**Mass Balance**
- Describes input/output relationship of snow, firn, and ice.
- Difference between accumulation and ablation is the net mass balance.
- Balance year is interval between time of minimum mass balance one year to the minimum the next year.

Equilibrium means glacier has to transfer mass from above to below the ELA; or net retreat or advance with negative or positive mass balance.

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**Economy of Glaciers**
- Regional Climate
- Energy balance
- Lags
- Net Mass Balance
- Quaternary Studies
- Geologic Record
- Landforms/deposits
- Glacial response time
- Lags
- Lags
- Lags
How does a glacier's morphology and elevation profile influence response time?

Glacial response time

\[ = f (\text{length of the flow path and rate of flow}) \]

What controls these parameters?

Make a list……

At any point on the glacier

\[ b_n = b_w + b_s \]

- Where
  - \( b_n \) = net balance
  - \( b_w \) = winter
  - \( b_s \) = summer balance
- may be + or - depending on the yearly conditions

From Bill Locke, Bozeman

Lemon Creek, Cascades

Columbia Glacier, Cascades

Miller and Pelto, 1999
In the field - dig snow pits

- Stainless cylinders
- 500 cm$^3$
- Calculate volume of snow accumulated in meters of H$_2$O equivalent

$\text{b}_n \times \text{area} = \text{balance (B}_{\text{net}}\)$

Steady state glacier = ~65% accum area

What are the consequences of a rise or fall of the ELA?

Equilibrium Line Altitude (ELA)

controlled by
1. temperature
2. latitude
3. altitude
4. aspect
5. continentality
http://www.nichols.edu/departments/glacier/cache.htm

1916

1966

http://www.nichols.edu/departments/glacier/index.html

1937

Bradford Washburn

2006

David Arnold

http://www.uaf.edu/water/faculty/nolan/mccall/index.htm

http://www.uaf.edu/water/faculty/nolan/mccall/index.htm

SOUTH CASCADE GLACIER CHANGES THROUGH TIME

1960

1979

1991

McCall Glacier, located in Arctic National Wildlife Refuge Alaska, has the longest history of scientific observation for any U.S. Arctic Glacier. Observations began with International Geophysical Year in 1957-58 (pre-dating the Refuge).
Reconstructing Paleo ELAs pg 83-85 B&E

- Cirque Floor Elevations
  - Why is this a bad idea?

- Toe to Headwall Area Ratio (THAR)
  - Median elevation of 0.5, 0.6, 0.4 as ELA

- Maximum altitude of Lateral Moraine
  - Lateral moraines only below ELA
  - Problem of preservation; does it = steady state?

- Area Accumulation Ratio (AAR)
  - Ratio of Accumulation Area/total area
  - Assume steady at ~0.65 +/- 0.5; < .5 = neg mass balance
    and >0.7 is positive mass balance.

Athabasca Glacier
Canada
Note lateral moraines
Glacier Morphology - shape, elevation range

- No Topographic Control
  - Ice Sheets
  - Ice caps
- Topographic Controlled
  - Highland Ice caps
  - Valley Glaciers
  - Cirque Glaciers
  - Sidewall Glaciers
  - Spreading Ice Bodies
  - Ice Shelves
  - Ice Streams
  - Piedmont Glaciers

Response time to change in mass balance will vary

\[ f(\text{length flow line, velocity of ice}) \]

Antarctica in the world

Rapid Retreat
Alley et al, 2007; Alley et al, in review

Valley Glaciers

Cirque Glaciers
Piedmont Glaciers - Ellesmere Island (Evans)

To frontiers that still beckon...

R. Powell, NIU,
Ice Streams: Zones of fast flow

Floating Ice shelves

Andrill.org

Glaciology homework

- See handouts