Different models to calculate snow melt

GEO 4430, 21.03.2006

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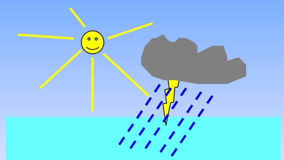
Snow melt and melt water runoff

Significance:

- Hydropower purposes
- Flood prediction
- Avalanche protection
- Research: effects of climate change

Snow melt and melt water runoff

Surface energy balance



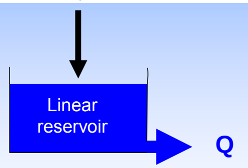
R + H + L + G + P + M = 0

R – net radiation
H – sensible heat flux
L – latent heat flux (evaporation)
G – ground heat flux
P – rain heat flux
M – latent heat flux (melt)

HBV - model

Temperature-index approach:

$M = C * (T-T_0)$



$Q = k * V$

Q – discharge
V – storage volume
k – storage konstant

Guidelines for Snowmelt Model Selection

1. Operation and calibration data availability
2. Expected physiographic and climatic conditions
3. Detail and type of results required.

Primary approaches to modeling snowmelt:

1. Ablation Stakes
2. Regression Analysis (linear or multiple)
3. Temperature Index Approach
4. Energy Balance Approach

Ablation Stakes

- Used to “model” distributed snowmelt over an area of interest.
- Stakes are placed in the snow and distance between snow surface and top of the stake is noted.
- Difference in depth between the two readings is the amount of snow depth lost over that time interval.

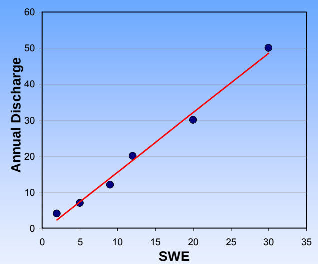
→ interpolation

Regression Analysis

- Provide estimated total discharge at a gaging site.
- Based on empirical regression equations.

$$Q = b + (SWE)\, x$$

SWE : measured at snow course sites
Q : annual or seasonal discharge at a gaging site



Requirements:

- Representative sites (to get a high r^2)
- Often only one SWE measurement station in a basin
- If more than one station, can run multiple regression
- Need long-term record, usually at least 10 years

Regression analysis

Advantages:

- Provides an estimate of total discharge from basin
- Simple
- Minimum data requirements
- Provide a good index for water resource managers

Disadvantages:

- Does not provide information on factors such as peak discharge.
- Threshold effects may occur.
- Assumes stationarity.
  - Climate boundary conditions can’t change.

Temperature-Index Methods

Based on the concept that changes in air temperature provide an index of snowmelt.

T-index approach:

$$M = C * (T - T_0)$$

Air temperature

- commonly measured meteorological variable.
- secondary meteorological variable that provides an integrated measure of heat energy.

Importance of individual components

Ohmura, 2001

sources	
longwave incoming radiation	~ 70%
absorbed global radiation	~ 20%
sensible heat flux	< 10 %
sinks	
longwave outgoing radiation	~ 70 %
melt	~ 10 – 30 %
ground heat flux	< 10 %

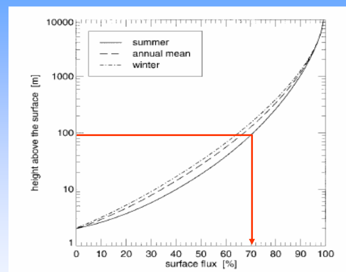
More trouble...

- The sensible heat flux contributes < 10%
- T-index approach:

$$M = C * (T - T_0)$$

Why does the T-index approach perform that well ??

The longwave incoming radiation is the largest contribution to melt (~ 70%)



About 70 % of the longwave incoming radiation originates from within the first 100m of the atmosphere

Variations of screen-level temperatures can be regarded as representative of this boundary layer

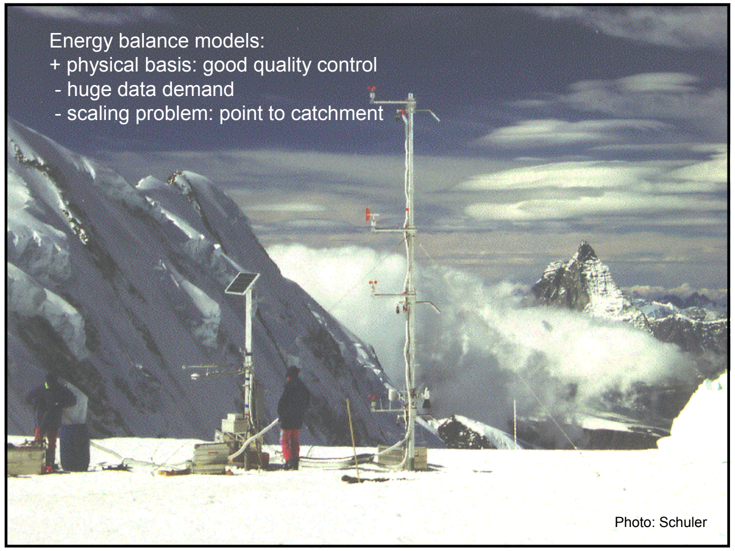
Energy Balance Models

$$0 = Q_R + Q_H + Q_L + Q_G + Q_P + Q_M$$

- Point or spatially distributed
- Run on measured data
  - contrast to empirical models, which run on only a few measured parameters and which rely on calibration parameters at the heart of the model.
- Only as good as your measured data and understanding of the system
- Includes some empirism anyway (turbulent exchange…)
- Sacrifice simplicity for complicated measurements and algorithms.

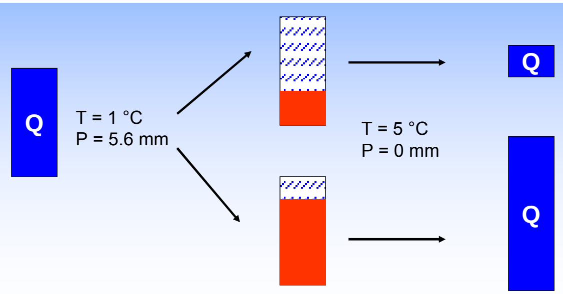
Energy Balance problems

- Energy Balance model (parameterizations of turbulent exchange)
- Spatial distribution
- Precipitation
- Snowpack model (refreezing, metamorphism, water retention)

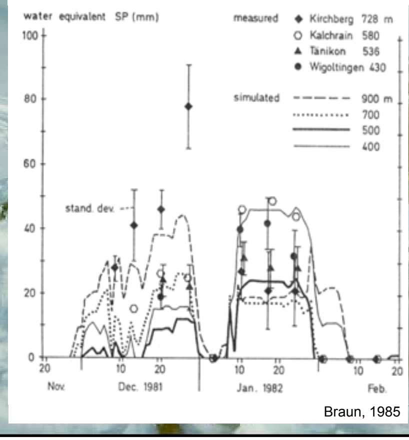


Trouble with empirism…

How to deal with this problem ??



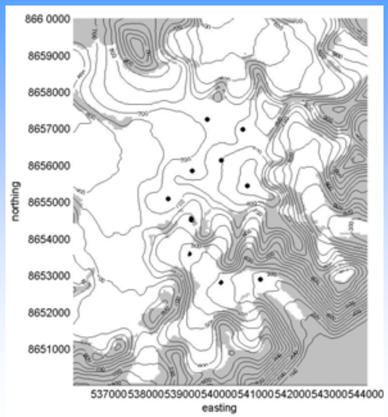
Validation of model results



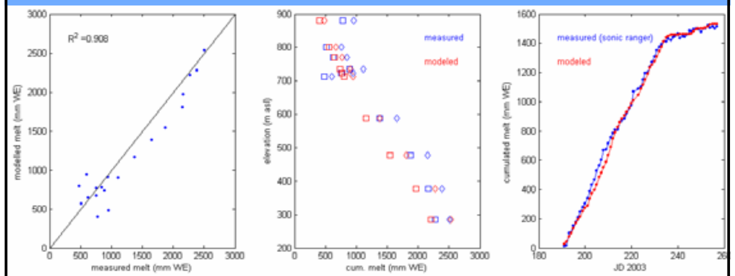
Braun, 1985

Photo: Braun

Melt model validation



Model validation



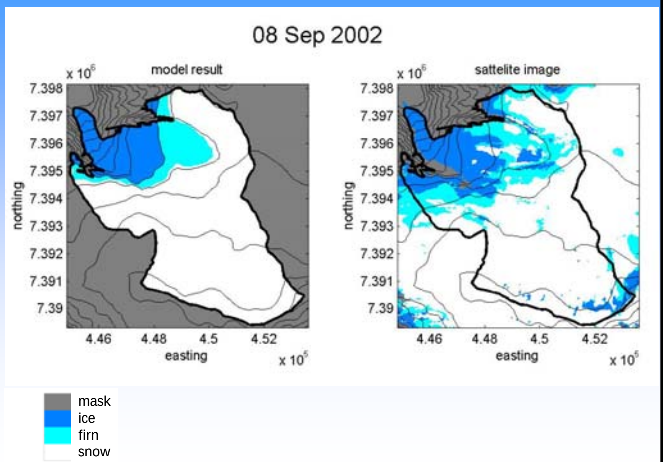
by comparing measured and calculated mass balance

Variability of snowmelt

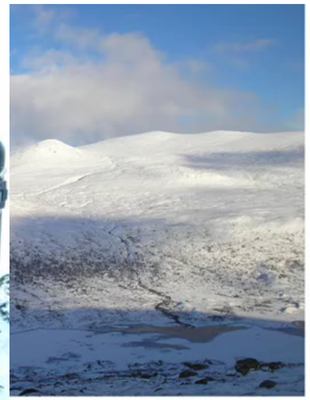
Distributed modelling

- Areal extent of snow cover
  (satellite, automat. camera)
- Spatial distribution of SWE
  (a harder problem)
- Spatial distribution of meteorological variables

Model validation



Automatic camera…



Some strategies (1980s)

<u>Use different formulations:</u>

T-index:

$$\mathbf{M = C * (T-T_0)}$$

T+wind-index:

$$\mathbf{M = (C1 + C2*u)\ (T-T_0)}$$

Combination method:

if no rain: **T-index**

if rain: **...some complex equation**

<u>Spatial variability:</u>
Apply the model to different elevation bands, aspect classes etc.

<u>Temporal variability:</u>
Temporal variable melt-factor (e.g. sinusoidal annual variation)

Advanced T-index models

Strategy:
include the second most important energy source (global radiation)

melt-factor variable in space and time

Hock 1999:

$$M = \boxed{(C_1 + C_2*I)} * (T-T_0)$$

radiation term

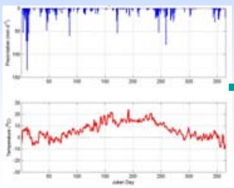
Pellicciotti et al. (in press):

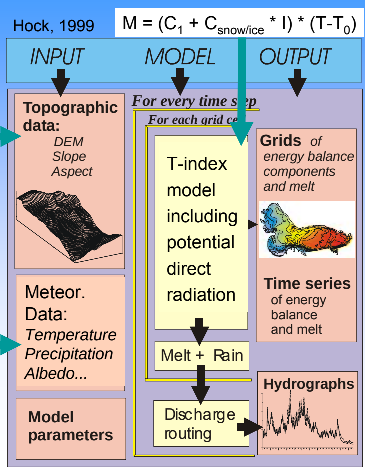
$$M = \boxed{C_1 * (T-T_0)} + \boxed{C_2*(1-\alpha)*I}$$

I – potential clear-sky solar radiation
α - albedo

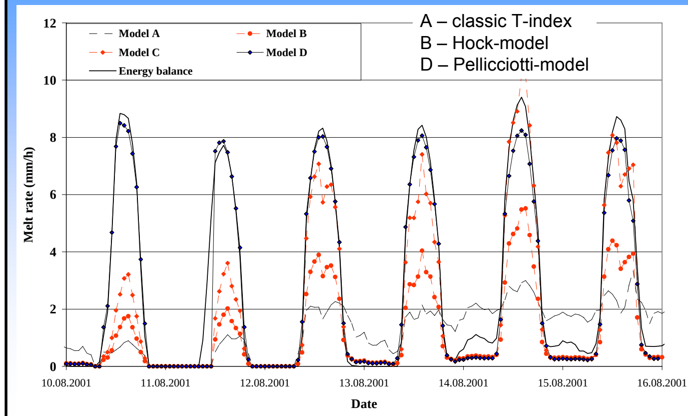
temperature term

Modelling strategy

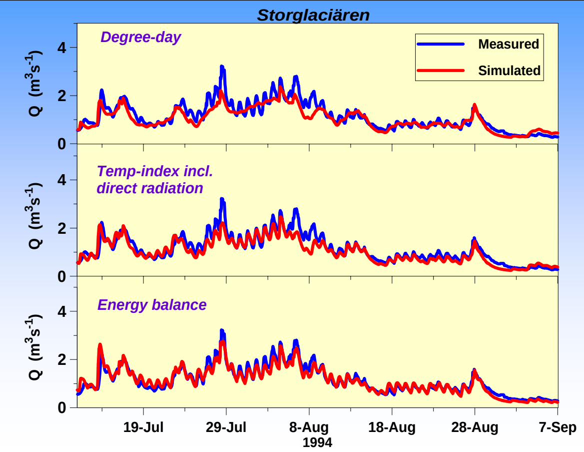




Model performance



Modelling: *Discharge*



Hock 1998

Summary

+ predictive power, assessability

- complexity, data demand, distribution

Interpolation
Regression models

T-index model

Enhanced T-index

Energy balance models