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Exercises: Glacier meteorology / Energy balance

Including answers

1.) ENERGY BALANCE – MELT CALCULATION

A glacier is polythermal with a cold surface layer. The glacier surface is at melting point. Assume there are no other processes that remove mass from the surface than the one apparent from the information below. The following variables (daily means): are measured at a weather station on the glacier.

Global radiation = 200 Wm^{-2}, Albedo = 0.4, longwave incoming radiation = 280 W m^{-2}, sensible heat flux = 30 Wm^{-2}, latent heat flux = 20 Wm^{-2}. Warming of the cold surface layer consumes 5 Wm^{-2}. Calculate the energy balance.

Note that ablation includes all process that remove mass from a glacier, i.e. not only melt. Ablation here is the sum of melt and sublimation. The latent heat of fusion (melt) is 334000 J/kg, the latent heat of vaporization is 2,883000 J/kg.

a) How much energy is available for melting?

> *Answer: Q=G+(1-albedo)G+Longin-longout+sensible+latent-groundheatflux. Longwave outgoing radiation is 316 W/m2 because the surface is melting.*
> *Q=200-(200x0.4)+280-316+30+20-5 =* ***129 W/m2***

b) How much **melt** occurs during that day (cm) ?

> *Answer: Energy available for melt converted to melt (m w.e.): 129 W/m2 / (334000 J/kg x 1000 kg/m3) = 3.862 x 10^{-7} m per second. Convert to per day (x 60 x 60 x 24) and cm =* ***3.3 cm****.*

c) How much **ablation** occurs during that day (cm) ?

> *Answer: Ablation is melt (computed above plus any losses by sublimation). Because there is no sublimation but condensation (the latent heat flux is positive) ablation = melt =* ***3.3 cm***

d) Assume the latent heat flux switches sign but all other components remain equal.
How much melt occurs during that day (cm) ?

> *Answer: If the latent heat flux switches sign, it is 20 W/m2, i.e. the energy available for melt is only 129 -40 = 89 W/m2 and melt is 2.3 cm.*
> *Sublimation is 20 W/m2 / (2830000 x 1000) x 3600 x 24 =0.06 cm*

e) How much ablation occurs (cm)?

> *Answer: Sublimation is 20 W/m2 / (2830000 x 1000) x 3600 x 24 =0.06 cm. Total ablation is 2.3+0.06=* ***2.4 cm****.*
> *Hence melt is much reduced if the latent heat flux switches sign because it takes 7.5 times more energy to sublimate than melt ice, i.e. for the same meteorological conditions otherwise less ice is removed if there is sublimation.*

2.) TIME SERIES

Figure 1 shows hourly time series of meteorological observations and energy balance components at a weather station on a glacier.

a) Label what is what on the figure.

Shown are air temperature (K), global radiation, latent heat flux, longwave incoming and outgoing radiation, net radiation, rain heat flux, sensible heat flux, relative humidity (%), and wind speed (ms^{-1}). All energy fluxes in W/m2.

> *Answer: from above: net radiation, sensible, latent, rain, air temp, humidity, wind speed, global, longwave in, longwave out.*

b) Identify a foggy and clear-sky day (Name at least 2 indicators).

> *Answer: foggy: very low global radiation, high humidity, high longwave incoming; clear-sky: the opposite*

c) Identify a period of surface melting and a period with surface temperatures below freezing.

> *Answer: melting when longwave outgoing radiation is constant at 316 W/m2.*

3.) SPATIAL DISTRIBUTION OF ENERGY BALANCE COMPONENTS

Figure 3 shows the modeled spatial patterns of the energy fluxes on Storglaciären, Sweden, averaged over the period 7 June to 17 September 1993. Shown are the turbulent heat fluxes (sensible and latent), global, direct, diffuse and longwave incoming and outgoing radiation, and net radiation (all in W m^{-2}), and melt (in cm) during the >3 months period.

Air temperature (not shown) is distributed assuming a linear decrease in temperature with elevation. Humidity and wind speed (not shown) measured at one site on the glacier were assumed constant in space. The glacier surface was at the melting point. Cloud cover was assumed uniform across the glacier.

Which component does each subplot show ?

> *Answer: by row: direct, diffuse, global, long in, long out, net, sensible, latent, melt*

4.) COLD CONTENT

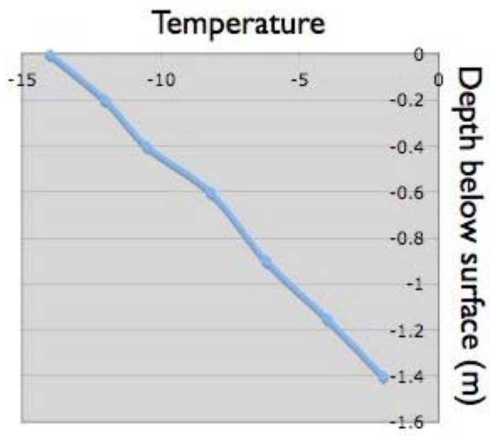
Figure 3 shows a temperature profile in the snow pack after a cold night. During the day air temperatures increase above the freezing point and it starts raining. The cold content can be eliminated by release of energy from refreezing water. How much rain (in mm) is needed to completely eliminate the cold content, C ?

$$C = -\int_0^Z \rho(z) c_p T(z) dz$$

Latent heat of fusion, Lf = 334 000 J kg^{-1} (Energy required to melt 1 kg of snow/ice)

Specific heat capacity, cp = 2009 J kg^{-1} K^{-1} (snow) (Energy required to warming 1 kg of snow by 1 K)

Mean density of snow = 500 kg/m^3



Answer: Rough overview calculation: Cold content = (14 (K) x 1.6 (m))/2 x 2009 J/kg/K x 400 kg/m3 =9 x10^6 J/m2.
Divide by density of water and latent heat of fusion to compute how much water needed to eliminate this cold content by re-freezing.
/1000/340000 = 2.7 cm.
Hence a uniform layer of 2.7 cm rain is enough to make this snowpack temperature (i.e. 0ºC)

5.) EFFECT OF CLOUDS ON MELT

Assume a clear sunny day on a melting glacier in summer, suddenly thick low clouds start moving in:
How will net radiation change? (Use numbers for illustration, for example assume G=800 Wm^{-2} (clear-sky), Lin =250 W m^{-2}.

Answer: Depends on albedo. If albedo is high the effect on short-wave radiation is not very large because much is reflected anyway. In that case the increase in longwave radiation may dominate and net radiation may actually increase despite more clouds. If albedo is low, i.e. much energy is absorbed by the surface, the decrease in solar energy will be larger than the increase in longwave radiation and net radiatio will decrease.

6.) EFFECT OF RAIN ON MELT

Assume a rainy day with 15 mm d^{-1}. Daily mean near-surface air temperature is 15ºC. Calculate the rain heat flux and compare it to typical values of net radiation and the turbulent heat fluxes (see Figure 3).

$$Q_R = \rho_w c_w R(T_r - T_s)$$

c_p=specific heat of air, 1005 J kg^{-1} K^{-1} c_w specific heat of water, 4180 J kg^{-1} K^{-}
rain intensity, R, and rain temperature, T_r.

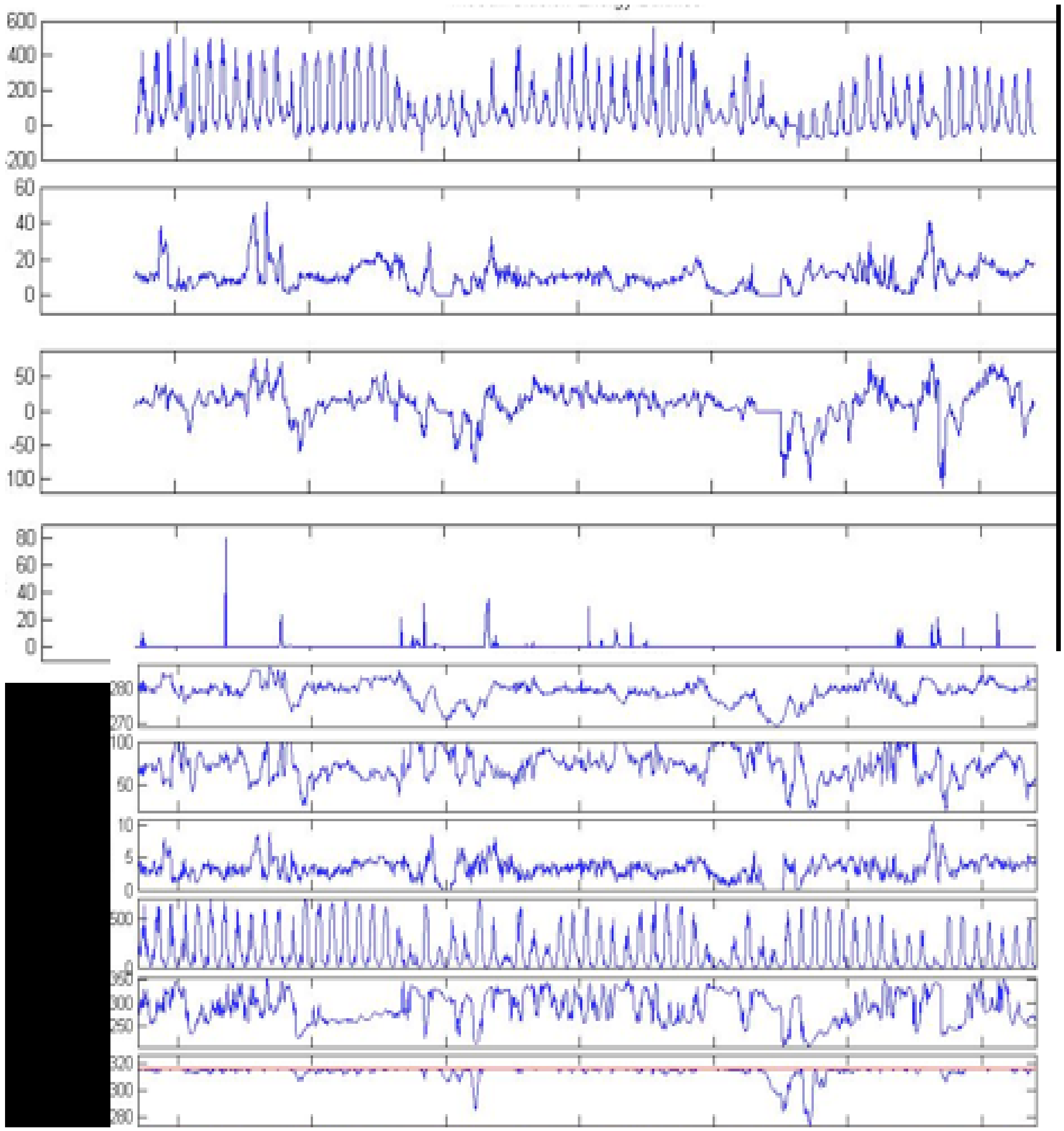


Figure 1. Meteorological observations and energy balance components on a glacier. Tics every 10 days.

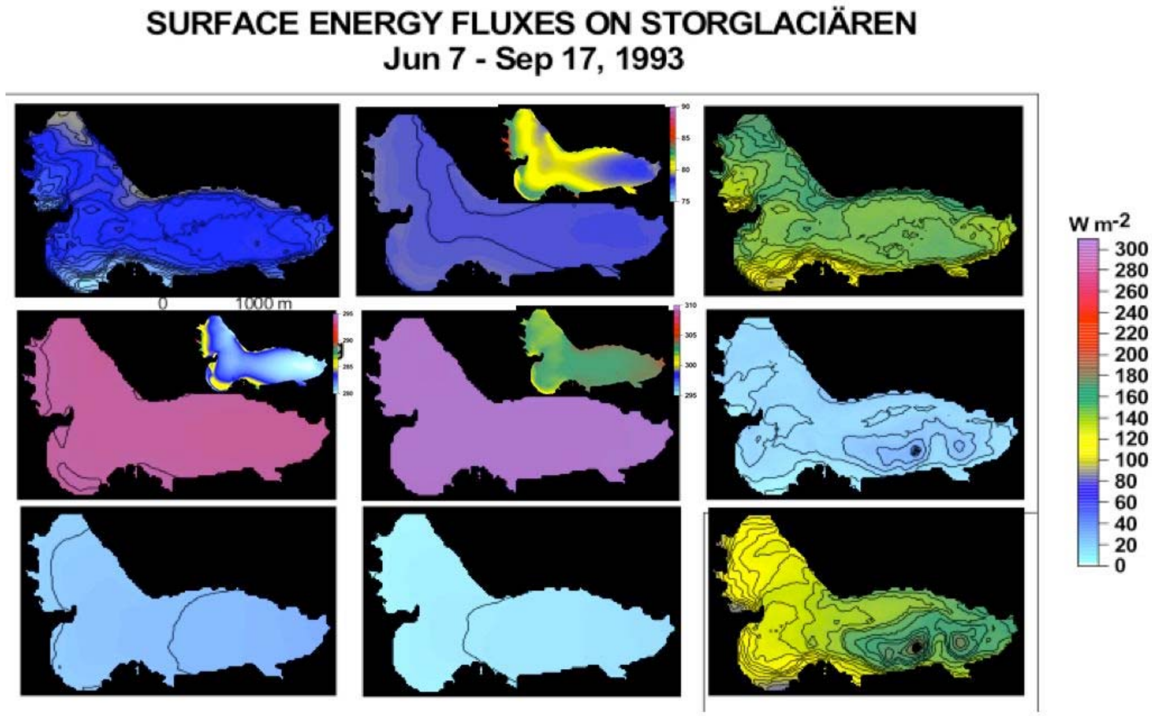


Figure 2. Energy fluxes on Storglaciären, Sweden, averaged over the period 7 June to 17 September 1993.