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Exercises: Glacier mass balance

1.) STAKE MASS-BALANCE MEASUREMENTS

Figure 1 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 winter and summer 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 mass minimum (Fig. 1). Also end winter snow density and end summer firn density need to be known.

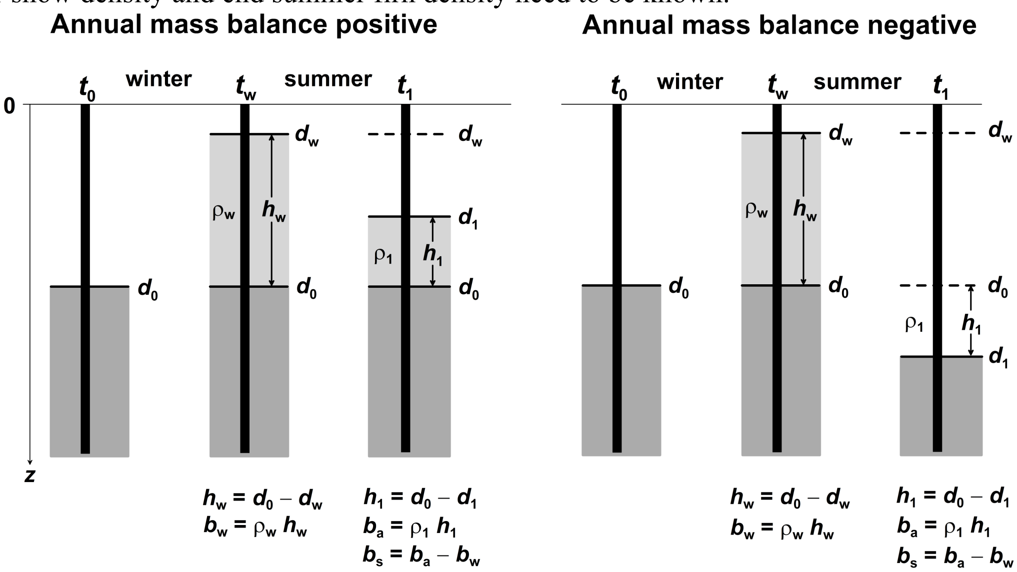


Fig. 1. Stake measurements of seasonal mass balances in a year of positive (left) and a year of negative (right) *surface mass balance*, with no *superimposed ice*. The vertical coordinate is positive downwards, and all distances are measured from the origin $z = 0$ at the top of the stake. Light shading represents *snow*; dark shading represents *firn* or *glacier ice*. Measurements are made at t_0, the start of the *accumulation season*; at t_w, the start of the *ablation season*; and at t_1, the end of the mass-balance year. The *winter balance* b_w is the change of mass between t_0 and t_w. The *summer balance* b_s is the change of mass between t_w and t_1. $\boldsymbol{\rho_w}$ and $\boldsymbol{\rho_1}$ are the mean snow densitites. $\boldsymbol{\rho_1}$ 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) (Cogley et al 2011).

Assume the firn line coincides with the equilibrium line and **compute the specific mass balance for the following 2 stakes drilled into the glacier surface**.

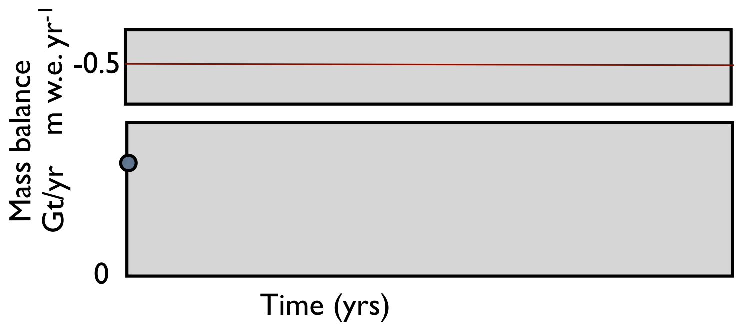
	Stake 1	b_w	b_s	b_a	**Stake 2**	b_w	b_s	b_a
End winter snow depth, h_w	**2 m**				**2 m**			
Stake reading (top of stake to snow/ice surface) at the end of winter, d_w	**0.5 m**				**0.5 m**			
Stake reading end of summer, d_1	**2 m**				**3 m**			
End winter mean snow density ρ_w	**400** kg/m3				**400** kg/m3			
Late summer snow density ρ_1	**500** kg/m3				N/A			
Ice density	N/A				**900** kg/m3			

Note: **1 kg/m^2 = 1 mm w.e**. (because the density of water is 1000 kg/m^3).

2.) MASS-BALANCE VARIATIONS WITH TIME

→ *Using different mass balance units*

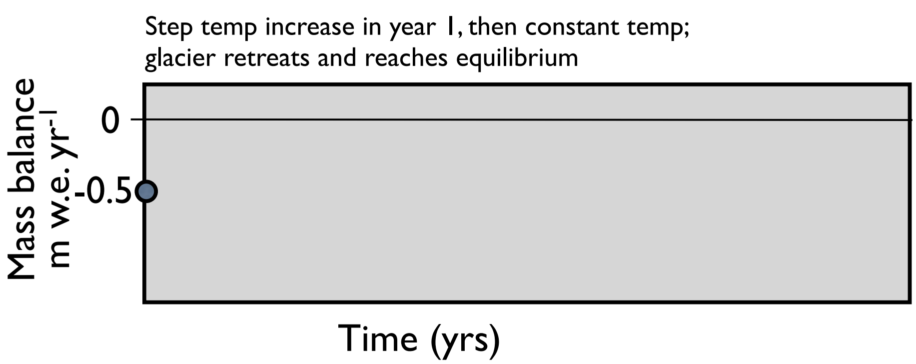
2.1 Case 1: The **specific mass balance rate** (i.e. mass per area, in kg/m^2 or m w.e.) of a 10 km long valley glacier is B= -0.5 m yr^{-1}, and the climate is such that the specific mass balance rate is constant for 100 years. The glacier retreats several km and disappears in year 100. How does the **mass balance rate in Gt/yr** vary with time? The specific rate is constant (see upper panel). Sketch the course of the **mass balance rate in Gt/yr** in the lower panel.



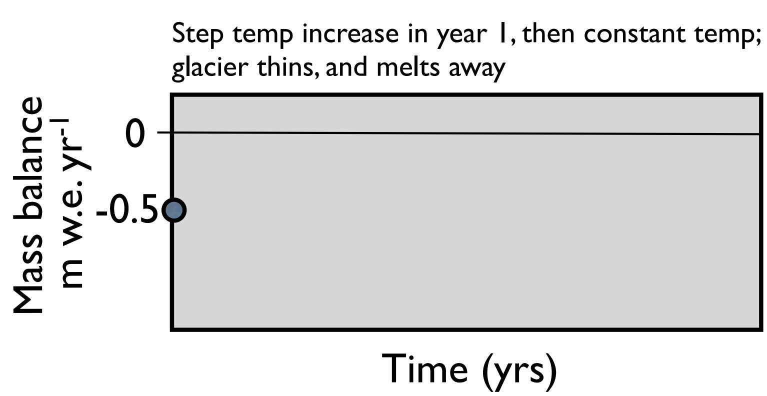
2.2 Case 2: Assume a sudden step-like temperature increase by 1ºC (i.e. constant teperature thereafter) which leads to increased melt of the glacier resulting in a specific glacier-wide mass balance rate of B= -0.5 m a^{-1} for the first year of the temperature increase. The glacier retreats by 2 km until it has reached a new equilibrium after 50 years. How does the specific mass balance (m w.e. yr^{-1}) vary with time?

a) **conventional** mass balance

b) **surface-reference** mass balance

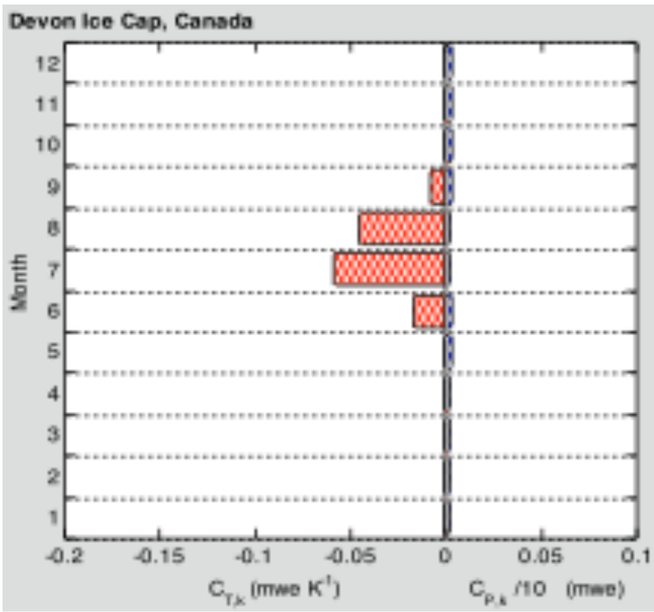


2.3 Case 3: As case 2 but the glacier does not retreat much but it **thins** considerably; it does not reach a new equilibrium but eventually melts away. How does the specific conventional specific mass balance vary with time?



3.) MASS-BALANCE SENSITIVITY – PROJECTING FUTURE MASS BALANCES

Background: Mass balance sensitivities give the change in mass balance in response to a step-change in climate, for example, a temperature or precipitation increase. A temperature increase will make the mass balance less positive or more negative; the opposite is true for an increase in precipitation (more snow). For example, assume the specific annual mass balance is -0.2 m w.e.; if the temperature increased by 1ºC the mass balance would be -0.6 m w.e.; then the annual mass-balance sensitivity to temperature is -0.4 m w.e. K^{-1}.



The figure shows the seasonal sensitivity characteristics of Devon Ice Cap, i.e. how the mass balance would change in response to a 1ºC temperature index and a 10% precipitation increase.

Exercise: A climate model projects an 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 specific mass balance rate is -0.5 m yr^{-1}.

a) Compute annual **mass-balance sensitivity** for Devon Ice Cap?

b) Estimate the **specific glacier-wide mass balance be** in 2050. Use the sensitivity approach based on 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?