A MASS-BALANCE, GLACIER RUNOFF AND MULTI-LAYER SNOW MODEL

DEBAM AND DETIM

DISTRIBUTED ENERGY BALANCE MODEL
DISTRIBUTED ENHANCED TEMPERATURE-INDEX MODEL

PROGRAM DOCUMENTATION AND USERS MANUAL

Regine Hock

Geophysical Institute, University of Alaska, Fairbanks
903 Koyukuk Dr, Fairbanks, Alaska 99775-7320, USA
regine.hock@gi.alaska.edu

Carleen Tijm-Reijmer

Institute for Marine and Atmospheric Research Utrecht
Utrecht University, NL-3584 CC Utrecht, The Netherlands
c.h.tijm-reijmer@phys.uu.nl

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FOREWORD

This manual is meant to support users in the application of the mass balance / discharge model and to document the program and parameterizations. With each application the model usually expands and changes. The manual is by no means complete or without ambiguities or errors but rather develops with user comments and model modifications and, thus is constantly updated.

A major expansion of the model occurred in spring 2005 by Carleen Tijm-Reijmer coupling a one-dimensional multi-layer snow model to the energy balance or temperature-index mass balance model.

In August 2012 the code became open source. Lyman Gillispie set up the model on github and built a download homepage (http://regine.github.io/meltmodel/). The code has largely been expanded in summer 2013. At the same time the debam and detim can no longer be used to optimize discharge, precipitation and melt parameters. Instead a new tool was developed and coded in Matlabl by Lyman Gillispie that greatly simplifies parameter calibration. This tool (*MultiRun*) is not described in this manual but only on the github page (http://regine.github.io/meltmodel/tools.html) where the tool can be downloaded.

1 INTRODUCTION

1.1 Purpose

The programme computes the short-term mass balance variations (ablation and accumulation) of ice and snow with a subdiurnal temporal resolution and simulates resulting discharge. The mass balance model is fully distributed, i.e. calculations are performed for each grid cell of a digital elevation model. **Ablation** can be computed either by an energy balance model or by various temperature index methods. **Discharge** is calculated from the water provided by melt plus liquid precipitation by three linear reservoirs corresponding to the different storage properties of firn, snow and glacier ice. Discharge simulations are optional, i.e. the mass balance model can be run independently of the discharge model. In addition, subsurface temperatures, water content and percolation can be computed by a one-dimensional **multi-layer snow model** that is forced by the surface energy balance.

The model is generally applicable to any location, including high latitudes. The pecularities of solar geometry beyond the polar circles (e.g. no sunrise during certain periods) are properly considered, as the model has been developed and tested for a basin north of the polar circle. Application of the melt model is not only restricted to glacierized areas, but can also be applied to any delimited snow-covered area delimited. In the case of discharge simulations, however, the area calculated must coincide with the drainage basin and it must be predominantly glaciated.

Generally speaking, the program can be used:

- to compute **short-term mass balance** variations of any snow-covered or/and glacierized area
- to calculate hourly to daily **discharge** of any drainage basin with a large percentage of ice cover
- to predict the spatial distribution of **topographic shading** and **potential solar radiation** for selected time intervals
- to investigate the spatial and temporal variations of the **energy balance components** simulated
- to model **subsurface glacier temperatures** and **water content**.

The model and its application to Storglaciären, a valley glacier in Sweden, is described in Hock and Noetzli (1997), Hock (1998, 1999), Hock and Holmgren (2005) and Noetzli (1996) the latter specifically focuses on the discharge routing model. Reijmer and Hock (2008) describe the addition of the subsurface model.

1.2 Resolution

The model is **not limited in spatial resolution**, i.e. there is no scale dependence in model algorithms, concerning both the area size and the grid point spacing. Limitations are, however, imposed by hardware constraints and the degree of representativity of the climate data for the area. In addition, because all calculations concerning solar geometry refer to the geographical coordinates of one point, the area should not exceed approximately 5° in longitude and latitude.

The temporal resolution ranges from **any fraction of a day to one day**. It is governed by the measurement intervals of the climatic data. The discharge algorithm requires a time step of one hour. The model operates at a minimum cycle of one day, although no boundaries are assigned for initial and final dates.

1.3 Model inputs

Main data requirements are **climatic data** from one station representative of the area modelled, a **digital terrain model** and associated boundary and derived grids. Most of them are easily retrievable from the digital terrain model and from a map.

Tab 1: Data requirements for the mass balance (MB) and discharge model (Q). The data necessary are marked by *x*, those necessary only in certain parameterization options are marked by '(*x*)'.

Data		**MB**		**Q**	**Source**
		Energy balance	**Temp index**		
Climate	1. Air temp	x	x	x	
	2. Humidity	x	-	-	
	3. Wind speed	x	-	-	
	4. Global radiation	x	(x)	-	
	5. Reflected shortwave radiation	5 and 6 or 7	- -	- -	data taken from one climate station
	6. Net radiation		-	-	
	7. Cloud cover	(x)	-	x	
	8. Precipitation	x	x		
Grid data					
Grid cell data	1. Elevation	x	x	-	digitization of a map
	2. Slope	x	(x)	-	calculated from 1.
	3. Exposition	x	(x)	-	calculated from 1.
	4. Sky-view factor	(x)	-	-	calculated from 1.
	5, Snow water equivalent at the starting day	5 or 9	5 or 9		Measurements of snow depth and density or accumulation model output
Boundary data	6. Drainage basin	x	x	(x)	digitization of boundaries in map
	7. Glacier area	x	x	x	digitization of boundaries in map
	8. Firn area	(x)	(x)	x	mapping of previous years equilibrium line
	9. Surface conditions for defined periods	9 or 5	(x)	-	Observations or photographs of snow line retreat
	10. Debris cover	-	(x)	-	Mapping

1.4 Parameterization options

The model offers alternative methods of calculating individual energy balance components, varying in the level of sophistication as well as in computer time consumption and data requirements (Tab. 2). For instance, global radiation can be extrapolated with or without explicit separation into direct and diffuse radiation, albedo can be prescribed using digitized snowline maps or it can be generated internally by the model, and longwave incoming radiation can be assumed to be constant in space or it can be calculated variant in space taking into account the effects of surrounding topography. In case of temperature index modelling three different parameterizations are possible to compute melt. Whichever method is most suited for a specific application mainly depends on the availability of climate data in the area considered.

Tab : Parameterization options for various model components

Component	**Parameterization**	**Input data specific to the method**
ENERGY BALANCE MODEL		
Global radiation	1. interpolation of global radiation using the ratio of measured global radiation and theoretical clear-sky radiation 2. interpolation of direct and diffuse radiation separately	
Albedo	1. Allocating constant albedo values to different surface types (snow, ice, ...) 2. generating albedo internally as a function of surface type, age, snow depth etc. 3. as 2 but including a modification of albedo according to parameterized cloud cover 4. according to Oerlemans & Knap, 1998 including dependency on snow depth or Douville, et al 1995	Initial snow waterequivalent raster map
Longwave irradiance L↓ at climate station	1. obtained as a residual from the measurements of global, reflected shortwave and net radiation 2. from direct measurements of L in	Reflected shortwave and net radiation data longwave incoming measurements

	3. parameterizations	cloud cover data
Interpolation of L↓	1. assuming it spatially constant 2. taking into account the effects of complex topography (terrain irradiance and reduction of sky irradiance)	parameterization of surface temperatures outside the glacierized area
L↑ at climate station and rest of area	1. assuming melting surface (constant 0°C -> 315.6W/m2) over entire area to be computed 2. by iterating surface temperature (closing energy balance: if negative -> lower surface temperature) (spatially variable) 3. from direct measurements of L↑ that are assumed constant over glacier ro decrease in surface temperature with increasing elevation 4. from multi-layer snow model (spatially variable)	Longwave outgoing radiation measurements
Turbulent heat fluxes	aerodynamic bulk approach 1. According to Escher-Vetter (1980) 2. according to Ambach (1986), no stability	
	3. as 2 but including atmospheric stability	
TEMPERATURE INDEX MODEL		
Melt	1. simple degree day factors (DDFice/snow) 2. including a radiation term in terms of clear-sky direct radiation 3. including global radiation	Global radiation data

1.5 Output and Visualization

Ablation and discharge results and a variety of intermediate results (e.g. all components of the energy balance, topographic shading, clear-sky direct radiation) can be written to output files, providing the opportunity to investigate temporal and spatial variations, to control simulations and to trace potential errors. Results may either be written to **time series files** or to **grid files**. The former include various output variables for each time step, thus revealing their temporal variations. Output may refer to the spatial mean of the entire grid considered or to individual grid cells specified by the user. Grid output files contain modelled results for each grid cell, thus representing the spatial variations of result variables. In this case, the model supports output for each time step, as daily means or as averaged values for over the entire period calculated. All outputs are optional, and any combination of potential output files can be requested by the user within one run. Various generally applicable programs have been written in ***IDL-Interactive data language*** to enable visualization of results.

1.6 Structure

The model is written in **C**. It is constructed so that application to different locations is straight-forward. All input parameters specific to one area are read from a controlling input file (namelist file: 'input.txt') which needs to be adjusted prior to each location by the user. This file defines filenames, model parameters, output options, parameterization options, geographical data, the period to be calculated etc.. No changes in the source code are required, when applying the model to another area. The structure is based on independent modules, allowing for a convenient exchange of algorithms by additional routines and functions if desired. Hence, the model can easily be expanded by different parameterization approaches of any model component

In addition, emphasis was put on a user-friendly programming style, allowing ease of application for users not familiar with programming. A large variety of potential erroneous user input data or formats are recognized by the programme and the programme is exited printing an appropriate error statement to the screen.

1.7 Programs

Two programs (energy balance model DEBaM and temperature index model DETIM) are available. Both program use the same set of files that include the model routines. Since fall 2013 the programs can no longer be used to optimize precipitation or discharge parameters. Instead the Matlab program MultiRun is available since fall 2013.

Due to its modular structure, the model may easily be coupled with other models, e.g. with other discharge routing methods (e.g. in order to simulate discharge in non- or less glaciated snow-covered basins). Melt may also be integrated over defined areas (e.g. elevation belts or hydrotopes) to provide the water input to less distributed discharge models. Further expansion may also include an extended interpolation scheme for the climatic input data if several climate stations are available.

1.8 Limitations

The version to date is subject to certain restrictions, which, however, can easily be eliminated by modifying the source code, if these are a problem:

- Area size: The area calculated must not be too large, because solar geometry calculations refers to the geographic coordinates of only one point inside the area.
- Leap years: Leap years are not considered explicitely in the program. The errors introduced in the calculations concerning the solar geometry are considered negligible. However, modifications might be required for the handling of climate input data (e.g. by including missing values for febr. 29 in non-leap years) *(changes in globcor.c, initial.c).*
- Time step of calculations. If subhourly time steps are requested, the name pattern for the output files has to be modified *(writeout.c).*
- The model operates at sub-diunal intervals but the minimum cycle is one day. For instance, if the starting day is 190 and the time step is one hour, calculations are performed from 1am to 24pm of day 190; it is not possible to start calculations e.g. at 5am.

2 PARAMETERIZATIONS OF THE ENERGY BALANCE MODEL

(Not all parameterizations and model options are described in detail. The reader is referred to the published papers on the model. Some details that are not given in the papers are described here).

2.1 Energy balance

Within the **ice/snow melt** model all components of the radiation balance, the sensible heat flux and the latent heat flux are estimated at each time step and at each gridpoint using measured climate data. The energy available for melt is calculated as the residual term in the energy balance equation. Energy fluxes directed towards the surface are defined as positive and those from the surface negative and the following equation describes the balance.

$$Q_M = G(1-\alpha) + L_{Net} + Q_H + Q_L + Q_G + Q_R$$

G	global radiation
α	albedo
L_{Net}	longwave radiation balance (incoming minus outgoing)
Q_H	sensible heat flux
Q_L	latent heat flux
Q_G	ground heat flux (heat flux in the ice/snow)
Q_R	sensible heat supplied by rain

Often different computation methods are offered for each energy component. A simpler method is applied in Hock and Noetzli (1997), and more sophisticated methods B in Hock (1998, Paper 5) and Hock and Holmgren (2005).

2.2 Net radiation

2.2.1 Global radiation

Global radiation can be calculated by 2 methods either by interpolating global radiation directly (method A, Hock and Noetzli, 1997) or by separating measured global radiation into direct and diffuse radiation and interpolating these components individually (method B, Hock 1998, Paper 5). Both methods require the calculation of potential direct solar radiation, which is also needed in the modified temperature index method suggested in Hock (1999).

Potential clear-sky solar radiation (I) for a horizontal unobstructed surface is calculated for each grid by (Oke, 1987):

$$I = I_0 * \left(\frac{r_m}{r}\right)^2 \Psi_a^{\left(\frac{p}{P0}/\cos Z\right)} \cos Z$$

I_0	= solar constant [1368 W/m^2]
r	= distance earth - sun, the subscript m refers to the mean
ψ_a	= vertical atmospheric clear-sky transmissvity
p	= atmospheric pressure
P0	= standard atmospheric pressure [101325 Pa]
Z	= zenith angle

By multiplying with cos(Z) radiation refers to a horizontal surface. Calculations are done using the geographical altitude and latitude of the approximate centre of the area considered, i.e. the geographical coordinates are taken invariant for all grids. The area must be sufficiently small to justify this simplification. Calculated values will only vary from grid to grid according to grid elevation (h), which is expressed in terms of the air pressure (p) by:

$$p = e^{(-0.0001184*h*P0)}$$

The ratio p/P0 accounts for the effect of altitude (lower air pressure yields higher solar radiation). The introduction of cos(Z) in the exponent expresses the variation of the path length with sun altitude. The bulk effect of reflection, scattering and absorption of solar radiation by gases, droplets and particles in the atmospheric is taken into account by the atmospheric transmissivity. This must be considered a first approximation, as individual components of radiative transfer are not treated individually. The transmissivity generally varies between 0.6 and 0.9 (Oke, 1987).
The radius earth to the sun is calculated from:

```
teta = (2*pi*jd)/365;
radius2sun = 1.000110+0.034221*cos(teta)+0.001280*sin(teta)+
                              0.000719*cos(2*teta)+0.000077*sin(2*teta);
```

The zenith angle (Z) is calculated using the following equations (Oke, 1987). The angles refer to degrees.

$$\cos Z = \sin\Phi \sin\delta + \cos\Phi \cos\delta \cos h$$

$$\delta = -23.4 \cos[360^\circ (t_j + 10)/365]$$

$$h = 15(12 - t)$$

ϕ	latitude (positive in northern hemishere, negative in southern hemisphere)
δ	solar declination (angle between the sun's ray and the equatorial plane, function of the day of the year)
Z	solar zenith angle
h	hour angle (angle through which the earth must turn to bring the meridian of the site considered directly under the sun, funtion of the time of day)
t_j	julian date (number of the day in the year)
t	local apparent solar time

Local apparent solar time is calculated by first adding (subtracting) 4 minutes to local standard time for each degree of longitude the site is east (west) of the standard meridian and by subsequently adding the equation of time.
Solar radiation, calculated according to the equation above applies to a horizontal unobstructed surface. In mountainous regions, the added effect of shade, slope and exposition are of crucial importance. Calculated solar radiation is corrected by a **correction factor** due to **shading**, **slope** and **aspect** of the grid. For each grid and each time step the correction factor is calculated as a function of slope, aspect, solar azimuth angle, slope azimuth

angle, zenith angle and the topography. The effects of slope and aspect are accounted for using the following relations (Radiation is given in terms of the beam radiation received on the horizontal):

$$I_{slope} = I\frac{\cos\Theta}{\cos Z}$$

$$\cos\Theta = \cos\beta\cos Z + \sin\beta\sin Z\cos(\Omega - \Omega_{slope})$$

$$\cos\Omega = (\sin\delta\cos\Phi - \cos\delta\sin\Phi\cosh)/\sin Z \qquad t<12$$

$$\cos\Omega = 360 - (\sin\delta\cos\Phi - \cos\delta\sin\Phi\cosh)/\sin Z \qquad t>12$$

Θ angle of incidence between the normal to the slope and the solar beam
β slope angle
Ω solar azimuth angle
Ω_{slope} slope azimuth angle
I_{slope} direct-beam solar radiation on a slope in terms of the beam radiation received on the horizontal surface (S).

Accordingly, the correction factor required is given by cosΘ/cosZ. By dividing by cos(Z) direct radiation is expressed in terms of the beam radiation received on the horizontal. The correction factor is modified according to whether or not the grid is shaded. Shading is determined for each gridpoint and for the middle of each time subinterval by an algorithm developed by Schulla (1996). The result is assumed valid for the entire grid cell represented by the gridpoint and to the entire length of the subinterval. If the grid cell is shaded, the correction factor is set to zero (There is no direct solar radiation). Additionally, in order to avoid unrealistic correction factors during times of low sun altitude, the correction factor is limited to 5, if the zenith angle exceeds 78° (1/cos(78°)=1/0.2=5). This is due to refraction and other effects which would have to be considered. (If cos(Θ)/cosZ > 5 → , cos(Θ)= 5 cosZ).

The calculations of shading, the exposition correction factor and potential direct radiation are done for a number of subintervals, e.g. if the time step is one hour, these variables can be calculated every 10 minutes. This option is essential, if time step are large, e.g. one day. This correction factor is calculated as a weighted mean of all correction factors for all subintervals within the time step. Accordingly, beam solar radiation for a horizontal surface is calculated for the middle of each subinterval and integrated over the period of the subinterval. This value is multiplied by the corresponding correction factor and all products within one and the same time interval are summed up and subsequently divided by the solar radiation integrated over the entire time interval. The number of subintervals within each time step is chosen by the user. With increasing number of subintervals the accuracy of the resulting correction factor is increased, especially during times of rapid change in sun altitude. The algorithms for the calculation of shading and the correction factor and some functions concerning solar geometry were taken from Schulla (1997).

Mean correction factor for one time step (n=number of subintervals):

$$\frac{\cos\Theta}{\cos Z} = \frac{\sum_{1}^{n} I * \cos Z\frac{\cos\Theta}{\cos Z}}{\sum_{1}^{n}(I * \cos Z)}$$

Mean potential direct radiation for one time step:

$$I = \frac{\sum_{1}^{n} (I * \cos Z \frac{\cos \Theta}{\cos Z} * \Delta T)}{\sum_{1}^{n} \Delta T}$$

In these formulas cos Z cannot be cancelled, because the ratio of cos(Θ)/cosZ is limited to 5, as mentioned above.

Method 1 (see Hock and Noetzli, 1997) *(variable methodglobal=1 in input.txt)*
The **ratio of measured global radiation and calculated clear-sky solar radiation** is used to distribute global radiation to each grid, thus accounting for the effects of clouds and diffuse radiation. If measured global radiation exceeds calculated direct radiation (ratio > 1), the difference indicates the amount of diffuse radiation. Measured global radiation less than calculated (ratio < 1) is caused by cloud cover. However, the ratio is only defined, if there is clear-sky solar radiation, i.e. the sun is above the horizon and the station grid is not shaded by surrounding mountains. With decreasing sunaltitude angle, the ratio will become more and more susceptible to errors due to decreasing amounts of solar radiation causing stronger inaccuracy of both, the measurement of global radiation and the calculation of solar radiation. Therefore, the calculation of the ratio is restricted to periods of sunaltitude angle exceeding 20°. For these periods the grid cell of the climate station is considered to be in shade. The same is true if the ratio calculated exceeds 1.3. For the calculation of the ratio, direct radiation of the climate station grid cell is calculated, assuming the grid cell to be horizontal, because the pyranometer usually is levelled horizontal, thus also refering to a horizontal surface.
When distributing global radiation to all grids, four cases are distinguished, depending on whether or not the climate station and the grid to be calculated are shaded.

*1. the climate station is in the **sun** and the grid to be calculated is in the **sun**:*
Calculated clear-sky solar radiation is multiplied by the ratio of measured global radiation at the climate station and calculated clear-sky solar radiation in order to obtain global radiation.

*2. the climate station is in the **sun** and the grid to be calculated is in the **shad**e:*
There is only diffuse radiation, which is approximated by a fixed percentage of clear-sky direct radiation which is prescribed by the user. This must be considered a minimum value, as the effect of clouds is not taken into account. *It is intended to distribute global radiation by using a relation between the ratio at the station and diffuse radiation*.

*3. the climate station is in the **shade** and the grid to be calculated is in the **sun**:*
Direct radiation is multiplied by the last ratio of measured global radiation and calculated clear-sky solar radiation that was obtained at the climate station before the station became shaded. Thus, it is assumed that cloud conditions have not changed. This ratio is used until a new ratio can be determined at the climate station. The overall error introduced by the assumption of constant cloud cover is considered rather small when the climate station is located at a site showing long potential sunshine duration, because the error is more likely to occur at times of high zenith angles when global radiation is small anyway. A new ratio is only calculated if zenith angle is less than 65°, even if the climate station is in the sun. This is necessary, because, during times of low sunaltitude shortwave radiation tends to be small and the ratio of two small numbers may be subject to substantial erros.

*4. the climate station is in the **shade** and the grid to be calculated is in the **shade**:*
There is no solar radiation at both, the grid of the climate station and the grid to be calculated. Measured global radiation is merely diffuse radation and it is assumed to be invariant over the area.

Method 2 *(variable methodglobal=2 in input.txt)*
Measured global radiation is split into direct and diffuse radiation using an empirical relationship between the ratio of global radiation to top of atmosphere radiation and diffuse radiation to global radiation. Two different empirical functions can be selected. Diffuse radiation is then extrapolated spatially variable. Details are given in Hock (1998, Paper 5).

2.2.2 Albedo

Albedo can be obtained from various methods:

1) it can be assumed to be constant for different surfaces. A different value can be assigned for snow and ice surfaces (Hock and Noetzli, 1997). *(in input.txt: methodsnowalbedo=1*)

2) Snow albedo can be modelled internally using a new function depending on the number of days since last snowfall and air temperature (Hock and Holmgren, 2005). The function was derived for the data set on Storglaciären and would need further testing on other glaciers and probably calibration of the coefficients *(methodsnowalbedo=2*).
3) Snow albedo obtained by method 2 can additionally be modified according to cloudiness following Jonsell et al. (2003). The ratio of measured global radiation to top of atmosphere solar radiation is used as a proxy for cloudiness. The maximum change in albedo due to the cloud effect from one time step to another is set to 20%. The method generates an unrealistic systematic decrease in snow albedo with time in case of lack of snow precipitation and needs further testing and most likely modification *(methodsnowalbedo=3*). Option is not recommended.
4) *Recommended option:* Snow albedo is computed to either according to Oerlemans and Knap (1998) or Douville et al. (1995). The option is specified in the source code (file: *variab.h*). The default is set to the former. If the latter option can be chosen by assigning the variable *douvilleyes* the value 1 instead of 0. According to Oerlemans and Knap (1998) snow albedo for each time step is given by

$$\alpha_{snow} = \alpha_{firn} + (\alpha_{frsnow} - \alpha_{firn})\exp\left(\frac{s-i}{t^*}\right)$$

   α_{firn}= albedo of snow below fresh snow, α_{frsnow}= albedo of fresh snow, t*= time scale determining how fast the snow albedo approaches the firn albedo after a snowfall, s=number of the day on which the last snowfall occurred.
   Albedo is adjusted to allow for smooth transition to ice albedo if snow depth (d) is small:

$$\alpha_{snow} = \alpha_{snow} + \alpha_{ice} - \alpha_{snow}\exp\left(\frac{-d}{d^*}\right)$$

   d* is acharacteristic scale for snow depth. When snow depth equals d*, the snow cover contributed 1/e to the albedo and the underlying surface (1-1/e).
5) As 4.) but including the cloud parameterization according to Jonsell et al. (2003).

In cases *methodalbedo* = 2 or 3 snow albedo can be increased with decreasing elevation according to a fixed percentage per 100 m elevation change to account for generally increasing debris accumulation downglacier.

2.2.3 Surface type

The surface type has implications for the simulation of albedo and also for the application of the linear reservoir model for discharge routing.
The surface type (snow, ice …) can be obtained from 2 methods:

a) by **prescribing the surface type** using surface maps of snow line retreat (method A). The method requires grid files containing information about the surface conditions of the glacier based on photographs or observations of the glacier surface and the location of the snow line on the glacier. Three types of surfaces are distinguished: snow/firn, slush, ice. Different files can be allocated to different time periods, thus accounting for the temporal evolution in surface conditions on the glacier throughout the melt season (see Fig. 2, Hock and Noetzli, 1997).

b) by **modelling the surface type** for each grid cell (method B) (Hock, 1998, Paper 5). This method requires a grid file containing the initial snow water equivalent for the first day of the simulation. The model melts or accumulates snow on each grid cell. Any grid cell with snow water equivalent exceeding zero are assigned the surface type snow, any others "ice", those free of snow but in an area defined to contain the firn area are assigned the surface type firn.

2.2.4 Longwave incoming radiation

Prior to extrapolating a value for the grid cell of the climate station needs to be obtained. This is possible by 3 methods:

a) the measurements of net radiation, global radiation, reflected radiation at the climate station on the glacier and from the assumed value of longwave outgoing radiation (L ↓ = net – glob + ref + L↑). If L↓ is less than 150 W/m2 it is set to 150 in order to avoid unrealistic values resulting from short-term instrument problems. L↑ is either assumed corresponding to melting surface or obtained from iteration procedure.

b) from direct measurements of longwave incoming radiation

c) from the parameterization proposed by Konzelmann et al (1995). This requires cloud data, but no data of reflected shortwave radiation and net radiation

d) from the parameterization by Brunt (1932), based on air temperature and humidity

$$L = \sigma T^4 \left(0.52 + 0.065\sqrt{e}\right)$$ with e=vapour pressure in hPa and T=temp in Kelvin

e) from the parameterization by Brutsaert (1975)
f) from the parameterization proposed by Konzelmann et al (1995) but cloud cover is parameterized according to Sedlar and Hock (2009) as a function of the ratio of global radiation to top of atmosphere radiation.

Extrapolation can then be done by 2 methods:
a) assuming longwave irradiance spatially constant (method 1)
b) spatially variable taking into account the effects of surrounding topography according to Pluess and Ohmura, 1997 (method 2). In this case it is also a function of surface temperatures.

2.2.5 Longwave outgoing radiation

As for the incoming radiation first a value for the climate station grid cell must be determined:

a) assigning 315.6 W/m^2, assuming melting surface (constant 0°C -> 315.6W/m2) over entire area to be computed
b) by iterating surface temperature (closing energy balance: if negative -> lower surface temperature). Hence, L↑ is spatially variable
c) using direct measurements of longwave outgoing radiation and assuming a linear decrease with increasing elevation in case the corresponding surface temperature is negative. In case of a 0-lapse rate, L↑ is spatially invariant.
d) using the multi-layer snow model. The surface temperature is computed for each grid cell from linear interpolation of the modelled temperature of the upper two layers.

2.3 Turbulent heat fluxes

The turbulent heat fluxes are estimated by the bulk aerodynamic approach, using screen-level data of air temperature, humidity and wind speed and the modelled surface temperatures. The model can be run without stability correction or inclusion of atmospheric stability according to Hock and Holmgren (2005). The roughness lengths for wind speed is prescribed while the roughness lengths for temperature and vapor pressure can be computed according to Andreas (1987).

Air temperature can be obtained in three ways:
a) The temperature read from file is distributed to each grid by using a linear change of temperature with elevation (lapse rate).
b) A lapse rate can be read from file for each time step and is then applied to the temperature read from file for one location.
c) Temperature can be read from existing temperature grids for each time step

Wind speed and **relative humidity** as determined at the climate station are assumed constant over the whole area.

The model offers 3 methods for the turbulent fluxes:

<u>Method 1 (according to Escher-Vetter, 1980)</u> (*variable methodturbul=1 in input.txt*)
The method has been derived empirically from data in the Alps. It has been applied by Baker et al (1982) and Mader and Kaser (1994). The **sensible heat flux** is calculated as a function of air temperature (T) and wind speed (u) at 2m (Escher-Vetter, 1980) by

$$Q_s = A * T$$

A is the transfer coefficient as defined by:

$$A = 5.7\sqrt{u}$$

The **latent heat flux** is calculated as a function of humidity and wind speed according to:

$$Q_s = A * 0.623 * \frac{L_v}{p * c_p}(e - e_0)$$

L_v = latent heat of evaporation [2514000 J/kg]
cp = specific heat capacity
e_0 = saturation vapour pressure of meting ice [611 Pa]
e = vapour pressure.

Method 2 (*variable methodturbul=2 in input.txt*)

The **sensible heat flux** (Q_H) is calculated from temperature and wind speed data from the following.

$$Q_H = c_p k^2 \frac{\rho_0 P}{P_0} \cdot \frac{u_2 T_2}{\ln(z / z_{0w}) \cdot \ln(z / z_{0T})}$$

c_p	specific heat of air at constant pressure (1005 J kg^{-1} K^{-1})
k	von Karman's constant (0.41)
P	atmospheric pressure
P_0	standard atmospheric pressure (101325 Pa),
ρ_0	air density at P_0 (1.29 kg m^{-3})
z	instrument height (2 m)

z_{0w},z_{0T} roughness parameters for logarithmic profiles of wind and temperature, respectively.

Analogously, the **latent heat flux** (Q_L) is caclulated from the measurements of humidity and wind speed. Relative humidity is converted to vapour pressure.

$$Q_L = 0.623 \cdot L\ k^2 \frac{\rho_0}{P_0} \cdot \frac{u_2 \cdot (e_2 - e_0)}{\ln(z / z_{0w}) \cdot \ln(z / z_{0e})}$$

L the latent heat of evaporation (2.514x10^6 J kg^{-1}) or sublimation (2.849x10^6 J kg^{-1})
e_2, e_0 vapour pressure at 2 m and at the melting surface (611 Pa), respectively
z_{0e} roughness parameter for the logarithmic profile of vapour pressure.

Method 3 (recommended) (*variable methodturbul=3 in input.txt*)

QH and Q_L are computed according to method 2 but considering **atmospheric stability** based on Monin-Obukhov-theory. The ratio z/L is computed by iteration. The value of z_{0w} is prescribed in *input.txt*. To avoid too much reduction in turbulent energy in case of very high stability, L is set to 0.3 in case it would be between 0 and 0.3.

For both methods (2+3) the values of z_{0T} and z_{0e} can be computed based on Andreas (1987) following Munro (1989) or by assuming a constant ratio z_{0T}/z_{0w} with $z_{0T}=z_{0e}$. A constant ratio between the roughness length z_{0w} over ice and the one over snow/firn can be applied.

Whether the **latent heat of evaporation** L_v or **sublimation** L_s is used, depends on the direction of the latent heat flux and the surface temperature. If the latent heat flux is directed towards the surface, the surface is expected to experience condensation, if the surface temperature equals zero. For surface temperatures below zero resublimation (phase change from vapour to ice) is assumed. For negative latent heat fluxes ice is assumed to sublimate, no matter of surface temperatures:

Latent heat flux ***towards*** the surface ($e-e_0$) = ***pos***			
	$T_s = 0$	==> condensation	$L = L_v$
	$T_s < 0$	==> resublimation	$L = L_s$

Latent heat flux ***away*** from the surface ($e-e_0$) = ***neg***   ==> sublimation $L = L_s$

2.4 Surface temperature

The computation of longwave outgoing radiation, the turbulent fluxes and the rain heat flux require a value of surface temperature for each grid cell. The surface temperature at the climate station grid cell can be determined

a) by assuming melting conditions (0°C) *(variable methodsurftempglac=1)*

b) by iteration from energy balance computations: In this case the surface temperatures are obtained in an iterative process by lowering surface temperatures in case of negative energy balances until the energy balance equals zero. *(variable methodsurftempglac=2)*

b) from measurements of longwave outgoing radiation, if available. If the surface temperature exceeds zero, it is set to zero. *(variable methodsurftempglac=3)*

c) from the snow model (linear interpolation of the temperature of the 2 upper layers) *(variable methodsurftempglac=4)*

2.5 Other heat fluxes

The **ground heat flux** is calculated if the snow model is run (*(variable methodsurftempglac=4)*.
Otherwise it is neglected or considered in an indirect way. If the energy balance is negative no melt will occur and the surface will cool. Hence energy will be needed to raise the surface temperature to zero before melt will occur. If the variables *methodnegbal* = 2, melt is not allowed before negative energy balances have been compensated for (see discussion in Hock, 1998, Paper 5).

The energy supplied by the **sensible heat of rain** is approximated by

$$Q_R = c_w R * (T_r - T_s)$$

c_s specific heat of water [J/kg/K]
R rainfall rate
T_r temperature of rain
T_s surface temperature

The rain temperature is assumed to be identical to screen-level temperature. Energy supplied by re-freezing rain is not considered.

2.6 Precipitation

It is corrected using a fixed percentage of gauge undertake and then spatially distributed according to three different methods:

a) using two **linear increase of precipitation with elevation**. One gradient is used below a given elevation and another one above. The gradients and threshold elevation are specified in *input.txt*.

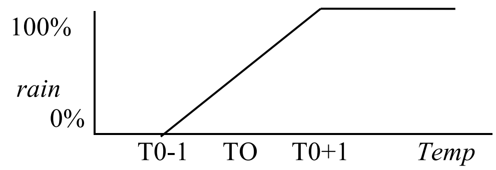
b) A **precipitation index file** can be read from file (multiplication factor for each grid cell by which the precip read from the AWS file is multiplied with)

*precip = prec+prec*preccorr/100.0; (precip read from file (prec) is corrected for undercatch)*
*precip = precip * precipindexmap[i][j]; (then value multiplied by value in index file for that location)*

c) option to **read precip grids from file** for each time step (analogous to temperature grid option). These can then also be corrected for gauge undertake but the snow multiplier is applied. If no correction wanted this should be set to 1.

precip = precipreadgrid[i][j]; (precip is set to value from input file for location i,j)
precip = precip+precip*preccorr/100.0; (precip is then corrected for undercatch)

Rain and snow are discriminated using a threshold temperature (T0). One degree below/above T0 all precipitation is assumed to fall as snow/rain. Within the two degree range the percentage of rain and snow is obtained from linear interpolation.



In addition, snow precipitation can be corrected further by applying an additional factor by which snow precipitation is multiplied. Different factors can be given for snow on and outside the glacier. Any snow precipitation is multiplied by *snowmultiplierglacier* or *snowmultiplierrock*, i.e. a factor that can be set different from 1 in input.txt to account for example for larger undercatch of snow compared to rain and for additional precip on glaciers compared to the surrounding unglacierized areas. This snow multiplier is applied to all methods of spatial distribution (i.e. also if a precipitation index file is used (option b) above) or if precipitation is read from grid files (option c) above).

2.7 Water equivalent

Finally, the energy available for **melt** as derived from the residual term in the energy balance equation is
is converted to water equivalent melt (WE [mm/timestep]) by

$$WE_{melt} = \begin{cases} \frac{Q_m}{L_f} * 3600 * timestep & Q_L < 0 \quad or\,(Q_L > 0\, and\, T_s < 0) \\ \left(\frac{Q_m}{L_f}\right) * 3600 * timestep & Q_L > 0\, and\, T_s = 0 \quad -> condensation \end{cases}$$

If the latent heat flux is negative only sublimation of ice is assumed not of water. If the latent heat flux is positive and the surface temperature is zero additional water is available through condensation. This condensed water, however, does not affect the mass balance (ablation).

Total **ablation** is obtained considering melt and (re-)sublimation

$$WE_{abla} = \begin{cases} \frac{Q_m}{L_f} * 3600 * timestep & Q_L > 0\, and\, T_s = 0 \quad -> condensation, no\,(re) sublination \\ \left(\frac{Q_m}{L_f} - \frac{Q_{subl}}{L_s}\right) * 3600 * timestep & O_L < 0 \; or\,(Q_L > 0 \; and\, T_s < 0) \end{cases}$$

L_f = latent heat of fusion (334000 J/kg)
L_s = latent heat of sublimation ($2.849 x 10^6$ J kg^{-1})

Melt is used further for **discharge calculations**, whereas **ablation** should be used to compare model results to **mass balance** measurements. The distinction is necessary because mass loss by sublimation does not contribute to glacial discharge. The difference may be significant in areas with high sublimation rates. A positive values of ablation indicates a mass loss, a negative values a mass gain (by re-sublimation).

Water for runoff (variable MELT): Melt	if Q_L positiv and T_s= 0 then Melt=Abla
Mass balance changes (variable ABLA) **Mass loss** = melt water equivalent - sublimation **Mass gain** = re-sublimation (vapour to ice)	 if Q_L is negative if Q_L is positiv and T_s<0

2.8 Accumulation

Accumulation of snow is only added to the glacier if the model (energy balance and temperature index) is run with an initial snow cover grid. Snow fall water equivalent is added to the snow cover grid of the previous time step. If surface type (snow/ice etc.) is read from file (for allocating albedo and snow/ice degree day factors) accumulation is not needed.

3 MULTI-LAYER SNOW MODEL

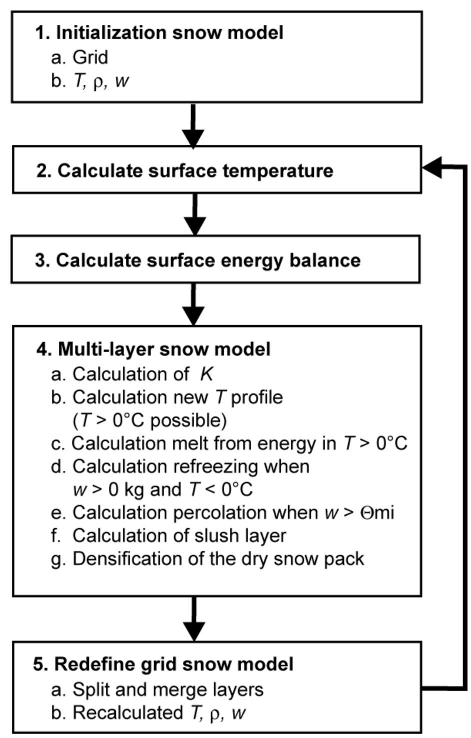
The snow model is based on the model described by Greuell and Konzelmann (1994). The flow chart illustrates the order in which the different parts of the model are calculated.

3.1 Parameterizations

The model solves the **thermodynamic energy equation** on a grid extending vertically from the surface to a given depth.

$$\rho c_{pi} \frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(K \frac{\partial T}{\partial z}\right) + \frac{\partial Q_t}{\partial z} - \frac{\partial}{\partial z}\left(ML_f\right) + \frac{\partial}{\partial z}\left(FL_f\right)$$

ρ = density (kgm^{-3}),
c_{pi} = heat capacity of ice (2009 Jkg^{-1}K^{-1})
T = temperature (°C)
δt = timestep (s),
K = effective conductivity (Wm^{-1}K^{-1})
Q_t = energy coming from the atmosphere (Wm^{-2})
M = melt rate (kgm^{-2}s^{-1})
F = refreezing rate (kgm^{-2}s^{-1})
L_f = latent heat of fusion (0.334 10^6 Jkg^{-1}).



Boundary conditions: At the upper most snow/ice layer the model is driven by the energy coming from the atmospher (Q_t). At the lowest snow/ice layer it is assumed that there is no heat flux to or from lower layers. The total depth of the model must be chosen such as to fulfill this requirement and is defined as depthdeep in input.txt.

Effective conductivity: K describes energy exchange through conduction and processes as convection, radiation and vapor diffusion. K is a function of snow properties and often described as a function of density. See Sturm et al. (1997) for an overview of different functions in literature. The model currently provides 5 options (typeconduc set in *variab.h*) with ρ in kgm^{-3}:

1. Van Dusen (1929) presented in Sturm et al. (1997): $K = 0.21 \cdot 10^{-1} + 0.42 \cdot 10^{-3} \rho + 0.22 \cdot 10^{-6} \rho^2$

2. Sturm et al. (1997):

$$K = 0.138 \cdot 10^{-1} - 1.01 \cdot 10^{-3} \rho + 3.233 \cdot 10^{-6} \rho^2$$

3. Douville et al. (1995): $K = 2.2\left(\frac{\rho}{\rho_{ice}}\right)^{1.88}$

4. Jansson (1901) presented in Sturm et al. (1997):

$$K = 0.2093 \cdot 10^{-1} + 0.7953 \cdot 10^{-3} \rho + 1.512 \cdot 10^{-12} \rho^4$$

5. Östin and Andersson presented in Sturm et al. (1997):

$$K = -0.871 \cdot 10^{-2} + 0.439 \cdot 10^{-3} \rho + 1.05 \cdot 10^{-6} \rho^2$$

Presently option 5 is the default option set in variab.h

Temperature profile: The temperature profile is first calculated in the model and calculations are based on the first two terms on the right hand side of the thermodynamic energy equation. As a result temperature can become larger than 0°C. The excess amount of energy in the layer with a temperature higher than 0°C is converted into melt according to:

$$dz_{melt} = \frac{Tmc_{pi}}{L_f}$$

dz_{melt} = the amount of melt (mm w.e.)
T = temperature (°C)
m = the dry snow mass of the layer ($m=\rho dz$, kgm^{-2})

The melt is added to the water content of the layer. Rain water is added to the water content of the upper most layer.

Water content (w): Water content consists of two parts, the irreducible water content θ_{mi} and slush (with water saturated snow). θ_{mi} is either constant (irrwatercont defined in input.txt) or calculated according to Schneider and Jansson (2004):

$$\theta_{mi} = 0.0143 \ \exp(3.3n)$$

n = snow porosity which is the ratio of pore volume to total volume of the snow:

$$n = 1 - \frac{\rho}{\rho_{ice}}$$

If the total water content exceeds θ_{mi}, the amount equal to θ_{mi} will remain in the layer, the rest will percolate further downwards until it reaches the lowest layer or until it reaches an impermeable ice layer. When reaching the lowest layer without hitting ice (possible in the firn area) the excess water is put into RUNOFF. When reaching an impermeable ice layer a slush layer (saturated snow layer) can develope on top of this layer. For a perfectly horizontal surface this layer can become as thick as the snow layer itself before runoff occurs. For a sloping surface gravity will prevent the buildup of a thick slush layer and runoff occurs before the slush layer reaches the surface. To mimic this behavior the following relation was implemented (own development):

$$dz_{slush} = 0.5dz_{firn+snow}\left(1+\cos(2\beta)\right)$$

β = surface slope
$dz_{firn+snow}$ = the combined thickness of the snow and firn layer.

In this way the thickness of the slush layer can never be thicker than $dz_{firn+snow}$. Note that since $dz_{firn+snow}$ can be considerable in higher areas of the glacier still thick layers of slush are allowed to form. This may not be very realistic. Other option van be played with in the routine slushformation() itself.

Refreezing: Refreezing occurs when water is present in the snow layer and temperatures drop below 0°C. The amount of refreezing is limited by either temperature, which cannot be raised higher than the melting point: $E_{Temperature} = |T|mc_{pi}$

or the available amount of meltwater: $E_{water} = wL_f$

or the available amount of pore space, water expands upon refreezing: $E_{pore} = (\rho - \rho_{ice})dzL_f$

The new layer temperature is then defined by:

$$T = -\frac{E_{Temperature} - \min\left[E_{Temperature}, E_{water}, E_{pore}\right]}{mc_{pi}},$$

and the dry snow mass added to the layer is defined by:

$$dm = \frac{\min\left[E_{Temperature}, E_{water}, E_{pore}\right]}{L_f}$$

Densification: Even without water in the snow pack the density of the dry snow will slowly increase with age of the snow pack. This densification of the dry snow pack is described in the model using the empirical relations of Herron and Langway (1980).

$$\frac{\partial \rho}{\partial t} = ka^b(\rho_{ice} - \rho)$$

a = the annual accumulation rate at a given grid point (m w.e.yr^{-1}), here defined by SNOW/100 at the start of the calculations. It assumes the calculations are started at the beinning of the melting season.
k and b are constants depending on ρ:

$\rho < 550$ kgm^{-3} b = 1 $$k = 11\ \exp\left(\frac{-10160}{RT}\right)$$

550 kgm^{-3} $\leq \rho$ b=0.5 $$k = 575\ \exp\left(\frac{-21400}{RT}\right)$$

R = the universal gas constant (8.3144 JK^{-1}mol^{-1})
Note that densification due to melt and refreezing will dominate the densification of the total snow pack.

Surface temperature: The surface temperature is calculated from the calculated temperature profile by linearly extrapolation of the temperature of the two upper most grid cells.

Definitions: For several arrays in the model the meaning of the content changes when using the snow model.
RUNOFF = all water that cannot be retained in the snow layer
MELT = all water that cannot be retained in the snow model excluding the contribution by rainwater.
ABLA = MELT + sublimation - condensation

3.2 Initial conditions

Grid definition: The thickness of each snow layer increases with depth based on:

$$dz_i = dz_{first} + \left(1 - \frac{dz_{first}}{dz_{deepest}}\right) z_{i-1/2} \quad ,$$

dz_{first} = thickness of uppermost grid cell (m snow, thicknessfirst defined in input.txt)
$dz_{deepest}$ = maximum grid layer thickness (m snow, thicknessdeep defined in input.txt)
A fixed boundary between 2 layers is defined where the previous winter snow fall (SNOW) ends and the firn or ice layer below it begins. With melt and snow fall the layer thicknesses change. An upper and lower limit is set to the layer thickness for a given depth. When a layer becomes half the size of the optimal layer thickness for that depth, the layer is merged with the layer below. When a layer becomes twice the size of the optimal layer thickness for that depth, the layer is split in two. Several exceptions are possible. The last snow layer on top of the ice of firn cannot merge with the layer below but will either merge with the layer above or decrease in size untill the absolute minimum thickness of 0.5*dz_{first} is reached, then will merge with the layer below and the snow layer has vanished. When snow fall occurs the layer will not be split in two equal size layers but an attempt is made to create a new layer consisting only of the freshly fallen snow. Furthermore, if the amount of fresh snow in 1 time step is not enough and the upper most grid layer cannot be splitted, the amount of fresh snow is also added to an array with which a new fresh snow layer can be formed at the moment the conditions are fulfilled.

Initial T, ρ, w profiles: Before calculations can be started the profiles of temperature T, snow and firn density ρ, and water content w must be defined. Water content is either set to 0 at initialisation or when a wet start is chosen in the input.txt the water content is calculated based on the density of the layer and the irreducible water content. Starting with a saturated snow layer is currently not possible.

There is one or two default setting for the temperature, snow and firn density profiles. These setting are chosen in *variab.h* by the following variables

init_layertemperature=1
init_snowlayerdensity=1 or 2
init_firnlayerdensity=1 or 2

Initial profiles should, if possible, be initialized using data from the study site to which the model is applied. In addition to the default settings, currently, a site-specific initialization is programmed for Storglaciaeren and run if the variables above are set to 3. The profiles are visualized in Fig. 6 in Reijmer and Hock (2008). New functions can easily be added (preferably in file *snowinput.c*) to allow for different initializations controlled by setting the variables above to 3, 4, etc. The initialization choices are programmed in the following functions from which depending on the user choice different functions are called where the profiles are calculated:

choice_layertemperature() → calls function *default_layertemp3grad*() or other site specific functions

choice_snowlayerdensity() → calls function *default_snowlayerdensity* () or default_snowlayerdensity3grad() or other site specific functions

choice_firnlayerdensity()→ calls function *default_firnlayerdensity* () or default_*firnlayerdensity1grad*() or other site specific functions

When adding a new snowlayer density function (init_snowlayerdensity) an extra function, called for in choice_snowlayermsnow, that calculates the snow depth in m snow must be added as well. It translates the array *SNOW* (water equivalents) in array *snowlayer* (m snow). The mass of the summed layers with density defined via choice_*snowlayerdensity*, must equal *snowlayer*.

choice_snowlayermsnow()→ calls function *default_snowlayermsnow* () or other site specific functions

Default temperature profiles

The default profile is approximated by 3 linear gradients at simulation start. The gradients are defined in *variab.h* for the site of the weather station. The first gradient is computed between the surface temperature (variable *tempsurfaceAWS*) and the temperature at a certain depth below the surface (variable *deptturnpoint1*). The second gradient is computed between the latter depth and a deeper depth (*depthturnpoint2*) and the corresponding temperature. A third gradient defines the temperature between that depth and the depth where the glacier becomes temperate (see Figure below). All depth-temperature pairs must be specified in *variab.h* based on observations or best guesses.

The surface temperature and the temperature at *depthturnpoint1* are extrapolated to the entire grid using the lapse rates specified in *variab.h*. The temperature of the deeper turning point are assumed spatially constant. Note that the model needs to be recompiled when changes are applied to *variab.h*.

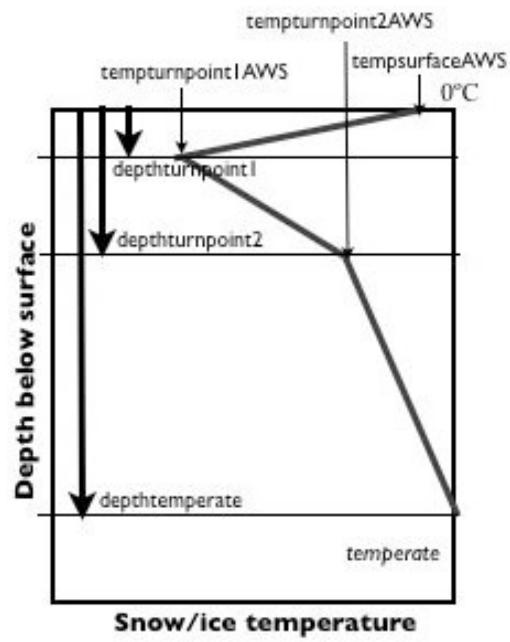


Figure. Variables to be specified in variab.h to define the initial snow/ice temperature profile at the first day of simulation. The profile is idealized by 3 temperature gradients defined by 4 temperatures at 4 specified depths.

Default snow density profiles

There are 2 default options:

a) The density throughout the snowpack is assumed constant and set to the value specified by the variable *densfirn* in *input.txt*. The option is chosen by setting *init_snowlayerdensity*=1 in variab.h.

b) The density profile is defined by 3 linear gradients analogous to the temperature profiles. Densities and for various depths are specified in variab.h (see variab.h for variable names). The option is chosen by setting *init_snowlayerdensity*=2 in variab.h.

The user specific density profile of Storglaciären (*init_snowlayerdensity*=3) is for the snow layer based on the cumulative density profile measured in May 1999. In the firn, layer density increases further based on the average density profile on which the cumulative profile was based. Maximum density is set to the ice density, which value is set in variab.h. The coefficients of the density profile is constant for each grid point. Only the thickness of the snow layer, firn layer and ice layer change. Note that for the firn layer not the cumulative profile is used. This means that when adding a different density profile, 3 new functions must be created default_snowlayermsnow, default_snowlayerdensity and default_firnlayerdensity. The figure illustrates the present default initial temperature profile at the climate station site, the Storglaciären initial temperature profile at the climate station site and the Storglaciären initial density profile for snow covered firn (Stake 29 on Storglaciären).

Note: The density of the firn layer is not coupled to the density of the snowlayer so the choice of firn density is not coupled to the choice of snowlayerdensity, although a smooth transition is preferred and therefore 3 new functions or the default firnlayerdensity must be chosen such that the transition is smooth.

Default firn density profiles

There are 2 default options:

a) The density throughout the firn is assumed constant and set to the value specified by the variable *densfirn* in *variab.h*. The option is chosen by setting *init_firnlayerdensity*=1 in *variab.h*.

b) The density profile is defined by one linear gradient. Densities for various depths are specified in variab.h (see *variab.h* for variable names). The option is chosen by setting *init_firnlayerdensity*=2 in *variab.h*.

In the area outside the firn area (as defined by the firn grid) the density of ice is assumed.

Numerical stability and time step: dz_{first} must be reasonably small to obtain a reasonable surface temperature (order of cm). A small dz_{first} requires also a small time step to ensure numerical stability. For a purely diffusive process the Courant Friedriechs Lewey coefficient defines a stability criterium:

$$\frac{K}{\rho c_{pi}} \frac{dt}{dz} < 0.5$$

Note that the thermodynamic energy equation is not a pure diffusion equation, but still this coefficient gives a reasonable estimate of stability. Given an upper layer thickness of a few cm, model time step must be on the order of minutes. However, input data is generally on a lower time resolution. To solve this problem, the input data is linearly interpolated between two time input data time steps to obtain input values on the model time step and melt and subsurface-processes are computed for all subtimesteps. Note that this procedure makes input data on time scales less than a few hours unsuitable as model input in case the snow model is used. Note also that output is only produced at the time step of the input data.

Model options: The following parameters are predefined in the model (can easily be changed in *variab.h*)

- Density of ice = 900 kg/m3
- The minimum surface temperature that can be obtained = -20°C (lower modelled temperatures are set to this value; can be changed in *variab.h*)

3.3 Limitations

The snow model can currently only be applied if the area calculated coincides with the glacier.
The model does not consider lateral water movement
The model has not been tested in multi year runs.

4 MODELING GLACIER RETREAT

The model includes an option to model glacier retreat using volume-area scaling. Since total glacier volume is unknown changes in volume are related to changes in area. Two options are available:

$$\Delta V = c(\Delta A)^{\gamma} \quad \text{(Option 1: 'classical V-A scaling')}$$

$$\Delta V = c\gamma A^{(\gamma-1)}\Delta A \quad \text{(Option 2: differentiated form (Arendt et al., 2006)}$$

For each time step the area changes is computed from inverting option 1 or 2, then a new area is computed by substracting the area changes from the total area of the previous time step. From the area change it is computed how many grid cells need to be removed from the glacier. These are then removed in sequential order from the lowest lying grid cells. Currently the model does not allow the glacier to advance. If the mass balance is positive the area is kept constant. Coefficents (*c* and gamma) are specificed in *input.txt*.

5 DISCHARGE MODEL

River discharge is computed over the area defined by the drainage basin DEM from the sum of melt and rain water. The sum of melt and rain water for each pixel defined by the drainage DEM is converted into a single streamflow value for each time step using 4 linear reservoirs (Hock and Noetzli, 1997). For each reservoir a storage constant is specified in input.txt controling the speed at which the water is routed downstream. Each grid cell is assigned one of the four reservoirs depending on the surface characteristics. The four reservoirs are

a) 'firn', defined by the a constant firn DEM,
b) 'snow', refering to all grid cells that are snow-covered, no matter whether they are glacierzed or not,
c)'ice,' referring to all grid cells that are not in the firn area and not snow-covered
d) 'rock' referring to all grid cells that are outside the glacier but not snow-covered.

In case discharge data at some distance downglacier is available but only a glacier DEM (and no larger drainage basin DEM) is available, discharge from outside the glacier due to rain can be approximated in the following way. Discharge of the glacier is computed using 3 linear reservoirs (firn, snow, ice). Then the total rainwater in the ice reservoir is augmented by a factor depending on the glacierization percentage of the drainage basin which drains to the stream gauge:

rain=rain + rain/glacier% * (100-glacier%).

Hence, the rain falling outside the glacier is scaled according to the 'missing area' and 'dumped' on the glacier (ice reservoir). However, any streamflow contributions due to snowmelt outside the glacier are neglected. This option is only recommended during periods where these contributions can be assumed negligible.

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Papers based on the application of the model code

Extended temperature index model including potential direct radiation

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(3) Flowers, G. and G. Clarke, 2000: An integrated modelling approach to understanding subglacial hydraulic release events. ***Annals of Glaciology*** ,31, 222-228.

(4) Flowers, G.E. and G.K.C. Clarke, 2002. A multicomponent coupled model of glacier hydrology. 2. Application to Trapridge Glacier, Yukon, Canada. ***Journal of Geophysical Research***, 107B(11), 2288, doi: 10.1029/2001JB001124.

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(15) de Woul, M**.,** R. Hock, M. Braun, T. Thorsteinsson, T. Jóhannesson, S. Halldorsdottir, 2006. Firn layer impact on glacial runoff – A case study at Hofsjökul, Iceland. ***Hydrological Processes***, 20, 2171-2185.

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(9) Schneeberger, C., 2003. Glaciers and climate change - a numerial model, ETH Zürich, PhD Thesis, #14743, ETH Zurich, Switzerland.
(10) Huss, M. 2005. Gornergletscher - Gletscherseeausbrüche und Massenbilanzabschätzungen. Diploma (MSc) thesis, ETH Zürich, 204 pp.
(11) de Woul, M. 2008. Response of glaciers to climate change. Dissertation series no. 13, Departement of Physical Geography and Quanternary Geology, Stockholm University, PhD Thesis.
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(13) Østby, T. I., 2010. Distributed Energy and Surface Mass Balance Modeling of Austfonna, Svalbard. MSc Thesis Oslo University.
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(15) Petlicki, M., 2011. Modelowanie bilansu masy i energii lodowca Arie na Spitsbergenie, PhD Thesis, Poland.
(16) Truessel, B., 2013. Yakutat Glacier, PhD Thesis, University of Alaska Fairbanks.
(17) Young, J., 2013. Kahiltna Glacier, MSc Thesis, University of Alaska Fairbanks.

7 INPUTFILES AND FORMAT REQUIREMENTS

All format requirements refer to both the ***energy balance model*** *and the* ***temperature index methods****. Statements marked by* ***(E)*** *refer only to the energy balance model and those marked by* ***(T)*** *are only needed for the temperature index models.*

The model requires the following input data:

1. grid files containing **terrain information** (digital elevation model and derived files)
2. **climate** data
4. controling **input file** ('input.txt')

The latter contains all data and settings to apply the model to a specific area and it is described in detail in chapter 4. All grid files and the climate data must be in the folder that is specified by the user in the controlling input file (input.txt). Direct radiation grids can be computed a-priori once and read from file. These can be in a different folder that is specified in *input.txt*.

Tab 4 : Names and formats of input files

Files	Names	Format
GRIDFILES - Digital elevation model - drainage basin area - glacier area - slope - aspect - sky-view factor - snow cover -surface conditions (*different files for different periods*) - firn area (incl. debris area)	names specified in input.txt	binary
CLIMATE DATA	name specified in input.txt	ASCII
DISCHARGE DATA*	Data given in climate data file	ASCII
MASS BALANCE POINT DATA*	Data in separate file named '*measuredpointbalances.txt*'	ASCII
Mass balance measurements dates*	Name specified in *input.txt*	ASCII
Controlling input file	'*input.txt'*	ASCII

*not needed to run the model, but if available, the model can compute the agreement between measured and modelled discharge, and can compute the point mass balances for the locations of observations and for the exact periods these observations refer to.

7.1 ***GRID DATA***

7.1.1 Digital terrain models (DTM)

1.) DTM including a valid elevation for each grid cell of the rectangular grid. No missing or negative values allowed !!! It must be sufficiently large in order to include all mountains that may shade grid cells of the area to be computed (DTM 2). DTM 1 is required for all cases.

2.) DTM covering the <u>area to be calculated</u>. (e.g. **Drainage basin grid** in case of discharge simulations)
Grid cells outside the area to be calculated are marked by missing value (e.g. -9999). All grid cells inside the area to be calculated must contain the same figures (elevations) as DTM 1. Calculations are performed for all grid cells not equal to missing value. If discharge is to be calculated the area must cover the area of the drainage basin. DTM 2 differs from DTM only such that all grids cells that should not be calculated (e.g. outside the drainage basin) are replaced by missing value. The rest is identical.
DTM required in any case.

3.) DTM covering the glacierized area. (**Glacier grid**)
For any grid cells of this area ice or firn melt will occur after the snow cover has been removed. It thus denotes the glacier grid. This file must exist even if the area to be calculated does not contain any glaciers. In this case this grid file must contain only missing values. If only the glacierized area is to be calculated, DTM 2 and 3 must contain the same data. Although they are identical in this case, they must have different names. Hence, two different files must exist with different names although there are identical in content. **Note that all grid cells that are not missing values in DTM 3 must also be non-missing values in DTM 2!** This might not be the case due to digitization inaccuracies when digitizing glacier boundaries, and must be checked prior to running the model. Computing only the glacierized area is also possible if discharge is calculated although rain and melt water from outside of the glacier contribute to discharge. However it should only be used, if melt contributions from the hillslopes are negligible.
DTM required in any case.

4.) DTM containing **slope** data (in degrees). Data must be available for the entire area of DTM 1.
Required in any case.

5.) DTM containing **aspect** data (=exposition) (0-360°). Data must be available for the entire area of DTM 1. If the slope is zero, the aspect should be zero. The angles are positive and measured clockwise from north to a projection of the normal to the slope plane. Grid cells exposed exactly north = 0, east = 90, etc.
Required in any case.

6.) DTM containing the **sky-view factor**. This file is only necessary, if direct radiation and diffuse radiation are interpolated separately and if longwave incoming radiation is interpolated spatially variable. Values range from 0 to 1, 0 refering to an fully obstructed sky, 1 to an unobstructed sky. Not needed for temperature index modelling. Data must be available for the entire area to be calculated and also for the climate station grid cell (in case the station is located outside the computed area).

7.) DTM delimiting the **firn area** and **debris** covered area.
This file is needed to allow the model to identify which grid cells are in the firn area and which ones are outside (i.e. the longer-term ablation area). In addition, in case of temperature index modelling, the file labels the grid cells in the ablation area that are heavily debris covered and thus allows the simulation of reduced melt over debris cover. All grid cells in the firn area of the glacier defined as the approximate area above the equilibrium line must contain any positive number except for missing value, zero or -1. The remaining part of the glacier (refering to the ablation area) must contain zero. The extent of the firn area might change from year to year. In this case different firn-files can be produced and used for different years. The ice area is the area that is bare ice after the seasonal winter snow cover has melted away; the firn area is the area where firn is below the winter snow cover.

Summary:	**firn area**	**firn depth in m, if not available any positive number**
	ice area	**0**
	debris covered area	**-1**

Energy balance model:
This file is required e.g for albedo generation (*methodsnowalbedo = 2)*, i.e. to decide whether firn or ice will be melted after. The area labelled 'firn' will never be allocated the value of ice albedo. In case of discharge simulation, rain and melt water produced in the firn area will be routed through the 'firn' linear reservoir. The file is also needed in case the snow model is run.
Temperature index model:
In case of temperature index modelling the file is needed to assign the melt factor for ice or snow after the initial snow cover has melted away. In the ice area (labelled by value 0) the melt factor for ice will be used if there is no snow (array SNOW[][]=0).

8.) DTM containing **initial snow water equivalent** values in **cm**. Data must be available for the entire area calculated (DTM 2). The model can be run either by prescribing the surface type (see 9.) by raster maps or by providing this grid containing initial snow cover equivalents. This is true for both energy balance and temperature index modelling. This grid or alternatively grids of surface type must be provided if grids of surface types are not available.

9.) **Surface-type grids**

These grids are only needed if the model is not run with an initial grid of snow water equivalent (grid 8). *NOTE: This option has not been run for a long time and may not be functional anymore.*

The surface type for each grid can be determined from files containing information about the surface condition of each glacier grid. This information is used to allocate snow or ice albedo (energy balance model) and the appropriate melt factors (temperature index model) and also to allocate the storage constant for the linear reservoirs in case of discharge modelling. The model distinguishes between ice, slush and firn/snow. For each grid cell to be calculated (not missing value in DTM 3) a value must exist as follows:

snow/firn	**1**	
slush	**2**	
ice	**3**	(all winter snow has melted away)
rock/other	**4**	(needed in case DTM 2 and 3 are different)

As the snow-line tends to change strongly with time, different files need to be allocated to different periods in the input file (see Fig. 2 in Hock and Noetzli, 1997). Each file will then be valid for a certain period of time determined by availability of such grids.

The surface-type grids are not to be confused with the firn grid (grid 7). In contrast to the latter the surface-type grids show the actual snowline changes, which are highly variable over the melt season.

7.1.2 Format requirements for all grid-files

- All grid files must be in matrix-format where element (1,1) is the **northwest** corner.
- The data start in the upper left corner and end in the lower right corner of the matrix.
- **All grid files (DTM1 – DTM9) must have identical size (same number of rows and columns, same cellsize and exactly the same corner coordinates; this means the 6 header lines must be exactly the same).**
- All grid files must be of **binary format**.
- The first 12 data must contain the following grid information (only the figures): The actual figures of the last six grid info rows are not relevant. If they are not available, any number can be written there.

1. Number of columns
2. Number of rows
3. x-coordinate of left lower grid cell (*see below)
4. y-coordinate of left lower grid cell (*see below)
5. Cellsize [m]
6. Nodata_value
7. Number of values (without missing values)
8. Minimum value
9. Maximum value
10. Sum of all values (without missing values)
11. Mean value (without missing values)
12. Standard deviation

If an Ascii-grid contains the first 6 rows followed by the grid data, the file can be converted to a binary file using the program *ascigrid.exe* by Schulla (1997). The output file, thus obtained contains the data of the required 12 rows in front of the actual grid data. The format for the grid files corresponds to the one suported by ARC-INFO.

Table. Example of a grid file in ASCII-format before convertion with ascigrid.exe into the binary format required for all grid-files. The elevation 1200 refers to the northwest corner of the area, the last row refers to the most southern part of the area. Note the number must not be presented in this form: e.g. 1.20e+003.

```
ncols           6
nrows           4
xllcorner       2500
yllcorner       1000
cellsize        30.0000
nodata_value    -9999.0000
1200 1249 1293 1293 1293 1290
1221 1220 1201 1202 1202 1209
1222 1224 1203 1201 1202 1209
1230 1231 1232 1290 1221 1220
```

Coordinates of the left lower grid cell:
There are two options:

1) The coordinates refer to the lower left corner of the lower left grid cell, hence the grid cell in the table above would span between the x-coordinates 2500 and 2530 and the y-coordinates between 1000 and 1030. This is called *xllcorner* and *yllcorner* in ArcInfo.
2) The coordinates refer to the center of the grid cell, hence the grid cell in the table above would span between the x-coordinates 2485 and 2515 and the y-coordinates between 985 and 1015. This is called *xllcenter* and *yllcenter* in ArcInfo.

Which of the two options the grid data used refers to is specified in the input parameter file. The coordinate reference only matters if grid cell model output is to be compared to e.g. measurements from ablation stakes given in coordinates. In this case the ablation stakes need to be placed into the "right" grid cell.

Table : Summary of grid input files. The boundary files contain elevation data for the area defined. Any grid cells outside are marked by missing values.

Grid	Description	Purpose
Grid data		
1. Digital elevation model	contains elevation for all grid cells, no missing values allowed	- to calculate topographic shading
2. Slope	surface slope of all grid cells [in °]	- to calculate direct radiation
3. Exposition	in °, clockwise from north (=0°)	- to calculate direct radiation
4. Sky-view factor		- to interpolate diffuse radiation and longwave irradiance
5. Snow water equivalent	at starting day, must cover the area of DTM	- to calculate albedo, decide which surface type - to decide which recession constant to be used (snow or ice)
Boundary data		
6. Drainage basin	Defines the area to be calculated, it must coincide with the drainage basin in case of discharge calculations, and with the glacierized area if only the glacier is to be computed	
7. Glacierized area	covers glacierized area	- to determine if ice/firn melt continues after the snow cover has been removed
8. Firn area / Debris cover	defines area of firn under last winters snow and area of heavy debris cover in ablation area	- for albedo calculations, if albedo is generated internally, firn albedo is used after snow cover has been removed in this area (E) - for discharge calculations, to decide if firn recession constant to be used (E+T) -to reduce melt over debris (T)
8. Surface conditions	contains distinct integers for different surfaces (ice, snow ...)	- albedo calculations: allocate an albedo value to surface characteristics - discharge calculations: to decide which recession constant to be used - multi-layer snow model

7.2 Climate data

The following data of one climate station is required in case of energy balance modelling:

1. air temperature (at 2m) [°C]
2. relative humidity [%]
3. wind speed (at 2m) [m/s]
4. global radiation [W/m^2]
5. precipitation [mm/timestep]

Depending on the parameterization method the following data may also be necessary:

6. reflected shortwave radiation [W/m^2]
7. net radiation [W/m^2]
8. longwave incoming radiation [W/m^2]
9. longwave outgoing radiation [W/m^2]
10. cloud cover (eights, number range from 0 to 8)

In case of **temperature-index modelling** at least air temperature and precipitation data must be available. The climate station does not have to be located in the area covered by DTM 1. In this case the elevation of the station (for applying lapse rates) is read from input.txt instead of being taken from the digital elevation grid. However, for energy balance modelling, currently the climate station does not have to be located in the glacierized area, but it has to be located within the area coverd by the DTM 1 (to allow for the calculation of the ratio of measured and calculated direct insolation). However, in both cases the data should be representative for the area modeled. Furthermore, it is desirable that the station is located in a position that is subject to relatively long potential sunshine duration within the area modelled. (The ratio of measured global radiation and potential direct radiation or the ration of direct radiation to clear-sky direct radiation is not defined, if the station grid cell is shaded, which deteriorates the accuracy of the distribution of global radiation to other grids.)

All climate data must be organized in one **ASCII-file**. The first 2 rows can be used for comments. They will be ignored by the program. The first column is the **year**, the second column is the **julian day** (real or integer. The third column is the **time** (=the end of the time interval, e.g. if hourly values, 12 refers to the mean value for the hour between 11-12.00). The values of the third column must lie between 0 and 24 (not 2400 as given by Campbell dataloggers !). In case of **daily timesteps** the third column can contain any data (a value of **24** is needed but this is done automatically in the programm). There are 3 options how the **midnight** can be presented (see examples below).
The data refers to the time interval preceding the corresponding time (e.g. julian day 190, time 2 and time step 2 ==> the data represent the mean (total for precipitation) of the period between 0 am and 2 am). The following columns contain the climate variables. The order of columns is arbitrary, because allocation of columns to climate variables will be specified by the user in the file *´input.txt´*. The columns must be separated by at least one blanc. There maybe more columns in the file with data not needed for the modelling, but, he maximum number of columns is currently limited to 50 (can easily be changed).

In front of the first row to be calculated, there must be at least 2 additional rows (the preceding time step). If e.g. the first day to be calculated is 191 and the time step is 1 hour, there must exist the preceding time step (191 0) containing any data (it will be ignored in any case, but the program needs it to identify the starting day of calculations). The same is true for the last row. Two lines of additional (fictitous) data must be added beyond the last time step to be calculated (due to some programming flaw).

Table: Example of a part of a climate input file with hourly timesteps. The columns are allocated to the corresponding climate parameters by the user in the file *´input.txt´*. The file may contain more columns than actually needed. There are 3 options how to represent the timestep preceeding midnight. Midnight values are marked in bold. In all cases the julian day can be given in decimals or as integer numbers.

Option 1 (variable *formatclimdata* = 1 in *input.txt*)

Year	JD	time	Temp	RH	Wind1	Wind2	Max	dir	Glob	Refl	Net	Prec
Storglaciären, meteorological station, 2004												
2004	203.88	21	8.34	73.0	3.45	3.89	7.16	277.4	2.58	1.01	26.88	1.50
2004	203.92	22	8.95	69.5	2.18	2.40	6.09	242.3	0.00	0.00	21.95	0.00
2004	203.96	23	8.48	68.6	1.92	1.96	3.70	274.8	0.00	0.00	20.28	0.00
2004	**204.00**	**0**	7.17	83.3	1.98	1.98	4.00	215.3	0.31	0.00	3.37	0.00
2004	204.04	1	7.44	84.3	1.60	1.63	4.84	231.9	0.00	0.00	17.25	0.50
2004	204.08	2	7.61	77.3	1.95	2.06	4.24	245.2	1.35	0.10	17.36	0.00 ...

Option 2 (variable *formatclimdata* = 2 in *input.txt*)

Year	JD	time	Temp	RH	Wind1	Wind2	Max	dir	Glob	Refl	Net	Prec
Storglaciären, meteorological station, 2004												
2004	203.88	21	8.34	73.0	3.45	3.89	7.16	277.4	2.58	1.01	26.88	1.50
2004	203.92	22	8.95	69.5	2.18	2.40	6.09	242.3	0.00	0.00	21.95	0.00
2004	203.96	23	8.48	68.6	1.92	1.96	3.70	274.8	0.00	0.00	20.28	0.00
2004	**204.00**	**24**	7.17	83.3	1.98	1.98	4.00	215.3	0.31	0.00	3.37	0.00
2004	204.04	1	7.44	84.3	1.60	1.63	4.84	231.9	0.00	0.00	17.25	0.50

2004	204.08	2	7.61	77.3	1.95	2.06	4.24	245.2	1.35	0.10	17.36	0.00 ...

Option 3 (variable *formatclimdata* = 3 in *input.txt*)

Year	JD	time	Temp	RH	Wind1	Wind2	Max	dir	Glob	Refl	Net	Prec
Storglaciären, meteorological station, 2004												
2004	203	21	8.34	73.0	3.45	3.89	7.16	277.4	2.58	1.01	26.88	1.50
2004	203	22	8.95	69.5	2.18	2.40	6.09	242.3	0.00	0.00	21.95	0.00
2004	203	23	8.48	68.6	1.92	1.96	3.70	274.8	0.00	0.00	20.28	0.00
2004	**203**	**24**	7.17	83.3	1.98	1.98	4.00	215.3	0.31	0.00	3.37	0.00
2004	204	1	7.44	84.3	1.60	1.63	4.84	231.9	0.00	0.00	17.25	0.50
2004	204	2	7.61	77.3	1.95	2.06	4.24	245.2	1.35	0.10	17.36	0.00 ...

Tab: Example of a part of a climate input file with **daily timesteps** for temperature-index modelling. The first data row (JD 364) refers to the daily means (Temp) and total (precip) of julian day 364. The column 'Time' can contain any number. It will be set to 24 in the program no matter what is in the file.

Year	JD	time	Temp	Prec
Storglaciären, meteorological station, 2004				
2003	364	24	8.34	1.50
2003	365	24	.8.5	0.00
2004	1	24	8.2	0.00
2004	2	24	7. 5	0.00
2004	3	24	7.2	0.50...

There must exist **data for midnight** for every day. The program uses midnight, in order to decide if a new day started (for calculating daily means).

Climatic data must be available at least once per day. The lowest resolution of the model is one day (because daily means can be calculated). Data must be available at a **constant intervals** (=time step in ´*input.txt*´). If the time step is one hour, there must be climate data for every hour of the simulation period. **No breaks or data gaps** nor missing values are allowed in the data file. The data set has to be continuous containing valid data for each time step. Gaps or missing values have to be interpolated prior to application of the model. The model checks the plausibility of the data. The program is exited if any of the following variables is outside the given range:

air temperature	-60 to 50
precipitation	0- to 300
relative humidity	0 to 100
global radiation	0 to 1500
reflected shortwave radiation	0 to 1500 (must not exceed global radiation)
net radiation	–400 to 1000
cloud cover	0 to 10
longwave incoming radiation	50 to 900
longwave outgoing radiation	50 to 320

The program is only exited if the variable found to be outside the range is needed for the specified model run. E.g. if the temperature index model is run the values of the non-relevant variables are ignored.

In case of **temperature index modelling** only temperature, precipitation and depending on the chosen model global radiation data are needed. The files may contain additional data. The format requirements are identical to the ones for energy balance modelling.

7.3 Discharge data

Discharge data are not necessary to model discharge. If data are available they can be read by the model and model performance is assessed by computing Nash-Sutcliffe R^2-values. The measured discharge must be included as a separate column in the **climate input file**. Discharge must be given in $\mathbf{m^3/s}$. Discharge data do not need to be available for the entire period of simulation. In contrast to the climate data the time series may contain gaps but these must be filled with missing values. The value of missing values can be different from the one of the grid files and is given by the user in *input.txt*. The measured data must not contain 0 m^3/s. Such values need to be increased or replaced by missing value. The discharge data is read from the climate data input file. It can be any column.

7.4 Mass balance measurement dates

The mass balance can be computed for different periods every mass balance year instead of a fixed-date scheme. In this case the dates (julian days) over which periods the mass balance is to be computed must be read from file. A mass balance year can thus be less or longer than one year. The periods for winter and summer mass balance are defined in a file according to the following example:

Tab: Example for a file with different mass balance periods for different years. E.g. the mass balance year for 200/2001 starts on JD 250, 2000 and ends on JD259, 2001. The winter balance ends on JD 128, 2001.

```
Year   summerstart winterstart
Dates for mass balance on Storglaciären
2000      130      250
2001      129      260
2002     135       258
2003     140       260
2004     130       260
```

8 OUTPUT FILES

8.1 Overview

A large variety of variables can be written to file, either as **grid files** or as **time series files**. **For temperature index modelling** far less variables are possible and these are described in detail in Chapter 7, but the types of possible outputs are the same and described here. Only few output files are generated by default; most output is optional and must be specified by the user in the input file (*input.txt*). All output files are written to the output path specified in the file *input.txt*.

Regarding the spatial and temporal resolution of output, the model supports different types of output files. Any one or any combination of these can be selected by the user:

Time series files:

1) Time series of the **spatial means** of the output parameters above averaged over the whole glacier for each time step (default name '*areamean.txt*')
2) Time series of the standard output for **individual grid cells** for each time step (max 300 locations)
3) Time series of **cumulative mass balance** for up to 50 locations (default name '*cummassbal.txt*')
4) Time series of **cumulative ablation** for up to 50 locations (default name '*cumablation.txt*')
5) Time series of number and percentage of grid cells that are **snow-free** (only if run with initial snow cover) (default name '*snowfree.txt*')
6) Time series of **discharge**
7) Annual series of **seasonal and annual specific mass balance** (default name '*seasonalmassbal.txt'*)
8) **Seasonal and annual mass balance profiles** for each year and mean profiles over entire simulation period
9) Time series of **snow model output** (output for each layer)
10) **Point balances for sites of observations** (requires input file with observations). The model outputs the corresponding mass balance for each site's observation and integrates over the exact time period the observation refers to. Each observation may refer to a different period.

Grid files:

1) Grid files of variables for different time averages.
   available time steps: - each time step
   - each day
   - the whole period of calculations
2) Grids of **seasonal/annual mass balance** for each year (cumulated mass balance over periods defined in input.txt)
3) Grid file of **surface characteristics** (snow, ice ...) or snow water equivalent once per day

OUTPUT FILES		
Type of output	***Name of output file***	***Format***
Control file	***modellog.txt***	ASCII
Time series files (output every time step)		
1. Time series of standard output of **spatial means** of entire glacier for each time step	***areamean.txt***	ASCII
2. Time series of standard output for **individual grid cells** for each time step	names defined in *input.txt*	ASCII
3. Time series of **ablation** and cumulative **mass balance** of individual grid cells	***cumablation.txt*** ***cummassbal.txt***	ASCII
4. Time series of number/percentage of **snowfree grid cells**	***snowfree.txt***	ASCII
5. Time series of simulated discharge	name defined in *input.txt*	ASCII

6. Time series of **snow model output**	***Subsurf***+*name defined for 2*	ASCII
Time series files (output not every time step)		
7. Time series of seasonal/annual mass balance (output once a year)	***seasonalmassbal.txt***	ASCII
8. Mass balance profiles (output once a year)	***Massbalpriofle+year.txt*** ***Massblprofilemean+year1+yearlast.txt***	ASCII
9. Point balances for sites of observations (requires input file with observations)	***Pointbalances.txt***	ASCII
Grid files (frequency user-determined)		
1. **Temporal means** for each grid cell of the entire area calculated (grid files)	names created by program incorporating into the name the time the data refers to: - each time step (e.g. *net19012.bin*) - each day (e.g. *net190.bin*) - whole period (e.g. *netall.bin*)	binary
2. Grids of surface characteristics	***sur***+date, e.g. *sur190242004* (JD 190, 2004) ***sno***+date e.g. *sur190242004* (JD 190, 2004)	binary
3. Grids of mass balance for each year	names created by program incorporating into the name the year the data refers to and the julian day of the end of the mass balance year or in case of winter mass balance of the winter season: e.g ***winbal2004_135.bin***, ***sumbal2004_256.bin***, ***massbal2004_256.bin***	binary

8.2 Time series files

8.2.1 Time series of spatially averaged model output

For each time step, **all output variables are averaged over the entire domain** defined by DEM 2 (drainage basin DEM). All mass balance output is integrated over the domain of the glacier area (DEM 3). Model results are written to a file called by default ***areamean.txt.*** The first two rows are comments. The columns refer to the following data. (If direct clear sky direct radiation is read from existing files, columns C,D and E contain 0. The same is true for direct and diffus if they are not interpolated individually).

Energy balance model output variables. All energy fluxes are in W/m^2.

Col	Name in first row of file	Meaning
1 A 2 B 3 C	year julian day time	 1-365 in real numbers (no leap years allowed) refers to the times given in the climate data file; time is 24 for daily time steps
4 D	shade	amount of shading: (sun=0 or shade=1 under clear sky conditions, if shading is calculated as a weighed mean of a number (split) subintervals and the sun rises or sets within the time interval considered, shade can be any fraction of one (e.g. 0.5)
5 E	exkorr	correction factor for direct radiation to account for the effect of shade, slope and aspect of the grid cell (cosθ/cosZ), defined as clear-sky direct radiation devided by clear-sky direct radiation of an unobstructed sky (∑Isenk*cosθ / ∑Isenk*cosZ), (if grid is shaded, factor=0)
6 F	solhor	clear-sky direct radiation, assumed the grid cell was horizontal and unobstructed (no slope and no topographic shading)
7 G	dirclearsky	clear-sky direct radiation corrected for the effects of shading, slope and exposition
8 H	direct2	Actual (cloud affected) direct radiation corrected for the effects of shading, slope and exposition (global-diffus), includes the effect of clouds
9 I	Diffus	diffuse radiation
10 J 11 K 12 L 13 M	Global reflect albedo Swbal	global radiation (shortwave radiation) Reflected shortwave radiation Albedo shortwave radiation balance

14 N 15 O 16 P	Longin longout LWbal	longwave incoming radiation longwave outgoing radiation longwave radiation balance
17 Q	Netrad	net radiation
18 R 19 S 20 T 21 U	Sensible Latent ground rain	sensible heat flux latent heat flux ice heat flux energy supplied by the sensible heat of rain
22 23 24 25 26 27	Enbal melt abla massbal cummassbal surftemp	energy balance (sum of all computed components) water equivalent melt (mm/timestep), defined positively ablation (mm waterequivalent/timestep), sum of melt and mass loss due to sublimation, defined positively mass balance (cm/timestep), mass gain is positive, loss is negative Cumulative mass balance (mass change since simulation start in cm) surface temperature

For the **temperature index model** (*detim*) the output will contain columns 1-7, and in addition *(see Chapter 9 for more details):*

1. melt (mm/time step)
2. air temperature at the output location (deg C), but if it is <less thant hreshold T, it is 0
3. air temperature of the weather station (i.e. the input from the climate input file)
4. DDFcalc (computed degree day factor from melt divided by positive degree day sum) Note in case of simple degree-day modelling DDFcalc corresponds to the DDF given in input.txt, however, in case of DDF model 2 or 3 this is not the case.
5. mass balance (cm)
6. cumulative mass balance (cm since simulation start)

8.2.2 Time series of individual locations (station output)

For up to 300 different grid cells in the area calculated (glacierized area) a default series of output variables (see table) can be written to file for each time step (text-file). The locations are specified in *input.txt* by giving the row and column (seen from the upper left corner of the DTM) for each grid cell to be outputted. A file is created for each specified grid cell. The first two rows are comments. The elevation of the grid cell, taken from the DEM is printed into the second row.

The output columns are the same as for the time series of the spatially averaged model output (*areamean.txt*, see above), but in addition the following is added:

Col	Name in first row of file	Meaning
27 X	Exkhor	correction factor for the climate station grid cell, if this grid cell was horizontal
28 Y	Ratio	Measured global radiation/clear-sky direct radiation (slope of climate station grid cell assumed to be horizontal for calculations of correction factor) *(methodglobal=1)* or the ratio of direct and clear-sky direct radiation is given (*methodglobal=2*)
29 Z	Dirhor	clear-sky direct radiation, assumed the grid cell was horizontal, corrected for topographic shading (*solhor*exkhor*)
30 AA	Snow	Snow water equivalent in cm (only if *methodinisnow* = 2, otherwise -99), variable *snowcover*
31	S(m)R50mod	snowlayer (m snow or m ice) can be compared with SR50 – measurements (water equivalent converted to surface elevation changes) (variable *snowlayer*)
32	MBsum	snowprec*factinter – ABLA (m we), mass balance (variable *MBsum*) Mass balance computed by Carleen (should be the same as mass balance columns above (not tested yet)
Output snow model (the following columns will only be produced if the snow model is run)		
33	Runoff	RUNOFF (m we), MELT + RAIN only when *methodsurftempglac* = 4 (-> snow model is run
34	Super	*superice* (m ice) thickness firn or snow layer with dry density > 700 kgm-3 only when *methodsurftempglac* = 4
35	Water	*watercontent* (kgm2 = mm we) total water content of snow model only when

		methodsurftempglac = 4
36	Slush	*slushthick* (m snow) thickness of saturated layer only when *methodsurftempglac* = 4
36	Surfwat	Surface water
37	Coldsn	coldcontentsnow (Wm^{-2}) amount of heat necessary to raise temperature of snow layer to melting point only when *methodsurftempglac* = 4
38	Coldtot	coldcontentice (Wm-2) amount of heat necessary to raise temperature of total snow model to melting point (extra added layers below lowest at start calculation are not included) only when *methodsurftempglac* = 4
Additional variables is *outglobnet* = 1		
39	Globmeas	measured global radiation at climate station
40	SWbmeas	measured shortwave radiation balance (global radiation minus reflected shortwave radiation)
41	Netmeas	measured net radiation

Columns 1-32 will be produced in any case. A value of -99 will appear for those variables that are not generated in the specific run (e.g. clear-sky direct radiation for a horizontal grid cell in case direcd radiation is read from file). If direct radiation is read from files the columns of shade, exkor, exkorstation and solhor contain -99. All energy units are Wm^{-2}.

In addition, some data from the measured climate data file can be written to file (variable *outglobnet*=1 in *input.txt*). This provides the opportunity to compare model results with data from climate stations on the glacier in order to allow for the comparison of measured and calculated values at the climate station. This type of output can be requested by the user for any grid cell. The measured data, however, refers to the grid cell of the climate station (variable outglobnet=1 in input.txt). Column number depends on whether or not the snow model is run.

8.2.3 Time series of mass balance components of individual grid cells

For up to 300 grid cells specified in *input.txt*, the cumulative ablation and cumulative mass balance (**cm**) can be written to file. The first three columns contain the **year, julian day and the time** and the following **columns contain the mass balance component** for the different locations. The locations are defined by coordinates or row/col number at the end of *input.txt*, and the total number that should be written to file is given by *maxmeltstakes* in *input.txt*. The first (second) row of coordinates in input.txt is the location of the first (second) column in the output file, etc.

Output files:

a) **cumulative ablation** (file ***cumablation.txt****, array MELT for detim.c or ABLA for debam.c*)
b) **cumulative mass balance** (file ***cummassba.txt****, array MASSBALcum*). This file is useful to compare simulations with **ablation stake readings**.

The ablation (including mass changes by the latent heat flux) and the mass balance (snow accumulation – ablation) is cumulated for the entire period of computation defined by *jdbeg* and *jdend* no matter of the periods defined in *input.txt* for the winter and summer mass balance. *cumablation.txt* includes any water provided by condensation and the mass change by sublimation. The mass balance in addition to that includes snow precipitation. Thus, the difference between both files is snow accumulation. If there is no snow fall the output is identical.

(For output of more than 300 grid cells, change variables *stnrow* and *stncol* in *variab.h*.)

In case the subsurface snow model is run ('methodsurftempglac' = 4) additional files are generated: *cummassbalst.txt*. ???

8.2.4 Time series of snow line retreat

For each timestep the number and percentage of grid cells that are snowfree are written to file. This output only makes sense if the model is run with an initial snow cover file. It is useful to follow the snow cover depletion.

	Columns
1 2 3	Year julian day time
4 5 6	total number of grid cells of the area to be calculated number of snow-free grid cells in that area percentage of snow-free grid cells

8.2.5 Time series of discharge

Discharge can be computed and written to file even if no discharge data are available.

	Columns	Description
1	Year	
2	Julian day	
3	Time	
4	Qmeas	measured discharge (m3/s)
5	qcalc	simulated discharge (m3/s)
6	Qfirn	discharge from firn area
7	qsnow	discharge from snow-covered area outside firn area (glacier and non-glacierized area)
8	qice	discharge from ice exposed area
9	qrock	discharge from the region outside the glacier (only when when not snow-covered, if snow-covered water is part of qsnow
10	Qground	groundwater discharge (constant amount added to total discharge)
11	cumvolmeas	cumulated measured discharge [100 000 m3]
12	cumvolcalc	cumulated calculated discharge
13	cumdiffc-m	accumulated difference of calculated-measured discharge

8.2.6 Time series of annual and seasonal specific glacierwide mass balances

This file is only meaningful if several years are computed in one run. For each mass balance year, the winter, summer and annual mass balances are given for all years the model is run. The model must be started on the day for which the winter balance starts (*winterjdbeg*), for the result of the mass balance to represent the annual mass balance (winter balance + summer balance). The file is called per default ***seasonalmassbal.txt***. The file is generated per default if *winterbalyes* and *summerbalyes* are set to 1 in *input.txt*. The summer and winter start dates can be fixed dates defined in input.txt or can vary from year to year and in that case must be provided in an additional input file the name of which is specified in *input.txt*. The file must be under the input folder.

	Columns	Description
1	Year	mass balance year, e.g. 2003/2004
2	winter balance	Accumulation-ablation for winter period
3	summer balance	Accumulation-ablation for summer period
4	mass balance	Accumulation-ablation for period starting with first day of model run
5	winterjedbeg	day from which winter balance is accumulated (e.g. in year 2003)
6	summerjdbeg	day from which summer balance is accumulated (e.g. in year 2004)
7	summerjdend	last day over which summer and specific mass balance is accumulated for each mass balance year (e.g. in year 2004 for mass balance year 2003/2004

8.2.7 Mass balance profiles

For each mass balance year, the winter, summer and specific mass balance are given in a separate file. The file is generated per default if *winterbalyes* and *summerbalyes* are set to 1 in *input.txt*.

	Columns	Description
1	No	Running number (starting with lowest elevation band
2	elevation	Elevation (m) of the middle of the elevation band
3	pixels	Number of pixels in elevation band
3	area	Area of elevation band
4	bw	Winter balance (m) for each elevation band
5	bs	Summer balance (m) for each elevation band
6	bn	Annual (net) balance (m) for each elevation band

Also in the same format the mean mass balance profile over the period of simulation is written to output (filename: *massbalprofilemean+year1+last year.dat, e.g. massbalprofilemean19701980.dat refers to the period of mass balance years 1969/1970 to 1979/1980*). The width of the elevation bands is read from *input.txt*, and the profiles are computed for all elevation bands that cover the range of the glacier DEM.

8.2.8 Point mass balances

If measured point balances are available a file (named by default ***pointbalances.txt***) can be created that allows direct comparison of measured and modelled values. If the ouput of the cumulative mass balance of individual grid cells is requested for those same locations (*maxmeltstakes* >0 and coordinates or row/column numbers are given at the end of input.txt) the model takes the model output *cummassbal.txt* and computes the balances for the periods corresponding to the measurements. The observations can span over any period of time and also be different for each stake, i.e. they do not have to be seasonal or annual balances but can span shorter or longer periods. A file called '***measuredpointbalances.txt***' must be available in the folder of the input data and contain the following data after two header lines (note the first 2 lines are not read by the model):

	Columns	Description
1 2 3	X-coordinate Y-coordinate Elevation (m)	First 3 columns are not used by the model but are usually available as part of the input data. Any number can be put in any of these columns if data not available.
4	Mass balance (m)	Mass change over the period of time defined by start and end dates below. Values must be in meter.
4 5 6 7	Start year Start day number End year End day number	Defines the period of the mass change

The ouput file includes the exact same data as above plus another column with the modelled mass balances for each location.

Note that the order of the observation locations in the measured point balance file must be exactly the same as the order of the locations for which cumulative mass balance (output ***cumassbal.txt***) is requested, given at the end of *input.txt*. Also *maxmeltstakes* (*input.txt*) must be set to the exact number of data rows in *measuredpointbalances.txt*.

8.2.9 Time series of snow model output

Various variables from the subsurface model can be written to file at regular intervals, e.g. every timestep or every second time step, for individual grid cells. Output is generated for each sublayer starting from the surface. Thus, for the same timestep there are several rows representing one subsurface layer each.

The filenames start with ***subsurf*** to which names given in *input.txt* are added to

	Columns
1 2	julian day time
3 4 6 7 8 9 10 11 12 13 14	Layer number Surface temp Layer density Layer mass Layer water content Snowlayer Snow cover (water equiv. in mm) number of snow-free grid cells in that area percentage of snow-free grid cells layer ID (1=snow, 2=firn, 3=ice) irreducible water content

8.2.10 Profiles of snow model output

Various variables from the subsurface model can be written to file for 3 given profiles on the glacier (centerline and 2 cross profiles). These lines are for the moment defined for Storglaciaren (but it is intented to make this option more general). Each profile is written to file at given time (jdsurface, input.txt). Output is generated for each sublayer starting from the surface. Thus, for the same location there are several rows representing one subsurface layer each. The filenames start with subsurfline to which the julian days of the output given in input.txt are added.

8.3 Grid files

8.3.1 Temporal means for certain time steps

Intermediate results of the energy balance calculations can be written to Output-gridfiles (one file per requested time interval). All output grid files have the same gridsize, number of rows and columns and the same coordinates as the input grids. The frequency of output is specified by the user in the input file (input.txt). Five options are possible:

- every time step
- daily means
- means of the entire period calculated
- daily means and means of the entire period

If grid output-files are requested, the output files with the data below can be generated. Any selection is possible. Direct radiation grids can be generated by the program or read from existing files. If the latter option is used, the first 3 grids can not be generated and clear-sky direct radiation grids are only written to output, if daily or period means are requested by the user. Energy variables are in W/m^2.

Variable		Default name scheme *(_includes numbers or letters according to table below)*
1. shade (1=shade 0=sun)		(***sha_.bin***)
2. correction factor for the global radiation	(=0 if shaded)	(***exk_.bin***)
3. clear-sky direct radiation (no slope correction)		(***sol_.bin***)
4. clear-sky direct radiation slope-corrected		***(dir_bin)***
5. (actual) direct radiation slope-corrected		***(dis_bin)***
6. diffuse radiation		***(dif_bin)***
7. global radiation		(***glo_.bin***)
8. albedo		(***alb_.bin***)
9. shortwave radiation balance		(***swb_.bin***)
10. longwave incoming radiation		***(lin_.bin)***
11. longwave outgoing radiation		*(lou_.bin)*
12. net radiation		(***net_.bin***)
13. sensible heat flux		(***sen_.bin***)
14. latent heat flux		(***lat_.bin***)
15. rain heat flux		(ren***_.bin***)
16. energy balance (energy available for melt, W/m2)		(***bal_.bin***)
17. melt (water equivalent)		(***mel_.bin***)
18. ablation (water equivalent in cm)		(***abl_.bin***)
19. surface temperatures (in Celcius)		***(sut_.bin)***
20. surface characteristics (snow, ice ...)		***(sur_.bin)***
21. snow cover in water equivalent in cm		***(sno_.bin)***
Only for period mean:		
22. rain (sum of precip in form of rain)		***(raiall.bin)***
23. snow (sum of precip in form of snow)		***(snoall.bin)***

In case the **multilayer snow model** is run additional grids can be written to file

1. runoff (=melt+rain), in m we	***(run_.bin)***
2. total (not mean!) superimposed ice in m ice thickness firn or snow layer with dry density > 700 kgm-3	***(sup_.bin)***
3. water content in mm we	***(wat_.bin)***
4. thickness of saturated layer	***(slu_.bin)***
5. cold content of snow layer = amount of heat necessary to raise temperature of snow layer to melting point	***(cos_.bin)***
6. cold content of whole layer computed	***(cot_.bin)***

(amount of heat necessary to raise temperature of total snow model to melting point (extra added layers below lowest at start calculation are not included)

Only for period mean:

7. refrozen melt water (only snow model) ***(masall.bin)***
8. capillary water content firn at end of period (only snow model) ***(wacall.bin)***
9. total water water content firn at end of period (only snow model) ***(wasall.bin)***

(note watall includes water content snow)

For **temperature index modelling** the melt grid and 2 additional grids can be generated:

1. degree-day factor (MELT/POSTEMP in mm/d/K) *(ddf_.bin)*
2. mean of positive temperatures *(pos_.bin)*
   (POSTEMP=temp if temp>0)

Melt and ablation grids can be given in cm/timestep, cm/period, m/timestep or m/period calculated. The names in bracket refer to the names of the output file, respectively. The first 3 letter will be followed by figures indicating the time the files refer to according to the following pattern:

Table: Name pattern of output gridfiles

frequency of output	added to first 3 letters:	**example** (global radiation)
every time step	julian day, first 2 digits of the time after transformation to integer	*glo19012.bin* (=jd 190 12 pm) midnight -> hour = 24
daily means	julian day	*glo190.bin*
entire period	All	*gloall.bin*

In all grid output files 2 - 4 (exkor,solhor,direct), output of the climate station grid refers to the actual slope, although for the calculation of the ratio of global radiation and direct radiation the grid slope was assumed to equal zero. Grids 1-4 cover the entire area covered by the digital elevation model, whereas any other grids contain valid data only for the area of digital terrain model 2 (grid cells outside contain missing values). Surface temperature grids and longwave radiation grids are only possible if a spatially variable parameterization is chosen.

8.3.2 Snow cover and surface charcteristic grids

If grids 20 or 21 (surface characteristics or snow cover) are requested, files are written to file maximum *once per day* at midnight (in contrast to the grid files above). Three options are possible: (1) once per day, (2) at regular intervals, e.g. every fifth day, (3) for individually specified julian days (max 20 days). The file allows a comparison between observed and simulated snow line retreat. The output is only useful if the model is run with an initial snow cover file (methodinisnow = 2). The **surface characteristics** grid contains intergers refering to:

1 = snow
2 = firn area (initial snow has melted and no new snow on grid cell)
3 = ice
4 = rock (grid cells outside the glacier but not snow-covered)
5 = debris cover on grid cell outside firn area.

The **snow cover file** refers to how much snow is left (cumulated for each time step initial snow cover minus ablation plus snow fall).

The surface characteristics (array surface) are also used in the model to decide which of the four linear reservoirs will be assigned to each grid cell. Debris (5) will be assigned the ice reservoir).

8.3.3 Mass balance grids

If the model is run for mass balance seasons the specific mass balance, summer and winter mass balance (all in cm) can be written to grid files. The mass balance grids are only created for the area defined in DTM3 (glacierized area). The time periods over which summer and winter mass balance are cumulated are defined in *input.txt*. There is two options:

a) same periods for every year in case of multiple-year model runs
b) different periods for different year. In this case the periods for winter and summer mass balance are defined in a file (see Input data) according to the following example:

```
Dates for mass balance measurements
Year    summerstart   winterstart
1990    140 260
1991  141 265
1992  142 262
1993  130 260
1994  130 265
1995  130 260
1996  130 260
1997  130 265
1998  130 260
1999  138 258
2000  135 260
```

For example, the summer balance for the mass balance year 1999/2000 starts on day 135 (year 2000) and ends on day 259 (year 2000, thus one day before the winter balance for the following mass balance year would start). The winter balance balance is computed over the period between day 258, 1999, and day 134 the following year (2000).

Warning ! If the time step is less than one hour, the internal creation of the filename may not be clear in case of output files for every time step. Files may be overwritten. Consequently, the pattern to create filename has to be changed in the program for subhourly time intervals (*function startwritehour*).

8.4 Control file

An output file ***modellog.txt*** is generated by default including information from the model run:

1) Information about all output variables that are reset to different values than given by the user in input.txt. If given output variables are not possible, these are reset by the model. For example if detim is run but output of global radiation grids requested.
2) Then the entire *input.txt* is written to this file.
3) All 'hidden' parameters (parameters that can be adjusted by the user but are not part of input.txt)
4) In addition each time unrealistic values are produced by the model but the program is not exited, these values are written to *modellog.txt* along with the time step. This is mostly used in connection with the snow model. For example each time the surface temperature falls below a predefined value (in *variab.h*) a comment is put to modellog.txt. To avoid the risk of filling the harddisk if the total number of such occurrences exceeds 50000 (can be adjusted in variab.h) the program is exited.

This file is meant to facilitate model changes for users altering the source code. Any model input and output can be written to the file, thus offering the opportunity to trace potential erraneous calculations.

8.5 Model performance file

The model generates per default a file called *modelperformance.txt*. In addition to 3 header lines the output includes one row of data:

	Columns	**Description**
1 2	Q_r2 Q_lnr2	R2 and logarithmic R2-values indicating the agreement between measured and modelled discharge over the entire period of simulation (only for time steps with valid discharge data)
3 4 5	Qvolumesim Qvolumemeas Difference(sim-meas)	Simulated discharge volume (in 100,000 m3) over entire simulation period Measured discharge volume over the time steps with valid discharge data Difference
6 7 8	Nsteps nstepsdis massbalance	Number of simulated time steps Number of time steps with valid discharge data Total glacier mass change over entire simulation period

If any of the variables are not available they are replaced by missing value -9999.

The file is read by the optimization program '*MultiRun'* written in Matlab where an output file is created that includes these columns plus additional performance variables for a many model runs using different parameters. (see http://regine.github.io/meltmodel/tools.html).

9 APPLICATION OF THE MODEL

9.1 Modes of calculating potential direct radiaton

The model offers two different approaches of application:

1. All calculations are performed by the programm *debam or detim.c*.
2. **Clear-sky direct radiation** (slope corrected) of the entire grid is read from existing input files, i.e. the calculations of topographic shading, correction factors, direct radiation of unobstructed horizontal surfaces and slope-corrected direct radiation are not done by the model. The advantage is that calculation times are reduced considerably, because the shading calculations are very time-consuming. The disadvantage is that much disk space is needed to provide one direct radiation grid file for each time step. The grid files of direct radiation can be generated by the program ***shading.c*** or also by *debam.c* or *detim.c*. If disk space is available to it highly recommended to generate the direct radiation files in advance.

The same is true for the degree day model if the model containing direct radiation is applied.

(A third option is partially included in the model: The shade information is read from existing files, but the correction factors and direct radiation are calculated by the model. This option is included in function *schatten*, but not yet completed in file *writeout.c.)*

9.2 Download and instal the model

The model is hosted on a github repository and can be download at: http://regine.github.com/meltmodel/.
Download the 'master' version' which contains the latest version. A complete instalation guide is given on the homepage. Unzipping the release you will have several folders and files:

Folders:
Folder ***src*** contains the source code (i.e. all files listed below)
Folder ***util*** contains two subdirectories:

- **grid tools**: contains programs to convert asci-grids into binary format and vice versa
- **shading**: contains program shade.c to compute potential direct solar radiation and store files

Files: The content of all files and directories is explained in the text file **organization.md**.

A complete description of the files and more details are given on the github page

9.3 Model files

The model contains of the following files.

Model

main programs (3 files)	**debam.c** (energy balance model) **detim.c** (temperature index model) **(ddfopt.c)** (temperature index, optimization), program is outdated and is no longer available
functions (16 files) Each of these files has a header file with the same name but extension .h (16 files)	**closeall.c** **discharg.c** **disopt.c** **globcor.c** **input.c** **initial.c** **radiat.c**

	tindex.c **turbul.c** **userfile.c** **writeout.c** **snowmodel.c** **snowinput.c** (new file in 3/2010) **scaling.c** (new file in 11/2011) **skintemperature.c** (new file in 2013) **grid.c** (new file in 7/2012)
variables (2 files)	**variab.h** **variabex.h**
controlling parameter file	**input.txt**
Batchfiles for compilation (not needed if make-file used)	**meltmod.bat** **degree.bat** **ddfopt.bat**
offline-direct radiation computation (separate program)	**shading.c** (main program) **shading.par** (parameter input file) **shading.bat** (batch-file to compile)

GIS-programs

ascigrid.c (convert grid data in ARC-INFO-Ascii-format into binary format of model input)
run program: *name executable <inputfile> <outputfile>*

gridasci.c (convert grid data in binary-format (model output) into Ascii-format of model input)
run program: *name executable <inputfile> <outputfile>*

dgmcut.c (cut out a rectangular part of a larger grid, input file: **dgmcut.par**)

Example files: *datesmassbalance.dat* (if floating-dates for mass balance measurements are used)

IDL-programs
(only most important ones listed here)

Visualization of grid data	**grid.pro** (needs files readinputline.pro, colorbar.pro) **grids2.pro** (needs files readinputline.pro, colorbar.pro) **shade.pro**
Visualization of time series	**linesdiff.pro** **discharg.pro** **disdiff.pro** **lines.pro**
Files with functions (called from most programs)	**inputgrid_read.pro** **inputline_read.pro** **colorbar.pro**
parameter files (to adjust user specific variables)	**inputgrid.par** (for grid plot programs) **inputline.par** (for line plot programs)

Matlab visualization files
See github homepage for description of files downloaded from github page.

9.4 How to run the model

A C-Compiler must be available to compile the program. The compiler must include GMP and MPFR libraries. All model files and the controlling input file (*input.txt*) must be copied to the same directory. All input files must be copied to the directory specified in *input.txt*. If direct radiation is read from files, these files can be read from a different directory, as specified in *input.txt.* The output path specified in *input.txt* must be created. All paths specified in *input.txt* must exist in advance. It is suggested to follow the installation of the model as described on the download homepage: http://regine.github.com/meltmodel/install.html and to compile the model with **make**. This will result in two executable files**: debam** and **detim**. You run the model by typing *debam* or *detim* on the command line of a terminal.

***NOTE*: The file *variab.h* contains a number of variables that can be adjusted but are not relevant for most users, and therefore are not included in *input.txt*. Before compiling the model you should go through the 'hidden' variables in *variab.h* and make sure they are set to the values you want to use.**

9.4.1 How to compile the model

We strongly recommend that you compile the models using ***make*** following the instructions on the download homepage. However, you can also compile them the following way (at terminal):
compile the program (in UNIX-environment use gcc or cc)

(g)cc debam.c ....*all .c files* -o debam –lm –m32
(g)cc detim.c ....*all .c files* -o detim –lm –m32

Compile debam.c:

gcc debam.c closeall.c disopt.c discharg.c turbul.c radiat.c writeout.c input.c globcor.c initial.c tindex.c userfile.c snowmodel.c snowinput.c grid.c skintemperature.c -o debam.exe –lm -m32

Compile detim.c:

gcc detim.c closeall.c disopt.c discharg.c turbul.c radiat.c writeout.c input.c globcor.c initial.c tindex.c userfile.c snowmodel.c snowinput.c grid.c skintemperature.c -o detim.exe –lm -m32

Use the corresponding _.bat files to compile (which include the lines above)!

(The compiler option "-o" is the option to give the executable file any name, here as example *debam.exe* and *detim.exe*, but any other name is possible)

Running the model with Windows Visual-C
(this may be outdated, check the github page for current instructions):

1. *File*, *open*, search for debam.c or detim.c (depending which model to be used)
2. *Build*, *compile*, enter, enter
3. Click on *meltmod/degree classes* (to the left)
4. *Project, add to project, files*
5. select all .c and .h - files except for mains (i.e. not *debam.c, detim.c* or *ddfopt.c* !), multiple select by keeping ctrl pressed
6. *Build*, *rebuild all* -> warning may occur, but not errors should occur; a new directory debug is created in which the executable file _.exe is generated.
7. *Build, execute* (alternatively, once the _.exe has been created once, the model can be run without opening Visual-C by opening a command prompt and going into the directory where the _.exe file is located and write: _.exe.

How to compile with VISUAL-C, so that parameter files (arguments) can be given:

- go into WORK SPACE (to the left)
- klick on ***File View*** (not class view) below
- set cursor on file in work space window above
- klick with right mouse
- Settings
- klick on ***Debug***
- write the name of the parameter file into the window ***program arguments***

9.4.2 Running the model

Checklist:

a) Before you run the model plot all input data (all grid files and the climate data) and make sure the data makes sense !
b) Adjust the controlling input parameter file ***input.txt*** (see below).
c) Adjust 'hidden' parameters in ***variab.h***, necessary (see below)
d) Copy all input files to the folders specified in *input.txt*
e) Run the model (type *debam* or *detim* in command line mode)

Multiple model runs in batchmode:

When calibrating the model many model runs with different parameter constellation are necessary. Under UNIX (SUN) it is recommended to make multiple model runs (for e.g. calibration) using a batch file. The batch file contains a sequence of commands that are executed in sequential order.

1. create one directory for each model run (each run is specified in a separate *input.txt*)
   e.g. \run1, \run2, \run3 ...
2. create one directory each for the model output
   eg. \out1, \out2, \out3 ...
3. copy the model (exe-version, e.g. meltmod.exe) and *input.txt* into each of "run"-directories
4. adjust *input.txt* in each directory (make sure to specify a new output path for each run !)
5. create a "run-"batch file called e.g. *run.bat*. This file needs to contain all commands to make multiple runs, e.g.:
   ```
   cd run1
   debam
   cd ..
   cd run2
   debam
   cd run3
   debam
   ```
6. change the permission of the batch file to executable (*chmod u+x run.bat*)
7. run the batch: *run.bat*

The tool *MultiRun* (Matlab) developed in fall 2013 offers an automated way of making multiple runs with different parameter constellations.

Generation of direct solar radiation files:
If the potential direct solar radiation files are read from files, they must be created first either with the program *shading.c* (recommended, see Chapter 8: Additional programs) or they can also be created with meltmod.exe. In the latter case the following parameters in ***input.txt*** must be adjusted:

- adjust input/output path
- set any output options to 0, except for grid output diryes, timestep every hour
- adjust variable split (e.g. 4-6)
- directfromfile=0 (to generate files, not to read from file)
- slopestation=0
- all methods options=1 (is generally faster than options 2).

9.5 If the model does not work

If the model does not work the problem is often an incorrect *input.txt* or incorrect data input (wrong format etc). However, since the model continuously develops there may still be source code errors.
Typical errors are:

a) There is an error message on the screen, for example according these lines: *'Error in input.txt. Variable XXX can not be larger than XXX.*
   This is one of the most common errors when beginners start using the model and is in 99% of the cases a user problem. It means that the model is expecting a certain value for the row it is reading and finds one that is not within the logical limits expected. For example if the *input.txt* has a value >1 the program will exit and output that this parameter is wrong. One needs to go into *input.txt* and check if the value is correct. What often happens is that the value actually is correct. This means the error occurs sometime before that, for example if a user adds incorrectly another number into the line before, the model will assign this number to the next variable. If this happens check the screen output (which includes a number of input.txt variables but not all) and check until when the model correctly reads the individual lines. The error is somewhere between the last line that is correctly read and the variable written to screen as wrong. You need to go through these lines in your *input.txt* and compare your file with the example *input.txt* and check the description of each line of *input.txt*.

b) The model stops and says '**bus error**' or '**segmentation error**'. In this case often an array which is dimensioned with a certain size is exceeded with the data you want to feed it. This should be captured by the program and needs to be fixed in the source code.

<u>Trouble-shooting</u>:
If *input.txt* is correct there will this screen output indicating that your input.txt is read correctly:
    ************END OF INPUT-FILE **********************
If you don't get this, the problem is *input.txt*.

If *input.txt* is correct but the model does not run, check your input data (climate, grids). This is one of the most common errors. Go, LINE BY LINE through the format requirements of the climate input data and check that your data complies with the format. Do you for example have a few extra rows before yours simulation start ?

If the model runs correctly, the last screen output you get is:

    ********* PROGRAM RUN COMPLETED ************

If you don't get this something is wrong and you should start checking your climate input data.

9.6 Controlling input file **input.txt**

The model requires a **controling input file (parameter/configuration file)**, called *input.txt*, which contains all information necessary to run the program (Example in Appendix). Here, the user can make all adjustments necessary for the application of the model to the specific area under investigation. It contains information about filenames, input data, physiographic data and also provides the opportunity for the user to specify model output files. An example of the file is given in the Appendix. The entire *input.txt* is written to the control output file *modellog.txt* to be able to track the options and parameters used for a specific model run.

Input.txt must be adapted by the user to the specific conditions of the current application. The structure is fixed. All variables are followed by a comment briefly explaining their meaning and by the name of the variable in the programme. The comments are ignored by the program. On each row anything behind % is comment and anything can be written there. The comments are not fixed in position, e.g. there may be more or fewer blancs between any variable and the following comment. But, there must be at least one blanc between the variables and the corresponding comments. It is not allowed to include more lines or delete existing lines (with a few exemptions, which are outlined below (e.g. albedo and output parameter part)). Depending on the type of the model (energy balance or temperature index) and on the choice of parameterizations, only part of the variables in *input.txt* are actually needed by the program. However, the entire file is read by the program in any case. Therefore, even if a variable is not needed in the model run specified, ***DO NOT DELETE*** any number in *input.txt* without replacing it by another number of the same type !!! Variables which are not needed are read, but will then not have any importance.

Filenames including fullpaths must not be longer than 100 characters (dimensions can easily be changed in the source code). Most file names, which have to be specified by the user are arbitrary. Any names are possible except for:

input.txt
areamean.dat
modellog.txt
melting.dat
cummassbal.dat
snowfree.dat
the names of all program files (e.g. debam.c etc.)
and those names which may be created by the program for grid output (see name pattern in 3.5).

'Hidden' options
A number of variables are adjustable as 'hidden' options in the beginning of the file *variab.h*. These are generally variables that are not necessary to change for most applications but can be very useful sometimes. To avoid *input.txt* becoming too long, these are not put in *input.txt*. **It is highly recommended to have a look at *variab.h* and its 'hidden' variables.** For example, the instrument height can be changed (set to 2 m as default) or the emissivity (set to 1 as default). Here, the user can also choose if the Ascii output files should have the extension .dat or .txt. **When the subsurface snow model is used (*methodsurftempglac*=4) the temperature and density profiles must be adjusted in *variab.h*.**
Make sure you check the hidden options before starting a simulation and adjust them if necessary. Note that when a variable in *variab.h* is changed the model must be recompiled.

Description of *input.txt*

E = must be adjusted for energy balance modelling (programme *debam.c*)
T = must be adjusted for temperature index modelling (programme *detim.c*)
If a variable is not required for the model run, just leave the numbers/names that are in the default input.txt !!! So, if you run detim.c do not bother about any rows that have 'E' alone, just leave those rows as they are

The parameters in ***input.txt*** are described line by line below. The **bold lines** are copied from an example input.txt followed by explanation of the parameter specified at the beginning of each line. Most lines contain only one single parameter. All parameters are at the start of the line. All text/numbers following % are comments, i.e. behind % you can add or delete freely; the last word of each line refers to the name of the variable in the code.

dayssscreenoutput (E+T)

100 %output to screen every X day daysscreenoutput

The year, julian day and time under computation are written to screen every Xth day specified here (here every 100 days). This is to track how far the model run has come; the less output the faster the model run.

input / output path (E+T)

/meltmodel/studies/glacierX/indata/ % Path for Inputfiles. inpath
/meltmodel/studies/glacierX/output/out1/ %Path for Outputfiles. outpath

Directory names containing all input and output data. In Unix the path must include the backslash at the end, e.g. /model/output/. In Windows applications two backslashs may be needed, e.g. c:\\model\\output\\
All input files (gridfiles and climate data) execept for the file *input.txt* must be in the directory specified by *inputpath*. All output files are written to the output path.

first and last julian day and year to be calculated (E+T)

244 2005 %first julian day to be calculated. jdbeg yearbeg
365 2008 %last julian day to be calculated. jdend yearend

Julian day and year must be given in the same row separated by at least one blanc. The shortest time period for a model run is one day. It is not possible to run the program only over a time period of a few hours. The model can be run over several years.
If the same day is given for both (first and last day), calculations are done for exactly one day. Climate data must exist for the entire period of calculations (no gaps, no missing data). *Note:* If the starting day is changed several parameters must also be adjusted to provide the proper initial values for the new starting day, e.g. initial snow cover file etc. (see Appendix).

discharge to be calcuated (E+T)

1 %discharge to be calculated: 1=yes,0=no,2=yes, but no discharge data. disyes

0 = no discharge calculation
1 = discharge calculation and the climate input file contains a column with measured discharge data (may contain gaps)
2 = discharge calculation, but discharge data are not available (useful for scenario runs)

Calcgridyes (E+T)

1 %1=whole grid computed, 2=only grid cell of weather station. calcgridyes

1 = compute whole grid (this is the normal mode)
2 = compute only location of the climate station (point-model). Useful option for testing the model and changes in the code. Requires adjustmenting parameters to specific application in *variab.h*.

***** 1.) MODEL OUTPUT PARAMETERS ******

variable maxmeltstakes (E+T)

0 %number of stakes for melt output. maxmeltstakes

number of individual grid cells for which cumulative ablation and cumulative mass balance should be written to output (rows and columns of these cells are defined at the end of the file). This output is useful to compare model results to ablation stake measurements (Output filse= *ablation.txt, cummassbal.txt*). If *maxmeltstakes* >0, two files are written to output, one for cumulative ablation and one for cumulative mass balance.

variable plusminus (E+T)

1 %cum massbal multiplied by this factor in melting.dat plusminus

defines if cumulative mass balance *in ablation.txt* is written as positive or negative values. Mass balance is negative if ablation exceeds accumulation. If positive numbers in case of negative mass balance are wanted for the mass balance output in *ablation.txt*, put –1, otherwise 1.

variable do_out (E+T)

3 %0=no output 1=every step, 2=daily, 3=whole period 4=2and3. do_out

This determines the frequency of grid output of all standard output variables.

0 = no output
1= output every time step
2 = output every day (daily mean)
3 = output of whole period, i.e. from *jdbeg* to *jdend*
4 = output of every day and whole period

NOTE: Option 2 is not possible for computations with daily time step (programs sets automatically *do_out* = 0, if *timestep*=24). However daily means can be written to file by option 1 (every timestep).
In case *maxmeltstakes* >0, do_out is set per default to 3 or 4, so that the period mean is also computed (needed for program technical reasons).

2 lines: ..shayes, exkyes ... etc (E+T) (see Appendix)

%shayes exkyes solyes diryes dir2yes difyes gloyes albyes swbyes linyes loutyes
0 0 0 0 0 0 1 0 0 0 0
%netyes senyes latyes raiyes enbyes melyes ablyes surftempyes posyes ddfyes
0 0 0 0 1 0 0 0 0 0 0

defines which results should be written to grid output, 0=no output, 1=output. In the example above grids of global radiation and energybalance will be written to file.
In case of energy balance modelling all paramters except the last two (*posyes*, *ddfyes*) can be set to 1. However, if potential radiation files are read from files (*directfromfile=1*) the first 4 parameters (*shayes ... diryes*) cannot be set to 1. This is also true for temperature index modelling including potential direct radiation. The parameters *dir2yes* and *difyes* can only be set to 1 if methodglobal=2, *linyes* (longwave incoming radation) and *louyes* (longwave outgoing radiation) if the spatially variable parameterization is chosen.
In case of temperature index modelling, all parameters are set to 0 by the programm for those grids that are not possible, no matter what the users enters in *input.txt* (e.g. global radiation: *gloyes=0*). The same is true for *shayes, exkyes* and *solyes*, if direct radiation is read from files. The first 3 letters define the grids (Output chapter: Temporal means for certain time steps): e.g. *gloyes* refers to global radiation, *senyes* to sensible heat flux etc.

Surface condition (variable surfyes) (E+T)

2 %surface conditions to grid file (2=for specified JDs) surfyes

If the model is run with an initial snow cover, the surface conditions (ice, snow, ...) can be written to a grid file every day at midnight:

0 = no such output
1 = yes, every day or every X-th day (how often is specified below)
2 = yes but for a number of julian days that are specified below.

This output is useful to compare the snowline retreat with observations obtained for example from automatic cameras. It is only possible if the model is run with an initial snow cover grid. (*Surfyes* is set to 0 in the program *(input.c)* if it the user sets it to 1 and the run is not with an initial snow cover grid).

Output: 1=snow
2=slush (only if surface type maps prescribed), =firn (if surface type generated)
3=ice
4=rock
5=debris.

Snow cover to grid file (variable snowyes) (E+T)

0 %snow cover to grid file at midnight. snowyes

The snow water equivalent can be written to output every midnight (as above)

0 = no output
1 = yes, every day or every X-th day
2 = yes but for a number of specified julian days.

This output is similar to the one produced by *surfyes=1*, but in contrast to that one, not integer numbers for each surface type, but the actual snow cover equivalent (decimal numbers) is written to file. (Only for run with initial snow cover).

Snow or surface written to file if jd dividable by this value (variable daysnow) (E+T)

1 %snow or surface written to file if jd dividable by this value daysnow

This parameter allows to reduce the number of output grid files for the surface conditions and the snow cover. If this parameter is set to 1, the output is generated for every day at midnight, if it is 2, the output is only generated for every second day (only for the julian days dividable by 2 without decimals) etc. If this variable is set to 2, then output is given for julian days 180, 182, 184 etc. It is not possible to have output for days 181, 183, etc.

variable numbersnowdaysout

2 %number of jd for output of surface type/snow cover numbersnowdaysout

The snow cover and surface grids can be written to file for up to 20 julian days. Here the number of days is given. Put 0, if output is wanted at intervals of every X day as defined above. If 0 is put, the next line is ignored by the programme.

If the snow model is run, as many output files are created as the number given here. The output of each of these files refers to the julian days given below. The day number will be included automatically in the output file name (e.g. sno190242010.bin = day 190, 24 stands for midnight (day is over), year=2010).

Julian days

190 210 %jd to be written to output for surface type and snow cover

If *numbersnowdaysout* > 0, give a corresponding number of day numbers for which grid output is wanted. The day numbers must be separated by at least one blanc. Any more numbers or text will be ignored. If this output is wanted the variables *surfyes/snowyes* must be set to 2.

Note: It is essential that there are at least as many day numbers given here on the same row as specified by the parameter above (numbersnowdaysout). It can be more but not less.

------------------ **2.) MASS BALANCE** ---

winter mass balance (variable winterbalyes) (equivalent for summer mass balance)

1 %gridout winter mass balance yes=1, no=0 winterbalyes

0=no output, 1=output of grid of winter mass balance (defined between 2 julian days (can in principal be any period, not necessarily winter mass balance)

variable winterjedbeg, winterjedbeg

244 135 %julian day winter starts and ends winterjdbeg winterjdend

The first and last julian day over which the winter mass balance should be accumulated. These dates are used for each year

summerbalyes

1 %gridout summer mass balance yes=1, no=0

0=no output, 1=output of grid of summer mass balance (defined between 2 julian days (can in principal be any period, not necessarily summer mass balance)

variables summerjdbeg summerjdend

136 243 %julian day summer starts and ends summerjdbeg summerjdend

variable datesfromfileyes

0 %1=dates for MB meas read from file, 0=fixed dates datesfromfileyes

Defines whether or not the periods for which winter and summer mass balance are calculated are constant from year to year defined by the variables above, or vary from year to year (following the days measurements were actually taken).

0=fixed dates as defined by variables *winterjedbeg, winterjedbeg, summerjdbeg* and *summerjdend*

1=dates are read from file. The name of the file is specified in next row.

File name namedatesmassbal (E+T)

dateswintersummerbalance.dat %file containing the dates of massbal meas namedatesmassbal

File name of file containing the dates when winter and summer mass balances were taken each year. Only needed if

beltwidth (E+T)

20 % vertical extent of elevation bands (m) for mass balance profiles beltwidth

Defines the output of the mass balance profiles, i.e. over which elevation bands the area-averaged mass balance is written to file (output mass balance as function of elevation), *beltwidth* is the vertical range of all bands (m), values between 20 and 100 m are generally reasonable.
The first elevation band includes all elevations z >= *elevbeltmin* and <(*elevbeltmin*+*beltwidth*).
Minimum elevation of the lowest elevation belt and the maximum elevation of the hightest elevation belt are computed by the model so that the former is lower than any elevation of the glacier and the latter is higher. For example if the elevation spans from 1010 m to 3995 m a.s.l. and the beltwidth=20, then the output will include 1000-1020 as lowest elevation band and 3990 – 4000 m as highest elevation band.

snow2zeroeachyearyes
1 %set snow cover to 0 at start of each massbal year snow2zeroeachyearyes
The snow cover can be set to 0 at the beginning of the mass balance year over the entire glacier. This can be done to avoid endless snow accumulation in the firn area. Snow at the end of the mass balance year thus becomes firn. (Note, the model does not include a model that converts snow to firn and ice. Hence, the snow cover in the accumulation area becomes thicker and thicker, which is not realistic.
0=no, 1=yes

time series snowfree pixels (E+T)
1 %times series file with number of pixels snowfree written to file snowfreeyes
Time series file with number of snowfree pixels written to file if parameter set to 1, 0=no output. This option is also possible if *methodinisnow*=1
----
cumulated melt (E+T)
0 %gridoutput of melt cumulated=1 or mean=0 cumulmeltyes
Grid output of melt and ablation can be given as a mean per time step (0) or accumulated over the entire period calculated (1).

cm or m (E+T)
1000 %if cumulated, output in cm=10 or m=1000 cm_or_m
If cumulated grid output can be given in cm (10) or m (1000).

Output of time series of spatial mean (E+T)
1 %time series of spatial mean to output (yes=1 no=0) do_out_area
0=no output, 1=written to file

outgridnumber: Output of individual grid cells (E+T)
1 %number of individual grid points for which model result output outgridnumber
%*====read if number > 0============================***
%*Outputfilename ** row/x-coord ***column/y-coord *** glob and net data included from input data**
pointoutput.txt 528686 6464504 0

It is possible to define up to 300 output files, containing results of the energy balance / degree-day model calculations for individual grid cells of the area modelled. Each line must contain a **filename** and the location of the grid cell for which the results are to be written to file.
The **location** can be defined either by row number and column number or given in x- and y-coordinates (row followed by column or x-coordinate (Easting) followed by y-coordinate (Northing)). The format is specified by the parameter '*coordinatesyes'* close to the end of *input.txt*. (In case of row/column number the numbering refers to the upper left corner of the digital terrain model). The last parameter per line must be 0 or 1 and it controls, if, besides modelled output, also measured data should be written to the file
0 = only modelled results (option A in Chapter III)
1 = measured radiation components and other variables are included in the output file (option B) .
A parameter of 1 is useful for the climate station grid cell to allow for the comparison of measured and simulated values of radiation components (only useful for energy balance model)
In case the **snow model** is run (*methodsurftempglac*=4) for all the locations an additional file each is generated to which **output of the snow model** is written to. The names of these files start per default with ***subsurf*** to which the names given here are added.

Note that the number given for the variable '*outgridnumber'* must correspond to the number of lines with the information on file name, coordinates and 0/1. For example if you want 2 output files you need to add another line with the information of the second location.

******* 3.) METHODS ENERGY BALANCE COMPONENTS *******

The parameters below specify which parameterization to apply for different components (mostly energy balance).

1. line (variable methodinisnow) (E+T)

2 %1=surface maps 2=start with initial snow cover methodinisnow

1=grids with surface types for different periods are provided

2=model run with initial snow cover file: this is the normal case, i.e. you need initialize the model with a grid file that specifies the snow water equivalent for each grid cell at the start of the simulation. **Note** that if you change your start date (see above 'jdbeg') you may need a different intial snow cover file.

2. line (variable methodsnowalbedo) (E)

1 %1=constant for surface types, >2=alb generated methodsnowalbedo, 6=zongo

method used to compute albedo (Option 4 is recommended as default as a start):

1= albedo assumed constant in space and time (values specified below)

2= snow albedo is generated by the model on snow and firn (only possible for hourly (or similar) time steps) according to PhD thesis Hock, Chapter 5

3= snow albedo obtained by method 2 is further modified considering cloud cover according to Jonsell et al. (2003) and applied in Hock and Holmgren (2005); (not recommended due to unrealistic systematic decline in albedo with time)

4= snow albedo is computed either according to Oerlemans & Knap (1998) or Douville et al. (1995). The latter is specified as "hidden" option in *variab.h*, i.e. it must be specified in the source code (file: *variab.h*). The default is set to the former option. The latter option can be chosen by assigning the value 1 to the variable *douvilleyes* instead of 0 (in file *variab.h*). In this case the source code must be newly compiled.

5= as 4 but including cloud cover according to Jonsell et al. (2003), (not recommended).

6=modified version of Oerlemans and Knap by Sicart, PhD thesis, p.243. Does not work properly at the moment.

Recommended choice: 4.

variable methodglobal (E)

1 %1=direct and diffuse not separated, 2=separated methodglobal

method used to compute global radiation:

1= global radiation is interpolated without separation into direct and diffuse radiation (see Hock and Noetzli, 1997): ratio of global radiation and potential direct radiation at the weather station is assumed constant over the entire grid.

2= direct and diffus radiation are interpolated separately (see Hock and Holmgren, 2005): global radiation is split into components based on empirical functions and then extrapolated to each grid cell.

variable methodlonginstation (E)

1 %1=longin from net,glob,ref (Tsurf=0),2=meas,3-6=from paramet methodlonginstation

method used to compute longwave incoming radiation at the climate station:

1= from the measurements of net radiation, global radiation and reflected shortwave radiation at one weather station

2= from direct measurements at one weather station

3= from parameterization according to Konzelmann et al (1995)

4= from parameterization according to Brunt (1932) (so far this option never tested)

5=according to Brutsaert

6=as 3, but cloud cover is parameterized using coefficients derived for Storglaciaren by Sedlar and Hock (2009)

variable methodlongin (E)

1 %1=longin constant, 2=spatially variable methodlongin

method used to distribute longwave incoming radiation to each grid cell:

1=spatially constant
2=spatially variable (according to Pluess and Ohmura, 1997)

variable methodsurftempglac (E)

1 %1=surftemp=0, 2=iteration 3=measurement+(decrease height), 4=snowmodel methodsurftempglac

1= surface temperature (and longwave outgoing) are assumed constant (T=0°C)
2= spatially variable, surftemp lowered by iteration, if computed energy balance turns negative (see Hock and Holmgren (2005)
3= surface temperature computed from longwave outgoing measurements and then assumed to be spatially constant or decrease with elevation
4= computed by the **multi-layer snow model** (linear interpolation of the temperature of the 2 upper sublayers

****

variable methodturbul (E)

3 %1=turbulence accord. to Escher-Vetter, 2=Ambach 3=stabil methodturbul

method used to compute the turbulent heat fluxes: 1=method A (according to Escher-Vetter, 1980),
2=method B (according to Ambach, 1986), no stability correction;
3=as 2, but including stability correction and modelling of z_{0T} and z_{0e}.
4=same as 3, but differently programmed (by Carleen in 2006)
recommended options: 3 or 4.

variable methodz0Te (E)

1 %1=z0T/z0w fixed ratio 2=according to Andreas (1987) method_z0Te

1=fixed ratio between z0w and z0T, z0e (ratio defined below)
2=computation according to surface renewal theory by Andreas (1987) based on Reynolds number

variable methodiceheat (E)

1 %1=no ice heat flux 2=ice heat flux methodiceheat

1=no measured ice heat flux data included
2=ice heat flux data for specific application to Storglaciären.
This parameter should be 1 unless additional routines for a user's application are added.

variable methodnegbal (E)

1 %1=neglected 2=neg energy balance stored to retard melt methodnegbal

1= if energy balance is positive, the entire energy is converted into melt, no matter whether or not the energy balance has been negative before.
2=melt is retarded after negative energy balances, melt is only allowed after cumulative negative energy balances have been compensated for (*methodsurftempglac* must be 1, otherwise due to the iteration there are no negative energy balances). This option assumes that when the energy balance is negative, the surface layers will cool. Energy then first will be needed to raise surface temperatures to zero, before melt can occur. Other than for sensitivity studies this option is not recommended because in reality the cold content will be eliminated much faster than this method would suggest because warming occurs largely through the release of latent energy by refreezing of percolating melt water.

%********* SCALING ********************************

Parameters below define parameters for computing glacier retreat according to volume-area scaling. Area is removed from below, i.e. the lowest lying grid cells are removed first.

variable scalingyes (E, T)

0 % V-A scaling yes=1, no=0, scalingyes

0=no volume area scaling, 1=volume area scaling

variable gamma and c_coefficient (E, T)

1.375 % gamma in V-A scaling gamma
0.6 % coefficient in V-A scaling c_coefficient

*******4.) NAMES OF INPUT FILES ******* (E+T)

Here the names of input grid files and the climate data file are given. The names must not be longer than 20 characters. Grid files that are not needed by the specific model run do not need to exist, e.g. there is no need for a skyview file with the name specified in input.txt to exist if the temperature-index model is run, however a name must be given, i.e. no line can be deleted.

NOTE: Even if the grid of the area to be calculated and the glacier grid are identical (if only melt for the glacier is calculated) two different files with different names must be provided ! (Just copy the gridfile to another name !)

*******5.) GRID INFORMATION ******* (E+T)

Longitude (E+T)

-134.5048 %geographical longitude [degree] laenge

must be given in degrees: 0-180 east of Greenwich, 0 to -180 west of Greenwich. Longitudes west of Greenwich are negative!

Solar geometry including sunrise and sunset and sun altitude angle are computed for the coordinates given here and assumed constant throughout the grid, i.e. computations are not performed for each grid cell but only for one single point of the grid. Therefore coordinates should be given for the approximate center of the domain that is computed.

Latitude (E+T)

58.5117 %latitude breite

must be given in degrees: positive on the northern, negative on the southern hemisphere

reflongitude (E+T)

-120 %longitude time refers to reflongitude

longitude to which the time in the climate input file refers to: usually it corresponds to the closest meridian dividable by 15 within decimals (0,15,30,45,60 .. 180 and negative numbers for longitudes west of Greenwich).

Examples:

- Data collected in England using standard time (UTC, no day-light savings time) → reference longitude is 0
- if the area is located at longitude 18° and the data was logged in local standard time, a value of 15 must be entered here.

row, col (E+T)

120 %row in DTM where climate station is located rowclim

130 %column of climate station colclim

Row (from above) and column (from left) where climate station is located refering to the upper left corner of the digital elevation model.

climoutsideyes, heigthclim (T)

1 230 %take this elevation for AWS yes/no climoutsideyes heightclim

In case of temperature index modelling the climate station can be located in the area to be calculated or anywhere outside the area. In the latter case the elevation of the data has to be given here.

climoutsideyes: 0=weather station is in the area covered by digital terrain model 2, i.e the area to be computed.
1=the elevation for the climate station is taken from the value below and not from the grid cell defined by rowlim/colclim
2=the elevation for temperature distribution is taken from the grid cell defined by rowclim/colclim, but for precipitation extrapolation using gradients the elevation defined in heightclim is taken

heightclim: is the elevation (m) of the climate station in case of *climoutsideyes*=1 or 2 (otherwise value is irrelevant but there must be a value.

For energy balance modelling this option is as yet not possible, because most parameterizations need the climate station on the glacier.

gridsize (E+T)

100 %gridsize in m gridsize

Distance between neighboring grid cells in the digital elevation model (in m).

timestep (E+T)

24 %time step in hours timestep

It refers to the time step of calculations of all energy balance components. It is given in hours and must not exceed 24. There must be one calculation per day. The time step has to be chosen in such a way that 24 divided by the time step must be an integer (e.g. times steps of 1, 1.5, 2 or 6 are possible; 5 or 7 is not allowed). This is because calculations are done for every time step and a calculation must be performed for midnight (in order to calculate daily means). The time step must correspond to the time step of the climate data input file. In case of daily computations timestep = 24.

*****6.) CLIMATE DATA AND DISCHARGE DATA*****

Format of the midnight time indicator in the climate / discharge data files (E+T)

3 %1=midnight time is 0, 2=time is 24, 3=24 but previous day formatclimdata

1= midnight time is 0
2= time is 24
3= time is 24, but day number is the previous one (see Chapter 7.2)

number of columns in the climate data file (maxcol) (E+T)

3 %number of columns in climate file maxcol

Here the exact total number of columns in the climate data file (including the date/time columns). This parameter is crucial so that the climate data file is read correctly.

columns in climate data file (E+T)

4 %columns in climate input file: temperature coltemp
20 %column containing relative humidity colhum
20 %column wind speed [m/s] colwind
20 %global radiation colglob
20 %reflected shortwave radiation colref
20 %net radiation colnet
20 %longwave incoming radiation collongin
20 %longwave outgoing radiation collongout
5 %precipitation colprec
30 %cloud cover (number of eigths) colcloud

The column number for the individual climate variables and discharge data must be entered. Column 1 is the year. The first climate data can be in column 4. For climate / discharge data not available (e.g. if you run the temp-index model and only temperature and precipitation data are available, give any number (so just leave the numbers in the file unaltered).

coltempgradvarying (E+T)

30 %time variant lapse rate (neg=decrease) coltempgradvarying

Column of temperature lapse for each time step (e.g. determined from 2 stations on the glacier, lapse rate must be computed during pre-processing). If not available, put any number.

coldis (E+T)

8 %column of discharge data coldis

Column of measured discharge data (if available, if not give any number).

***** Corrections to climate input****

manipulate temperature input data (ERAtempshift) (E+T)

0 %add this to ERA temp to get to elevationstation ERAtempshift

This amount is added to the temperature that is read from file. The option allows, for example, the user to apply a bias correction to the input data (e.g. when ERA re-analysis data is used).

manipulate wind input data (ERAtempshift) (E+T)

0 %add this to ERA wind to get to elevationstation ERAwindshift

This amount is added to the wind speed read from file. The option allows, for example, the user to apply a bias correction (e.g. when ERA data is used).

*****7.) LAPSE RATES / SCENARIOS *****

method how air temperature data is distributed across the grid (E+T)

1 %1=const lapse rate 2=variable 2AWS 3=grid methodtempinterpol

1=constant lapse rate (degree/100 m). Negative values indicate decrease in temperature with increasing elevation
2=variable lapse rate read from climate input file (column must be specified above)
3=existing temperature grid is read for each time step

temperature change with elevation (E+T)

-0.6 %temperature change with elevation [degree/100m] tempgrad

A negative sign denotes a decrease in temperature with increasing elevation. Values should generally be between -0.4 and -0.8.

tempscenario (E+T)

0 %climate perturbation: temp + this amount tempscenario

The amount given here is added to the temperature data read from file. E.g. 2 means that 2 degrees C are added to the temperature read from file. This allows simple temperature sensitivity experiments to be calculated.

precscenario (E+T)

0 %climate perturbation: precip + this amount in percent precscenario

Precipitation at the climate station is increased by this percentage.

%on/off	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
0	0	0	0	0	-0.432	-0.308	-0.388	-0.322	-0.362	-0.362	0	0	%monthtempgrad(yes)
0	0.5	1	1	1	1	1	1	1	1	1	1	1	%monthtempscen(yes)
0	10	10	10	10	10	10	10	10	10	10	10	10	%monthprecipscen(yes)

monthtempgrad, monthtempscen, monthprecipscen

These parameters allow the user to apply a constant monthly variable temperature lapse rate and temperature or precipitation scenario (set first column 1 to turn option on; 0=off). The variables *tempscenario* and *precscenario* are turned off if this option is used.

monthtempgrad

lapse rate to be applied to each month

monthtempscen

temperature added to data of each month

monthprecipscen

increase in precipitation applied to corrected precipitation data of each month

***** 8.) SURFACE TYPE / ALBEDO ***** (E+T if initial snow cover option not used)

n_albfiles, jdstartalb, namealb

Different files containing information about surface conditions (snow/firn, slush, ice) can be allocated to different periods of time. First give the number of files (variable *n_albfiles*) and then add one line containing the filenames for each file. If *n_albfiles*=5, 5 lines with julian days and corresponding filenames must follow.

```
Example:    2
            190    alb19294.bin
            194    alb19594.bin
```

The first file (*alb19294.dat*) will be used for the period from julian day 190 and 193. From julian day 194 on, the second file will be used. There must be one filename per row in chronological order. There may be more files in the list than needed for a specific run, if the number of files is stated properly. The program will automatically search for the first one needed for a specific run.
In case of temperature index modelling these files are used to decide whether or not a grid cell is snow, ice or rock covered.
If this option is not needed (if model run with initial snow cover file), one can put 0 for *n_albfiles* and delete any following rows containing filenames. However, it does not disturb the model run, if files are specified in input.txt. It is only important that the number of files specified in the variable *n_albfiles* coincide with the number of subsequent lines containing a julian day and a filename.

albsnow
albedo for snow (on ice) and firn area (snow-covered or not), if albedo is assumed constant (methodsnowalbedo = 1). If snow albedo is generated by the model (*methodsnowalbedo* = 2) this variable contains the start value for snow albedo for the first time step of simulation.

albslush
albedo for slush (usually around 0.5), only if surface type is read from file and grid cells in the grid are marked as slush (value for array *surface*=2). This variable is not relevant in run with initial snow cover.

albice
albedo for ice, no matter if *methodsnowalbedo*and *methodinisnow = 1 or 2*

albfirn
albedo for grid cells in the firn area:
a) it is the start value for first simulation time step, if snow albedo is generated and computation with initial snow cover (value in array *surface=2*)
b) it is the value for albedo in the firn area (defined by firn grid DTM7) if run with initial snow cover (*methodinisnow* = 2) and constant albedo (*methodsnowalbedo*=1)

albrock
albedo for rock outside the glacier if not snow-covered; only relevant if area to be calculated is larger than glacier; needed for mean albedo of drainage basin for extrapolation of diffuse radiation

albmin
minimum value snow albedo can assume if snow albedo is generated (*methodsnowalbedo* = 2). Albedo decreases as a function of time and temperature, but cannot drop beyond this value.

snowalbincrease
increase in snow albedo per 100 m of decreasing elevation in case methodalbedo is 2 or 3 (need to check this).
Recommendation: set to 0.

albiceproz
decrease of ice albedo with increasing elevation in %. A value > 0 allow to vary ice albedo spatially as a function of elevation, accounting for a general increase in debris downglacier and thus average decrease in albedo.

ndstart
number of days since snowfall at simulation start, only for *methodsnowalbedo=2*.

****************** 9.) RADIATION ******************************

number of shade calculation per time step (E+T only if potential direct radiation calculated)
The calculation of the correction factor for calculated clear-sky direct insolation can be calculated from a mean of results from several subintervals. Here, the number of subinterval can be given. If a value of 4 is chosen here and if the time step is hour, the correction factor for the global radiation is calculated every 15 minutes (time step/4) for the middle of each subinterval (Schulla, 1997). If direct radiation is read from file, any integer number can be written here, as the program will set it to one.

prozdiffuse (E)
percentage diffuse radiation of global radiation, only relevant if *methodglobal=1*

trans (E+T, if direct radiation needed)
transmissivity in calculation of clear-sky direct radiation (generally 0.6-0.95)

ratio (E)
the ratio of global radiation and clear-sky direct radiation at simulation start (to have an initial value for extrapolation of global radiation using *methodglobal=1*, i.e. extrapolation of global radiation and not of

direct and diffuse separately. The ratio is about 1 for clear-sky conditions and 0.2 for complete overcast conditions.

ratiodir2dir (E)

the ratio of actual direct and clear-sky direct radiation at simulation start (if direct and diffuse radiation are extrapolated individually).

startlongout (E)

longwave outgoing radiation at the climate station at simulation start (only relevant if longwave outgoing radiation not taken from measurements, i.e. *methodlonginstation* is not 2

surftemplapserate (E+T)

decrease in surface temperature per 100 m elevation increase; only relevant in case longwave outgoing radiation is taken from measurements. If 0 is given the value measured at the climate station is assumed spatially constant over the computed area.

directfromfile (E+T if potential direct radiation needed)

This parameter controls if direct radiation for each time step is calculated by the model or read from existing files (0=calculated, 1=read from file). If it is read from file the names of the files must begin with *dir*, followed by the julian day and the hour, and *bin* as extention, e.g. dir19012.bin. For daily time steps the files must end with 24, e.g. dir19024.bin = file for mean data for day 190. In case of daily computations the files must be created in advance. The program set *directfromfile* = 1, if *timestep* = 24.

Path for direct files (E+T if potential direct radiation needed)

contains the path name where all direct radiation files are stored, in case direct radiation is read from files and not generated when running the model. The path can be different from the path of the other input data.

variable daysdirect (E+T if potential direct radiation needed)

This parameter defines how frequent diurnal sequences of direct radiation files are available. It is possible to run the model with direct radiation files only available e.g every 2. or 3. etc day. The diurnal cycles do not change too much from one day to the other. In order to save disk space it might be necessary to reduce the number of files. If a value of 2 is given, direct radiation files with the julian day in the name dividable by 2 must exist (e.g. dir19012.bin, dir19212.bin). In case of 5, valid files e.g. are dir19012.bin, dir19512.bin, whereas a file called e.g. dir18912.bin would not be valid in this case as 189 is not dividable by 5. *Daysdirect* can only be set to a number higher than 1, if the direct radiation files are read from file. If they are generated by the model the computation of direct radiation is done for each time step and the parameter *daysdirect* is meaningless.

variable *slopestation*

must be set to 0 if the programme debam.c is used to create the direct radiation files for every time step, which are then used for subsequent model runs. The slope of the climate station grid cell is set to zero, because the global radiation instruments are also levelled horizontally. If direct radiation read from files put 1 here.

***** 10.) TURBULENCE ***** (only E)

variable iterstep (E)

step in degrees C by which the surface temperature is lowered for each iteration step in case the surface temperature is assumed spatially variable and obtained by iteration.

variable z0ice (E)

surface roughness for wind speed for ice in m (needed for *methodturbul = 2 or 3*).

variable dividerz0T (E)

surface roughness for wind speed is divided by this value in order to obatin the surface roughness for heat and moisture, i.e. 100 means that z0 for heat and moisture is 1/100 of the value given for z0ice. (only for *methodturbul = 2 or 3* and if *method_z0Te* set to 1 previously, otherwise no meaning)

variable dividersnow (E)

surface roughness for ice is divided by this value to obtain the surface roughness for snow, i.e. if z0ice=0.002 m and the divider is 10, then the surface roughness for snow is 0.0002 m.
(only for *methodturbul = 2 or 3*, also relevant if z0T computed according to Andreas (1987)

variable z0proz (E)

decrease in surface roughness for ice and snow per 100 m in %. If set to 0, the roughness lenths are assumed constant in space for the same surface type (only if z0T not computed by Andreas, 1987)

variable icez0min, icez0max (E)

minimum and maximum value for z0ice, only important if decrease in z0 with elevation is assumed. These parameters are important to contrain values within realistic limits (only relevant if z0T not computed by Andreas, 1987)

******* 11.) PRECIPITATION ******* (E+T)

variable *methodprecipinterpol*

Method how to distribute precipitation across the grid
1=precipitation lapse rate, i.e. change in precip with increasing elevation in % per 100 m
2=multiply corrected precipitation value by scaling factor read from a precipitation index map
3=read precipitation from grid for each time step

variable precgrad

precipitation gradient: increase with elevation in %/100 m.

variable precgradhigh and precgradelev

precipitation gradient which should be applied beyond the elevation given behind the gradient (on same line) (second usually lower gradient is possible to avoid unrealistically high precipitation in higher regions)

variable preccorr

percentage added to measured precipitation (gauge undercatch)
if *methodprecipinterpol* = 2, first *preccorr* is applied before multiplying by the index map
if *methodprecipinterpol* = 3, *preccorr* is applied to the value from file. Put 0 if no further correction wanted

variable snowmultiplierglacier

computed precipitation (after *preccorr* is applied) is multiplied by this factor in case of snow; this to account for larger wind error in case of snow precipiation; if no amplification wanted set *snowmultiplierglacier=1*.

variable snowmultiplierrock

same as above but for the grid cells outside the glacier but within the drainage basin.

variable threshtemp

threshold temperature to discriminate rain and snow. Above this temperature rain can occur, below snow fall. One degree above and below this threshold, the percentage of rain/snow of total precipitation is obtained from linear interpolation.

Melt calculation for whole drainage basin (variable onlyglacieryes) (only for discharge calulations)

This parameter controls the option that discharge of the entire drainage basin can be calculated even if melt is only calculated for the glacierized area

0 = calculations are performed for the entire drainage basin (glacier and area outside glacier), i.e. the area defined by the drainage basin DEM is larger than the glacier area defined by the glacier DEM, melt and rain water outside the glacier are routed through a forth (rock) reservoir or the snow reservoir (if snow-covered)

1= melt is only calculated for the glacier (i.e. the drainage basin and the glacier DEM are identical) In case of 1, rain outside the glacier is spread proportionally to the glacier. This is done by adding additional water to the modelled rain of each grid depending on the percentage of glacierization (glacierpart):

rain=rain + rain/glacierpart * (100-glacierpart).

The idea behind this option is that rain water falling outside the glacier will contribute to discharge. Melt outside the glacier is neglected. This option should only be applied if melt contributions from outside the glacier are neglibigle (i.e. the drainage basin must be highly glacierized). This option allows for a better simulation of discharge even if melt is only computed for the area of the glacier. The precipitation falling as snow is not affected.

Percentage glacierization (variable glacierpart)

Glacierized portion of the entire drainage basin (DTM 2). It is only relevant if discharge is calculated and if the previous parameter equals 1 (i.e. melt is only calculated for the glacier).

******* 12.) DISCHARGE ******* (E+T, but only if discharge is to be calculated)

nameqcalc

Name of output file with discharge data

nodis

Missing value of measured discharge data (the time series may contain gaps and these must be filled with a missing data value)

storage constants (variables firnkons, snowkons, icekons)

storage constants for the 4 linear reservoirs firn, snow, ice and rock given in hours. Generally the firn values should be largest (order of hundreds of hours), followed by the snow value (tens of hours) and the ice value (a few hours). Rock refers to the grid cells within the area to be computed but outside the glacier in case they are not snow-covered. This allows to route the water outside the glacier faster or slower than any of the other 3 reservoirs.

***** 13.) DISCHARGE STARTING VALUES **********

Start value discharge

For each reservour total discharge (m3/s) of the previous time step must be given here. The sum of all 4 values equals total discharge of the previous time step. Hence here the discharge is initialized. If the entire area is initially

Groundwater discharge

This value is added to the sum of discharge of each reservour (see Baker et al, 1982)

difference to start r^2

This allows a "warming up" period before r^2-calculations start. The figure given here refers to the number of days after the the discharge calculations started until the first day to be considered for r^2-calculation, e.g. if the value is 10 and discharge started to be calculated at julian day 190, r^2-calculations will start at jd 200.

********* 14.) SNOW MODEL METHOD ******** (E+T)

All variables under 14 are relevant only for the energy balance and if the multi-layer snow model is run (methodsurftempglac = 4).

Percolationyes

0= melt and rain water are not allowed to percolate into the snow but are assumed to runoff immediatedly; hence changes in subsurface temperature due to re-freezing is not accounted for. (Set to 0 in case no water to be expected, speeds things up)

1= melt and rain water percolates; refreezing and additional melt in subsurface snowlayer is modelled

slushyes

0= no slush formation

1= meltwater that has percolated through the entire snow/firn pack is retained in the lowest layers filling available pore spaces, thus forming a saturated water layer in the firn layer and a slush layer in the ablation area; the maximum value depends on surface slope and firn + snow layer thickness

densificationyes

0= snow density remains constant, this refers to the theoretical density the snow pack would have if it was dry

1=densification of dry snow due to aging (compaction, not because of water percolation)

wetstartyes

0= dry start (the snow contains no water)

1= wet start (no slush, but snow pack filled with maximum amount of water based on irreducible water content

ndepths

maximum number of vertical layers

factinter

defines how often the snow model computations are performed: number of subtimesteps for interpolation per main timestep (e.g. 10 with a time step of 1 hour would result in that the climate data is interpolated to 6 minute time steps for which the snow model computations are done. Weather station data is linearl interpolated to obtain values for each subsimestep

thicknessfirst

layer thickness of first layer (in m of snow/firn/ice, not w.equ.), recommended in the order of a few cm

thicknessdeep

layer thickness at deepest layer (in m of snow/firn/ice, not w.equ.), recommended in the order of a few m

depthdeep

maximum depth model (in m of snow/firn/ice, not w.equ.)

denssnow

density of fresh snowfall kg/m3 (ca. 150-300)

irrwatercontyes

0=constant irreducible water content, value given in next line

1=density dependent according to equation obtained from data on Storglaciären by Schneider&Jansson, 2004

irrwatercont

fraction of space irreducible filled with water (lower limit ca. 0.02)

`%---- Output ----------`

factsubsurfout

factor for subsurf output to file, e.g. 1=every timestep, 3=every third timestep, … 24=once per day at midnight in case of timestep=1 hour

offsetsubsurfout `(E+T)`

offfsetfactor for time of subsurf output, 12 means output at noon, 0 output at midnight, also determined output time of subsurflines output.

Runoffyes, wateryes, superyes, slushyes, coldsnowyes, coldtotyes (E+T)

variables determine whether or not superimposed ice, water content, slush (saturated layer), cold content snow, and cold content of the entire computed layer should be written to file as grid. 1=yes, 0=no. The determines the frequency of grid output is determined above by the variable *do_out.*

********* 15.) TEMPERATURE INDEX METHOD ****** (T)**

ddmethod

which temp index method to be used:

1=classical degree-day, 2=including potential direct radiation, 3=including potential direct and measured global radiation

DDFice/snow

degree-day factor for ice/snow, only relevant if *ddfmethod*=1 was chosen. The value for snow should not exceed the one for ice, as ice melt is expected to exceed snow melt due to albedo differences. The value is in mm d^{-1} K^{-1}).

variable meltfactor, radfactorsnow, radfactorice

the factor *MF*, *a_ice* and *a_snow* in melt equation, only relevant if *ddmethod* 2 or 3 are chosen. *MF* is in mm d^{-1} K^{-1}. The radiation factors are given here in mm m^2 W^{-1} $timestep^{-1}$ K^{-1}. In all cases they represent 1000* $r_{snow/ice}$. For example, a value of 0.3 corresponds to a value of 0.0003 used in the model (for simplicity, to avoid errors if too many zeros).

variable debrisfactor

computed melt is multiplied by this factor if the gridfile containing debris cover distribution contains the value 5. Thus melt can be reduced in case of thick debris cover. This parameter is only relevant for temperature index modelling.

******** 16.) OUTPUT STAKES (E+T) ******

Here the location of individual grid cells are given for which ablation and mass balance (file with stake output) and various variables are given (see parameter outgridnumber) for each time step are written to file.

Variable coordinatesyes

Defines how the locations of the output grid cells are defined:

1 = locations are defined by coordinates in the system the grids are given (see header of grid files), where the elevation marks the lower left point of the grid cell (xcorner, ycorner in ArcInfo)

2= as 1 but the point marks the center of the grid cell (xcenter, ycenter in ArcInfo)

3 = locations are defined by the row (from above) and column (from the left)

Following lines (one location per line):

Depending on 1 or 2 coordinates (x, y) or the row and column of the locations to be outputted are given (2 numbers separated by >1 blanc per line). Behind the second number any number or any comments can be given (e.g. stake numbering etc.).

If coordinates are given, they must correspond to meters from the reference coordinate as defined by the third and fourth row in the header of the digital elevation model (i.e. the corrdinates of the lower left corner of the DEMs). Longitude/latitudes or other systems cannot be given.

9.7 Model performance

In case discharge data are available the model computes the following performance values:

Criterium	Definition	Optimal value	Worst value
Efficiency criterium by Nash and Sutcliffe	$R^2 = 1 - \frac{\sum (Q_{meas} - Q_{sim})^2}{\sum (Q_{meas-} - \overline{Q}_{meas})^2}$	1	-∞
Efficiency using ln(Q)	$R^2 = 1 - \frac{\sum (\ln Q_{meas} - \ln Q_{sim})^2}{\sum \ln (Q_{meas-} - \overline{\ln Q}_{meas})^2}$	1	-∞
Mean difference of discharge volumes	$ACCDIFF = \sum_1^n (QV_{sim}) - \sum_1^n (QV_{meas})$	0	∞

Q=discharge [m3/s]
QV=discharge volume [m3]

R^2 is a crude estimate of model performance. It is site specific and specific for the time period modelled and depends on the quality of the observed data. It must be considered with caution when comparing different basins and different time periods because the initial variance (denominator) may be quite different. Thus, visual inspection of the discharge hydrographs is considered important for model evaluation.

10 DISTRIBUTED TEMPERATURE INDEX MODEL detim

10.1 Parameterizations

Melt is computed mainly as a function of air temperature. The model offers different methods (numbering refers to the value needed for the variable *ddmethod* in *input.txt*):

No. *	Parameterization	Description	Climate input data	Parameters
1	Melt = DDFsnow/ice*T	simple degree day factor, different DDF for snow and ice	Air temp	DDFsnow DDFice
2	M = (MF + $a_{snow/ice}$ *DIRECT)*T	including radiation factor to take into account the effects of topography due to shading, slope and exposition; assumption clear-sky conditions, clouds not considered	Air temp	MF a_{snow} $a_{/ice}$
3	M = (MF + $a_{snow/ice}$ *DIRECT*Glob/DIRECT)*T	as 2, but the radiation factor is scaled according to global radiation, small ratios indicate higher cloud amount and thus less impact on the topographic effects on direct radiation	Air temp Global radiation	MF a_{snow} $a_{/ice}$

DDF = degree day factor
DDFsnow,ice = degree day factor for snow or ice
DIRECT = clear-sky direct radiation
Glob = measured global radiation at the climate station
* The numbering refers to the variable *ddmethod* in *input.txt*.

<u>*Note*</u>:
> ´a´ corresponds to the variable *radfactorice* and *radfactorsnow* in *input.txt.*
> Method 1, 2 and 3 are the ones used in Hock (1999).

<u>Reduced melt over debris covered areas in the ablation area:</u>
For each grid cell assigned the number 5 in the grid file delimiting the firn area, computed melt by any of the methods above is multiplied by the factor given for the parameter *debrisfactor* given in input.txt. Thus, melt over heavily debris covered areas can be linearly reduced.

10.2 Input data

- Basically the same as for debam.c
- same formats
- reduced climate data requirements (air temperature, depending on method also global radiation)

10.3 Output files

The output files are similar to the type of output possible for the energy balance model. However the variables written to files are different. All 7 types of output described in Chapter 4.1 are possible, but the number of variables is reduced while some new variables can be written to file:

Grid files
Three files can be generated. (The user has to define the temporal resolution). Grid files refering to the computation of direct radiation (4 files, see Chapter Outputfiles) can only be generated if the chosen parameterization includes potential direct radiation and these files are not read from file.

a) melt (output name: *mel_.bin*)
b) positive interpolated temperatures (if temp < 0 it is set to zero)
c) "simple" degree-day factors (output name : *ddf_.bin*), defined as the degree-day factor needed to produce the same of melt as obtained with the method used, but using method 1:
ddf = Melt/postemp *24/timestep

Temporal series of spatial means or individual grid points
See chapter output files.

10.4 ***A note on units of model parameters***

The model including direct radiation was originally written for hourly time steps and has then been expanded to daily time steps (or any time step in between)

Melt, *M* (mm per time step), at the glacier surface is calculated according to

$$M = (MF + r_{snow/ice} I_{pot})T \qquad : T > 0$$
$$M = 0 \qquad : T \leq 0$$

It is programmed like this:

$$M = (MF / 24 + r_{snow/ice} I_{pot})T * timestep \qquad : T > 0$$
$$M = 0 \qquad : T \leq 0$$

- In *input.txt MF* is always in mm d^{-1} K^{-1}
- The unit for *timestep* is in hours

NOTE: in all cases $r_{snow/ice}$ must be divided by 1000 since the values for simplicity (to avoid errors if too many zeros) represent 1000* $r_{snow/ice}$.
For example, a value of 0.3 in *input.txt* corresponds to a value of 0.0003 used in the model

In order to present parameter values per hour or per day, do the following:

For hourly time steps
- *MF* is in mm h^{-1} K^{-1}, → divide value in *input.txt* by 24 !
- $r_{snow/ice}$ is in mm m^2 W^{-1} h^{-1} K^{-1}, take value from *input.txt* divide by 1000

For daily time steps
- *MF* is in mm d^{-1} K^{-1}, take directly from input.txt
- $r_{snow/ice}$ is in mm m^2 W^{-1} d^{-1} K^{-1}, $r_{snow/ice}$ must be multiplied by 24 (hours to day) and also be divided by 1000.

11 ADDITIONAL PROGRAMS

11.1 Program shading.c

The program should be used to create the direct radiation files, in case these are to be read from file instead of generating for each run.

The program calculates for a number of subsequent time steps (e.g hourly) for a defined number of days (see output energy balance model for further explanations)
- **topographic shading**
- **correction factor** for direct radiation to account for the effect of shading, slope and aspect (cosθ/cosZ)
- **direct radiation**.

The time period to be calculated (start/end julian day) and any other site-specific parameters are defined in a namelist file (*shading.par*).

<u>Input:</u>

- Gridfiles: digital elevation model, slope and aspect (same format as for melt model)

- namelist file (*shading.par*), includes e.g. names of input files, geogr. coordinates etc., requested output etc.

Output:

1. Gridfiles for each subdaily time step (e.g. hourly) or as daily means or as period means over any number of days (max one year)

- **shading**
- **correction factor** for direct radiation to account for the effect of shading, slope and aspect
- **direct radiation**

- Files can be individually requested by user, any combination possible
- Name pattern: first 3 letter *sha*, *exk* or *dir* then time indicator:
e.g. sha+julian day+hour.bin, i.e. dir19012.bin. = direct radiation for julian day 190 and the mean of the hour 10-12 in case of two-hourly calculation. Midnight hour = 24
In case of daily means the last 2 numbers are 24.
In case of period means the first and last julian day of the period computed are included in the filename, e.g. dir200_220.bin (period julian day 200 to 220 = 11 days)

It is not possible to output subdaily and daily means or/and period means during the same run. If e.g. daily and period means are needed, the programm has to be run twice.

2. Time series of one specific grid cell for every time step, named ***zenith.dat*** by default:

The file contains the following columns:

Output zenith.dat	ASCII-file with single grid output for every time step
1 jd, 2 time, 3 shade	
4 exkorr	= weighted mean of direct*exkorr for split subintervals=
5 direct	= clear-sky direct radiation slope/aspect/shade corrected
6 directhoriz	= no correction, i.e. as if grid was horizontal, NO topographic shading !!! (*strlsumme*)
7 topofatm	= top of atmosphere radiation (weighed mean: solar constant*cos(Z))
8 zenith	= zenith angle in degrees
9 declination	= in degrees
10 hour angle	= in degrees
11 12 sunrise, sunset	= refering to horizontal plane (no topographic shading), in real hours (i.e. 3.5)
suncoordinates : refer to the middle of the last of split subintervals of the time step calculated	

The **slope of the climate station** grid can be set to zero (set parameter *stationhorizyes*=1). This necessary, if the output of corrected direct radiation is read directly as input in the melt model. The pyranometer usually is levelled horizontally. Consequently, the ratio of measured global radiation and calculated clear-sky direct radiation must also refer to horizontal conditions. If *stationhorizyes* is set to **0**, the slope of the station grid is set to zero prior to further calculations. The location of the climate station is defined by the variables *rowclim* and *colclim* (specification refers to the upper left corner of the grid). All outputs are accordingly, i.e. DIRECT in *zenith.dat* refers to a horizontal slope of the grid cell written to output.

Shade calculations can be done for more timesteps (subintervals, *split*=number of subintervals) than the time step of calculation (e.g. *timestep* = 1 hour, *split* = 2 -> calculations at 15 minutes past and before every hour = SHAPE-Array), the weighted mean (=SHADE-Array) is written to output (see melt model). SHAPE-Arrays can also be written to file (names: *sub_* ,programmed inside the function schatten: *subinfileyes* must be set to 1, statistics are not ok in these files).

Daily means (set *dailyoutput* = 1)
In case daily means are requested calculations are performed at least every hour (time step is set to 1, no matter what is defined in *shading.par*). Denser intervals can be defined by assigning a value > 1 to *split* in *shading-par*. E.g. if *split* is set to 2, computations are performed twice per hour. Hourly means are computed and these are averaged over the day. *NOTE*: In case of daily means, except for DIRECT the columns in zenith.dat do not refer to daily means but to the last last (23-24) and thus wrong.

Period means (set *dailyoutput* = 2)

As for daily means calculations are performed at least every hour (time step is set to 1, no matter what is defined in *shading.par*). Calculation can be done for any period during a calendar year, but not over New Years.

Limitations

- The program has originally been written for hourly time steps (OBS: for subhourly time steps, the name pattern of files needs to be changed (in function *opengridoutput*). Larger time steps up to one day are no problem, however only time stepps are allowed if the result of 24 divided by the timestep yields an integer. Hence, time steps of 1, 2, 3, 4, 6, 8 and 12 hours are allowed, but not e.g. 5 and 7.
- calculation only within one year possible (e.g. not possible from December to January)
- Leap years are not explicitly considered (can be changed in function *jd2monat*)

NOTE: The disk space available should be checked prior to application, because depending on the length of the period calculated and the size of the digital terrain model, much space might be needed.

Numeric results	
shaded	==> **SHADE** = 1
sun	==> SHADE = 0
if *split* > 1, SHADE can range between 0 and 1 (e.g. 0.5)	
if shaded	== >**EXKORR** = 0
if not shaded and zenith < 78	==> EXKORR = (cosθ/cosZ), calculation cosθ if not shaded
	if Z> 78 cozZ = 0.2 kept constant, i.e. multiply by 5

Namelist file: *Shading.par*

The file contains all information necessary to run the program (see example below). It must be adapted by the user to the specific conditions of the current application. The structure is fixed. All variables are followed by the name of the variable in the programme and a comment briefly explaining their meaning and by. The comments are ignored by the program. The comments are not fixed in position, e.g. there may be more or fewer blancs between any variable and the following comment. In any case, there must be at least one blanc between the variables and the corresponding comments. It is not allowed to include more lines or delete existing lines. ***DO NOT DELETE*** any number/string in *input.txt* without replacing it by another number/string of the same type.

Explanation of some variables in *shading.par*

Startrow end row

It is possible to output only part of the initial size of the digital elevation model. The new size is defined by the variables *startrow*, *endrow*, *startcol* and *endrow*. *Startrow* and *endrow* are the first row from above and the last row from above, respectively, that should be included in the reduced matrix,. *Startcol* and *endcol* are the first and last column from the left to be included.

daysdirect

Output can be generated for each day of the requested period, but also only for a selection of days spaced equally apart, e.g. output every fifth day. If the first julian day is 120, the last one 130 and *daysdirect* is set to 5, output will only be created for julian days 120, 125 and 130. If the period mean is requested, computations are performed for every day, i.e. *daysdirect* is set to 1, no matter what is written in *shading.par*.

add2jd

This option is useful if the melt model is run over a period around New Years. In this case the climate data must have consecutive julian day numbering, i.e. 1 january is labelled by julian day 366 and not 1. With the help of *add2jd* the corresponding direct radiation files can be created. If *add2jd*=365, 365 is added to the julian day for creating the output filename. E.g. the file at midday on 1 Jan is called *dir36612.bin* and not *dir00112.bin*. The option is useful for summer melt calculation in the southern hemisphere.

Example namelist file *shading.par*

```
******** INPUT FILE FOR SHADING.C :  shading.par *****************************
/data/model/studies/engabreen/GMES/indata/  Inputpathname for DEM, slope, aspect
/data/model/studies/engabreen/GMES/test/    Outputpathname for direct rad files
test.bin     NAME OF INPUT DIGITAL ELEVATION MODEL
test2.bin    NAME OF SLOPE FILE
```

```
test3.bin      NAME OF ASPECT FILE
*******************************************************************************
1      jdbeg   first julian day to be computed
365      jdend   last julian day to be computed
*******************************************************************************
13.75    longitude   Greenland ETH camp = -49.28;  Stor18.475;  in degrees
66.67  latitude    Greenland ETH camp = 69.57   stor 67.9042 */
15       reflongitude    /*meridian time refers to, e.g. Greenwich time = 0*/
2       rowclim  /*row of grid cell for output of one single grid cell Stor: 54 104*/
2      colclim  /*column of this output grid cell*/
*************************************************
1    timestep      /*time interval of output: 1=hourly, 12=half-daily*/
6    split         /*number of subintervals per timestep for shade calculation*/
0    dailyoutput   /* 0=every timestep, 1=daily means, 2=period mean*/
******* TYPE OF GRID OUTPUT WANTED ***************
0    writeshade      0=no output, 1=output  (shading to output)
0    writeexkorr     exposition correction factor
1    writedirect     slope-corrected clear-sky direct radiation
0    writesinglegrid     SOLAR GEOMETRY WRITEN TO FILE zenith.dat FOR ONE GRID CELL*/
********SIZE OF GRID TO BE WRITTEN TO OUTPUT***********************************
1    wholegridyes      1= whole grid to output, 0=only part of grid to output
1 20  startrow endrow   first and last row to be outputted
1 4  startcol endcol   first and last columns to be outputted
*********************************************
2    daysdirect      write to output every number of days given here (2=every 2. day)
0    add2jd          add this number to jd of output grids, e.g. 365 for next year
0   stationhorizyes (1,0) 0=grid of climate station is taken to be horizontal*/
      /*this is necessary, if the output of direct radiation is used as input
        for debam.c, because the ratio of glob/direct must refer to a horizontal
        surface, because the instrument is levelled horizontally,
        in this case the slope of the climate station grid is set to 0 */
```

11.2 Program sundata.c

The programm is extracted from the program sundata.c. It calcuates for any location the following parameters and writes these to an output file ***sundata.dat*** in this order:

1. julian day
2. time
3. top of atmosphere radiation
4. zenith angle
5. sun azimuth angle
6. declination
7. hour angle
8. sunrise
9. sunset
10. the squared ratio of the mean distance sun to earth to the effective distance.

No input files are required. Input occurs via keyboard of:

- longitude and lattitude of the location
- first and last day and hour to be calculated
- time step
- number of calculations per time step (=variable split, see debam.c)

APPENDICES

11.3 APPENDIX A: Quick guide for melt modelling with UNIX

melt model

compile melt program with compile batch file
meltmod.bat
degree.bat (temperature index model)

run with ***meltmod.exe***
degree.exe

run model with batch files: create file *run.bat*:

```
cd run1
cd ..
meltmod.exe
cd run2
meltmod.exe ...
```

change permission to executable: ***chmod u+x run.bat***

- create run-directories and copy meltmod.exe and input.txt into each of them, adjust input.txt (esp different output path for each)
  - create output paths: e.g \out1 \out2 ...

results:

convert binary grid files to Ascii with
gridasci.exe name.bin name.dat

convert matrix ascii-files to binary with
ascigrid.exe name.dat name.bin

check statistics of grid
gridstat.exe name.bin

assign new values to grid data
remap.exe inputname.bin remap.dat outputname.bin

add 2 grids (can be used to "cut out" glacier out of larger drainage basin result grid)
gridadd.exe name1.bin name2.bin result.bin

visualisation with IDL

start IDL with ***idl***

compile IDL programs with ***.run name***
(IDL program must have extension .pro)

run IDL programs ***name***

exit IDL ***exit***

IDL-Programs:
grid (1 grid)
grids2 (2 grids and their difference)
shade (1, 4 or 24 grids)
linesdiff (2 lines and there difference)
discharg (measured and simulated discharge, temp, precip, wind, precipitation)
disdiff (measured and simulation discharge of different runs)
meltscat (scattergram measured and simulated melt at ablation stakes)

adjust programs to problem:
- change pathnames
- adjust window position (parameter *xpos*, *ypos* in *window*-command)
- adjust position of colour bar (parameters *topnormal* 0-1, *xposbar*)
- filenameoutside if outsidemissing = 1 (to show only glacier if data for larger area)

change colour scheme: ***xloadct***

APPENDIX B : Flow charts

(Compiled by Daniela Kuhn, model version of year 2000)

The following graphs show which options are possible and which parameters need to be adjusted for different model options. The variable names for the paramters are used. The variables names of the parameters that are possible and have to be adjusted are printed in italic.
Note that all flow charts have not been updated since 2000.

Graph B1: Parameterization options in the energy balance model

Graph B2: Parameterization options in the temperature index model

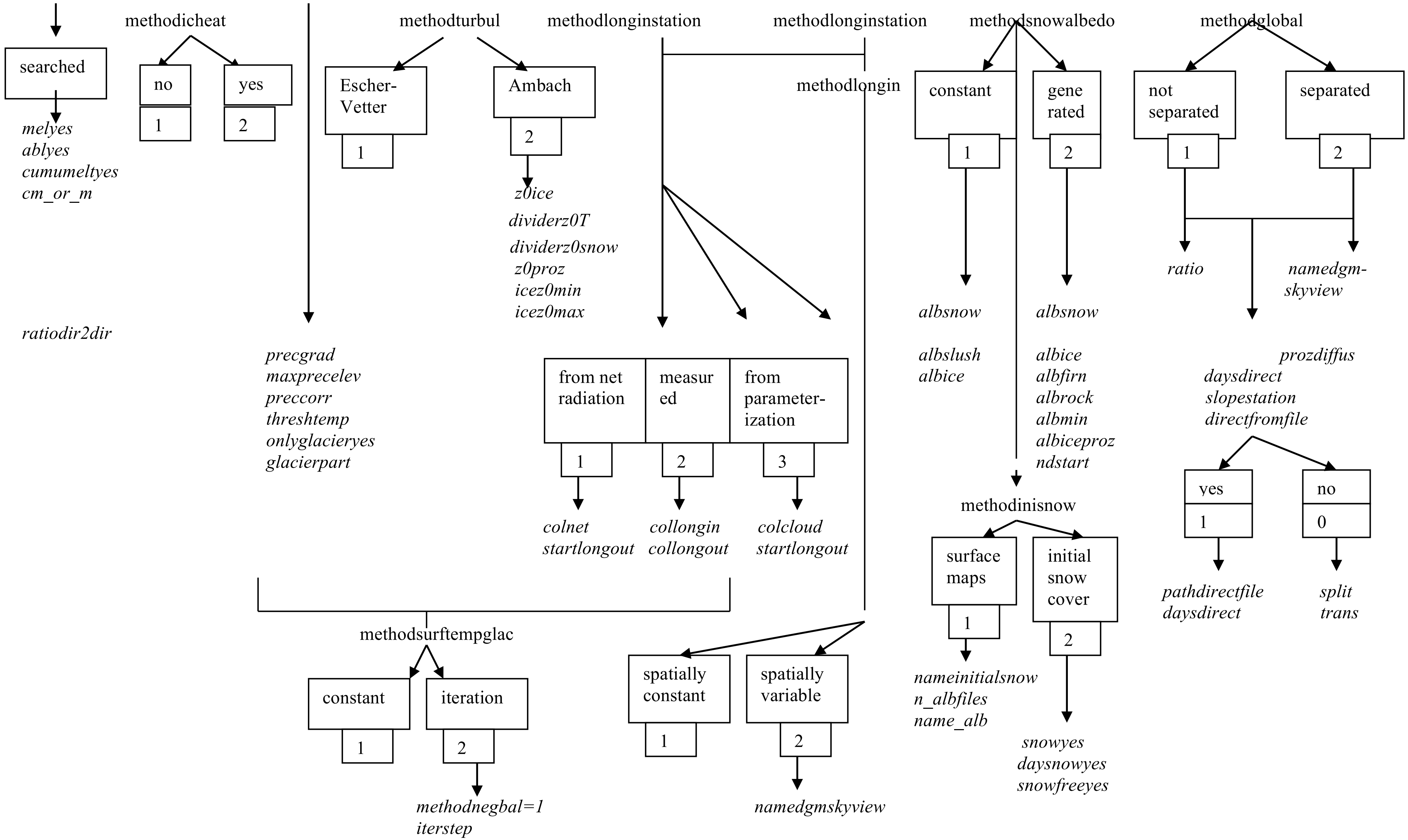
Graph B3: Optimization routines and parameters

Table B1: Parameters to be adjusted when simulation period is changed

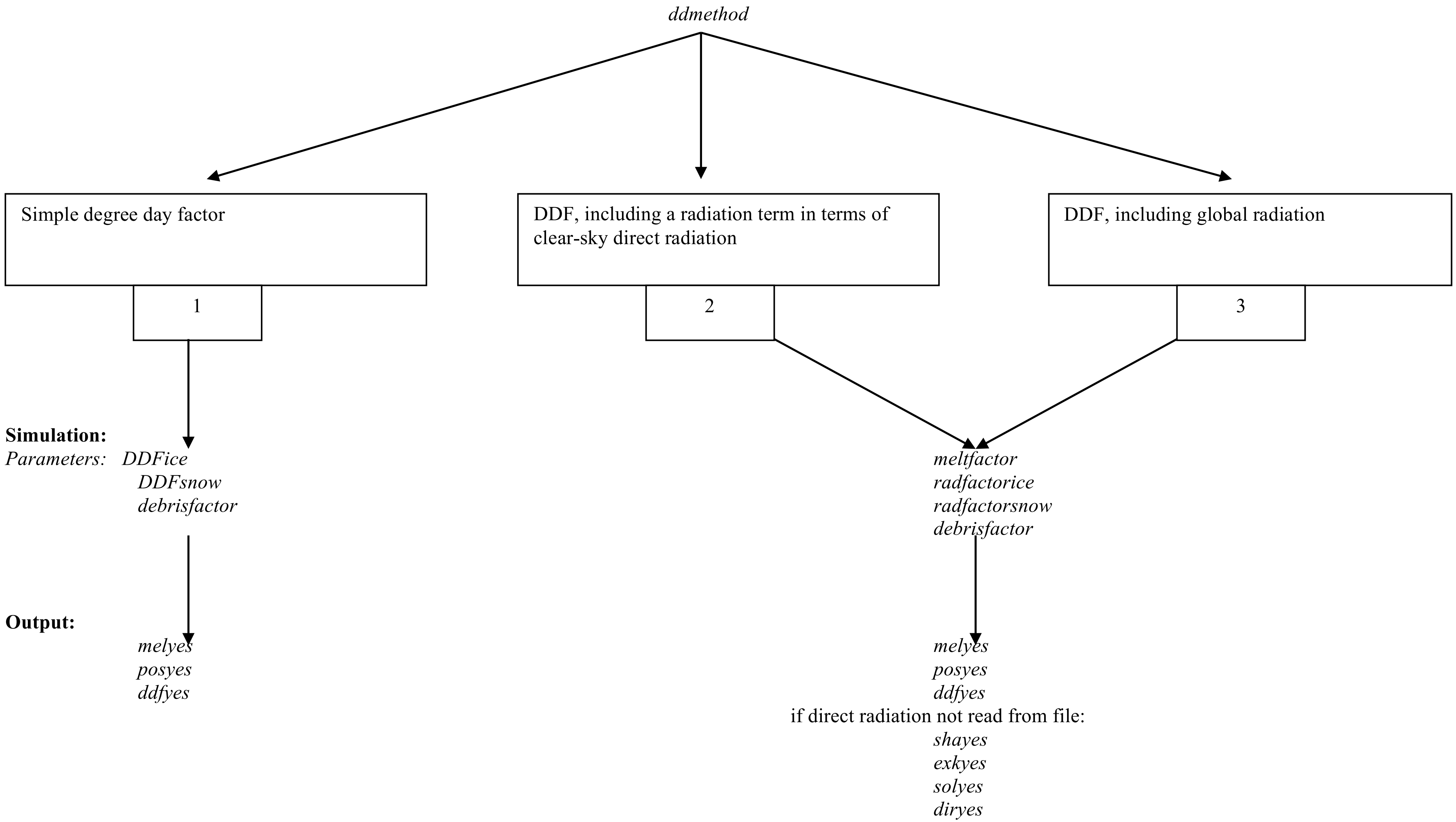
Table B2: Possible output options

11.3.1 Parameterization options in the energy balance model (not updated)

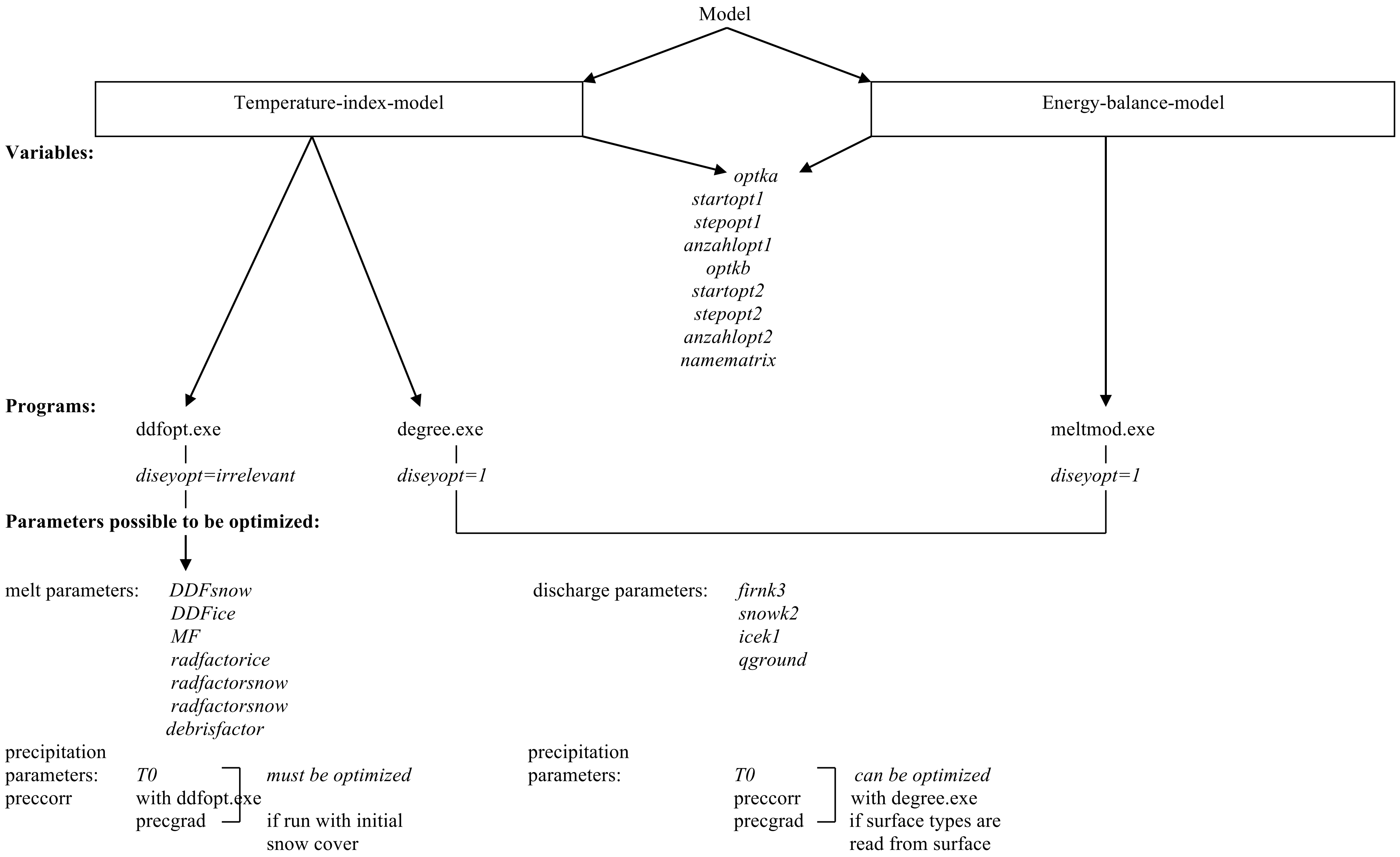
$$0 = Q_M + Q_G + Q_R + Q_S + Q_L + L\uparrow + L_S\downarrow + L_T\downarrow + (1-\alpha)\,(I + D_S + D_T)$$



11.3.2 Parameterization options in the temperature index model (parameters in *input.txt, not updated*)



11.3.3 Optimization routines and parameters (out of date)



11.3.4 Parameters to be adjusted when simulation period is changed

Adjust initial values:

Variable	Model	Consequensce
Nameinitialsnow	E, T	provide file with initial snow cover for the simulation start day if snow cover is calculated (methodinitsnow = 2)
Ratio	E	give initial ratio of global and direct radiation for the simulation start day if direct and diffuse radiation are not separated (methodglobal = 1)
ratiodir2dir	E	give initial ratio of direct and clear-sky direct radiation for the simulation start day if direct and diffuse radiation are separated (methodglobal = 2)
Qfirnstart	E, T	give starting values if discharge is calculated (disyes = 1)
Qsnowstart	E, T	give starting values if discharge is calculated (disyes = 1)
Qicestart	E, T	give starting values if discharge is calculated (disyes = 1)

E=Energy balance model (debam.c), T=Temperature index model (detim.c)

11.3.5 Possible output options

(Note this has not been updated)

x denotes that this output variable can be set to 1.

Variable	Energy-balance-model	Temperature-index-model
maxmeltstakes	X	x
do_out	X	x
shayes	if directfromfile=0	if ddmethod>1 and directfromfile=0
exkyes	if directfromfile=0	if ddmethod>1 and directfromfile=0
solyes	if directfromfile=0	if ddmethod>1 and directfromfile=0
diryes	if directfromfile=0	if ddmethod>1 and directfromfile=0
dir2yes	if methodglobal=2	
difyes	if methodglobal=2	
gloyes	X	
albyes	X	
swbyes	X	
linyes	if methodlongin=2	
loutyes	if methodsurftempglac=2	
netyes	X	
senyes	X	
latyes	X	
raiyes	X	
enbyes	X	
melyes	X	x
ablyes	X	
surftempyes	if methodsurftempglac=2	
posyes		x
ddfyes		x
surfyes	if methodinisnow=2	if methodinisnow=2
snowyes	if methodinisnow=2	if methodinisnow=2
daysnow	if methodinisnow=2	if methodinisnow=2
snowfreeyes	if methodinisnow=2	if methodinisnow=2
cumulmeltyes	x	x
cm_or_m	x	x
do_out_area	x	x
outgridnumber	x	x

11.4 *APPENDIX C : Example of input file 'input.txt'*

%Example input.txt: NOTE, YOU NEED TO ADJUST THE INPUT AND OUTPUT FOLDER (2. AND 3. ROW BELOW), AND MAKE AN OUTPUT FOLDER, THEN THE EXAMPLE SHOULD WORK !!!
%***
1 %output to screen every X day. daysscreenoutput.
/reginefolder/MODEL/SOURCE/github/source/meltmodel/example/example_data/ %Path for Inputfiles. inpath
/reginefolder/MODEL/SOURCE/github/source/meltmodel/example/example_output/ %Path for Outputfiles. outpath
129 1999 %first julian day to be calculated. jdbeg yearbeg
166 1999 %last julian day to be calculated. jdend yearend
1 %discharge to be calculated: 1=yes,0=no,2=yes, but no discharge data. disyes
1 %1=whole grid computed, 2=only grid cell of weather station. calcgridyes
%********* 1.) MODEL OUTPUT PARAMETERS: DEFINE WHAT IS WRITTEN TO FILE ***************

```
5   %number of stakes for melt output.  maxmeltstakes
1   %cum massbal multiplied by this factor in melting.dat.  plusminus
3   %0=no output 1=every step, 2=daily, 3=whole period 4=2and3.  do_out
%shayes exkyes solyes diryes dir2yes difyes gloyes albyes  swbyes linyes loutyes
  0    0    0    0    0    0    0    0    0    0    0
%netyes senyes latyes raiyes enbyes melyes  ablyes surftempyes  posyes ddfyes
  0    0    0    0    0    1    0    0         1    1
2   %surface conditions to grid file (2=for specified JDs).  surfyes
0   %snow cover to grid file at midnight.  snowyes
1   %snow or surface written to file if jd dividable by this value.  daysnow
2   %number of jd for output of surface type/snow cover.  numbersnowdaysout
190 210
%******************************* 2.) MASS BALANCE OUTPUT ******************************
1   %gridout winter mass balance yes=1, no=0.  winterbalyes
244  135   %julian day winter starts and ends.  winterjdbeg  winterjdend
1   %gridout summer mass balance yes=1, no=0.  summerbalyes
136  243   %julian day summer starts and ends.  summerjdbeg  summerjdend
0   %1=dates for MB meas read from file, 0=fixed dates.  datesfromfileyes
dummydates.dat   %file containing the dates of massbal meas.  namedatesmassbal
20   % vertical extent of elevation bands (m) for mass balance profiles.  beltwidth
1   %set snow cover to 0 at start of each massbal year.  snow2zeroeachyearyes
1  %times series file with number of pixels snowfree written to file.  snowfreeyes
----------------------------------------
0  %gridoutput of melt cumulated=1 or mean=0.  cumulmeltyes
1000   %if cumulated, output in cm=10 or m=1000.  cm_or_m
1   %time series of spatial mean to output (yes=1 no=0).  do_out_area
1   %number of individual grid points for which model result output.  outgridnumber
%***====read if number > 0===========================***
%***Outputfilename ** row/x-coord **colu/y-coord ** glob and net data included from input data
pointoutput.txt       100          100         0   %outgridname[][], stn_xcoordinate[i], stn_ycoordinate[i], &outglobnet[i]
%******** 3.) METHODS ENERGY BALANCE COMPONENTS *******************************
2   %1=surface maps 2=start with initial snow cover.  methodinisnow
1   %1=constant for surface types, >2=alb generated.  methodsnowalbedo, 6=zongo
1   %1=direct and diffuse not separated, 2=separated.  methodglobal
2   %1=longin from net,glob,ref (Tsurf=0),2=meas,3-6=from paramet. methodlonginstation
1   %1=longin constant, 2=spatially variable. methodlongin
1   %1=surftemp=0, 2=iteration 3=measurement+(decrease height), 4=snowmodel.  methodsurftempglac
%******************** TURBULENCE OPTION
1   %1=turbulence accord. to Escher-Vetter, 2=Ambach 3=stabil.  methodturbul
1   %1=z0T/z0w fixed ratio 2=according to Andreas (1987).  method_z0Te
1   %1=no ice heat flux 2=ice heat flux.  methodiceheat
1   %1=neglected 2=neg energy balance stored to retard melt.  methodnegbal
%********* SCALING ***********************************************
0   %V-A scaling yes=1, no=0.  scalingyes
1.375   %gamma in V-A scaling.  gamma
0.6   %coefficient in V-A scaling.  c_coefficient
%********* 4.) NAMES OF INPUT FILES ********************************************
dav_dem.bin   %name of Digital Terrain Model.  namedgm
dav_watershed.bin   %name of DTM with drainage basin.  namedgmdrain
dav_glacier.bin   %name of DTM glacier.  namedgmglac
dav_slope.bin   %name of DTM slope.  namedgmslope
dav_aspect.bin   %name of DTM aspect.  namedgmaspec
dummy.bin   %name of DTM sky view factor.  namedgmskyview
dav_firn.bin   %name of DTM firnarea.  namedgmfirn
dav_snow0.bin   %name of DTM initial snow cover.  nameinitialsnow
dav_climate_data.txt   %name of climate data file.  nameklima
%********* 5.) GRID INFORMATION************************************************
-134.50479   %geographical longitude [degree].  laenge
58.51169   %latitude.  breite
-120.0   %longitude time refers to.  reflongitude
100   %row in DTM where climate station is located.   rowclim
100   %column of climate station.  colclim
```

1 7 %take this elevation for AWS yes/no. climoutsideyes heightclim
100 %gridsize in m. gridsize
1 %time step in hours. timestep
%********* 6.) CLIMATE DATA **
1 %1=midnight time is 0, 2=time is 24, 3=24 but previous day. formatclimdata
14 %number of columns in climate file. maxcol
4 %columns in climate input file: temperature. coltemp
5 %column containing relative humidity. colhum
6 %column wind speed [m/s]. colwind
8 %global radiation. colglob
9 %reflected shortwave radiation. colref
10 %net radiation. colnet
11 %longwave incoming radiation. collongin
12 %longwave outgoing radiation. collongout
13 %precipitation. colprec
30 %cloud cover (number of eigths). colcloud
30 %time variant lapse rate (neg=decrease). coltempgradvarying
14 %column of discharge data. coldis
%********** (BIAS) CORRECTIONS TO INPUT DATA (TEMP, WIND) ********************************
0 %add this to air temp (e.g., to get to elevationstation). ERAtempshift
0 %add this to wind speed (e.g., to get to elevationstation). ERAwindshift
%********** 7.) LAPSE RATE / SCENARIOS ********************************
1 %1=const lapse rate 2=variable 2AWS 3=grid. methodtempinterpol
-0.6 %temperature change with elevation [degree/100m]. tempgrad
0 %climate perturbation: temp + this amount. tempscenario
0 %climate perturbation: precip + this amount in percent. precscenario
%on/off Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
0 0.0 0.0 0.0 0.0 -0.432 -0.308 -0.388 -0.322 -0.362 -0.362 0.0 0.0 %monthtempgrad(yes)
0 0.5 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 %monthtempscen(yes)
0 10.0 10.0 10.0 10.0 10.0 10.0 10.0 10.0 10.0 10.0 10.0 10.0 %monthprecipscen(yes)
%******** 8.) SURFACE TYPE / ALBEDO ***********************************
0 %number of transient surface type files
0.875 %albedo for snow and firn (fixed value). albsnow
0.55 %albedo for slush. albslush
0.3 %albedo for ice. albice
0.6 %albedo for firn (method 2). albfirn
0.1 %albedo for rock outside glacier. albrock
0.5 %minimum albedo for snow if generated. albmin
8.0 %increase snowalb/100m elevation for 1. time. snowalbincrease
0.0 %decrease of ice albedo with elevation. albiceproz
0 %number of days since snow fall at start. ndstart
%******** 9.) RADIATION **
6 %number of shade calculation per time step. split
15.0 %percent diffuse radiation of global radiation. prozdiffuse
0.75 %transmissivity. trans
1.0 %first ratio of global radiation and direct rad. ratio
0.95 %first ratio of direct and clear-sky direct rad. ratiodir2dir
-0.5 %decrease in surftemp with height if longout meas. surftemplapserate
0 %direct radiation read from file = 1. directfromfile
/Users/luser/Documents/example_data/direct/ %Path for direct files. pathdirectfile
0 %files only exist every number of days defined here. daysdirect
1.0 %0=slope at climate station is set to 0. slopestation
%******** 10.) TURBULENCE ***
0.25 %step for surface temp lowering for iteration. iterstep
0.001 %roughness length for wind for ice in m .0027. z0wice
100.0 %z0Temp is zow divided by this value. dividerz0T
1.0 %z0snow is z0wice divided by this value. dividerz0snow
0.0 %increase of z0 with decreasing elevation. z0proz
0.00000001 %min z0w ice. icez0min
0.02 %max z0w ice. icez0max
%********* 11.) PRECIPITATION ***
1 %1=lapse rate 2=scale AWS precip with index map 3=read grids. methodprecipinterpol

10.0 %precipitation change with elevation [%/100m]. precgrad
0.0 1900 %precipitation change with elevation beyond certain elevation. precgradhigh precgradelev
50.0 %35 precipitation correction, caused by losses. preccorr
1.0 %snow precip is multiplied by this factor. snowmultiplierglacier
1.0 %snow precip is multiplied by this factor. snowmultiplierrock
1.5 %threshold temperature rain/snow precipitation. threshtemp
0 %0=if massbal calculations for whole drainage basin, 1=only glacier. onlyglacieryes
50.0 %percentage of glacierization. glacierpart
%************* 13.) DISCHARGE STARTING VALUES*********************
discharge.txt %name of discharge output file. nameqcalc
-9999 %nodata value of discharge file. nodis
350 %storage constant k for firn. firnkons
50 %storage constant k for snow. snowkons
5 %storage constant k for ice. icekons
30 %storage constant k for rock(outside glacier non-snowcovered. rockkons
%************* 14.) DISCHARGE STARTING VALUES*********************
5.0 %start value for firn discharge (previous time step). qfirnstart
0.0 %start value for snow discharge (m3/s). qsnowstart
5.0 %start value for ice discharge. qicestart
5.0 %start value for rock discharge (outside glacier non-snowcovered). qicestart
0.0 %groundwater discharge[m3]. qground
0.0 %difference between start of calculation and start r2. jdstartr2diff
%=========== 15.) SNOW MODEL by C. Tijm-Reijmer 2/2005 =======================
1 %0=no percolation, 1=percolation+refreezing in snowlayer. percolationyes
1 %0=no slush, 1=meltwater accumulation in snowlayer. slushformationyes
1 %0=no densification, 1=densific. of dry snow due to aging. densificationyes
0 %0=dry start, 1=wet start. wetstartyes
30 %maximum number of vertical layers. ndepths
8 %number of subtimesteps for interpolation per main timestep 8. factinter
%----------------------------
0.04 %layer thickness of first layer (m snow). thicknessfirst
5.0 %layer thickness at deepest layer (m snow). thicknessdeep
30.0 %maximum depth model (m). depthdeep
200 %density of fresh snowfall kg/m3. denssnow
1 %0=constant irreducible water content, 1=density dep. Schneider, 2= density dep. Coleou. irrwatercontyes
0.02 %fraction of space irreducible filled with water. irrwatercont
%---- Output ----------
1 %factor for subsurf output, 1=every hour, 24=once per day at midnight. factsubsurfout
12 %offsetfactor for subsurf output to make print at noon possible. offsetsubsurfout
%runoffyes superyes wateryes surfwateryes slushyes coldsnowyes coldtotyes. for grid output
1 1 1 1 1
1 1
%===
% 16.) TEMPERATURE INDEX METHOD
%===
1 %which temp index method (1,2 or 3). ddmethod
8.0 %degree day factor for ice (only simple DDF method 1). DDFice
5.5 %degree day factor for snow (only simple DDF method 1). DDFsnow
%---
2.7 %meltfactor (only for modified temp index method 2 or 3). meltfactor
0.9 %radiation melt factor for ice. radfactorice
0.6 %radiation melt factor for snow. radfactorsnow
1 %factor to reduce melt over debris. debrisfactor
%******* 18.) OUTPUT STAKES *************************************
3 %1=stake locations given in local coordinates (x,y), 2=as 1 but center, 3=row/col. coordinatesyes
100 100
102 103
102 99
102 104
103 105

11.5 APPENDIX D: Visualisation with IDL

11.5.1 INTRODUCTION

The programs are designed to provide fast and easy visualization of the input data and results of the melt model. The visualization package is thus not meant for production of high-quality final figures, but greatly faciliated model application, calibration and validation. Some of the following IDL-programs are still under development and need improvements for more general applicability. Most useful and scrutinized are the programs **grid.pro, grids2.pro, shade.pro** and **lines.pro, linesdiff.pro**. The programs consists of two groups:

<u>Lineplots</u> (plot time series of input/output variables)

lines.pro (6 components of energy balance or melt)
linesdiff.pro (2 lines and the difference between them)
discharg.pro (measured and simulated discharge)
disdiff.pro (discharge of different model runs)
snowfree.pro (snow cover depletion of different model runs)

<u>Gridplots</u> (plot images, i.e. spatial distribution of input/output variables)

grid.pro (one image of any input/output variable)
grids2.pro (2 images and the difference between those)
shade.pro (1,4 or 24 images, to display daily variations of one variable)
snow.pro (several images of snow cover at different days)
snowcomp.pro (as snow.pro but displaying measured snow lines for comparison)
manygrids.pro (up to 20 grids)

<u>Input files ***inputgrid.par*** and ***inputline.par***</u>

The programs are generally applicable, i.e. no changes in the source code are needed. All user specific parameters (file names, path names, etc) are specified in an input file, that must be adjusted prior to running the programs. The input parameters for all lineplots are given in ***inputline.par***, the ones for all grid plots are defined in ***inputgrid.par***.
The reading of the input files is done by calling a routine in a separate file (program): ***inputline_read.pro*** and ***inputgrid_read.pro*** for line and grid programms, respectively.). These programms must be compiled separately before compiling the other programs.

Most parameters in the input files ***.par*** must only be adjusted once for a specific application. These parameters concern the location of the window and the colour bar on the screen, the main path name, file names of boundary files etc. The position of window and colour bar depends on the number of pixels but also on computer specific parameters such as screen size etc. The parameters are best fitted by trial and error.

The input files for line and grid plots contain parameters that are needed by all programms and parameters that are specific to each program. The specific parameters are identified by comment lines in the parameter file. For each program there is a section with specific parameters. For each program the general parameters and those specific to the program to be run must be adjusted. Any other parameters will be ignored, although the default parameters must not be deleted. Do not delete any rows in the input files (***inputline.par, inputgrid.par***). Any rows starting with an asterix are comments and contents can be changed, complemented etc. All variable names are written in bracket in the corresponding row in the parameter files.

Output can be either shown on screen or directed to a postscript file (set variable *plot2ps* to 1, under "for all plots"). In the latter case output is not displayed on screen.

11.5.2 How to apply the IDL-programs

UNIX

1. Copy all IDL-programms and parameter files (*.par*) into any subdirectory and start IDL from this path.
2. Adjust input file (*inputgrid.par* for grid programs and *inputline.par* for line plots

3. compile subroutines *inputline_read.pro*, *inputgrid_read.pro, colorbar.pro:*
   .run inputline_read.pro
   .run inputgrid_read.pro
   .run colorbar.pro
4. compile program to be run: ***.run program_name*** (e.g. ***.run grid***)
5. run program: ***program_name*** (e.g. ***grid***)

PC (VISUAL IDL)

6. open IDL, FILE, New, Project, give new name for project → file pops up in window to the left, click on project
7. Project add new files: add all files that contain main
8. click on main program in left hand window, so that program pops up in the right window
9. COMPILE ALL
10. F5 (run)

(Once a project exists, next time just open recent project).

The input files follow the following philosophy. Each file to be plotted is defined by a filename, a main path and a "pathrest". The programs generate the total filename by copying those parts together:

fullfilename = main path + pathrest + filename.

The main path or pathrest can also be empty in case the file to be plotted is located under the idl-directory (which should be avoided). The main path is specified at the end of the input file and should be the common path to all files to be plotted in one session. For each programme a pathrest is defined in the individual parts of the input file. The idea is to avoid that a long common pathname needs to be repeated every time a new file is to be plotted.

e.g. main path: /home/user/mode/storglac/
path rest: indata
filename: slope.bin

-> The file to be plotted is: /home/user/mode/storglac/indata/ slope.bin

for beginners:

- open *inputgrid.par* and adjust the main path at the end of *inputgrid.par*
- adjust the pathrest in *inputgrid.par* (at beginning of *inputgrid.par* under "Program grid.pro")
- adjust filename to be plotted (2 lines below pathname)
- make sure the variables *optboundary* and *optcut* are set to 0 (under "for all plots, what plot")
- run program: *.run grid*
- adjust the position of the colorbar by changing by trial and error the numbers under "positions of colorbars". The y-position is defined relatively, i.e. it varies between 0 and 1 (0 moves the colorbar to the botton, 1 to the top). The x-position is defined absolutely, i.e. number are arbitrarily adjusted until the colorbar appears in the position wanted (increasing the number moves the bar to the right).

How to run IDL on PC

- FILE open main program (e.g. grid.pro)
- RUN compile
- go to 'build order' (right panel)
- Add/Remove files
- Add subroutine files (e.g. colorbar.pro and inputgrid_read.pro for grid.pro)
- RUN Compile All
- F5 (to run program)

11.5.3 Description of programs

Lineplots

The following parameters must be specified for all graphics:

- first and last julian day to be plotted
- value of missing data in the file
- model path (the main path name is given at the end of the file; to that name a *pathrest* that is specified in the beginning of each program session is added)

PLOT:

- plot to postscript or to screen
- windownumber of graphic window
- additional parameters for postscript plot:
    - size of plot
    - offset of graphic on paper
- additional parameters for screen plot:
    - size of plot
    - position of plot

GRAPHICS:
- number of colourtable to be used
- colours for background and axes

linesdiff.pro

This program plots two lines in one plot and the difference between those lines in a second plot. Alternatively, it is possible to plot only one line. The purpose of the program is to visualize the difference between measured and modelled variables (e.g. global radiation) or between the same variable but 2 different outputs resulting e.g. from different model parameters.

Parameters:
- pathrests for both files, that means everything between *filename* and *model path* (without slashes at beginning and end)
- filenames
- columns in file to be plotted

lines.pro

This program plots 6 time series of different variables in 6 plots beneath each other. The variables have to be chosen in the parameter file. The purpose is to plot the time series of the energy balance and other components taken from *areamean.dat* or from the model output for individual grid cells.

Parameters:
- pathrest
- filename
- output parameters

discharg.pro

This program plots measured and calculated discharge (taken from model output) and temperature, wind, precipitation and global radiation taken from the input data file.

Parameters:
- pathrests for discharge and climate file
- filename for discharge and climate file
- columns for climate data in climate inputfile

(the columns in the discharge file are always the same in the model file and thus do not need to be specified).

disdiff.pro

This program plots up to ten plots of measured and calculated discharge. The purpose is to allow for comparison between different years or different parameter constelations.
(For printing, it is not useful to put more than five plots on one page.)

Parameters:
- number of plots (must be the same as number of pathrests, otherwise the inputline.par-file cannot be read by the program !!)
- number of columns in discharge file
- pathrests of the different discharge-files
- name of the discharge-file

snowfree.pro

This program plots the time series of snow cover depletion, i.e. the time series of the number of pixels snowcovered or snowfree. The data refers to the model output 'snowfree.dat'. Several lines resulting from different model runs can be *plotted into the same graph to allow for comparison of results from different parameter constelations. The number of overplots is not limited. In contrast to all other programs this program requires adjustments in the source code for any application, although the parameter file also needs to be adjusted.*

Parameters to adjust in the parameter file:
- time period to plot
- column to be plotted (snowcovered or snowfree pixels in % or absolute)

Parameters to adjust in the source code (snowdep.pro):
- number of files to be plotted
- path and filenames for each file.

Grid-Plots

The grid programs produce an **image plot** of the spatial distribution of a variable. In addition, the spatial mean, minimum and maximum are computed and printed to screen. For each run the full colour scale is exploited by scaling according to rounded values of the minimum and maximum values in the data set to be plotted.

Boundary plot
In order to identify relevant boundaries (e.g. the glacier boundary) polygons (boundaries) can be superimposed on the image plot. The variable *boundaryyes* must be set to 1 (middle of input file) and the number of files and filenames must be given (at the end of the parameter file). Each file must contain 2 coloumns with x and y-values of the polygon given in the same coordinates as the image. The polygon must be closed, i.e. the first row and the last row must be the same. Up to 20 polygons can be plotted. Each polygon is defined by a separate file. The number of files is adjusted at the very end of the inputgrid.par and all file names are listed at the very end of the *inputgrid.par*.

Blancing out parts of image
Besides using boundary lines another option is given to mark the area of interest. The variable *glaciercutyes* can be set to 1 and in this case a file name of any grid file containing missing values for all pixels that are not of interest (e.g. that are outside the glacier) must be given. In this case all pixels with missing value are assigned the same colour, thus clearly showing the area of interest (e.g. the glacier). This option is useful if the grid data contains data for all pixels (e.g. the direct radiation files or the DEM), but only the glacier is to be shown, particularly if a boundary file is not available. In the program *grids2* it is necessary to use this option if the grids compared have missing values, because otherwise the difference image shows the difference between the missing values, which does not make sense.

Scaling
The grids are scaled according to the mininum and maximum of the data to be plotted. If the variable *scale2tenth* is set to 1, the following rounding scheme is applied: If the data ranges from 0-1 or –1 to 1, it is scaled within these boundaries. Otherwise the minimum and the maximum are rounded to the lower and upper tenth, respectively. For example, if the variable ranges from 32.4 to 82.9, the colour bar ranges from 30 to 90. In grids2.pro the first 2 graphs are plotted according to the same scale using the minimum and maximum of both data sets, whilst the difference plot is scaled according to its minimum and maximum.

Parameters
The following parameters must be specified for all grid programs:
- model path (main path at end of input file)
- number of boundary files (up to 20 are possible) for printing the boundaries of glaciers
- name of boundary files

PLOT:
- windownumber (useful to keep different plots on the screen for comparison)
- contourlines desired (possible for *grid.pro* and *grids2.pro*):
(Choose boundary lines as well !!! Otherwise the overplots won't work properly !!)
    - minimum and maximum level, distance inbetween levels
    (give only first three for *grid.pro*, every nine for *grids2.pro*)
    - thickness of contour lines
    - colour of contour lines
- boundary lines desired :
(Not possible for animation runs, because the overplots don't work properly then !)
    - thickness of boundary line
    - colour of boundary line
- cutting out of glacier area desired:
    - pathrest including filename for cutting file

- animation run (only possible for *shade.pro* and *snow.pro*)
- plot to postscript or to screen
- additional parameters for postscript plot:
    - offset of plot on paper
- additional parameters for plot on screen:
    - size of graphicwindow
    - position of graphicwindow

GRAPHICS:

- number of colourtable to be used
- scale to tenth of colour bar
- positions of colourbars:
    - x-, y-position, width of bar
    (fill in first three in every case, fill in all nine for *grids2.pro*)

grid.pro

This program plots one single grid file.
Parameters:

- pathrest (this part is added to the main path given at the end of the parameter file, don´t add slashes)
- filename

grids2.pro

This program plots two grids and their difference (grid2 is subtracted from grid1). The purpose is to be able to evaluate the difference in the spatial distribution of one variable between runs using different model parameters. The first two grids are scaled the same for comparibility based on the minimum and maximum of both grids, while the difference grid is scaled according the minimum and maximum of the difference grid to visualize potential small differences.

Parameters:

- pathrests for both grids
- filenames for both grids

shade.pro

This program plots time series of grid output for one single day and different hours. The choice consists in either 1, 12, 4 or 24 grids. For these plots is an animation is possible. This program is useful to plot hourly grids of potential direct solar radiation of one day.

Parameters:

- pathrest
- identifier (first three letters of file to be plotted, for example dir, sur, ...)
- julian day to be plotted
- number of plots

snow.pro

This program plots time series of different days up to 24 series. An even number of plots is required, because the plots have to be arranged in rows and columns. the step inbetween the different days has to be equal.

Parameters.

- pathrest
- identifier (see *shade.pro* for explanation)
- first julian day to be plotted
- step inbetween days
- number of rows and number of columns in which plots should be arranged

snowcomp.pro

This program plots surface maps in comparison with output grids of snow water equivalent or surface type. The purpose is to allow for evaluation of the quality of snow line retreat simulations.

Up to 5 plots, i.e. images at 5 different dates can be chosen..
The first row contains the surface maps (for example photos), the second one includes the output grids of the model. The julian days for surface maps and and grids may be selected separately for larger assortement.

Parameters:
- pathrests for surface maps and for grids
- identifier for grids (*sur* or *sno* (for surface type or snow water equivalent))
- number of files to be plotted
- julian days to be plotted for surface maps (filename should be sur+jd+24.dat)
- julian days to be plotted for grids

manygrids.pro
This program plots up to 20 grids. It reads input parameters from grid-parameter file, but is not yet programmed generally. This means the filenames and the number of grids must be adjusted in the source code.

11.5.4 Error messages

Sometimes the programs do not compile or work although nothing seems to be wrong. In this case try typing a combination of the following:

close, /all (if too many unit open)
retall
recompile program

If nothing work exit IDL and restart IDL and recompile the programs.

Colour problem
If the programs compile and nothing or only part of the graph (e.g. only the axis but no plot) appears, the problem might be the definition of colours. When moving to a different computer and also on the same computer depending on how many other applications are running, colours may appear different, thus e.g. the plot might not appear because it is plotted white on white.
This can be adjusted by 3 ways:
a) change the variables *axiscol* (axis colour) and *backcol* (background colour) in the parameter file
b) choose a different colour table (parameter in parameter file)
c) change the number of the variable *farbe* in the source code (re-compile afterwards). This variable defines the colour of the line plots and is used in the function *oplot*. It can be changed between 1 and thousands.

Error message: end of unit encountered
check if there are empty lines in data file to be plotted. These have to be removed.

11.5.5 Compatability to PWAVE

The programs are compatible with PWAVE. Not compatibel are:

- the **mean function**

mean(array) must be replaced the function for standard deviation
a=stdev(array,mean)
print,mean --> prints the mean

- **/NAN** to identify missing values in array

The WHERE-function has to be used

In the programs both version are programmed and one of them is marked as comment (;).

11.5.6 Adjustments for change between SUN - PC environment

The following adjustment have to be made in the source codes when using PC instead of SUN:

SUN	PC
SET_PLOT,'**X**'	SET_PLOT,'**WIN**'

- SUN uses / as backslash, PC uses \.

- All IDL-programs construct filenames by copying pathnames and filesnames together. All commands concerning this operation have to be adjusted accordingly

11.5.7 Relevant file conversion programmes

<u>General format:</u> All model input and grid output is in ArcInfo format binary

1. conversion between binary and ascii ArcInfo format

Program ***ascigrid.c*** converts from Ascii to binary
UNIX: *ascigrid.exe* *<filename_input>* *<filename_output>*
Program ***gridasci.c*** converts from binary to Ascii
UNIX: *gridasci.exe* *<filename_input>* *<filename_output>*

2. replace values in grid file within a certain range with another value

(useful e.g. for generating firn file: all values in the DEM above a certain height can be set to the firn value, all below to the ice file)

Program ***remap.c*** (needs *statist.c* and *statist.h*)

Needs a parameter file (remap.dat) which contains which ranges to convert to which value
Run the program on SUN: *remap.exe <inputfilename> remap.dat <outputfilename>*

Example *remap.dat*:

```
 0  1000 :  5
1000 2000  : 10
```

This file would replace all values between >0 and 1000 with 5 and all values between >1000 and 2000 with 10.

3. Visualization with SURFER, format conversion of grid files

Program ***gridAI_gridSurf.c***

Converts ArcInfo format (Ascii) grid to .grd Surfer format (Ascii), it thus also flips the rows, since ARC-INFO Format refers to the upper left corner, SURFER to the lower.The nodata value can be set to SURFERS missing value 1.70141E+038.
The file needs a parameter file ***gridAI_gridSurf.par*** to give filenames and some more parameter choices. Put c-program and parameter file into same directory

Program ***surf3col_gridarcinfo.c***

Converts grid data in Ascii-format with 3 columns to ArcInfo format (Ascii) grid.
The file needs a parameter file ***surf3col_gridarcinfo.par*** to give filenames and some more parameter choices. Put c-program and parameter file into same directory

<u>convert SURFER-grids (binary) to ArcInfo grid format:</u>
1.) open grids in SURFER and save as Ascii (x,y,z)
2.) run program ***surf3col_gridarcinfo***