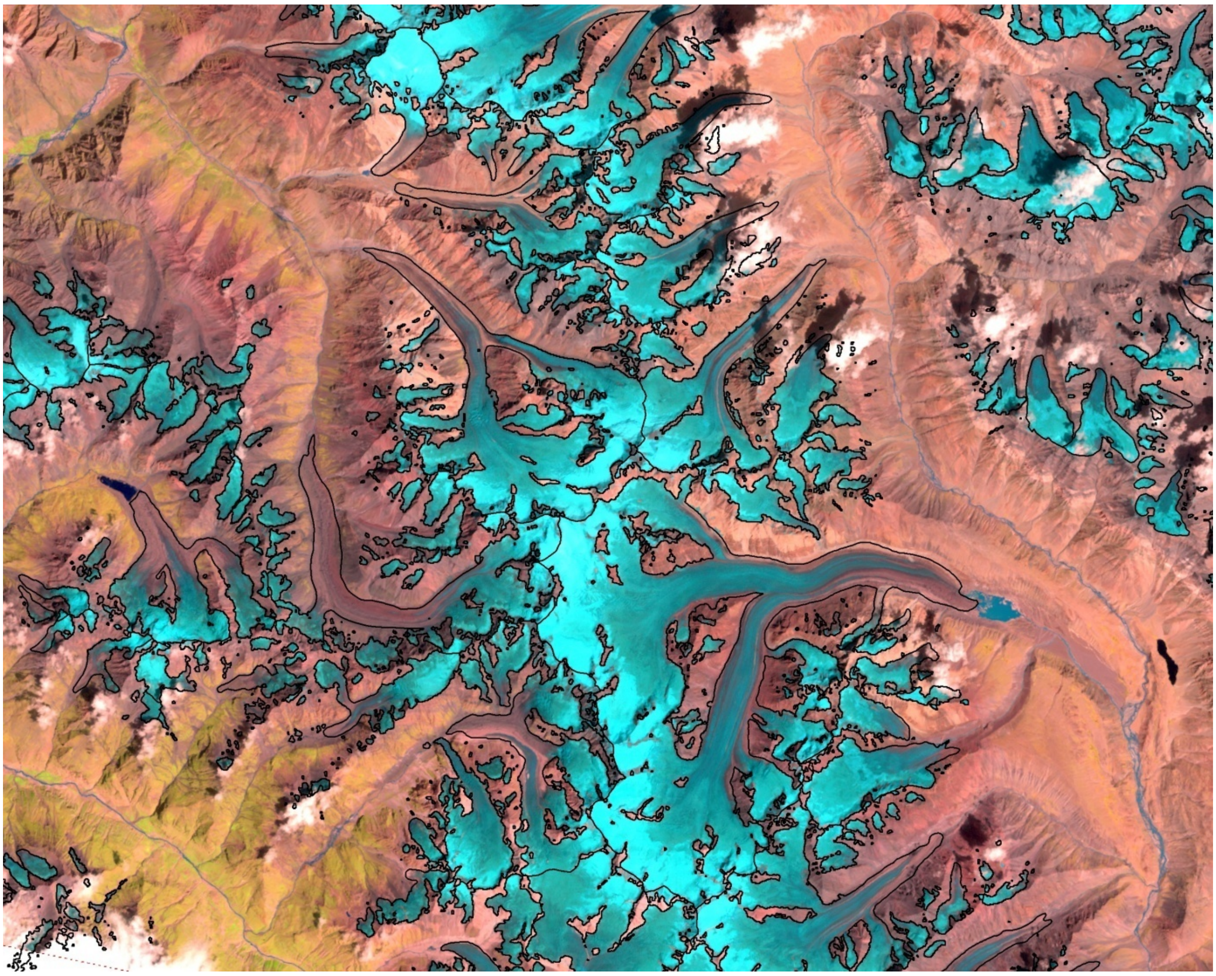
IHCAP

Indian Himalayas Climate Change Adaptation Programme



Capacity building programme “Cryosphere” Level-1

(August 18 - September 15, 2014)

Glacier and snow melt and runoff

Exercises

Exercise 1: Precipitation measurements

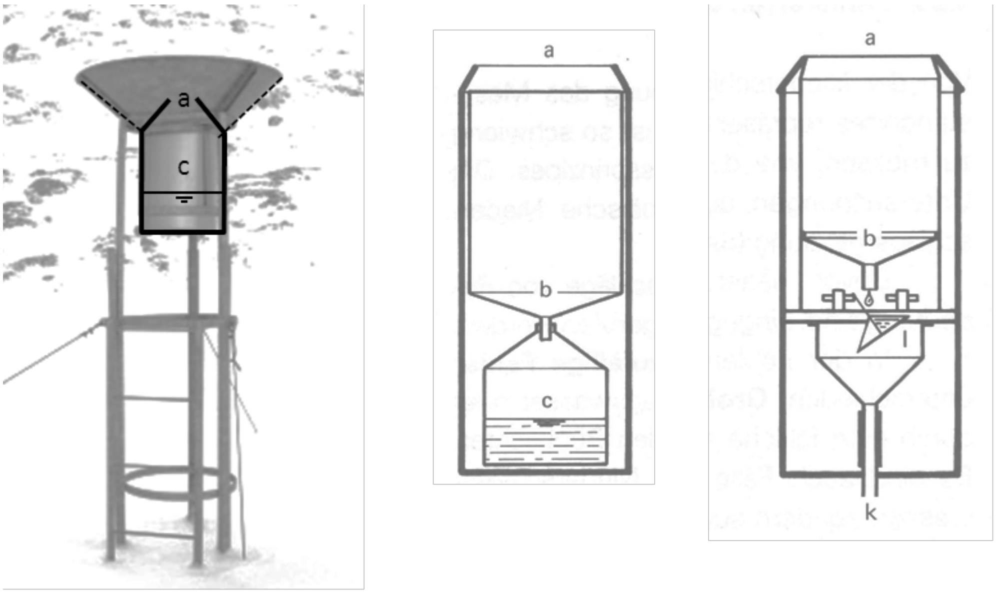
1. Aim

Precipitation is one of the most important hydrological model inputs. Especially in hydrological modelling of mountainous, high elevated areas, a representative estimate of solid precipitation is crucial. However, the measurement of solid precipitation remains a challenging task. Hydrologic modellers need to be aware of the limitations and uncertainties of precipitation measurements. Often, observations are underestimating precipitation and may be an important source for uncertainties. The main aim of this first exercise is to examine precipitation data from three different gauging types and to compare them to SWE observations.

2. Study site and data

On Weissfluhjoch test site, the SWE of new snow is measured manually every day at around 07:30 am at an altitude of around 2540 m a.s.l. The data for this exercise were observed in the winter season 1996/97. At this altitude and site between September and May, precipitation occurs predominantly in solid form. Therefore, the sum of the daily measurements of the water equivalent of new snow represents well the total precipitation over the accumulation season. Precipitation was additionally recorded by three different precipitation gauges (see Figure 1). Every gauge has its advantages and limitations, which are discussed in this exercise.

Data: WSL Institute for Snow and Avalanche Research SLF



totalisator unheatet Hellmann heatet tipping bucket

Figure 1: Illustration of common precipitation gauges: totalisator (left), unheated Hellmann (middle) and heated tipping bucket (right). The components of the precipitation gauges are:a) collecting area b) collecting funnel c) collecting tank l) rocker with two measuring cups and contacts k) outflow. (from Geiger et al., 1991)

3. Calculation

a) Plot the cumulative curves of the measured SWE and the precipitation data recordedby the three different precipitation gauges.
b) Compute the percentage of cumulative recorded precipitation at the end of the accumulation season (mid of May) compared to the measured SWE.

4. Discussion

a) Discuss possible reasons for the bias of the different precipitation gauges.
b) Which are main advantages and limitations of every precipitation gauge?
c) Which are advantages and limitations of daily measurements of SWE in the field?

Exercise 2: DDF of a melting snow pack

1. Aim

The aim of this exercise is to compute DDFs for a melting snowpack and to understand the variations of DDF, as well as limitations and advantages of this method. It is important to understand that the DDF is not a constant value for one location.

2. Study site and data

The exercise is based on snow and temperature measurements from a study site in Switzerland. The measurements are taken every morning at around 7 am since 1942/43 and deliver interesting data of snow melt and temperature that allow computing the DDF of a melting snow pack. The sampling site lies at around 890 m a.s.l. close to the artificial lake Sihlsee (47.15°N / 8.78°E). The region is generally snow covered between around November/December to March/April.

Data: Meteodat GmbH

Figure 2: Location of the study site, situated in the North of a relatively small artificial lake at an elevation of around 890 m a.s.l.(GoogleEarth)

To derive the DDF for a time period (without precipitation), you need daily mean temperatures and the change in snow water equivalent (ΔSWE). The data which ware used in this exercise are measured at daily and (approx.) weekly basis:

daily	- max. and min. temperature	T_{max}, T_{min}
	- precipitation	P
	- snow depth	d_s

weekly	-	weight of the snow column	m_s
	-	snow depth of the sampled column	d_s

Further information

For this exercise, it is important to take periods without precipitation in order to consider only the melt and not the accumulation process. The provided data were selected from a long time series, taking into account time windows without precipitation where density measurements were available.

It is assumed that the change in SWE during the observing period corresponds to melt. Other processes like sublimation, infiltration, or condensation are neglected.

The computed DDF depends strongly on the way temperature T is measured. In general, the temperature sensor is mounted 2 m above ground level. They should be ventilated and shielded from incoming and reflected sun radiation as well as from precipitation.

3. Calculation

Mean temperature

a) Compute the mean daily temperatures

Hint: Since we don't have hourly temperature data, the mean temperature can be computed as a mean of maximum and minimum air temperature. Singh and Kumar (1996) showed that the consideration of average temperature of a day as a mean of daily maximum and minimum air temperature instead of 24 hourly positive air temperature values, did not change the daily DDF value significantly. The average temperature of a day as a mean of daily maximum and minimum temperature can be used in the snowmelt runoff calculations when hourly data are not available.

$$T_{mean} = \frac{T_{min}+T_{max}}{2}$$

Positive degrees

b) Compute the positive degrees of every day

Hint: The computation of the DDF requires positive temperature of every time step. In our case we have time steps of one day. For every day you have to check whether mean temperatures are positive or negative.

Snow density and snow water equivalent

c) Compute the snow density for the days where snow depth and weight of the snow column are available.

Hint: Snow density is calculated by dividing the mass of snow by the volume of the probe. The SWE has to be calculated based on the available measurements: A tube (area: 70 cm²) is used to weight the snow of a certain depth d_s. First the empty tube is weighted and then inserted vertically to the snow pack. The tube is rotated and pulled out vertically, now containing snow from the entire column. The tube is weighted again with the core. The mass difference can be calculate and corresponds to the weight of the snow column above an area of 70 cm².

d) Compute the snow water equivalent of the snowpack

Hint:

The mass of snow is equal to the mass of water if melted: $m_s = m_w$
With the following equation: $m_w = \rho_w \cdot V_w = \rho_w \cdot A \cdot d_w$
follows the equation to compute SWE: $d_w = SWE = \frac{m_s}{\rho_w \cdot A}$

The area A of the sample column is 70 cm².

Degree day factor DDF

e) Compute the degree day factors

4. Discussion

The following figure shows the daily measured snow depth, DDF and min., max. and mean air temperature for one week in December 1996.

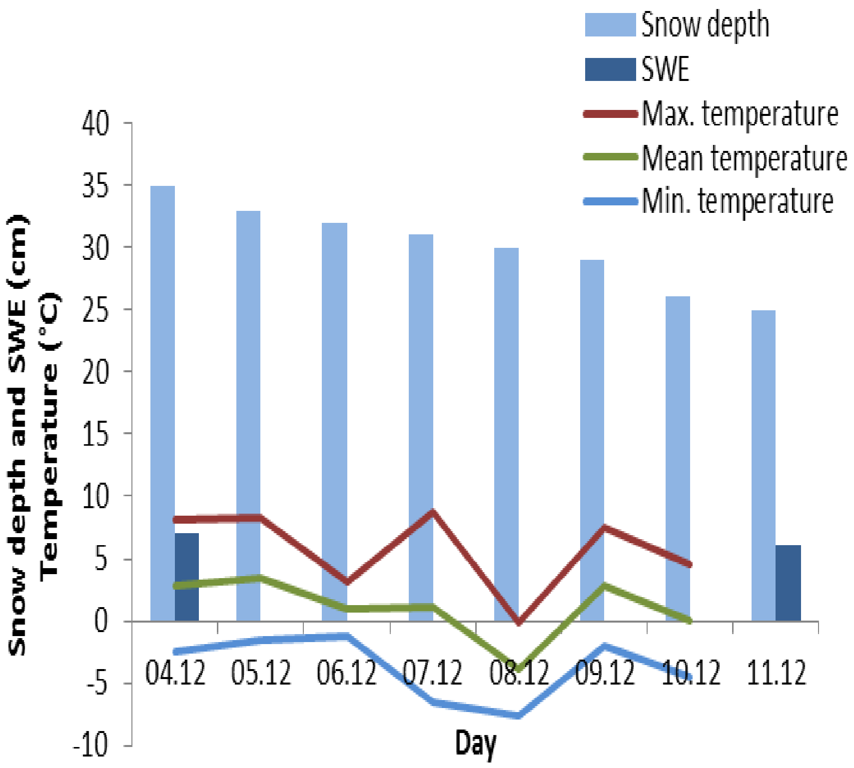


Figure 3: Daily measurements of snow depth, max. and min. temperature during eight days in December 1996. The mean temperature is computed as an average of max. and min. temperature. The dark blue bars show the computed values for SWE at the beginning and at the end of the measuring period.

Try to understand and discuss the differences in the DDF for the four periods based on your results and the figure above, following these questions:

a) Low DDF

Why is the DDF for the period 4th to 11th of December 1996relatively low?Discuss possible reasons.

b) Constant DDF

Which are uncertainties of the modelled melt, if calculated with a constant DDF? In which cases would melt be under- or overestimated?

c) Seasonal variations

Explain seasonal differences in DDF.

d) Mean air temperature

Which are problems using the mean air temperature? (see for example 10.12.1996 in Figure 3where the mean air temperature is 0°C)

e) Error in air temperature measurements

Imagine that your temperature measurements are constantly 1°C to high, at it is not ventilated. What happens to the computed DDF?

f) Factors influencing DDF

Which factors - aside from temperature - are influencing melt and could be included in a temperature-index model?

g) Limitations

Based on the questions above: Which are limitations of the DDF?

h) Climate change projections

Extra: To model melt under climate change conditions it is often assumed that the DDF is constant in time. Which could be possible constraints of this assumption?

Exercise 3: DDF of a highly glacierized catchment

1. Aim

In the previous exercise, the DDF of a melting snow pack was computed using SWE measurements and air temperature data. Here, we consideravery simple bulk method based on the correlation between a catchment discharge and air temperature. The aim of this exercise is to understand the relation between air temperature and catchment discharge and to model runoff using temperature data of two weather stations with different site characteristics. Note that the method used in this exercise is a strong simplification of all the physical processes in the catchment which finally lead to discharge. It is here used to give a first introduction to hydrological modelling of mountainous catchments using DDF.

2. Study site and data

The following figure shows the Aletsch watershed (red area) in Switzerland which comprises an area of 195 km^2. Around 66% of the catchment is glacierized. At the outlet of the catchment, discharge is measured by a gauging station (blue triangle). Meteorological measurements are sampled by two meteorological stations (red triangles), one situated at the upper part of the catchment (3580 m a.s.l.) and one situated at a distance of around 60 km in the bottom of the main valley. The valley station in Sion (482 m a.s.l.) recordsprecipitation data, which can be used to improve the modelled discharge.

Meteorologal data:	MeteoSwiss
Hydrological data:	Swiss Federal Office for the Environment FOEN

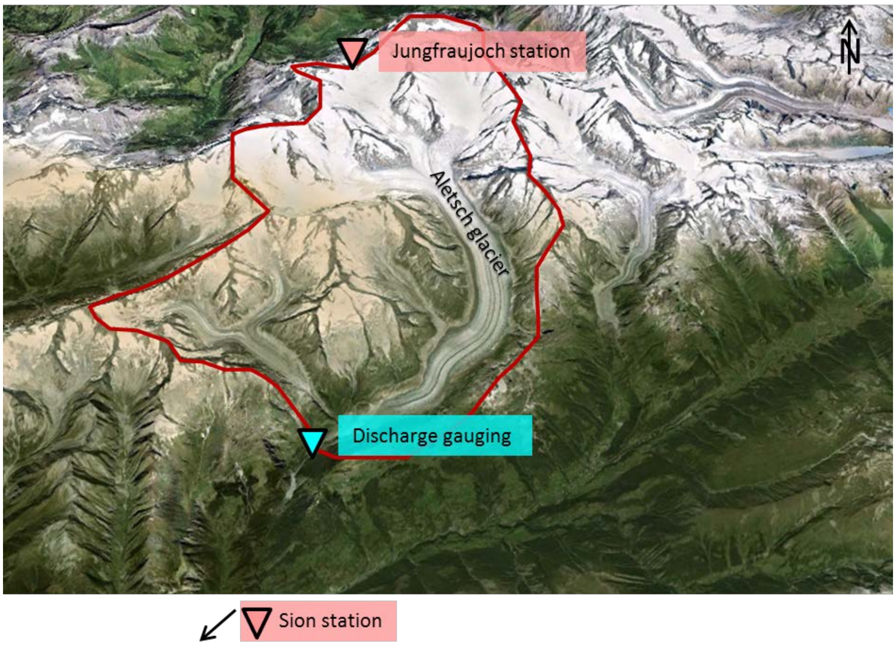


Figure 4: Aletsch glacier in the Swiss Alps. The red triangles show the locations where meteorological data are collected. The blue triangle shows the locations of discharge measurement. The red area indicates the catchment area of 195 km^2, with 66% glacierized area. (GoogleEarth)

The runoff data and meteorological variables are provided for the time of1 May until 30 September 2011, which is approximately the ablation season for glaciers in the Alps.

In the excel file you find the station data for Jungfraujoch and Sion. The numbers 06730 for Jungfraujoch and 06720 for Sion are the WMOidentification numbers. The following table shows the variables with their corresponding short names and the units.

Table 1: Meteorological variables recorded by the weather stations.

Meteorological variable	Abreviation	unit
Mean temperature	TEMP_MEAN	°C
Relative humidity	RELHUM_MEAN	%
Mean wind speed	WSPD_MEAN	Kn
Precipitation sum	RR_SUM	mm
Cloud cover	N_MEAN	1/8 *
Global radiation	GR	MJ/day

* The number 9 stands for situations where sky is invisible because of fog, snow storm or othermeteorological phenomena

3. Calculation

Relation of discharge versus air temperature

a) Plot the measured discharge Q against air temperature for both stations Jungfraujoch and Sion.
b) Calculate the coefficient of determination R^2 for both stations
Hint: use the trend line function in excel
c) Which correlation is higher and why?
Hint: see lecture material
d) Which station delivers more convenient data to continue with our calculations?

Seasonal constant DDF

We use the station data of Sion for further calculations.

e) Calculate the DDF using the sums of daily positive temperatures and daily discharge over the entire season.
f) Compute daily discharge over the entire season using the seasonal constant DDF.

$$\sum_{i=1}^{n} M = DDF \sum_{i=1}^{n} T^{+}\,\Delta t$$

M	melt (mm/d), here: discharge (mm/d);
DDF	Degree-day factor (mm d^{-1}°C^{-1})
T^{+}	positive air temperatures of each time interval (°$C^{-1}d^{-1}$)
n, Δt	amount n of time intervals Δt

Hint: Check if the volume of the computed discharge is thesame as the measured discharge

Monthly DDF

g) Compute monthly DDFs
h) Compute daily discharge over the entire season using monthly DDFs

Including precipitation

In a next step, precipitation data are considered.

i) Add the values for daily precipitation to the computed discharge

Hint: In a first step, discharge is converted from m^3/s to mm/d (using a catchment area of 195 km^2)

4. Discussion

a) Which are the improvements of each calculation step (constant DDF, monthly DDF, monthly DDF including precipitation)?

b) What could have happened to the precipitation peak on 18 June or 18 September?
Hint: Have a look at the meteorological data, e.g. temperature records

c) Why could discharge be overestimated between around 21 July to 2 August?
Hint: Have a look at the meteorological data, e.g. radiation and cloud cover records

d) Which could be reasons for the monthly variability of the DDF?