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Exercises: Glacier meteorology / Energy balance

1.) ENERGY BALANCE – MELT CALCULATION

A glacier is polythermal with a cold surface layer. The glacier surface is at melting point. The following variables (daily means) are measured at a weather station on the glacier.

Global (shortwave) 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}.

Latent heat of fusion L_f = 334,000 J/kg (needed to compute melt)
Latent heat of vaporization L_{fv} = 2,883000 J/kg (needed to compute sublimation)

a) How much energy is available for melting (**Calculate the energy balance**)? Note that you need to estimate the longwave outgoing radiation from the information given above.

Answer:
Net radiation = 200 – (200x0.4) + 280 – 316 = 84 W/m2
Energy available for melt = 84 + 30 – 20 – 5 = **89 W/m2**

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

Answer:
Divide energy by latent heat of fusion: 89/344000 x 60x60x24 = 23 kg/m2 = **2.3 cm w.e.**

c) How much **ablation** occurs during that day (cm) ? Note that ablation includes all process that remove mass from a glacier, i.e. here ablation here is the sum of melt and sublimation.

Answer:
Because the latent heat flux is negative indicates sublimation, i.e. there is additional mass loss to the mass loss through melt.
Mass loss by sublimation = 20/2883000= 0.6 kg/m2 = 0.6 mm w.e. = 0.06 cm w.e..
Ablation = 2.3+0.06 = **2.36 cm w.e.**

Note sublimation requires a lot more energy than melt. If the latent heat flux was positive in this case an additional 20/344000 = 5.2 kg/m2=0.52 cm w.e. would melt, i.e. total ablation would be 2.82 cm w.e.

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.

*Answe*r: from top to bottom: Net, Sens, latent, precip, temp, hum, wind, Glob, Long in, Long out

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

Answer: low global radiation, high long-wave radiation (high humidity is less good of an indicator)

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

Answer: melting when longwave outgoinng radiation is 316 W/m2, freezing: when it is less

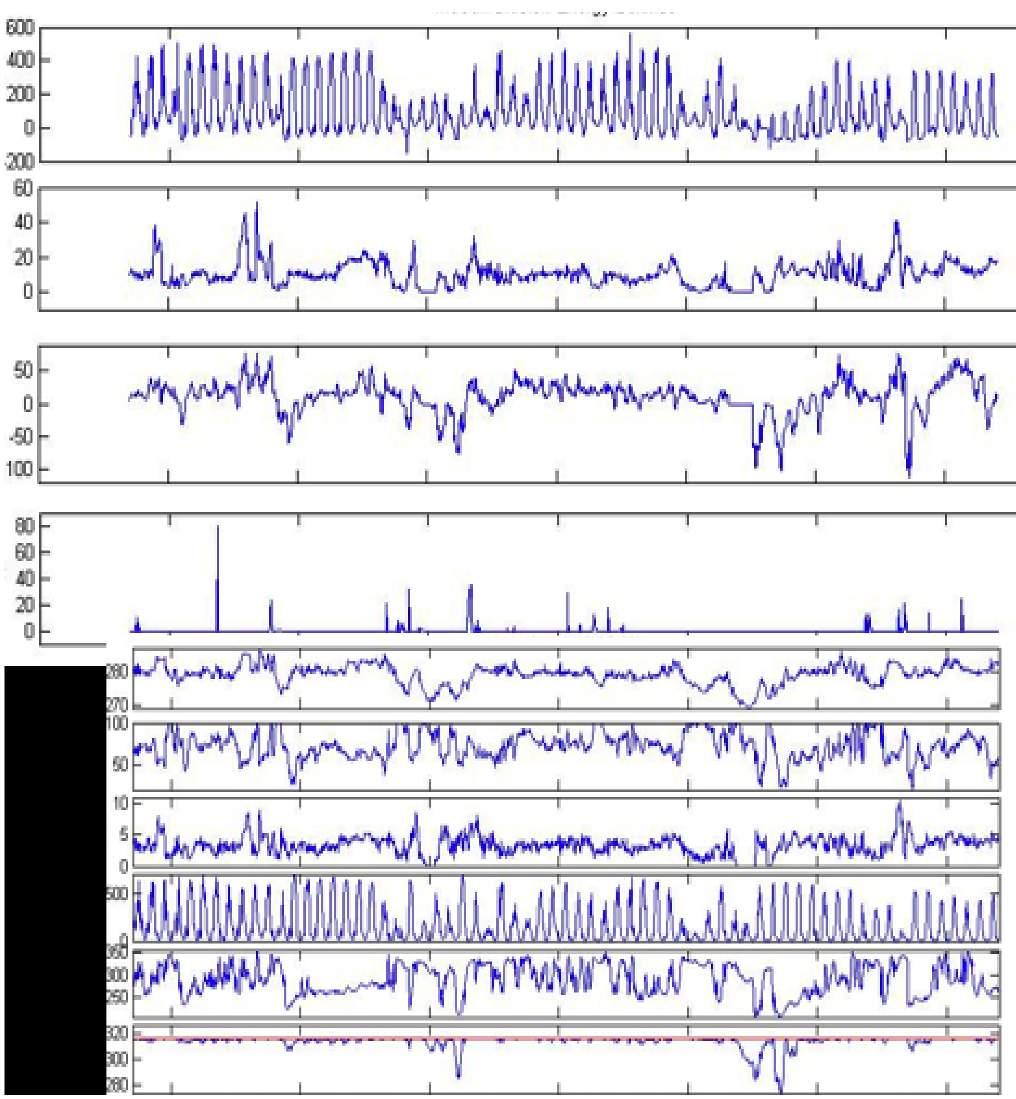

Figure 1. Meteorological observations and energy balance components on a glacier. Tics every 10 days.

3.) SPATIAL DISTRIBUTION OF ENERGY BALANCE COMPONENTS

Figure 3 shows the modeled spatial pattern of the energy fluxes on Storglaciären, Sweden, averaged over the period 7 June to 17 September 1993. The model is forced by weather station data from one station in the center of the glacier. Shown are the

- sensible heat flux
- latent heat flux
- global radiation
- direct radiation
- diffuse radiation
- longwave incoming radiation
- outgoing longwave radiation
- net radiation (all in W m^{-2}),
- and melt (in cm) ove the >3 months period.

Air temperature (not shown) is extrapolated in the model assuming a linear decrease in temperature with elevation. Humidity and wind speed (not shown) measured at the weather station were assumed constant in space. The glacier surface was at the melting point throughout the period. Cloud cover was assumed uniform across the glacier.

Which component does each subplot show ?

Answer: Per row from top to bottom: Direct, diffuse, global, long in, long out, net rad, sensible, latent, melt

SURFACE ENERGY FLUXES ON STORGLACIÄREN
Jun 7 - Sep 17, 1993

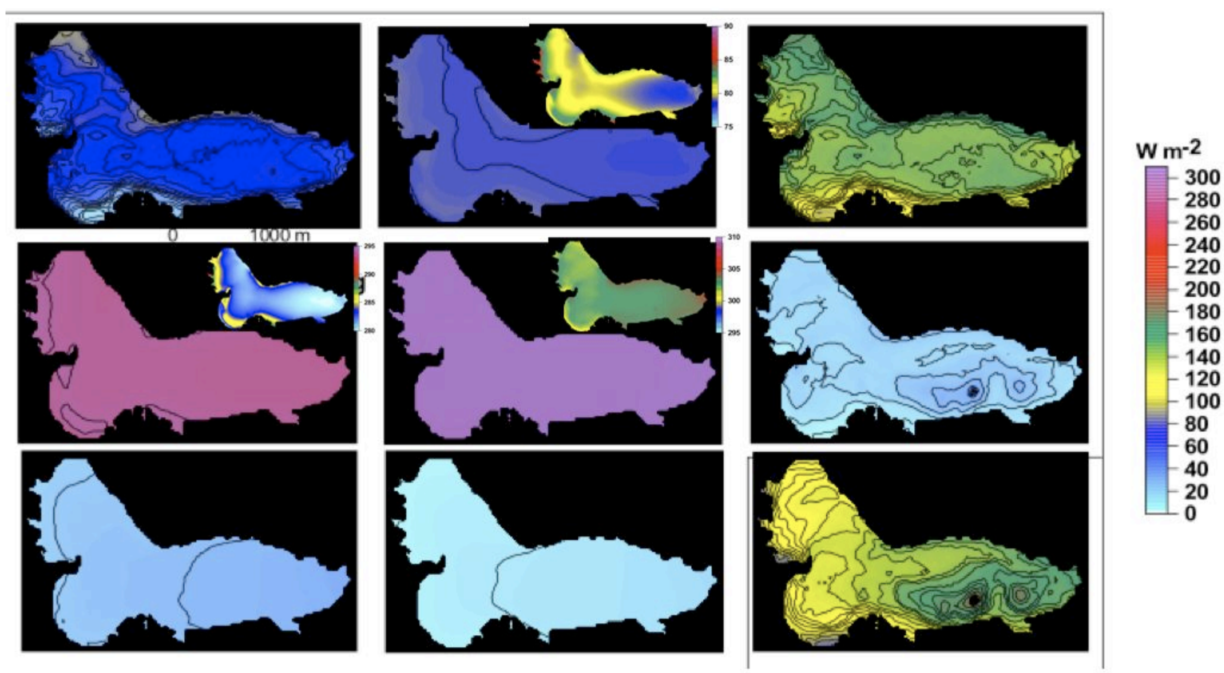

Figure 3. Energy fluxes on Storglaciären, Sweden, averaged over the period 7 June to 17 September 1993.

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), Longwave incoming radiation L_{in} is typically around 250 W m^{-2} during a sunny summer day, while it is around 300 W m^{-2} during foggy conditions. Longwave outgoing radiation is fixed when the surface is melting.

Answer: Global radiation will go down, longwave radiation will go up

Effect on net radiation depends on albedo, if albedo is very high, the change in net shortwave radiation does not change very much because almost all is reflected (>90%), so that the change in net longwave radiation may be bigger and the net effect that the radiation may turn positive in extreme cases.

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 2 and 3).

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

ρ_w = density of water (1000 kg/m3)
c_w = specific heat of water, 4180 J kg^{-1} K^{-1}
R = rain intensity (e.g. mm/day)
T_r = rain temperature (K or Celcius)
T_s = rain temperature (K or Celcius)

Answer:
1000 x 4180 x 0.015 m/d x 15 /(3600X24) = **10.9 W/m2**
Note that even with this heavy and warm rainfall, the energy supplied by the sensible heat of rain is small compared to the other heat fluxes.