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Exercises: Glacier mass balance

Including answers

1.) MASS-BALANCE SENSITIVITY

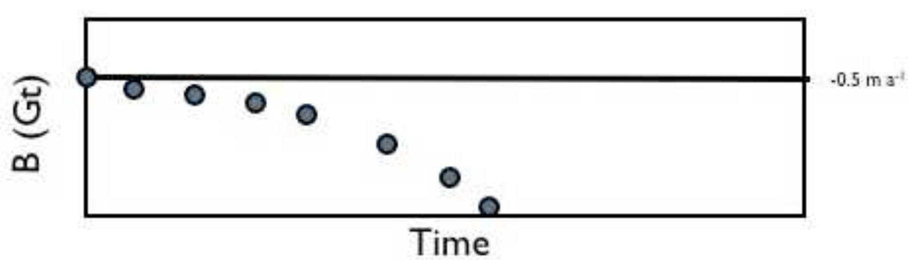
Figure 5 in the lecture notes shows the seasonal sensitivity characteristics of Devon Ice Cap. A climate model projects and increase in annual air temperature by 2050 by 2ºC. The temperature increase is not uniform throughout the year but warming is more pronounced in winter: The increase in winter (Oct-March) is 3ºC and in summer 1ºC. The current annual specific mass balance is
-0.5 m a^{-1}.

a) Compute annual mass-balance sensitivity for Devon Ice Cap?
b) What is the specific mass balance in 2050 using annual sensitivities and annual mean temperature increase?
c) What is the specific mass balance in 2050 using the seasonal sensitivity characteristic and the seasonally variable temperature increase?
d) Why do results differ?
e) In reality the specific mass balance will probably be different because there are a number of assumption. Will the specific mass balance be over- or underestimated by your approach? Why?

2.) MASS-BALANCE VARIATIONS WITH TIME

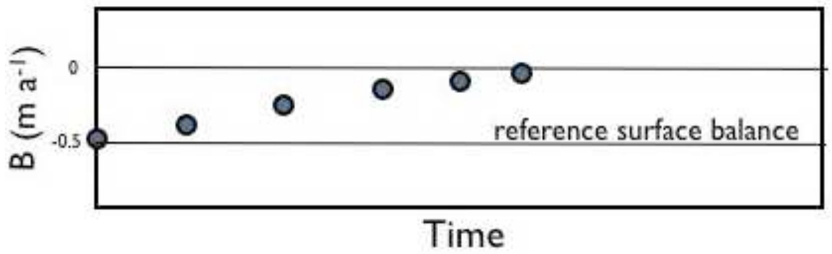
2.1 The specific mass balance of a 10 km long valley glacier is B= -0.5 m a^{-1} and the climate is such that the specific mass balance rate is constant for 100 years. The glacier retreats several km during this period and disappears in year 100. How does the mass balance (in Gt) vary with time?

Answer: The specific mass is constant, i.e. the amount of average thinning per year, however, as the glacier retreats it becomes smaller and there is less area over which the glacier things half a meter per year. Therefore the mass balance in Gigaton becomes less and less with time until it is zero. Mass balance in Gigatons is important for hydrological purposes, because it shows how much water is released from the glacier. The exact shape of the curve depends on glacier geometry and other factors.



2.2 Assume for the same glacier a sudden step-like temperature increase by 1ºC which leads to increased melt of the glacier with specific mass balance B= -0.5 m a^{-1} . The glacier retreats by 2 km until the glacier has reached a new equilibrium after 50 years. How does specific mass balance vary with time?

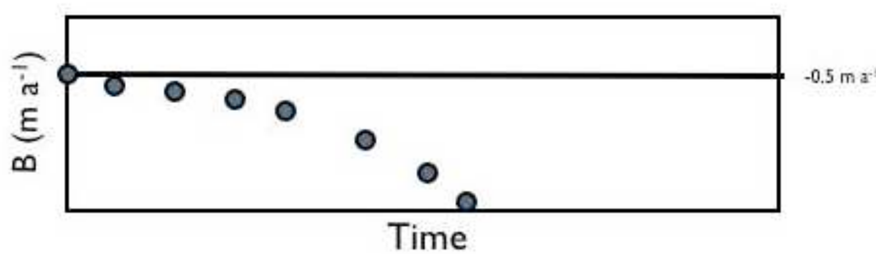
a) conventional mass balance
b) surface-reference mass balance



Answer: The conventional mass balance (integrated over the shrinking surface area) becomes less and less negative for the same specific balance rate, because low lying high ablation area are progressively lost and the glacier 'moves' to higher colder regions where there is less melt. The glacier reaches a new equilibrium and the specific mass balance will be zero. Although the climate does not change the conventional balance changes with time. Requires caution when interpreting long-term mass-balance series, which are usually reported over the actual area.
The reference surface balance does not change and therefore is a better indicator for climate. The climate does not change, and the ref-surface balance does not change.

2.3 Assume a steady temperature increase. The glacier will retreat and considerably thin at the same time and not reach a new equilibrium but eventually melt away. How does specific conventional specific mass balance vary with time?

Answer: There is 2 opposing effects: The retreat of the glacier to higher altitudes will stabilize the glacier (less melt higher up). However, the thinning of the glacier will destabilized the glacier (more area at lower elevations). It depends on which process is dominant whether or not the specific balance will approach zero or become more and more negative. The latter will happen here, because there is a steady temperature increase and considerable thinning. The specific mass balance will be become more and more negative.



3.) STAKE MASS-BALANCE MEASUREMENTS
Figure 2 illustrates how the specific mass balance is computed from ablation stakes drilled into the ice/firn of a glacier
In the **accumulation area** snow remains at the end of the summer, hence, all melt is due to snow.
In the **ablation area** all snow melts and part of the underlying ice/firn disappears.

The mass balance is computed from stake readings at the end of the accumulation season (when glacier mass is at a maximum) and at the end of the summer season (or mass-balance year) when glacier mass attains the annual minimum. Also end winter snow density and end summer firn density need to be measured.

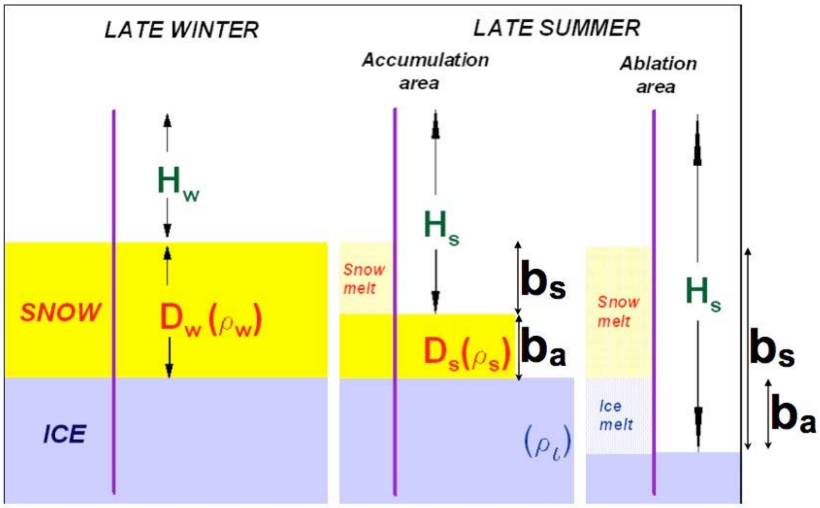


Fig. 2. Surface elevation changes at an ablation stake due to melt. *H* is stake reading, *D* is snow depth, ρ is density. Note that the snow density in late summer, $\boldsymbol{\rho_s}$ is usually higher than the one in late winter, $\boldsymbol{\rho_w}$. Ice density, $\boldsymbol{\rho_i}$ is often assumed to be 900 kg/m3 (0.9 kg/L).

Assume the firn line coincides with the equilibrium line and the following values for 2 stakes on the glacier:

End winter snow depth, Dw = 2 m
End winter snow density $\boldsymbol{\rho_w}$. =400 kg/m3
Late summer snow density $\boldsymbol{\rho_s}$ = 500kg/m3
Ice density = 900 kg/m3
Hw= 0.5 m

Compute the specific mass balance for 2 stakes on the glacier.

a) Stake 1: Hs=2 m

Answer: The winter balance is 2 x 400 /1000 (density of water) = 0.8 m w.e.
The stake is in the accumulation area because the drop in relative elevation is (2-0.5 m) 1.5 m, i.e. there is still snow left at the end of the summer
The summer balance is what was there in the first place (=0.8 m w.e.) minus what is left after the summer. What is left after summer is 0.5 x 500/1000 = 0.25 m w.e. The balance is 0.8 – 0.25 = 0.55 m w.e.

Stake 2: Hs = 3 m

Answer: The winter balance is 2 x 400 /1000 (density of water) = 0.8 m w.e.

The stake is in the ablation area because the drop in relative elevation is 2.5 m, i.e. there is snow snow left at the end of the summer.
What has dissappered is all snow (i.e. 0.8 m w.e.) plus the ice melt of 0.5 m, i.e. 0.5 x 900/1000 =0.45 m w.e. ice melt. Total summer balance is 0.8 + 0.45 = 1.25 m w.e.
The annual balance is 0.8 – 1.25 = -0.45 m w.e.

b) Give the equation how bs and ba can be computed from Hw, Hs, Dw and the densities.

Answer: $M_{ice} = \rho_w D_w + \left[H_S - H_W - D_w)\right]\rho_{firn/ice/s}$