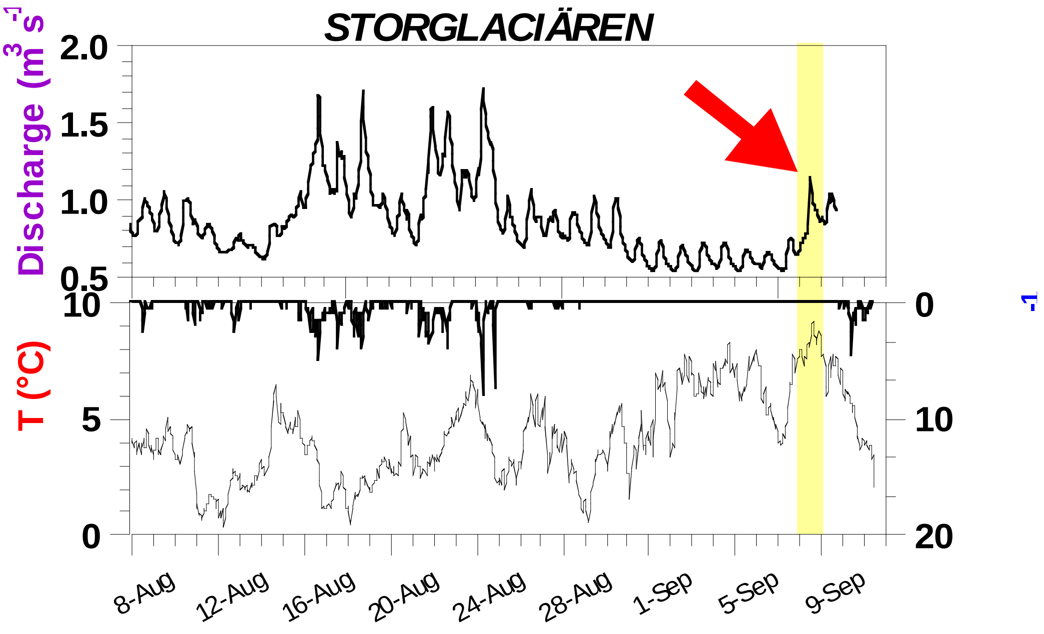
Exercise: Surface energy balance from AWS data

Purpose

The purpose of this exercise is to compute melt based on the energy balance method. The input data originates from a weather station on Storglaciären, which has recorded: air temperature (°C), relative air humidity (%), wind speed (m/s), global radiation (shortwave incoming radiation), reflected shortwave radiation, longwave incoming radiation, outgoing longwave radiation and precipitation (mm/h). All radiation components are in W/m^2.

Problem

The figure below shows hourly discharge data from Storglaciären in fall 1998. On 8 September discharge increases considerably after a period of low flow. The figure also shows that the air temperature was only little higher than during the preceding period and void of precipitation. A possible explanation for the sudden increase in discharge from a glacier is a so-called *subglacial release event*, which means that water stored in or under the glacier is suddenly released due to internal drainage mechanisms. By means of energy balance computations it is possible to determine if the high flow event on 8 September was such a subglacial release event or if it was caused by an increase in glacier melt although the temperature did not increase very much.



Exercise

1. Compute the following variables (data in *AWSdata.xls) (Equations are given in Appendix B):*
   - longwave radiation balance
   - net radiation balance (W/m^2)
   - sensible heat flux (W/m^2)
   - latent heat flux (W/m^2)
   - rain heat flux (W/m^2)
   - energy balance (i.e. sum of the fluxes above) (W/m^2); *NOTE: W = J/s, melt is in mm/hour*
   - melt (mm/hour).

   The file contains the year, day of the year (2. column) and the hour the data refers to (100 refers to the hour between midnight and 1 am). The following columns contain the climate data. The file contains hourly data between 20 August (day 232) and 11 September (day 254). see Appendix A.

2. How much is **total melt** during this period, i.e. how much has melted in total (in cm) according to the calculations ?

3. Discuss with the help of your energy balance results whether the increase in discharge on 8 September was a *subglacial release event* or not.

4. Around 1 September **melt** becomes **negative** according to the computations. How do you interpret this? What is happening in nature?

5. During which periods do **condensation** and **sublimation** prevail?

6. Which days were probably **foggy** and which ones were subject to **clear-sky conditions** ?

7. What can you infer about **cloud cover** from the data during the nights 31 August - 2 September ?

8. What is the **energy partitioning**, i.e. how much energy to the total is provided by net radiation, sensible heat flux, latent heat flux and the rain heat flux?

Appendix A: Table how to convert day numbers into dates. In case of leap year add one to all number > 60 (60 corresponds to 1 March in case of non-leap year, but to 29 February in case of leap year)

JULIAN DAY CALENDAR

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
JAN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
FEB	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60		
MAR	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
APR	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	
MAY	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151
JUN	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	
JUL	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212
AUG	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243
SEP	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	
OCT	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304
NOV	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	
DEC	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365

Add 1 to red values during leap years.

Appendix B:

Computation of the surface energy balance over melting snow and ice

Energy available for melt (W m^{-2})

$Q_M = Q_{Net} + Q_H + Q_L + Q_R + Q_G$

Q_{Net} = net radiation　Q_H = sensible heat flux　Q_L = latent heat flux　Q_R = rain heat flux
Q_G = ground heat flux (neglected in our calculations)

Net radiation (W m^{-2})

$Q_{Net} = G - R + L\downarrow - L\uparrow$

G = global radiation　R = reflected shortwave radiation
$L\downarrow$ = longwave incoming radiation　$L\uparrow$ = longwave outgoing radiation

Sensible heat flux (W m^{-2})

$Q_H = c_p \cdot P \cdot A \cdot u \cdot (T_2 - T_0)$

T_2 = air temperature at 2 m　T_0 = surface temperature (=0)　u = wind speed in ms^{-1}
C_p = specific heat of air (**1005 J kg^{-1} K^{-1}**)　P = air pressure at climate station (**85 000 Pa**)
A = exchange coefficient = **2.8885 x 10^{-8} kg m^{-3} Pa^{-1}**

Latent heat flux (W m^{-2})

$Q_L = 0.623 \cdot L_v \cdot A \cdot u \cdot (e_z - e_o)$

e_z = vapour pressure at 2 m
e_0 = vapour pressure at surface (= 611 Pa)
L_v see below, A see above

<u>*Computation of vapour pressure e_o from relative humidity (%):*</u>

Relative humidity RH [%] = e/E · 100 → e = RH · E/100

E = saturation vapour pressure for given temperature in Pascals (Pa)
T = air temperature in °C

$$E = 610.78\, e^{\frac{17.08085\, T}{(234.15+T)}}$$

Rain heat flux (W m^{-2})

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

c_w = specific heat of water (4200 J kg^{-1} K^{-1}), ρ_w = density of water (1000 kg/m3)
R = rainfall rate (mm/time step)　*(NOTE: Watt is Joule/**second**, but R is in mm/h !!!)*
T_r = temperature of rain (assumed to have temperature of air)
T_s = surface temperature (melting assumed = 0)

Conversion of energy (W m^{-2}), Q, into water equivalent melt WE (mm)

$$WE_{melt} = \frac{Q_M}{r_{water} L_f}$$

Latent heat of fusion　**L_f = 334 000 J kg^{-1}** (phase change ice – water)
Latent heat of vaporisation　**L_v = 2 430 000 J kg^{-1}** (phase change water – vapour)
(latent heat of sublimation = 2 830 000 J kg^{-1} (phase change ice – vapour))

1 W = J/sec
1 mm rain or melt = 1 litre/m^2 = 1 kg/m^2