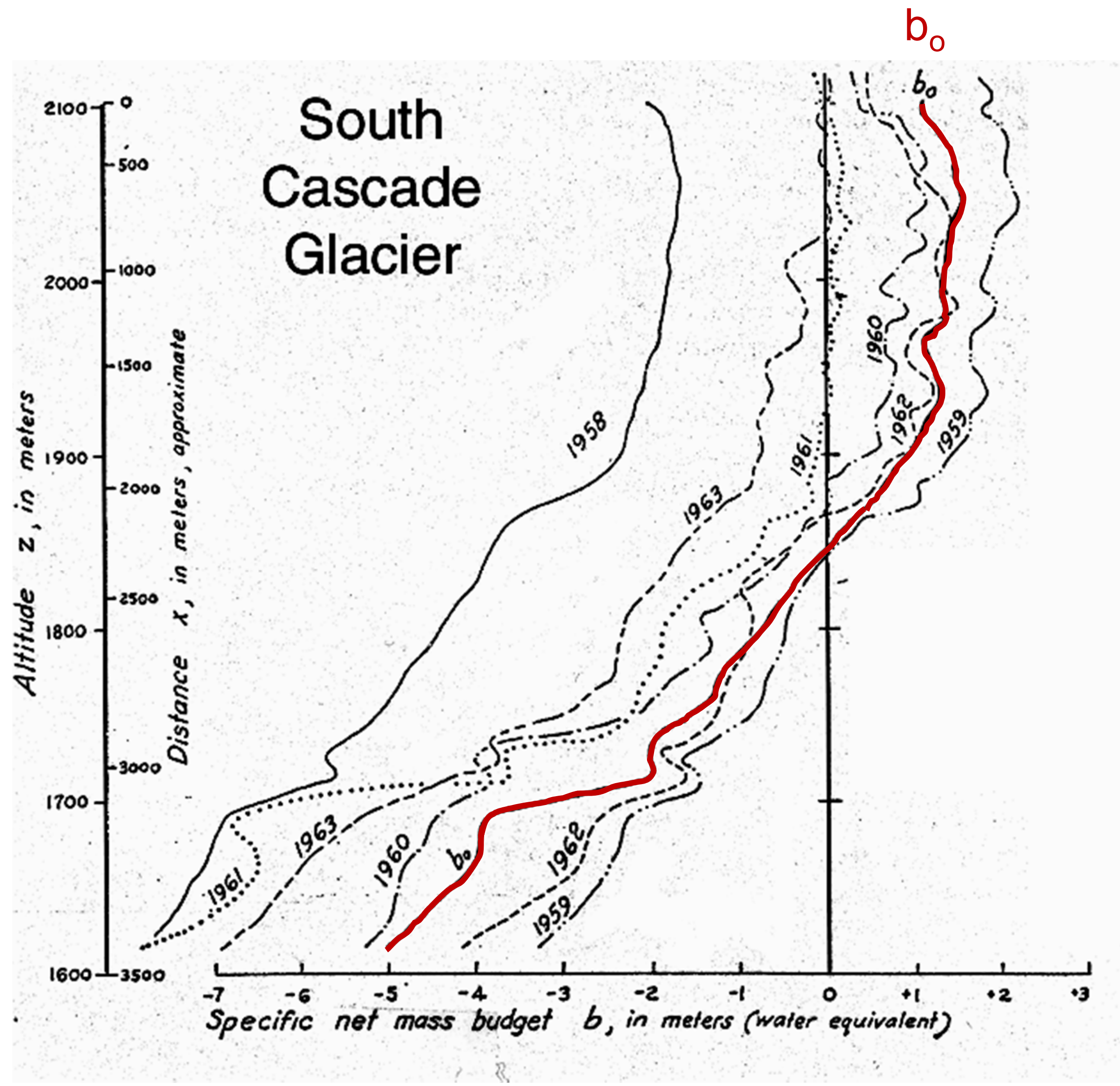
net balance

Calendar Year
$b_a$

annual balance

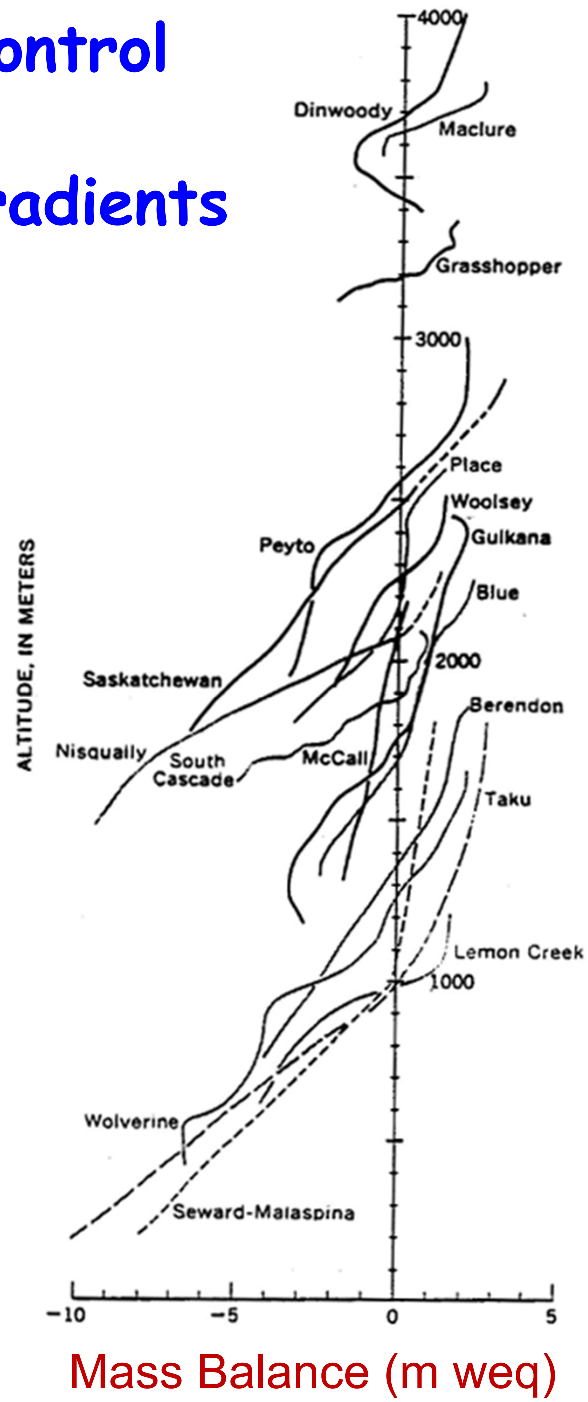



Mass Balance Nigardsbreen (1996-1997)
Elevation (m asl)
Mass Balance (m weq)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-14
-12
-10
-8
-6
-4
-2
0
2
4
6
winter balance (m weq)
summer balance (m weq)
net balance (m weq)



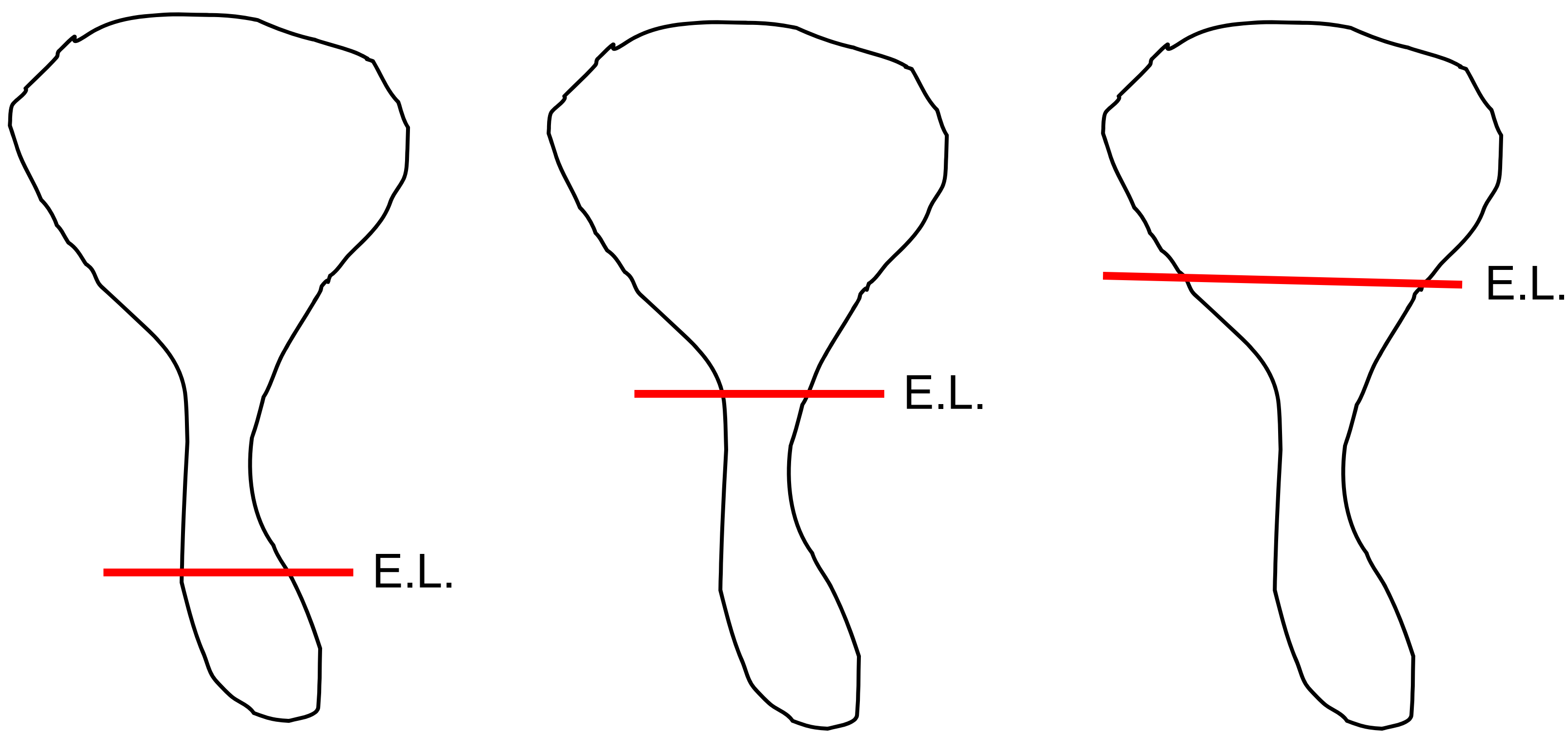
b₀
South
Cascade
Glacier
Altitude z, in meters
Distance x, in meters, approximate
Specific net mass budget b, in meters (water equivalent)
1958
1959
1960
1961
1962
1963
b₀

# The Climate Control Of Mass Balance Gradients

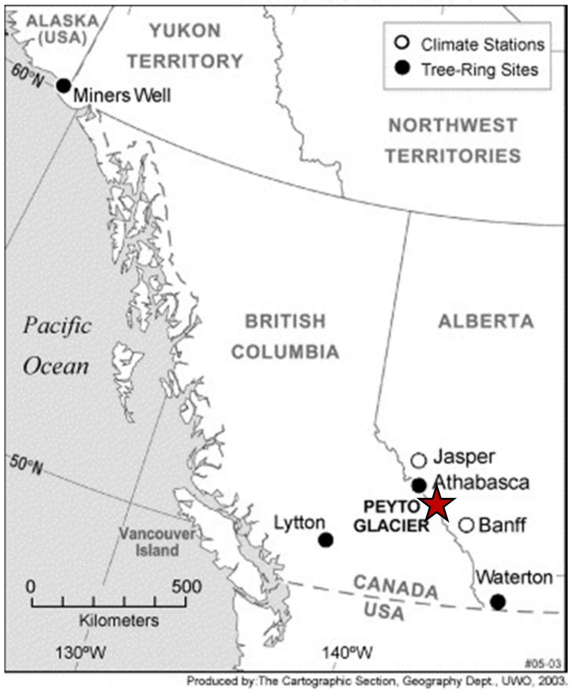


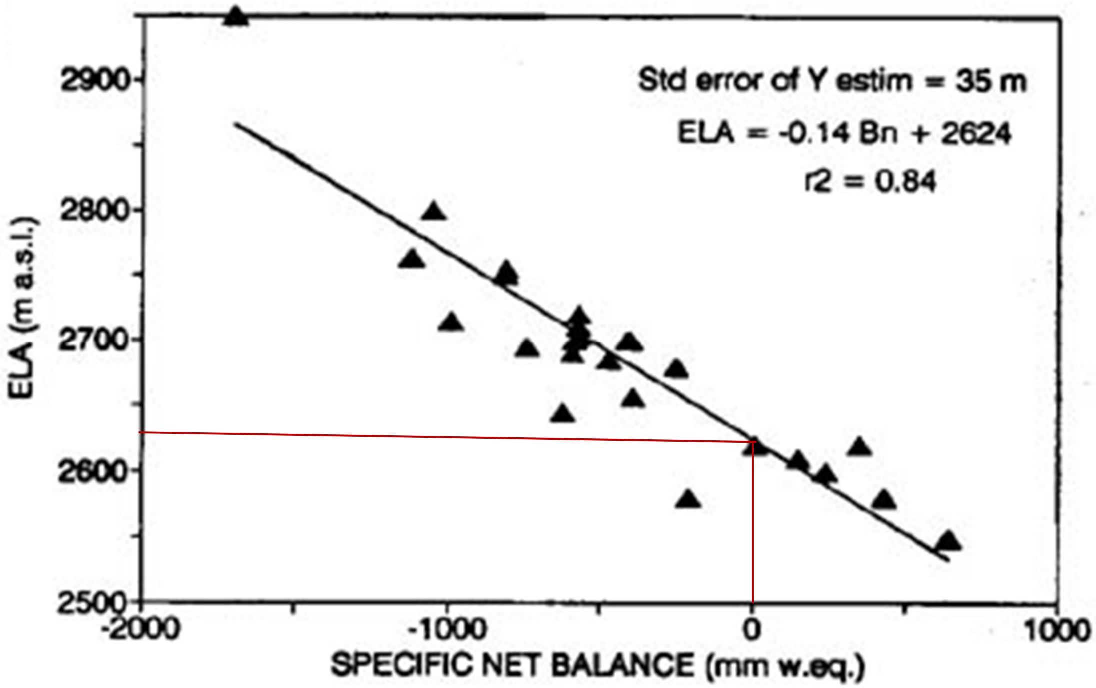

(Meier et al., 1971)

# Location of Equilibrium Line affects the mass balance



# Peyto Glacier ELA vs Net Balance (1966-1990)

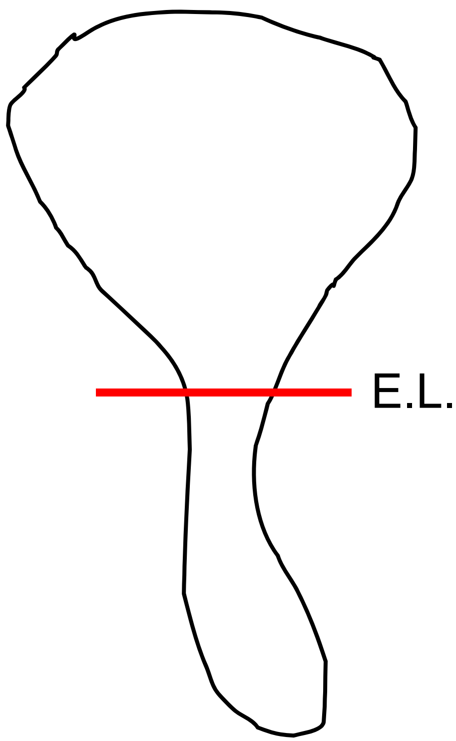


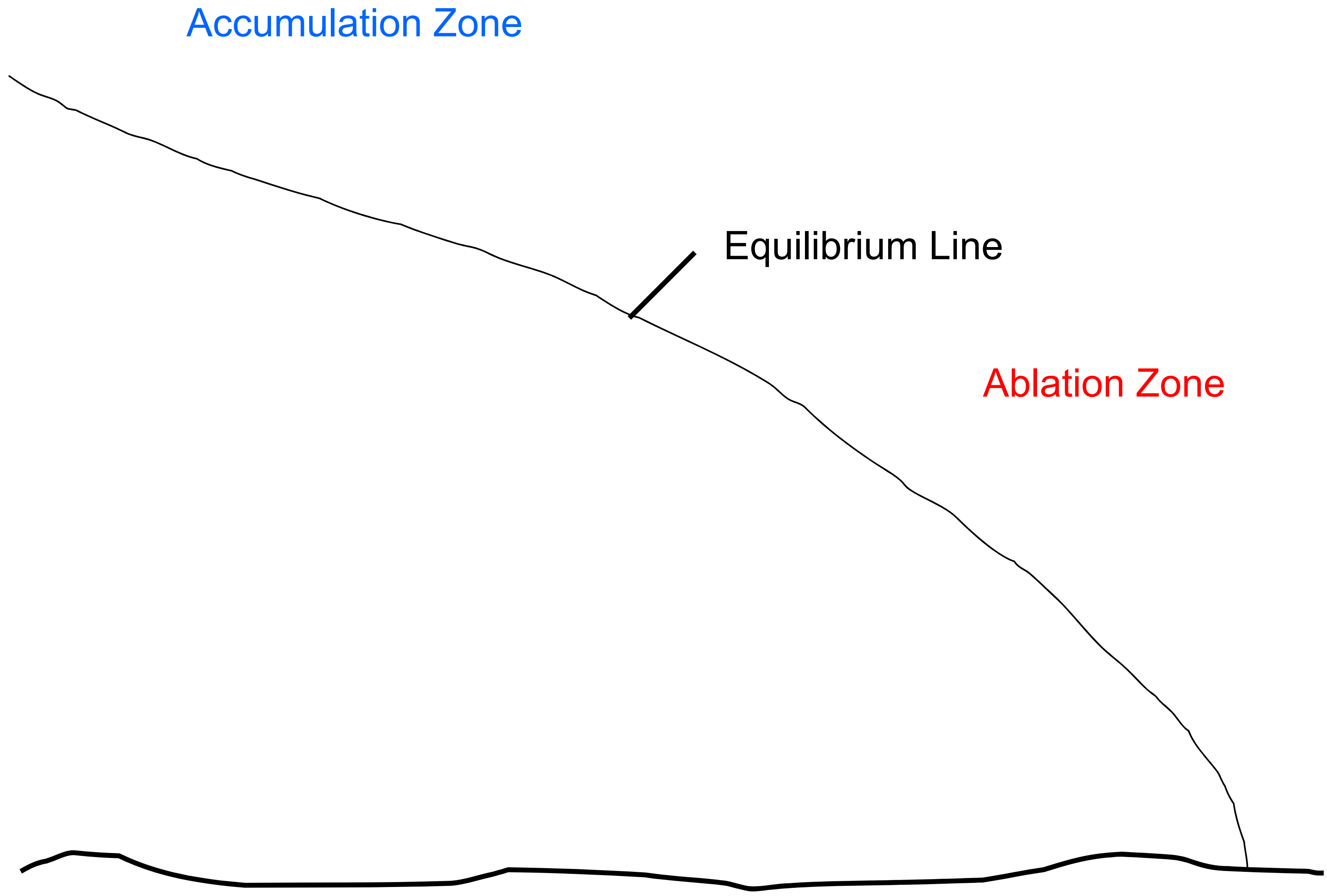




**ELA = Equilibrium Line Altitude**

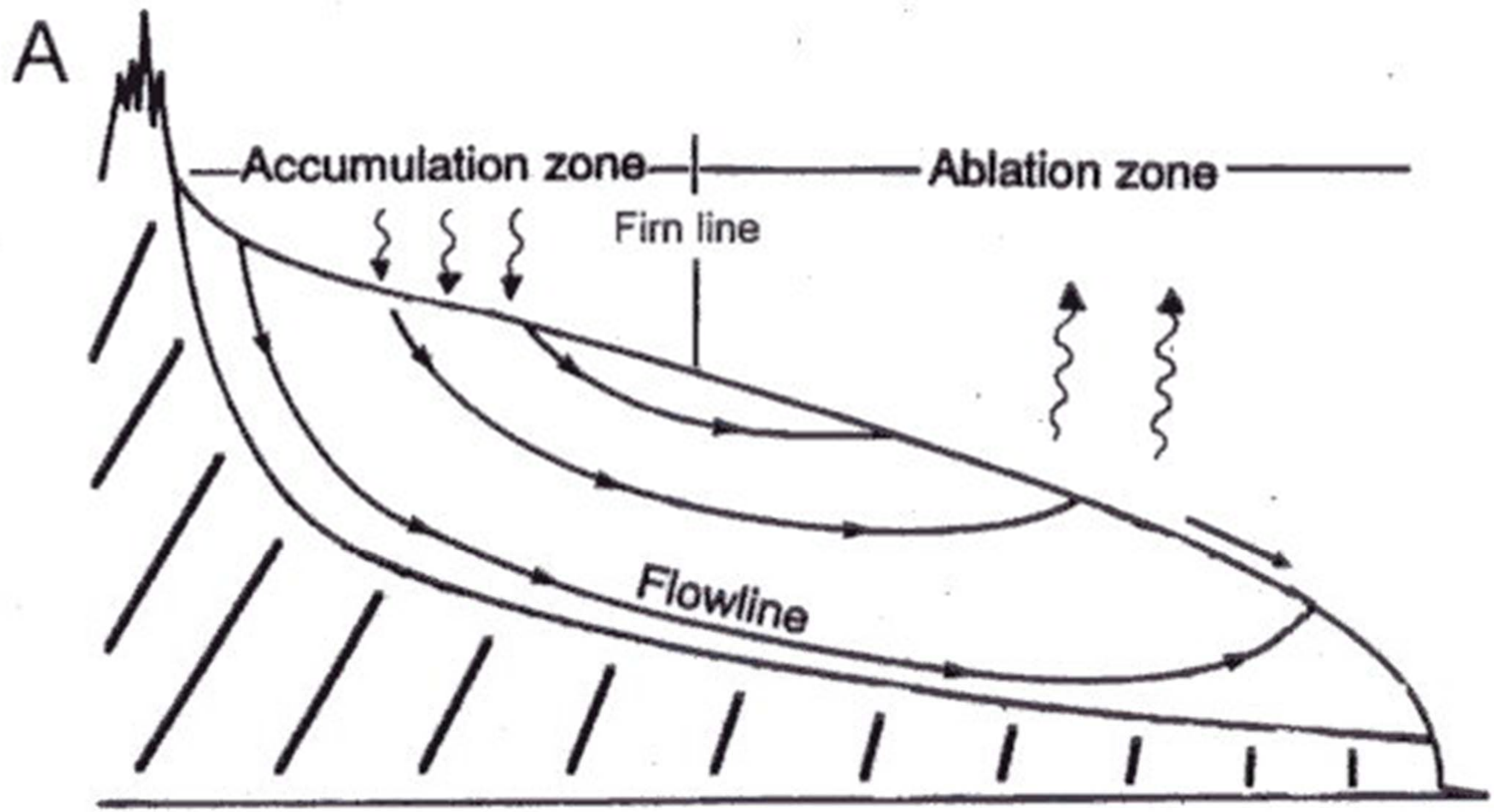
Equilibrium Line Altitude - a climate controlled glacier variable

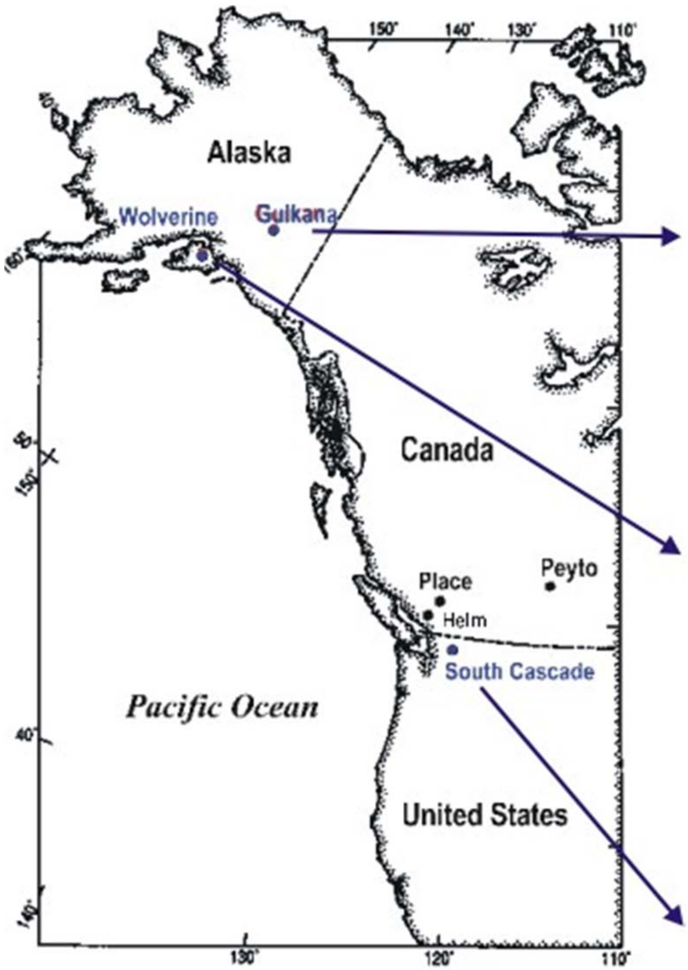
Accumulation Area Ratio - fraction of area above the ELA
nominally about 0.65

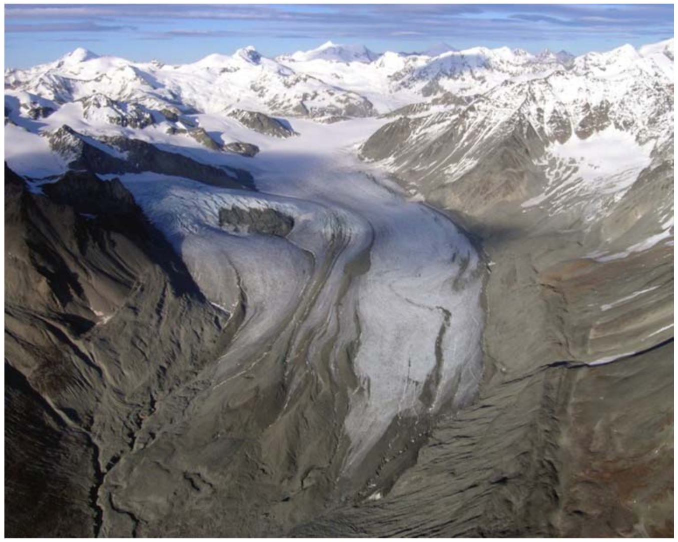


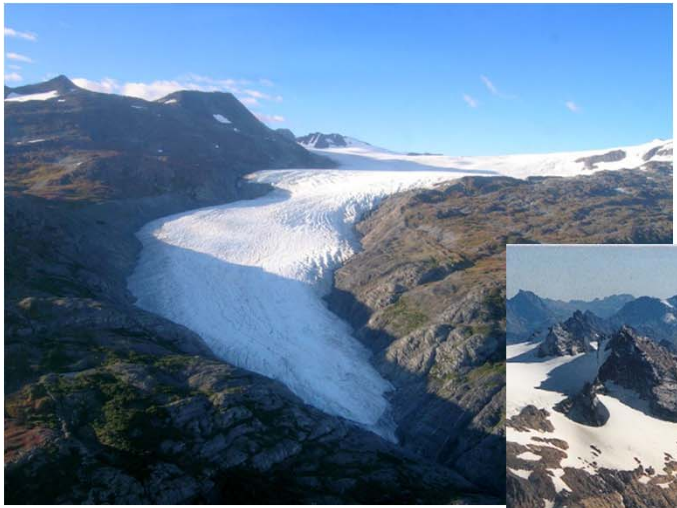


Accumulation Zone
Equilibrium Line
Ablation Zone

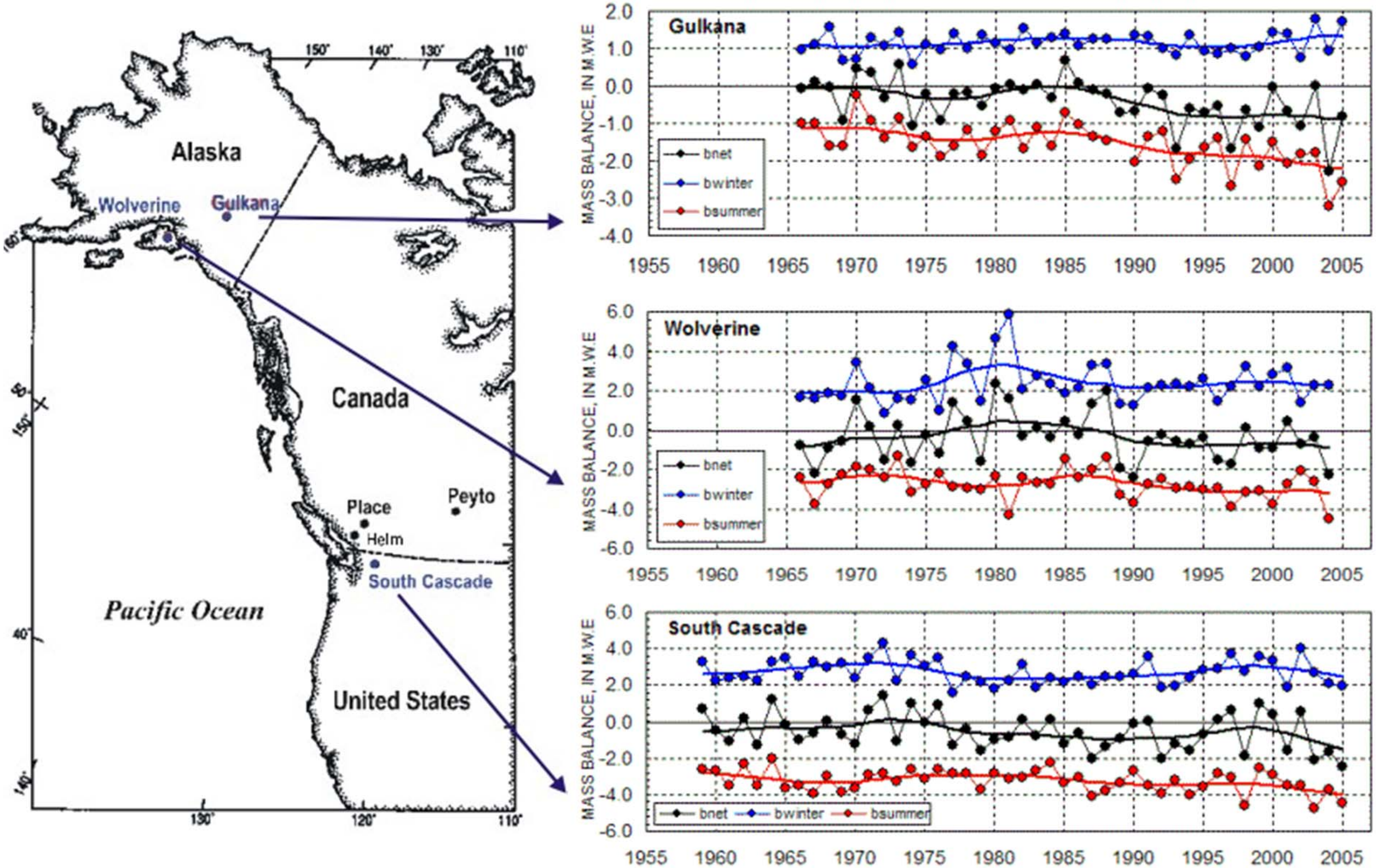

A
Accumulation zone
Ablation zone
Firn line
Flowline





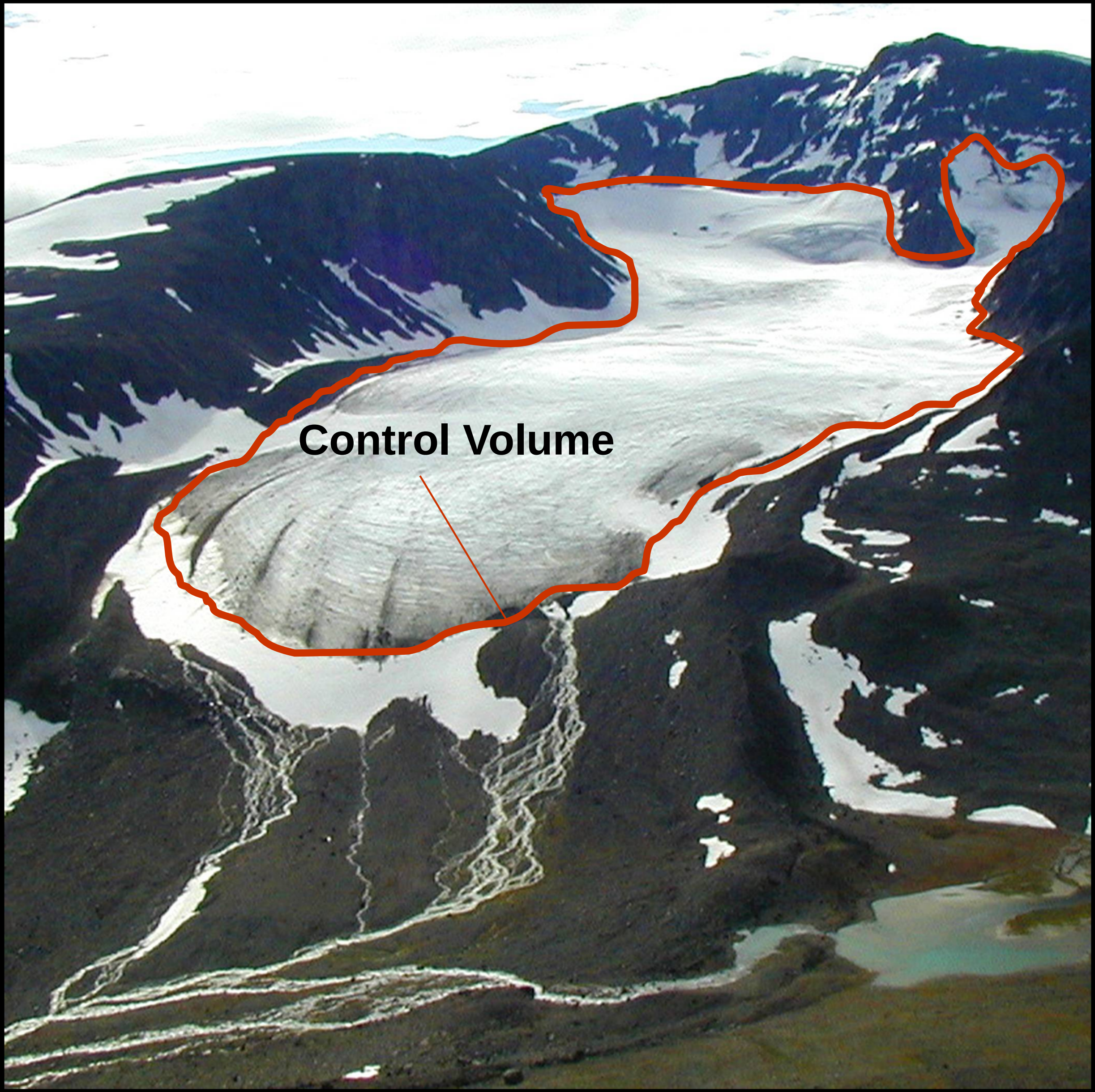
US Geological Survey




US Geological Survey

How is the mass balance measured on alpine glaciers?

The Basic Concept



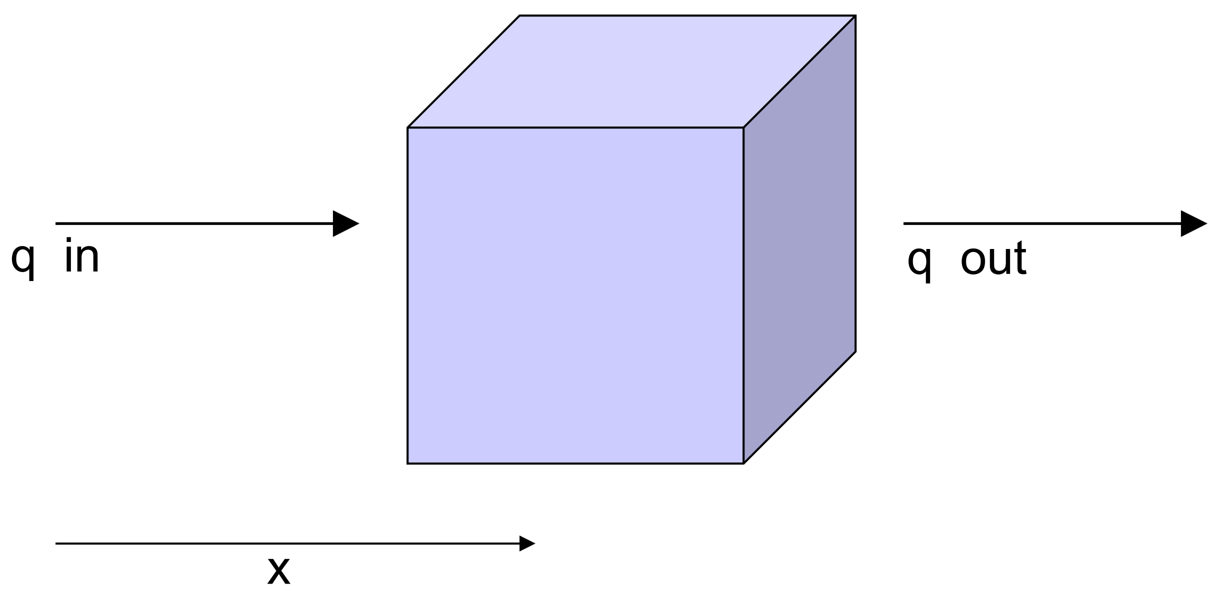

Storglaciären, Sweden

# Continuity Equation

Volume change = Input - Output

$$\frac{\partial h}{\partial t} = \dot{b} + \nabla q$$

$$\nabla q \quad = \quad \frac{\partial q}{\partial x} + \frac{\partial q}{\partial y} + \frac{\partial q}{\partial z}$$



Continuity Equation

$$\frac{\partial h}{\partial t} = \dot{b} + \nabla q$$

$$\dot{b} = \frac{\partial h}{\partial t} - \nabla q$$

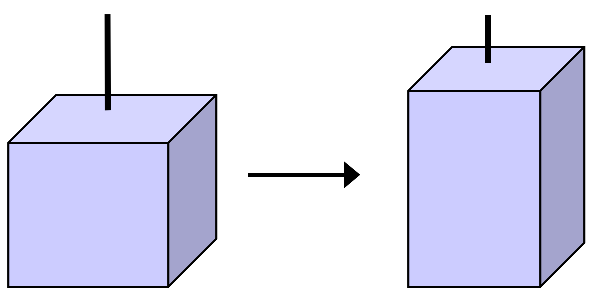
In theory, we need to evaluate each term of the equation

$$\dot{b} = \frac{\partial h}{\partial t}$$

In practice, we ignore the divergence.

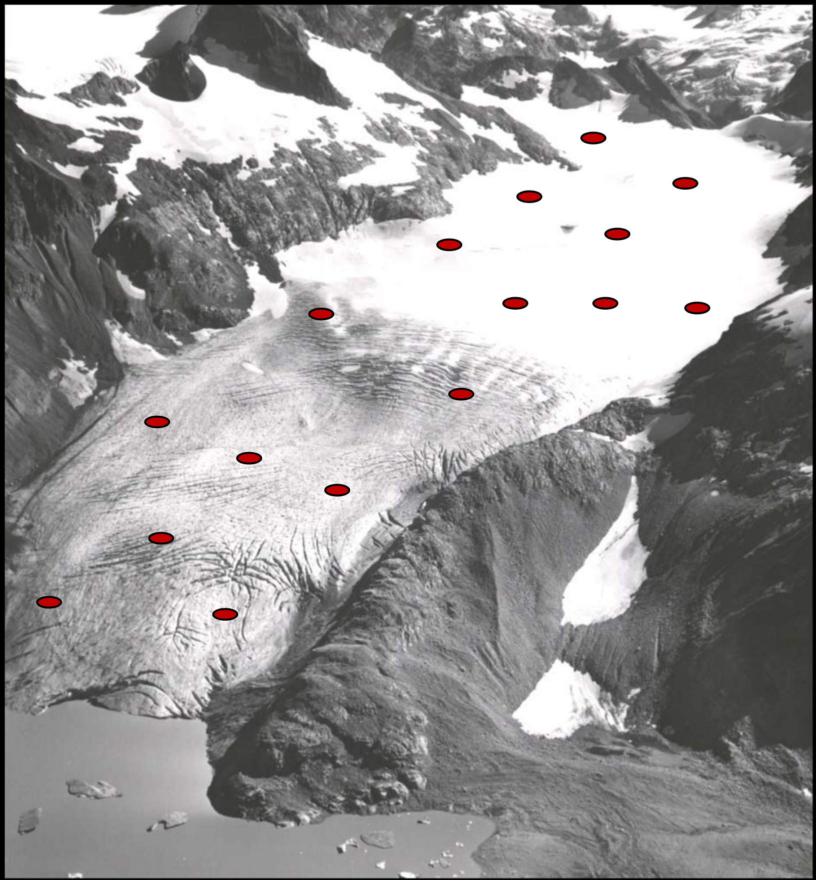
1. divergence is small and relatively constant with time and if we measure the entire glacier, it cancels out.

2. our frame of reference is the glacier surface and we measure the mass flux through the surface.



# 1. Measure accumulation of snow

# 1. Measure accumulation of snow, even if its low on the glacier

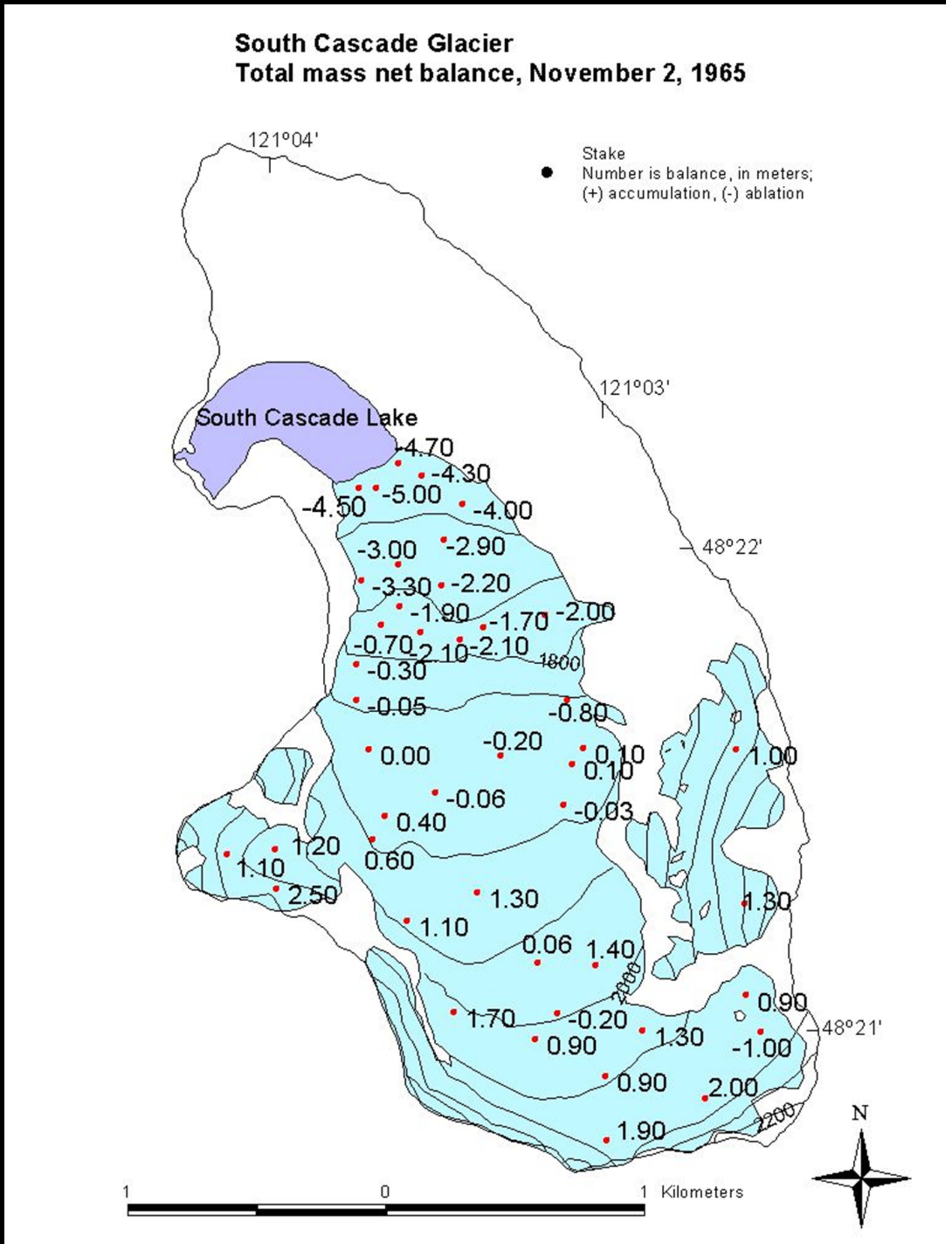


Make the measurements over the glacier surface.

## 2. Measure ablation of ice

We know the density of ice ~900 kg $m^{-3}$…..........but what about the snow?

# 3. Measure snow density




From the change in snow depth and its density the *specific* mass change is known

Mass / unit area = $\rho_s \Delta h$

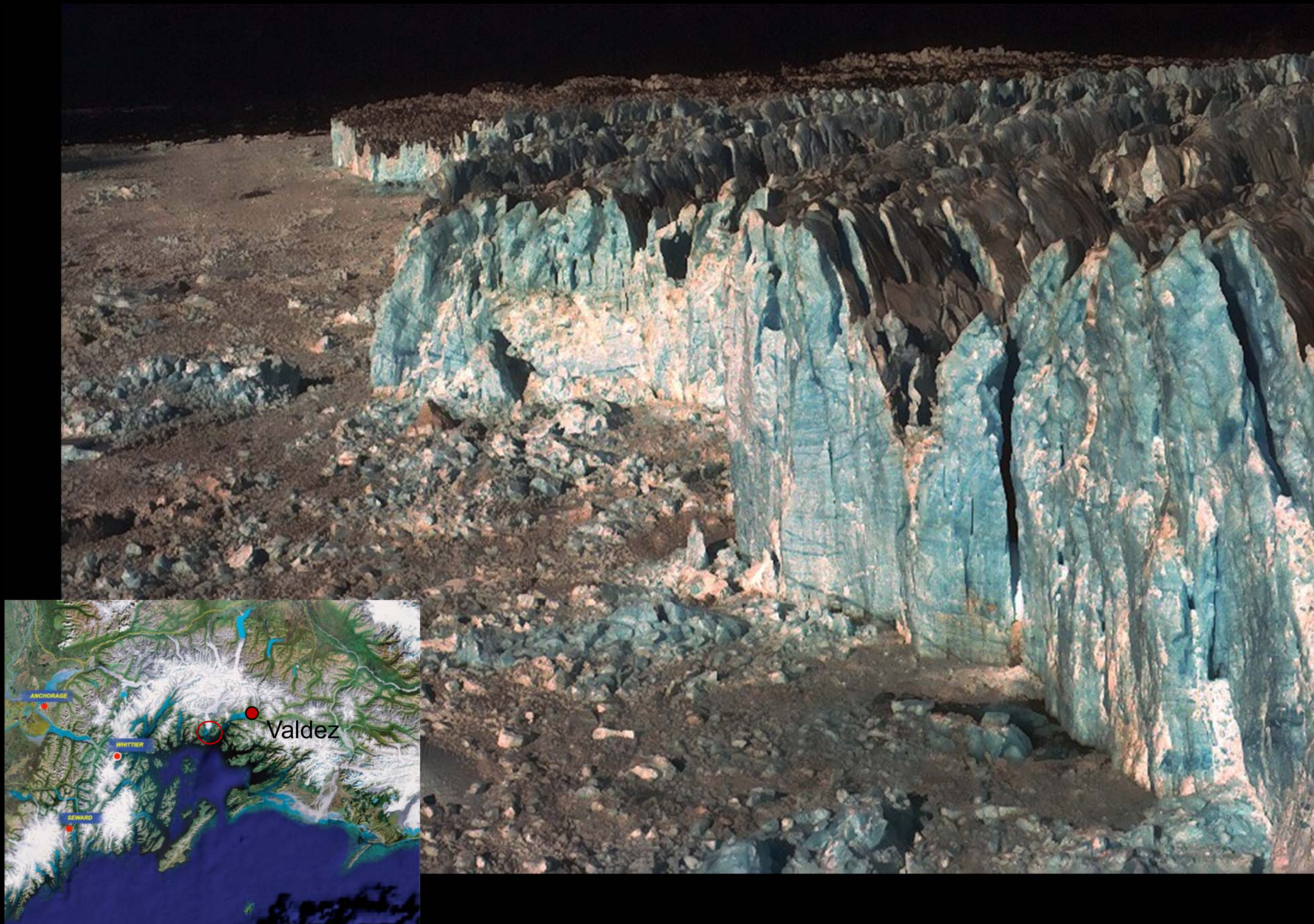
For ice

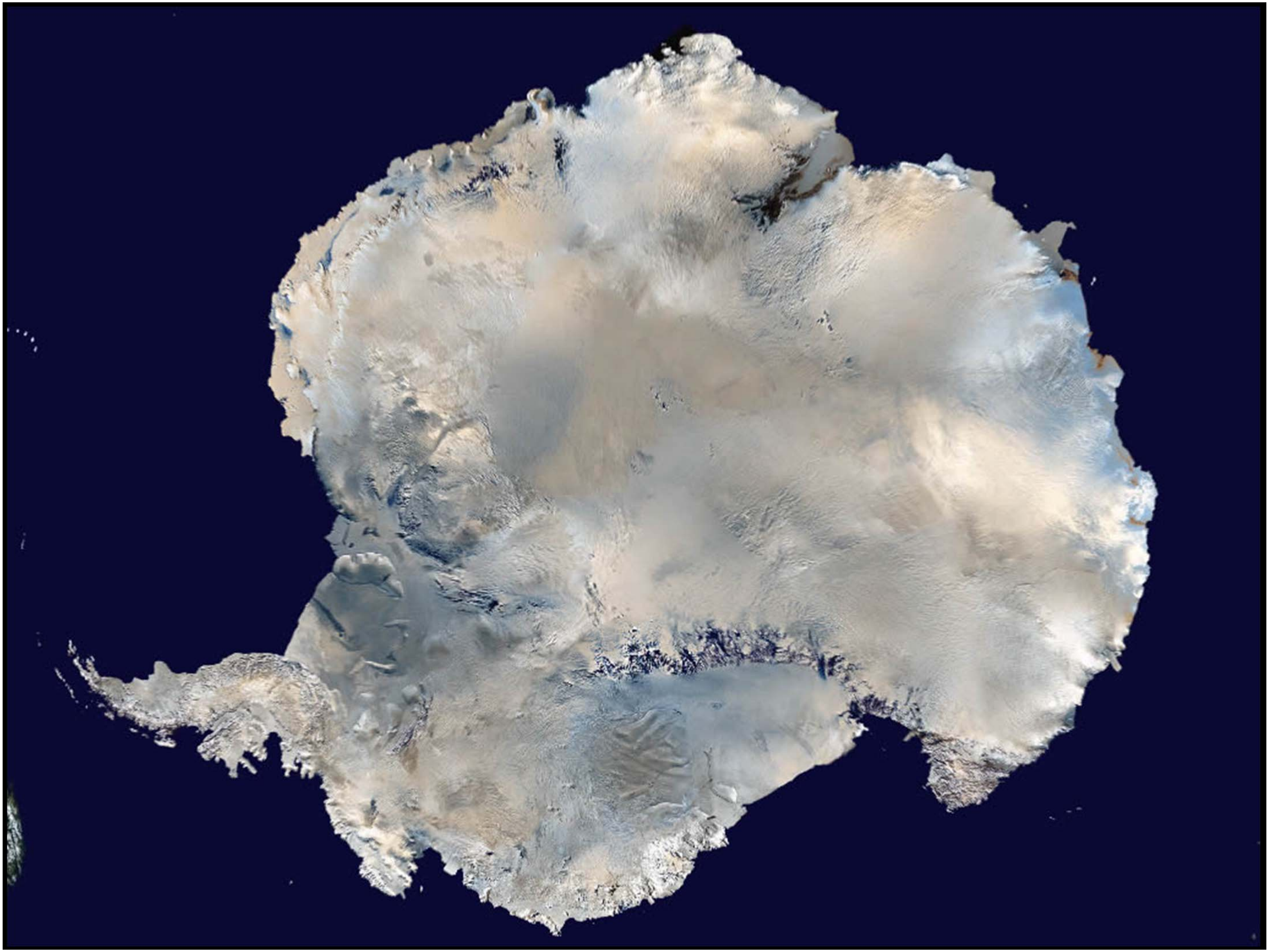
Mass / unit area = $\rho_i \Delta h$

Water equivalent (weq)

= Mass / unit area/ water density

m weq


ANCHORAGE
WHITTIER
SEWARD
Valdez

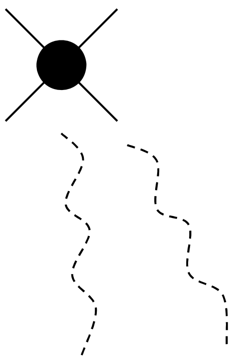


# Continuity Equation

$$\frac{\partial h}{\partial t} = \dot{b} + \nabla q$$

$$\dot{b} = \frac{\partial h}{\partial t} - \nabla q$$

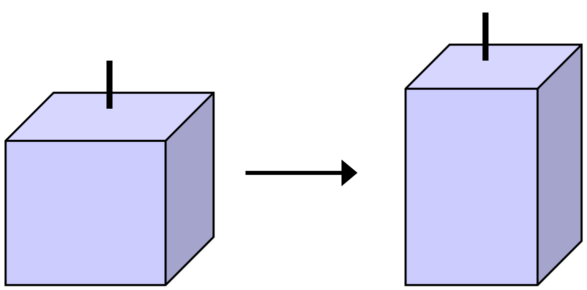
In theory, we need to evaluate each term of the equation

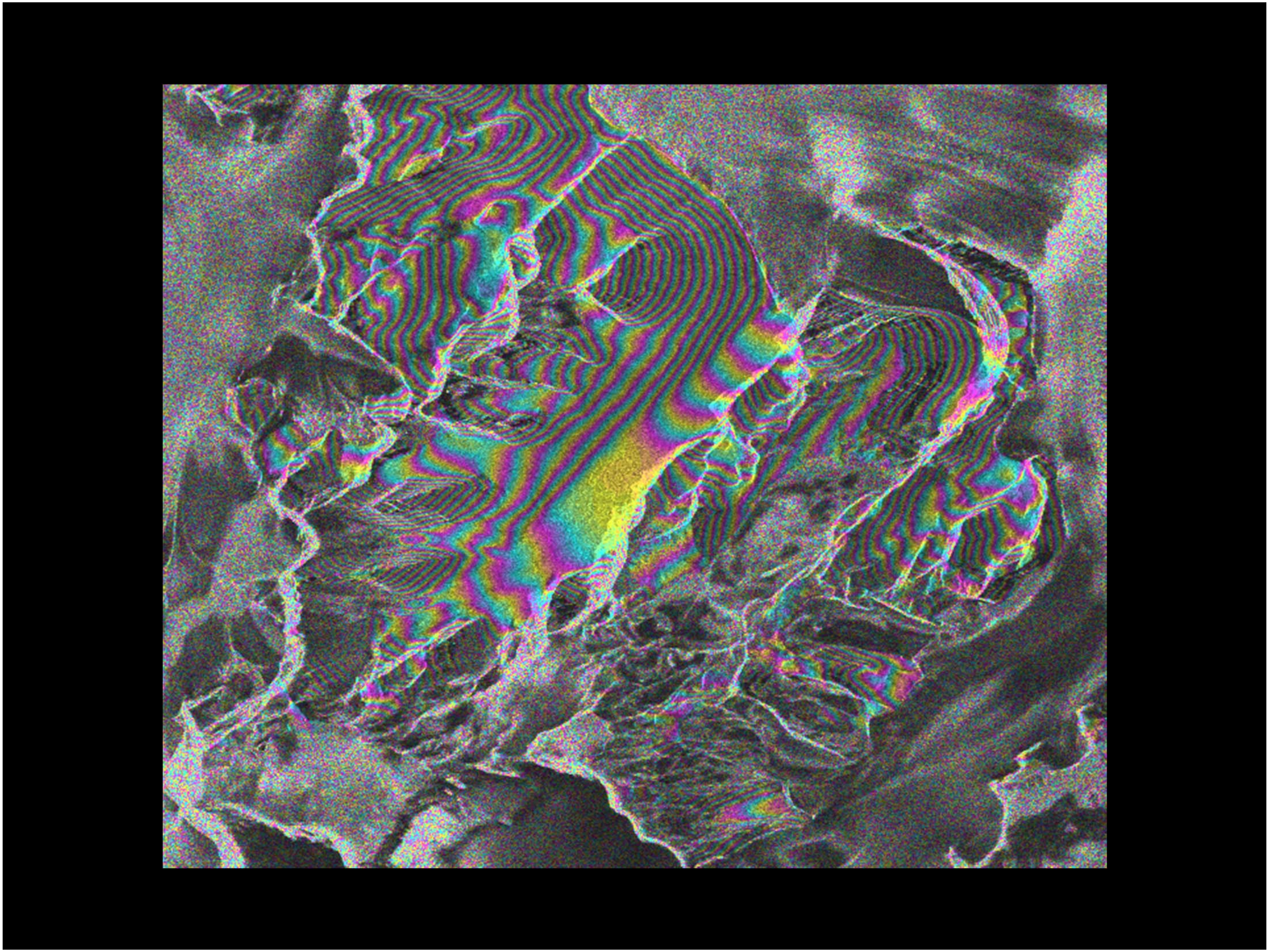


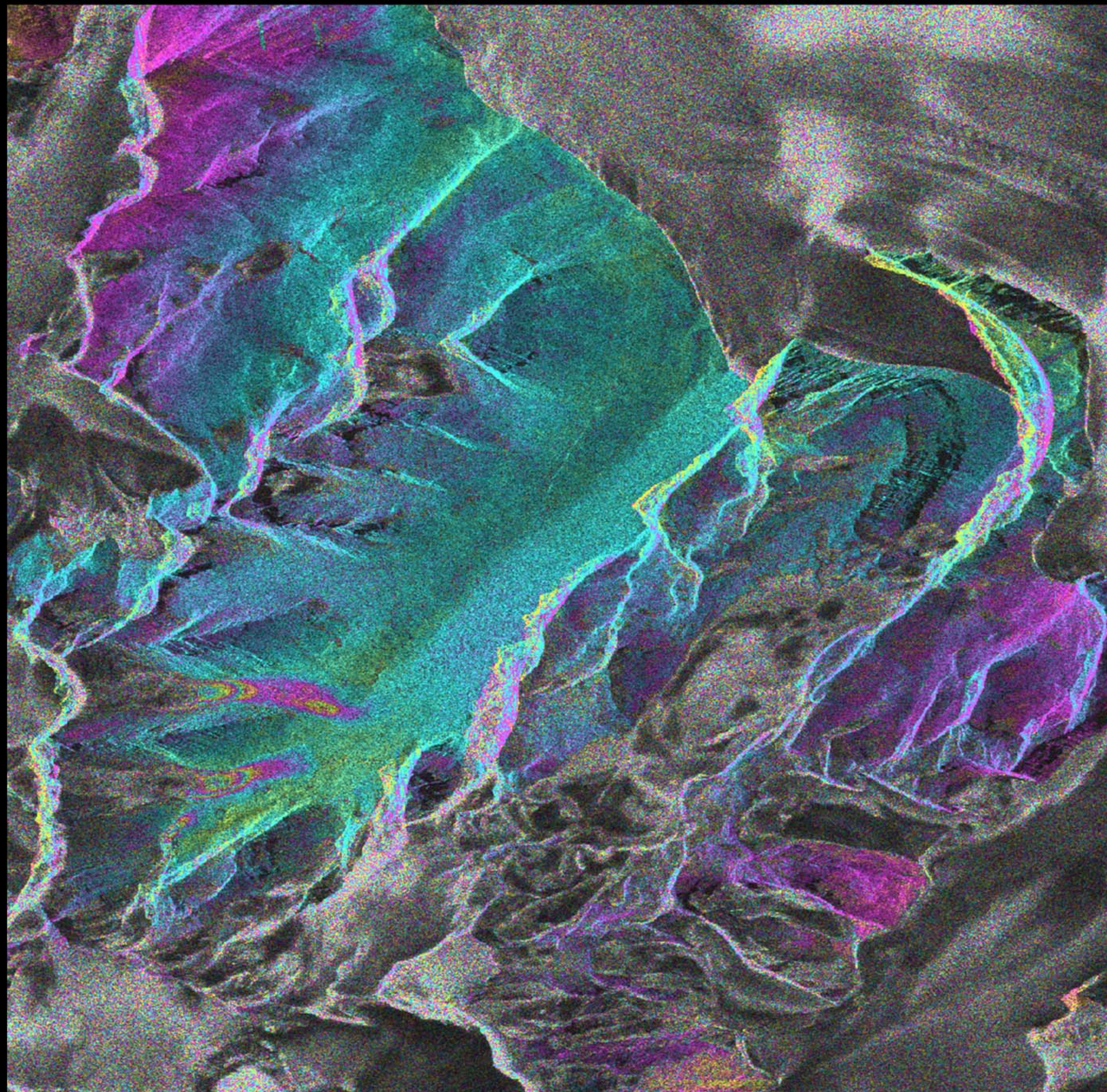
$$\cancel{\dot{b} = \frac{\partial h}{\partial t}}$$

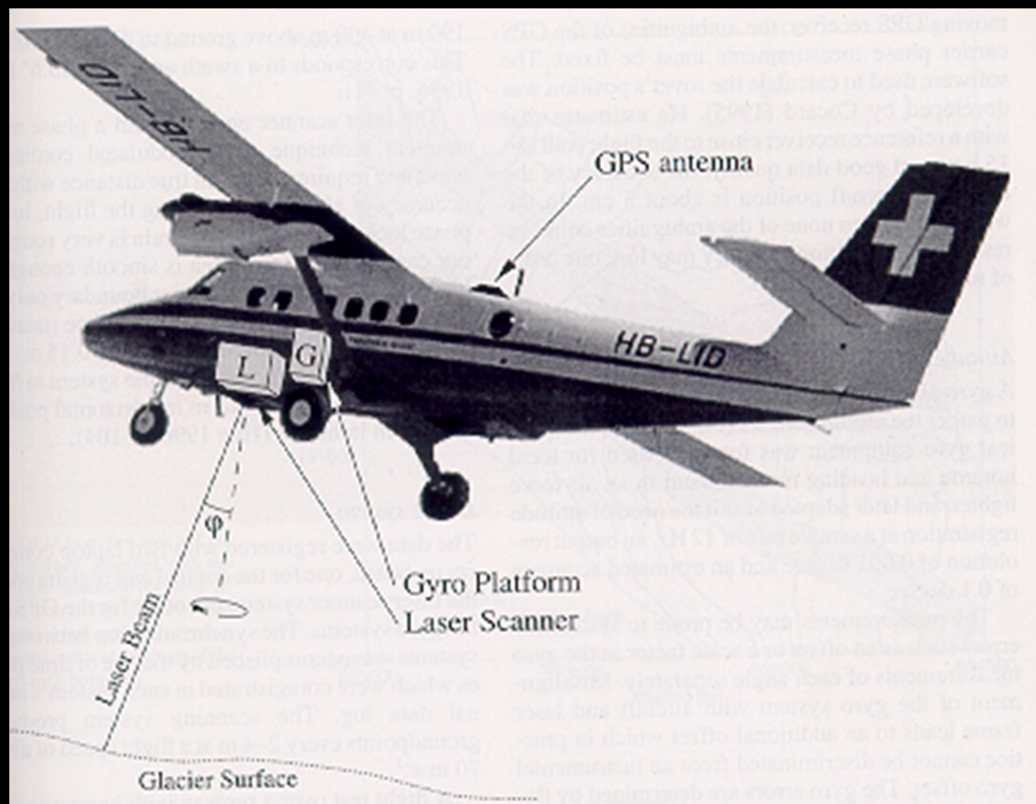
In airborne/satellite remote sensing we cannot ignore the divergence.

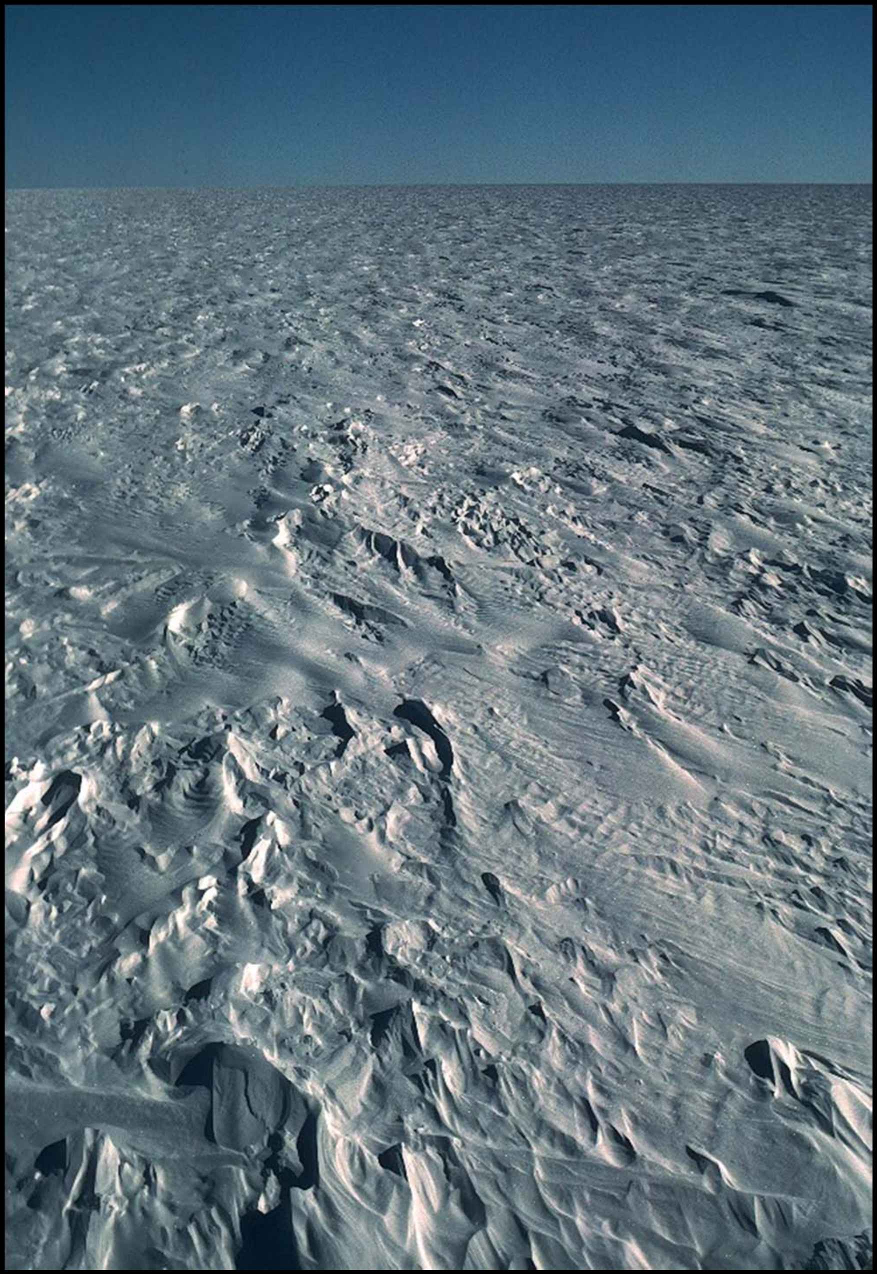
- Our frame of reference is a fixed reference.








GPS antenna
HB-LID
L
G
Gyro Platform
Laser Scanner
Laser Beam
Glacier Surface



<u>Remote Sensing Methods</u>

SAR

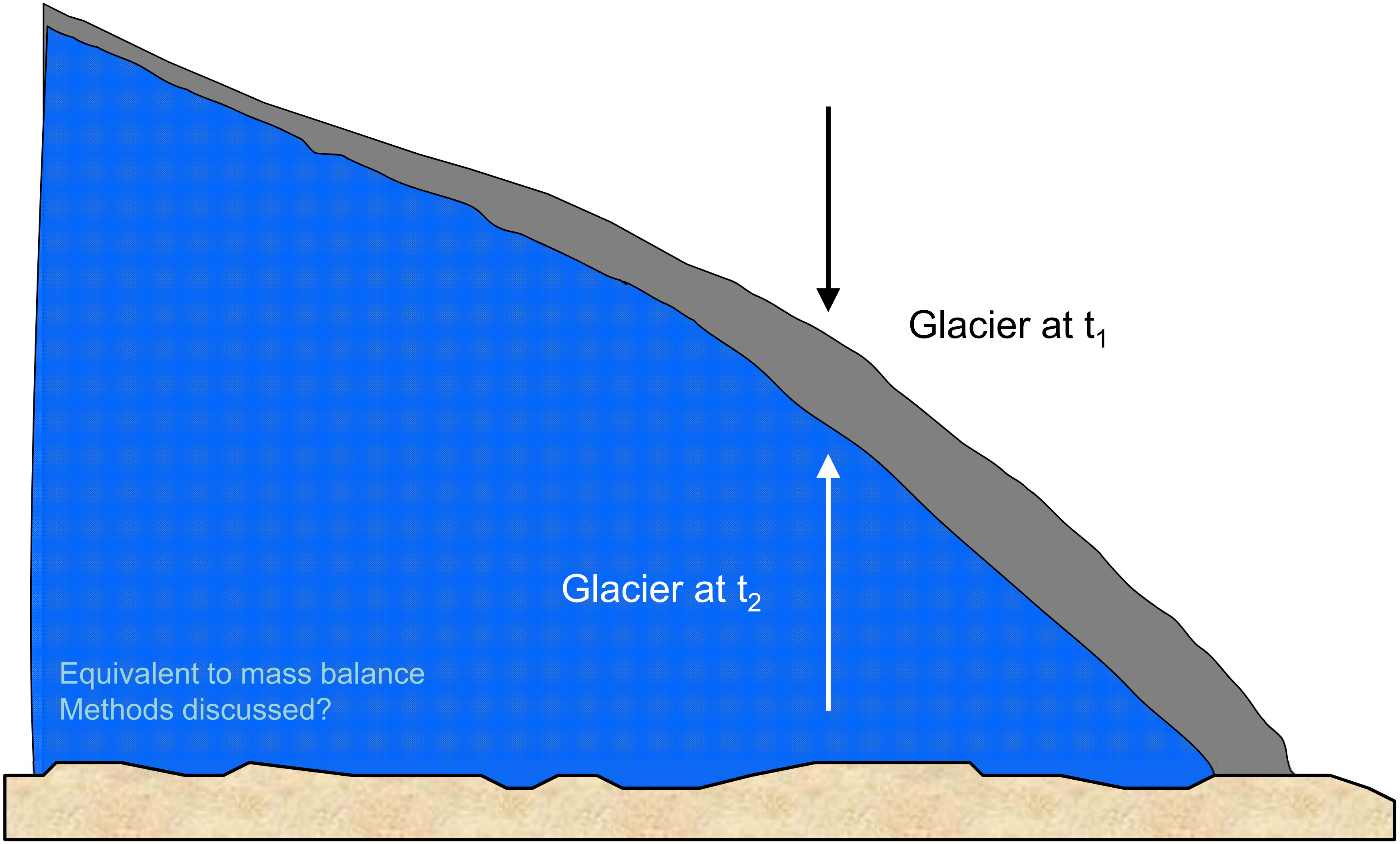
Photogrammetry

Laser Altimetry – LiDAR

GRACE?

Another Method

# Volume Change




END