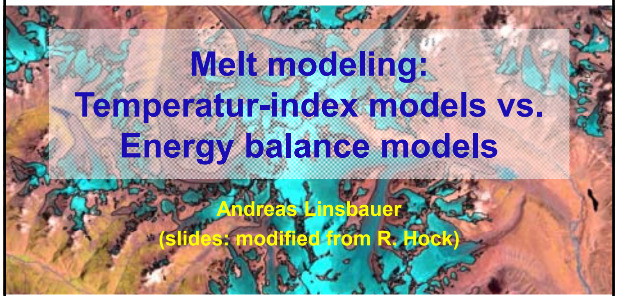
Melt modeling: Temperatur-index models vs. Energy balance models



Andreas Linsbauer
(slides: modified from R. Hock)

IHCAP – Indian Himalayas Climate Change Adaptation Programme
Capacity building programme "Cryosphere" Level-2 (Jan 5 – Feb 13, 2015)

How to model melt ?

- **1. Physically based energy-balance models**: each of the relevant energy fluxes at the glacier surface is computed from physically based calculations using direct measurements of the necessary meteorological variables
- **2. Temperature-index or degree-day models**: melt is calculated from an empirical formula as a function of air temperature alone

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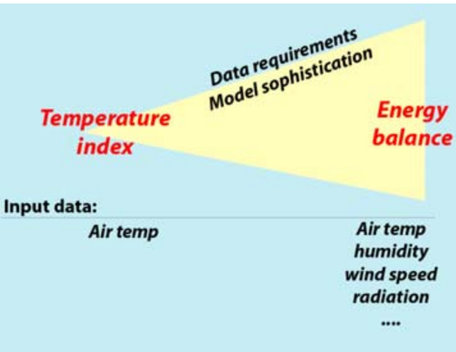
Melt Modelling



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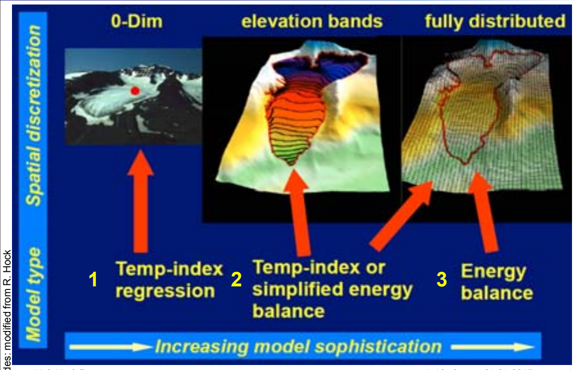
Mass balance models



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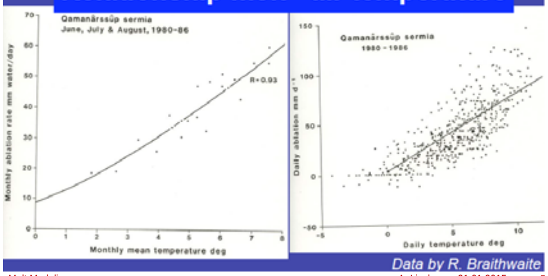
Temperature-index melt models

- Assume a relationship between air temperature and melt: *M=f(T), M=f(T⁺)*

Relationship melt - air temperature



Data by R. Braithwaite

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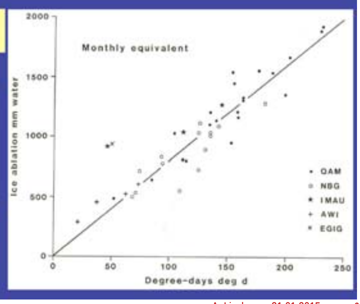
Temperature-index melt models

- Assume a relationship between air temperature and melt: *M=f(T), M=f(T⁺)*

Positive degree-day sum
PDD = ΣT⁺

Relationship melt – degree-day sum



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Physical basis of temp-index models

Air temperature directly affects several components of the surface energy balance

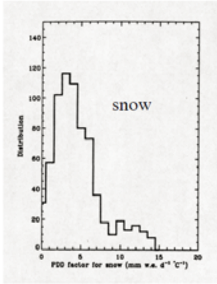
Longwave incoming rad: $L\downarrow = \varepsilon\sigma T^4$ — Sensible heat flux: $f(T)$ — Latent heat flux: $f(e(T))$

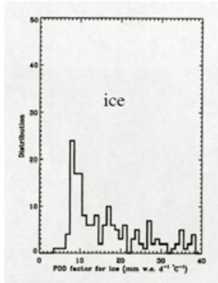
$$Q_M = G(1-\alpha) + L\downarrow - L\uparrow + Q_H + Q_L$$

- Longwave incoming radiation (L↓) is the largest contribution to melt (~70%)
  (Ohmura, 2001: Physical basis of temperature-index models)
- L↓ has low variability compared to other fluxes

Spatial variability of degree-day factors

Calculation of degree-day factors for various points on the Greenland ice sheet with an atmospheric and snow model (thesis Filip Lefebre)

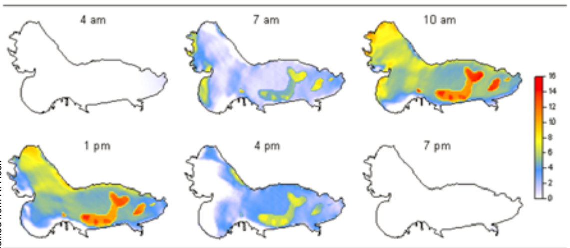




Degree-day factors [mm/day/K]

Spatial and diurnal variation
Derived from energy balance modeling

$M = DDF_{ice/snow} * T^+$

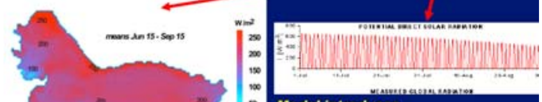


Hock, 1999, J.Glaciol.

Modified temperature-index model

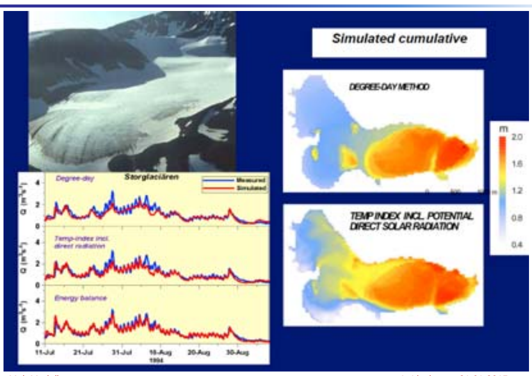
Including potential direct solar radiation — *Hock 1999, J. Glaciol*

- *Classical degree-day factor*
  $M = DDF_{ice/snow} * T^+$
- Including pot. direct radiation
  $M = (MF + a_{ice/snow} * DIR) * T^+$



Model introduces
- *a spatial variation in melt factors*
- *a diurnal variation in melt factors*

Modified temperature-index model



Distributed temp-index model

$$M = TF \cdot T + AF \cdot (1-\alpha) \cdot I \qquad T > T_T$$

Temperature — Albedo — Incoming shortwave radiation

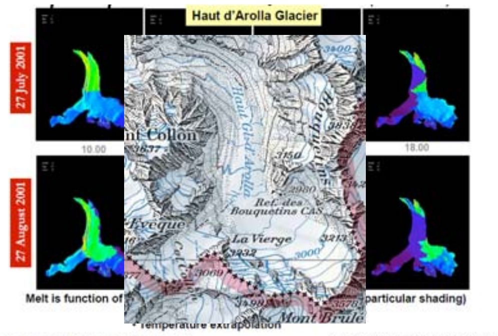
Albedo: Computed as function of accumulated maximum daily temperature since snowfall (*Brock et al. (2000)*)

Incoming shortwave radiation: Computed as function of daily temperature range

Model only requires air temperature
Global radiation and albedo parameterized

Pellicciotti et al, 2005, J. Glaciology

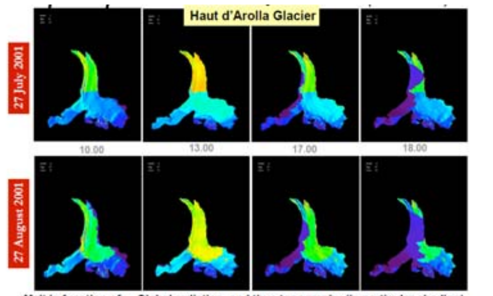
Spatial paterns of hourly melt rate (mm w.e. h^{-1})



Melt is function of ... particular shading)
• Temperature extrapolation

With courtesy of Francesca Pellicciotti — *Pellicciotti et al, 2005, J. Glaciology*

Spatial paterns of hourly melt rate (mm w.e. h^{-1})



Melt is function of
- Global radiation, and thus topography (in particular shading)
- Surface properties and particularly albedo
- Temperature extrapolation

With courtesy of Francesca Pellicciotti — *Pellicciotti et al, 2005, J. Glaciology*

Simplified energy balance model

Oerlemans (2001)

M = a * R + melt factor * T

$$M = (1-\alpha)G + c_0 + c_1 T$$

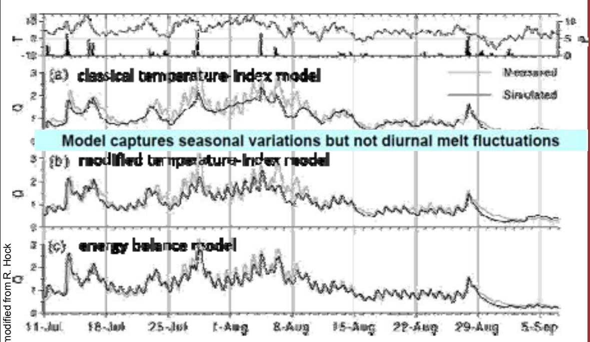
Shortwave radiation balance — Longwave balance and turbulent fluxes

→ *Gradual transition from degree-day models to energy balance-type expressions by increasing the number of climate input variables*

Temperature-index versus energy balance

	Temperature index	*Energy balance*
Advantages	• Wide availability of Temp-data • Easy interpolation and forecasting • Good model performance • Computational simplicity	• Physical based – describe physical processes more adequately • Projections more reliable
Shortcomings	• Empirical, not physically based • DDF vary, works on 'average conditions • Does not work in tropics • Model parameter stability under different climate conditions ?	• Large data requirements (often not available)

Model comparison



Summary

- Both temp-index and energy balance models are useful tools, choice depends on data availability
- Awareness of limitations
- Need for more approaches of intermediate complexity and moderate data input
- Both temp-index and energy balance models need calibration (parameter tuning)