Synergistic Use of Satellite Radar Observations and Meteorological Data for Modelling Glacier Mass Balance and Runoff

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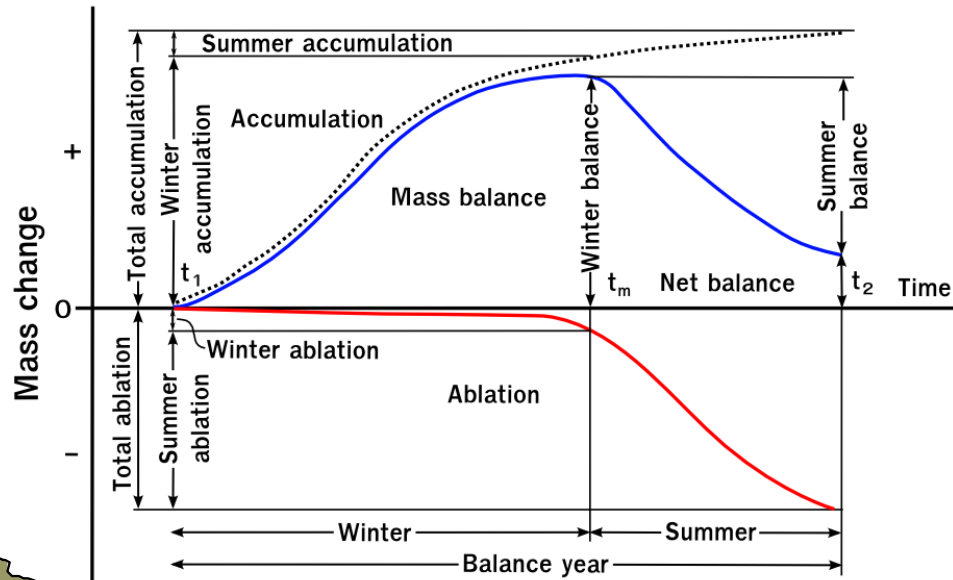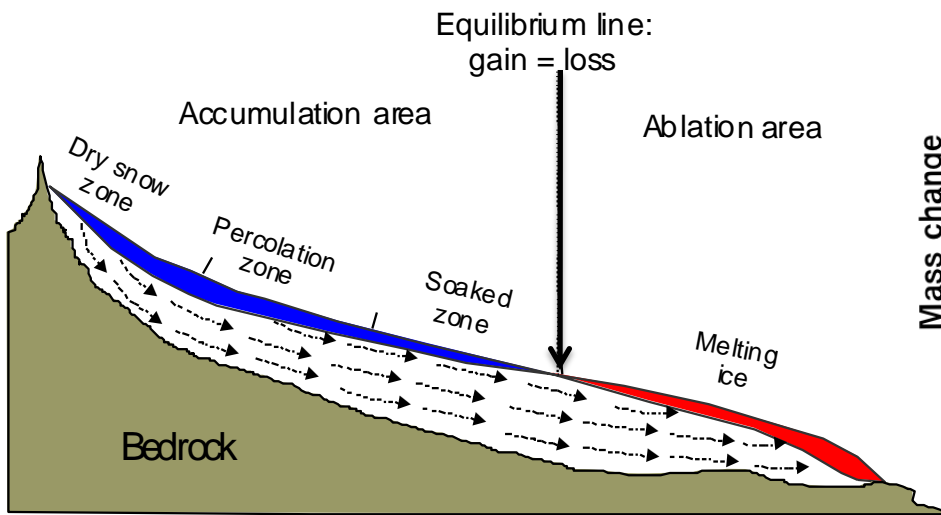
Glacier Net Balance, b_n:

$$b_n = \int_{t_1}^{t_2} \left(\frac{\partial c}{\partial t} + \frac{\partial a}{\partial t} \right) dt$$

Total Glacier Net Balance, B_n

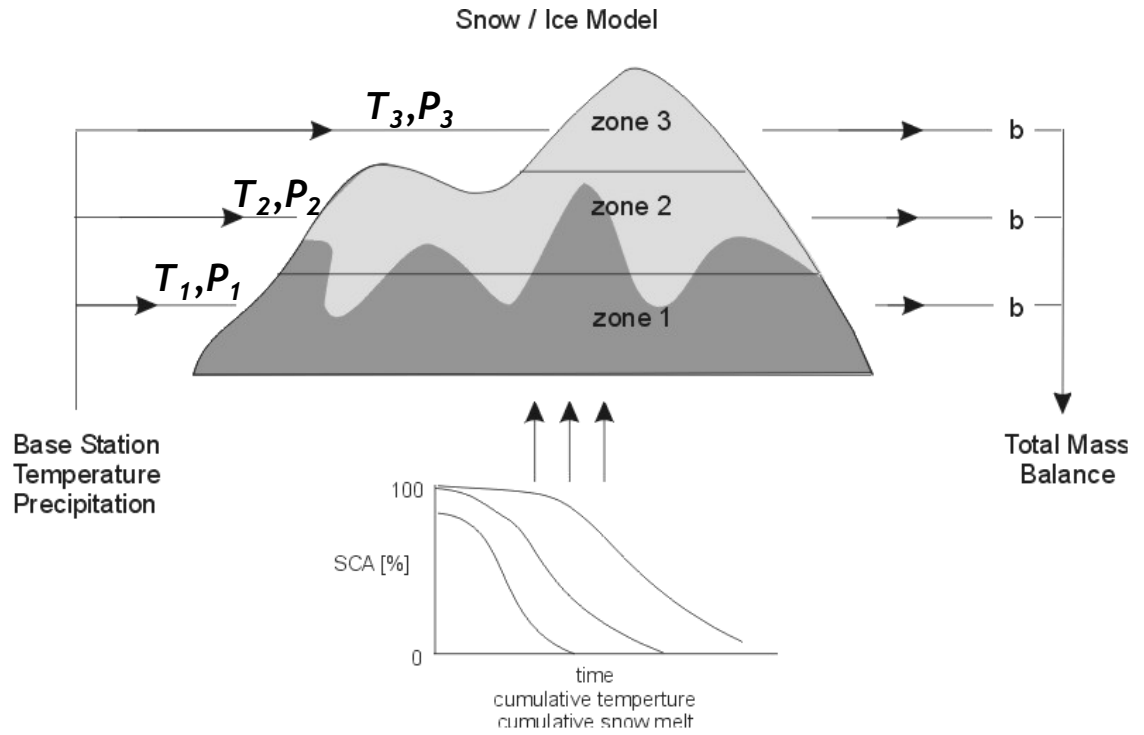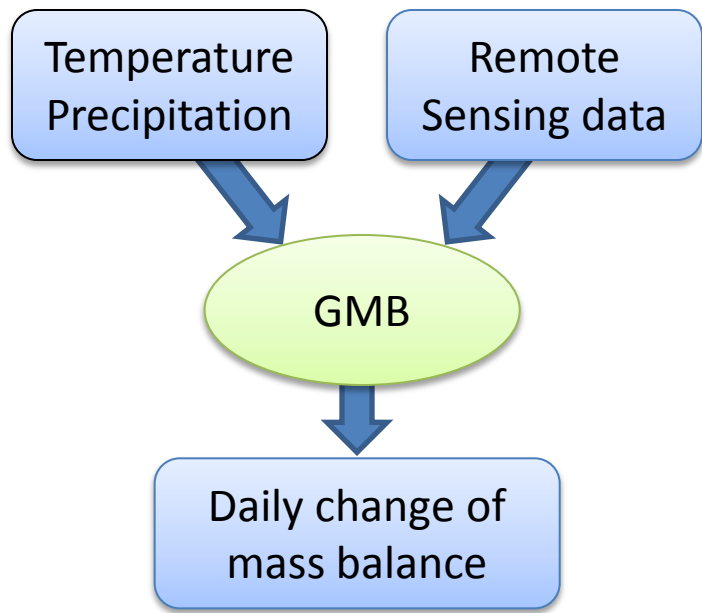$$B_n = \int_{S_c} b_n dS + \int_{S_a} b_n dS$$

S_c … accumulation area
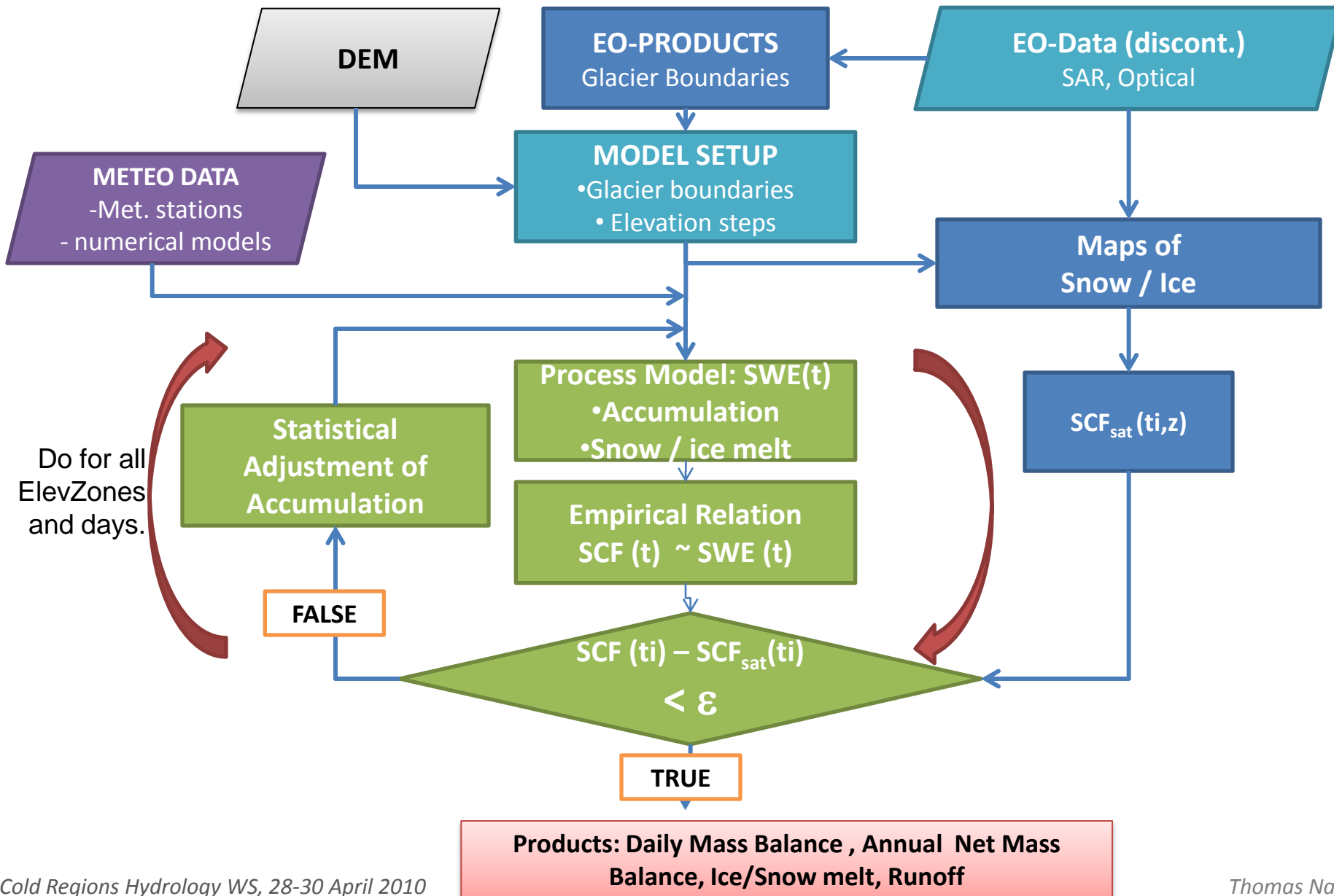S_a … ablation area

after Paterson, 1994

Concept of Glacier Mass Balance Model - GMB
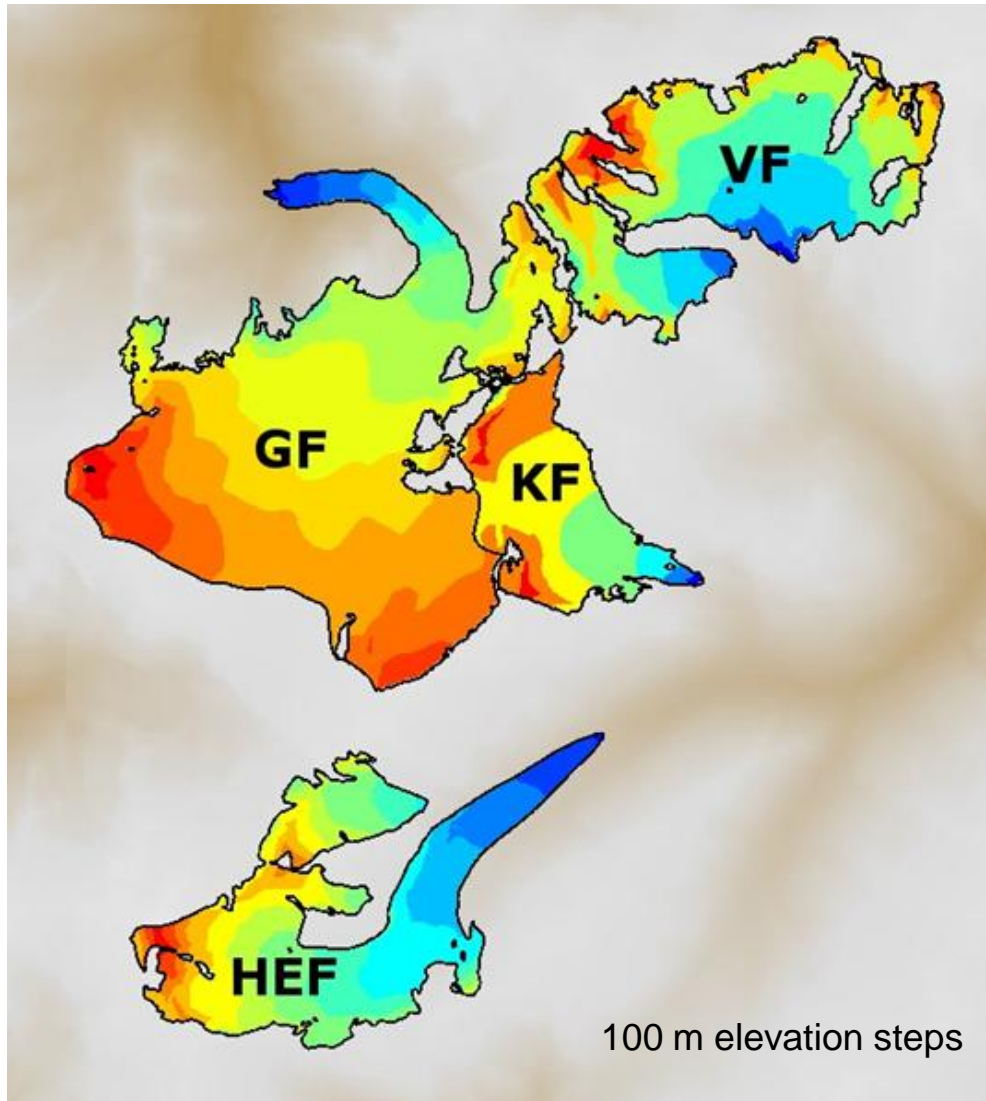

$$B_n(t) = C_{sn,i} DDF_{sn,i}(t) T_i^+(t) A_{sn,i}(t) + C_{ice,i} DDF_{ice,i}(t) T_i^+(t) A_{ice,i}(t) + f_p(T) C_{p,i} P_i(t)$$

$C_{sn,i}$, $C_{ice,i}$, $C_{p,i}$	*Correction factor for losses for snow melt, ice melt, rain at elevation zone i*
$DDF_{sn,i}$, $DDF_{ice,i}$	*Degree day factor for snow and ice at elevation zone i*
$A_{sn,i}$, $A_{ice,i}$	*Area of snow and ice at elevation zone i*
T_i^+	*Daily sum of positive degree days*
f_p	*Fraction of solid and liquid precipitation*
P_i	*Precipitation at elevation zone*

Processing Steps

DEM

EO-PRODUCTS
Glacier Boundaries

EO-Data (discont.)
SAR, Optical

METEO DATA
-Met. stations
- numerical models

MODEL SETUP
•Glacier boundaries
• Elevation steps

**Maps of
Snow / Ice**

Do for all
ElevZones
and days.

**Statistical
Adjustment of
Accumulation**

Process Model: SWE(t)
•**Accumulation**
•**Snow / ice melt**

$SCF_{sat}(ti,z)$

**Empirical Relation
SCF (t) ~ SWE (t)**

FALSE

$SCF(ti) - SCF_{sat}(ti)$
$< \varepsilon$

TRUE

**Products: Daily Mass Balance , Annual Net Mass
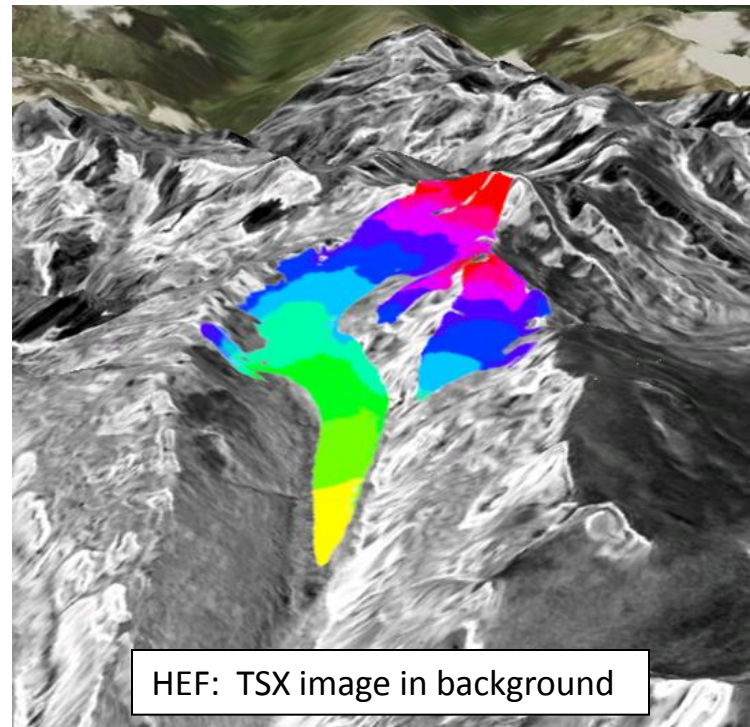Balance, Ice/Snow melt, Runoff**

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Application Example: Ötztal Glaciers

HEF – Hintereisferner, 7.7 km^2

GF   – Gepatschferner, 16.6 km^2

KF   – Kesselwandferner, 3.8 km^2

VF   – Vernagtferner, 8.3 km^2

100 m elevation steps

HEF: TSX image in background

Meteorological Data and SAR Images
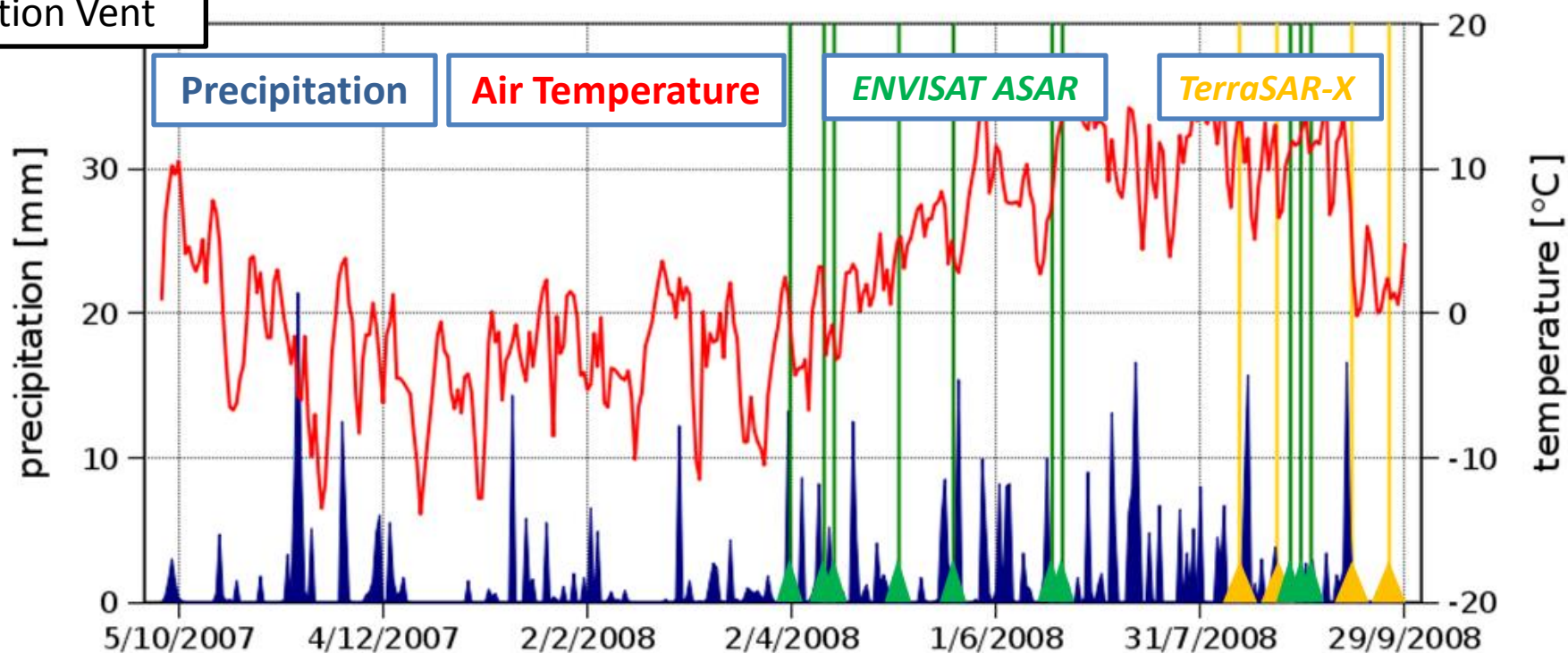
| Date	Mode	Track	Polarization	Used as
2007/10/30	Stripmap	078	HH	Reference
2008/07/20	Stripmap	078	VV	Snow Map
2008/08/11	Stripmap	078	HH	Snow Map
2008/08/22	Stripmap	078	HH	Snow Map
2008/09/13	Stripmap	078	VV	Snow Map

Daily mean Temperature
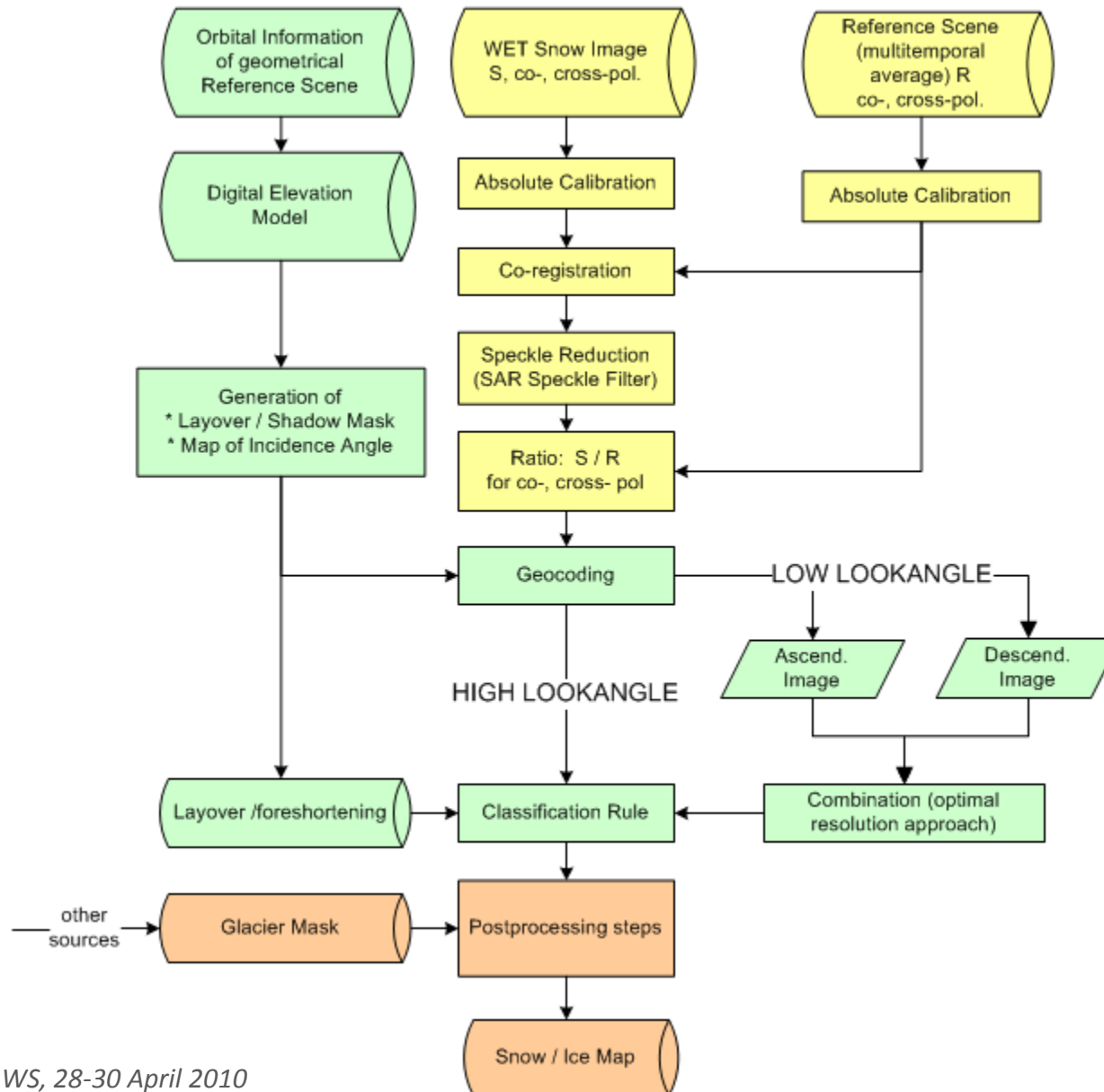## Daily Precipitation

Temporal integration

Spatial interpolation
(takes elevation dependence
into account)

Spatial integration
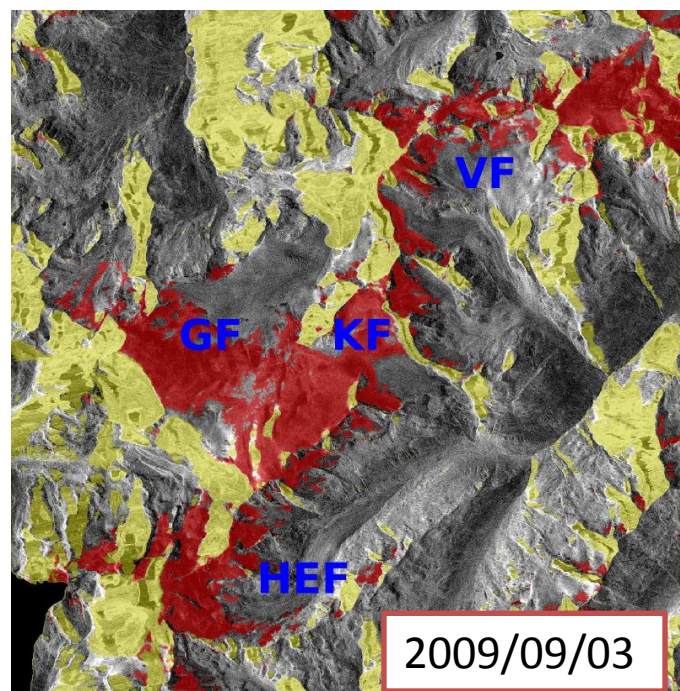grid ⟶ elevation zones
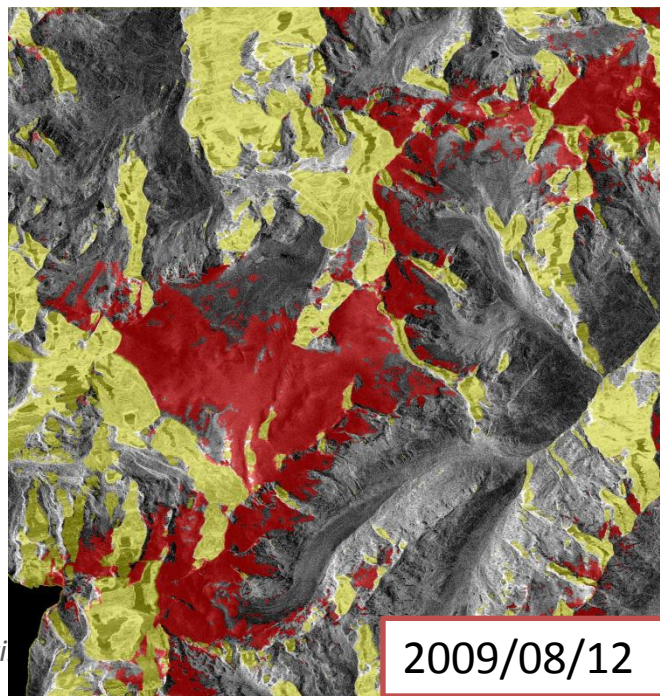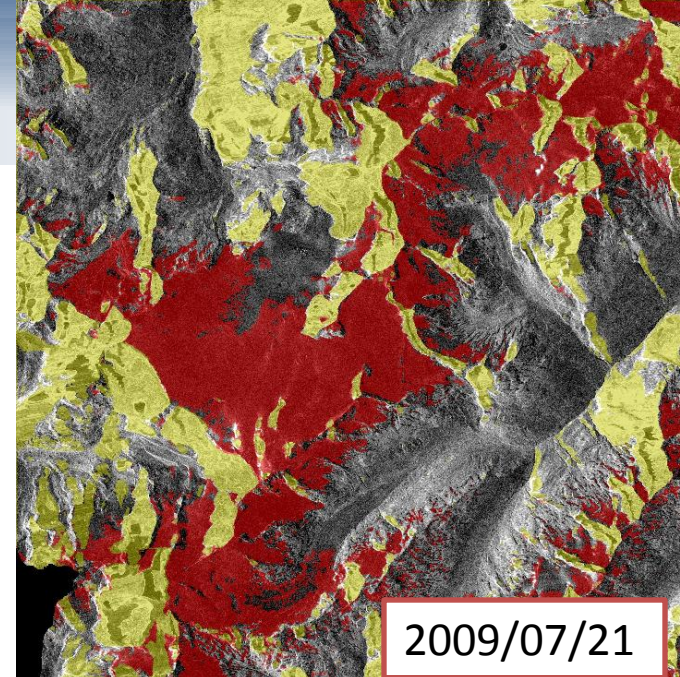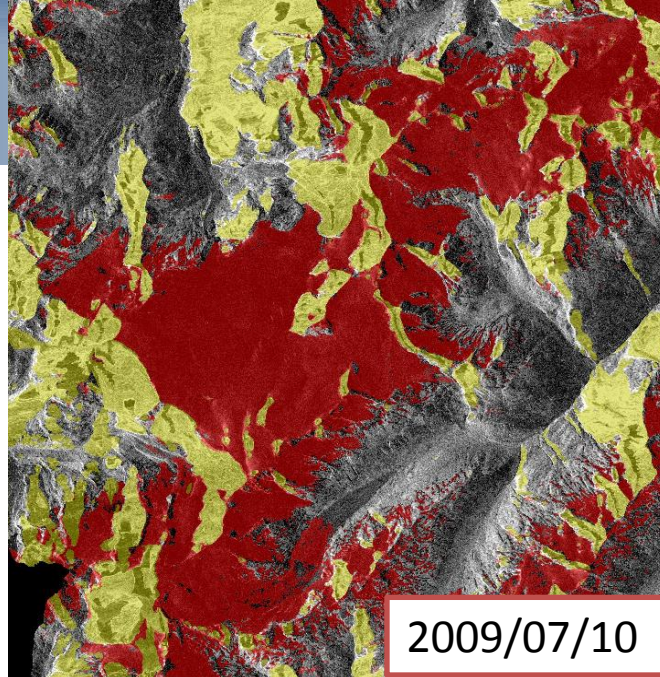
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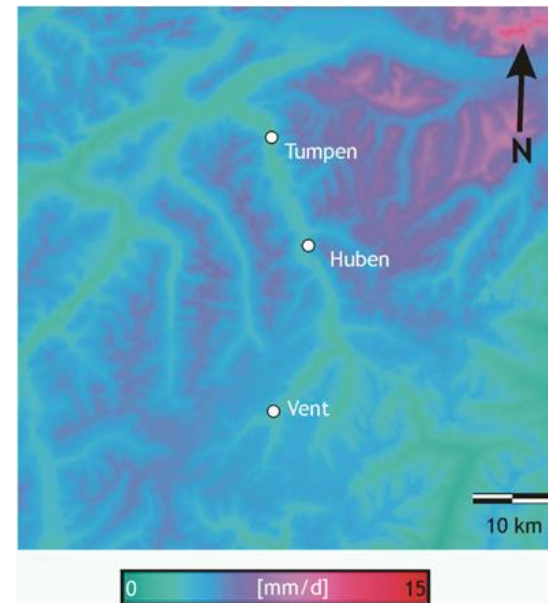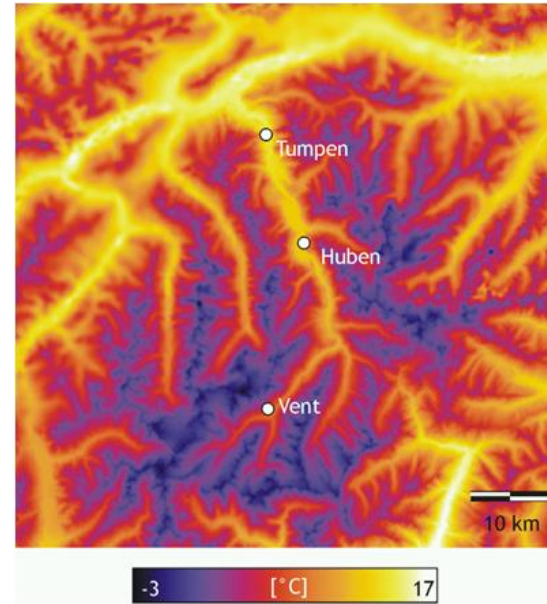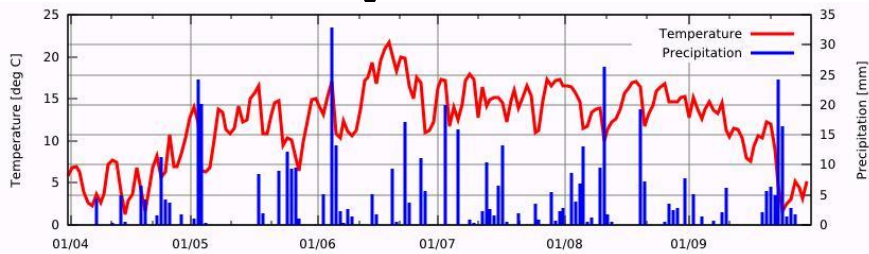
Snow / Ice Area Mapping on Glaciers from SAR Data

TerraSAR-X Maps of Wet Snow Extent

Stripmap Mode
VV Pol.
θ = 31 deg.

Red - Snow
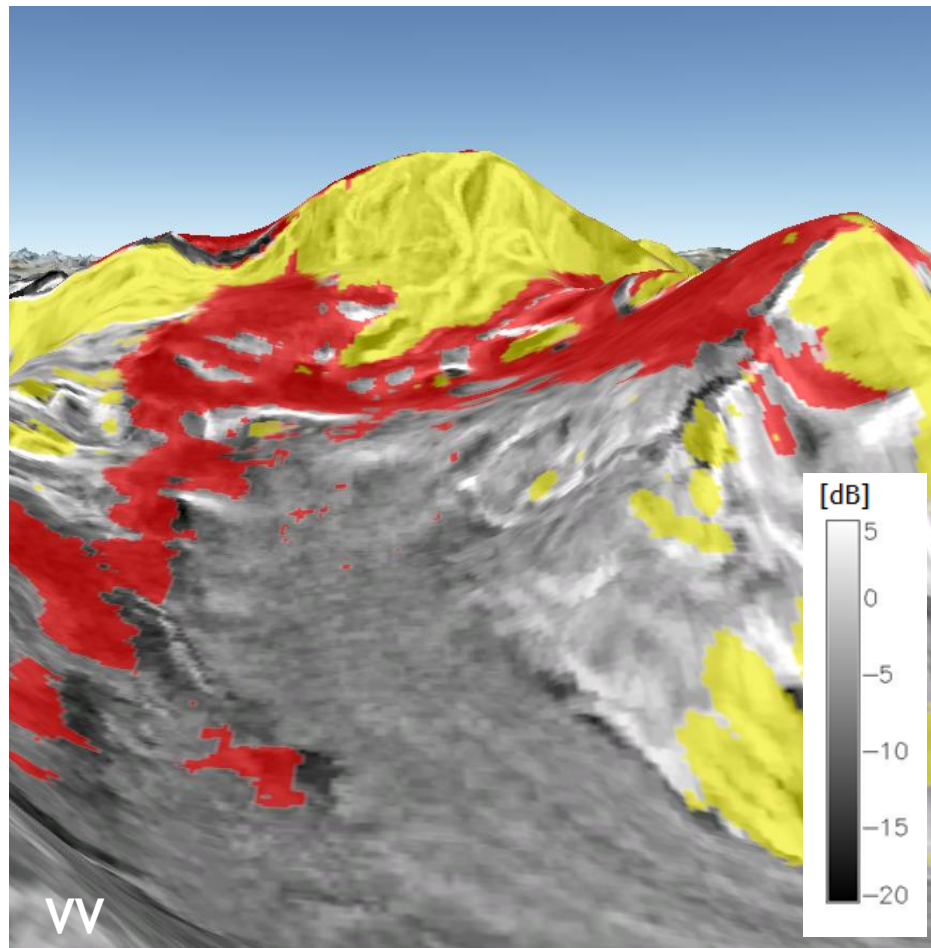**Yellow** - Layover / foreshortening

2009/07/10

2009/07/21

2009/08/12

2009/09/03

VF
GF KF
HEF

Comparison of TSX-1 Snow Map with Oblique Photo

13 September 2008

9 September 2008

[dB]
5
0
-5
-10
-15
-20

VV

©IMGI

red - Snow   yellow – layover

oblique photo taken from aircraft

Total specific Mass Balance b_n = -1232 mm (modelled),
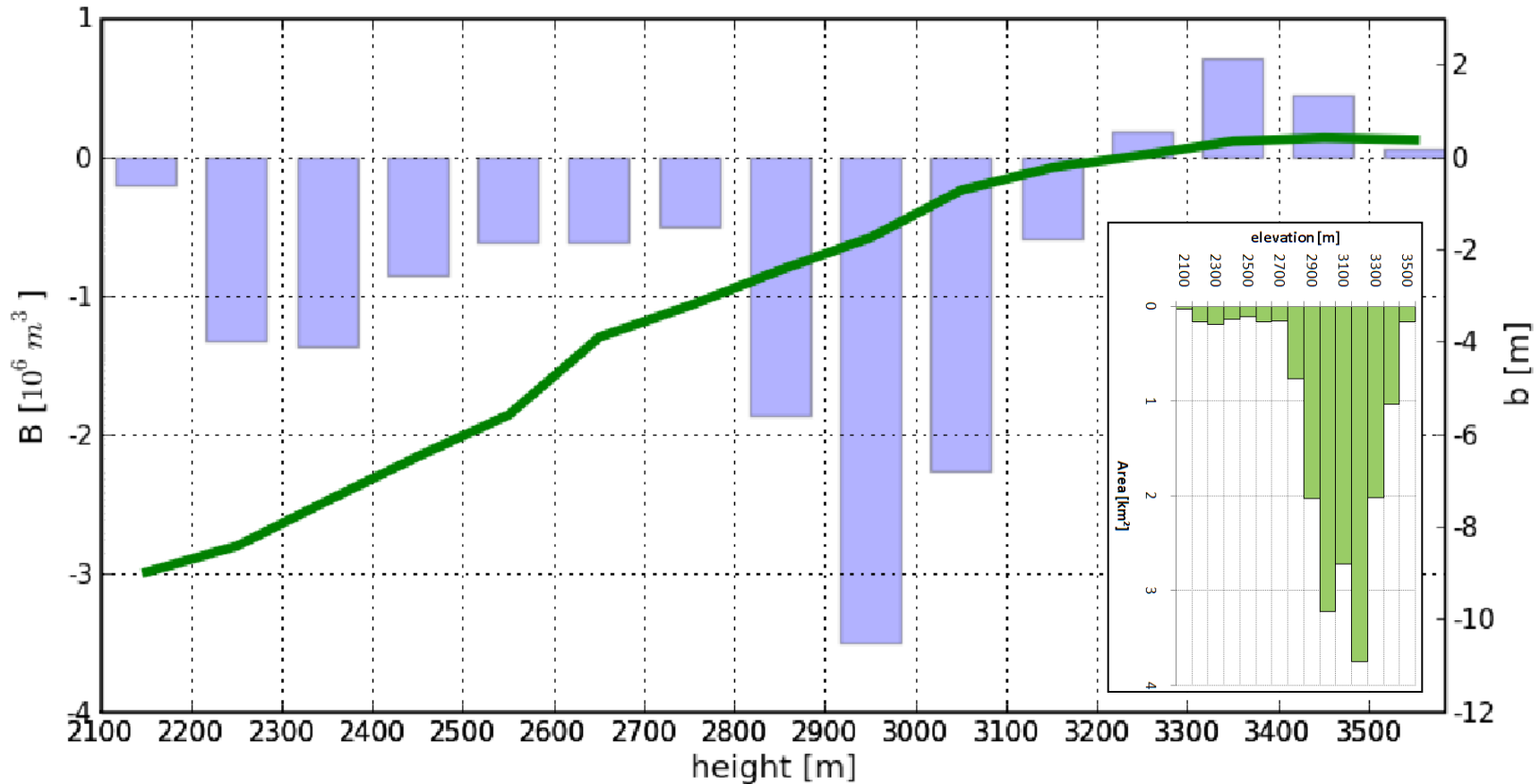b_n = -1235 mm (measured, IMGI)

Computed Mass Balance – Hintereisferner 2009
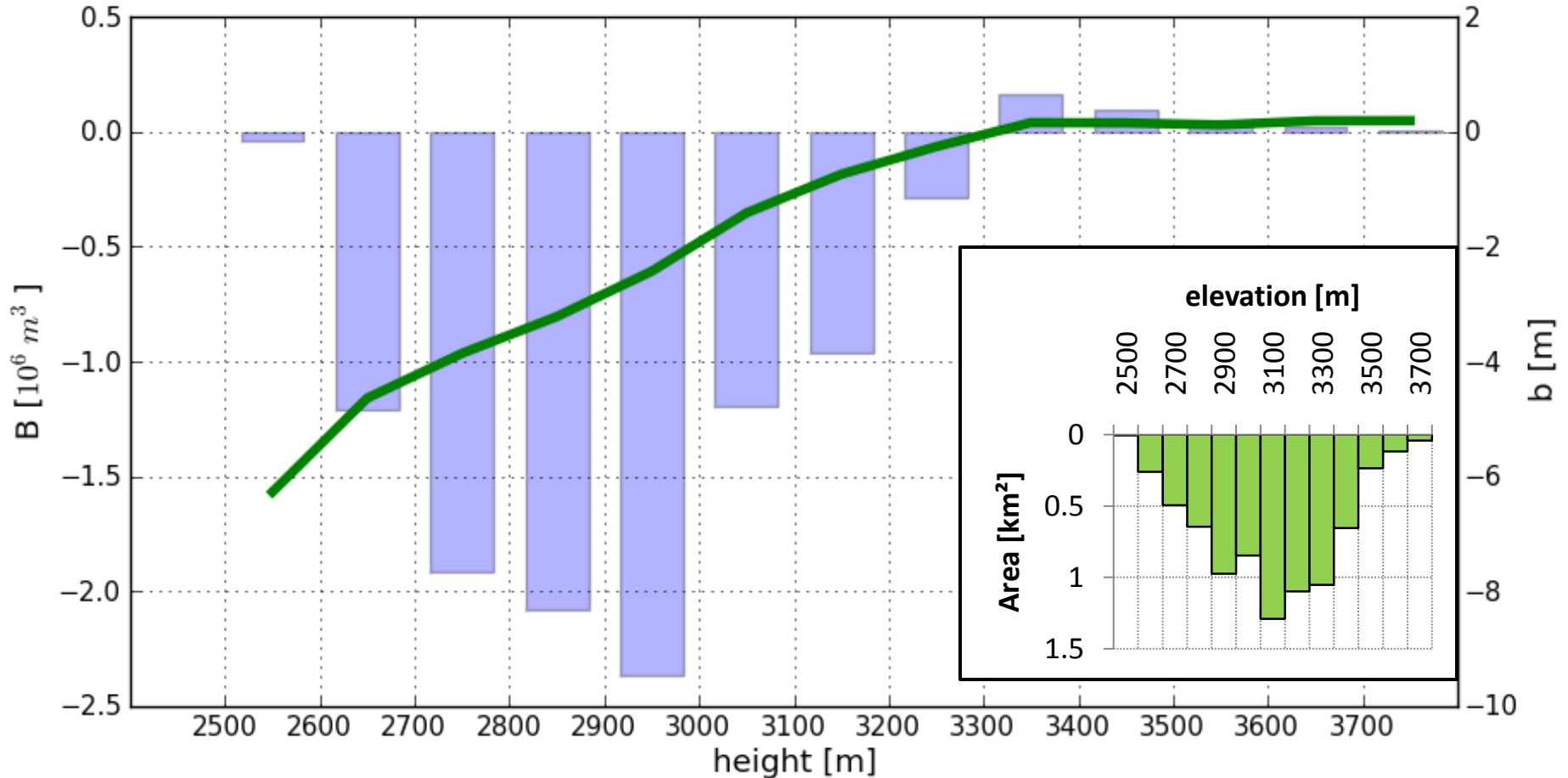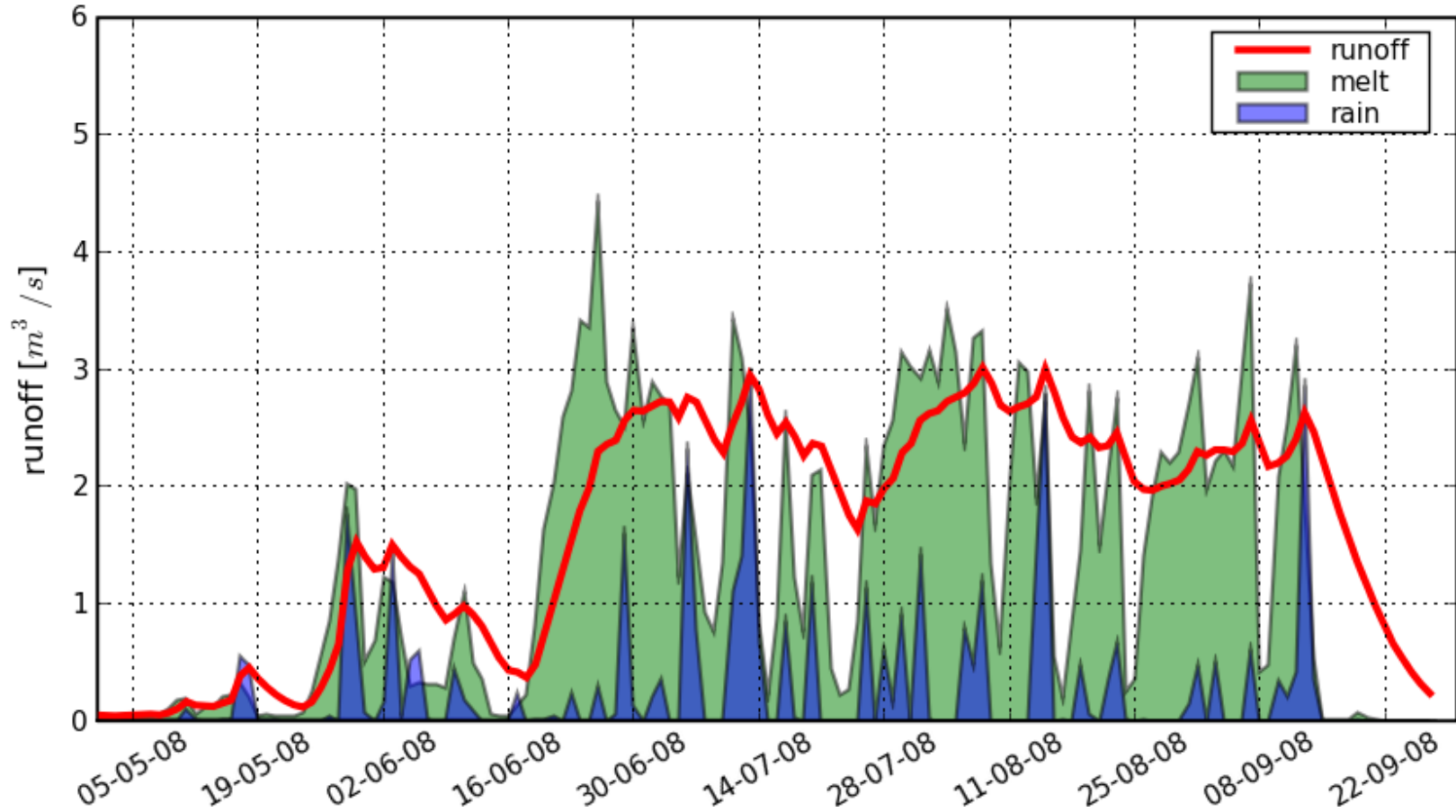

Total specific Mass Balance b_n = -1261 mm (modelled)
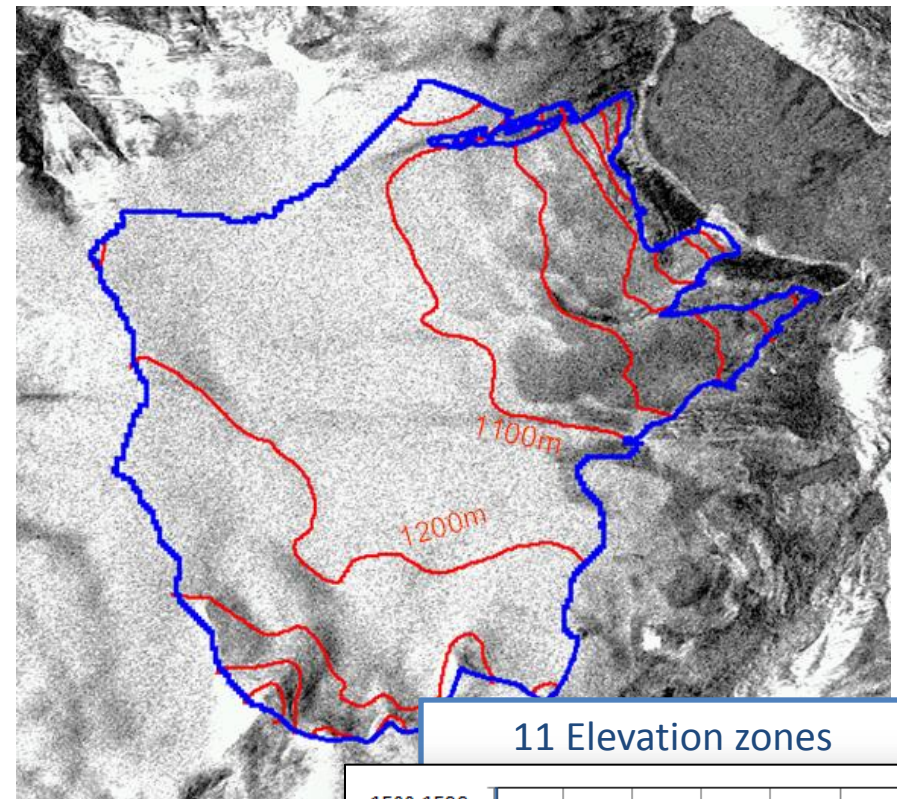
Computed Mass Balance - Gepatschferner

2007/2008

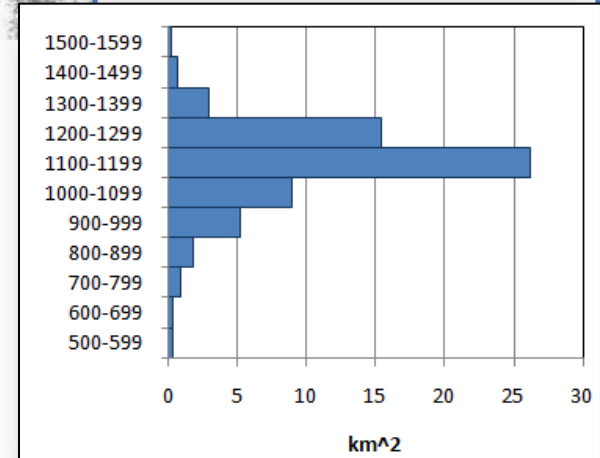Total specific Mass Balance b_n = -744 mm (modeled)

Calculations of Glacier Runoff Contributions

Hintereisferner 2007/2008

Model Application to Storglombreen Glacier, Norway

Bodo, 31 m

Glomfjord, 39 m

Storglombreen

1100m

1200m

11 Elevation zones

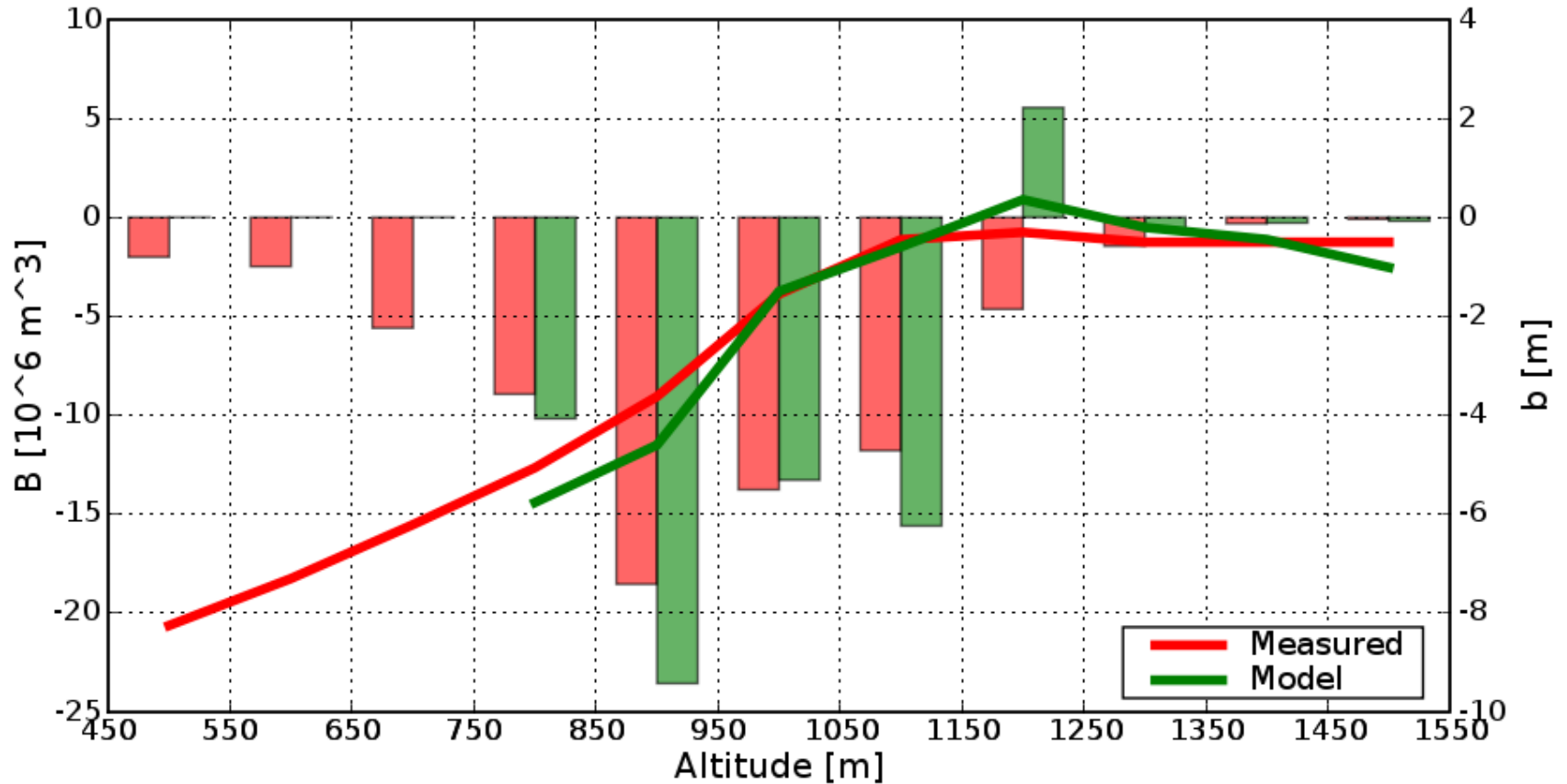| Elevation (m)	km^2
1500-1599	
1400-1499	
1300-1399	
1200-1299	
1100-1199	
1000-1099	
900-999	
800-899	
700-799	
600-699	
500-599	

May – Oct 2002: Time series of 22 snow/ice maps from optical and SAR satellite data
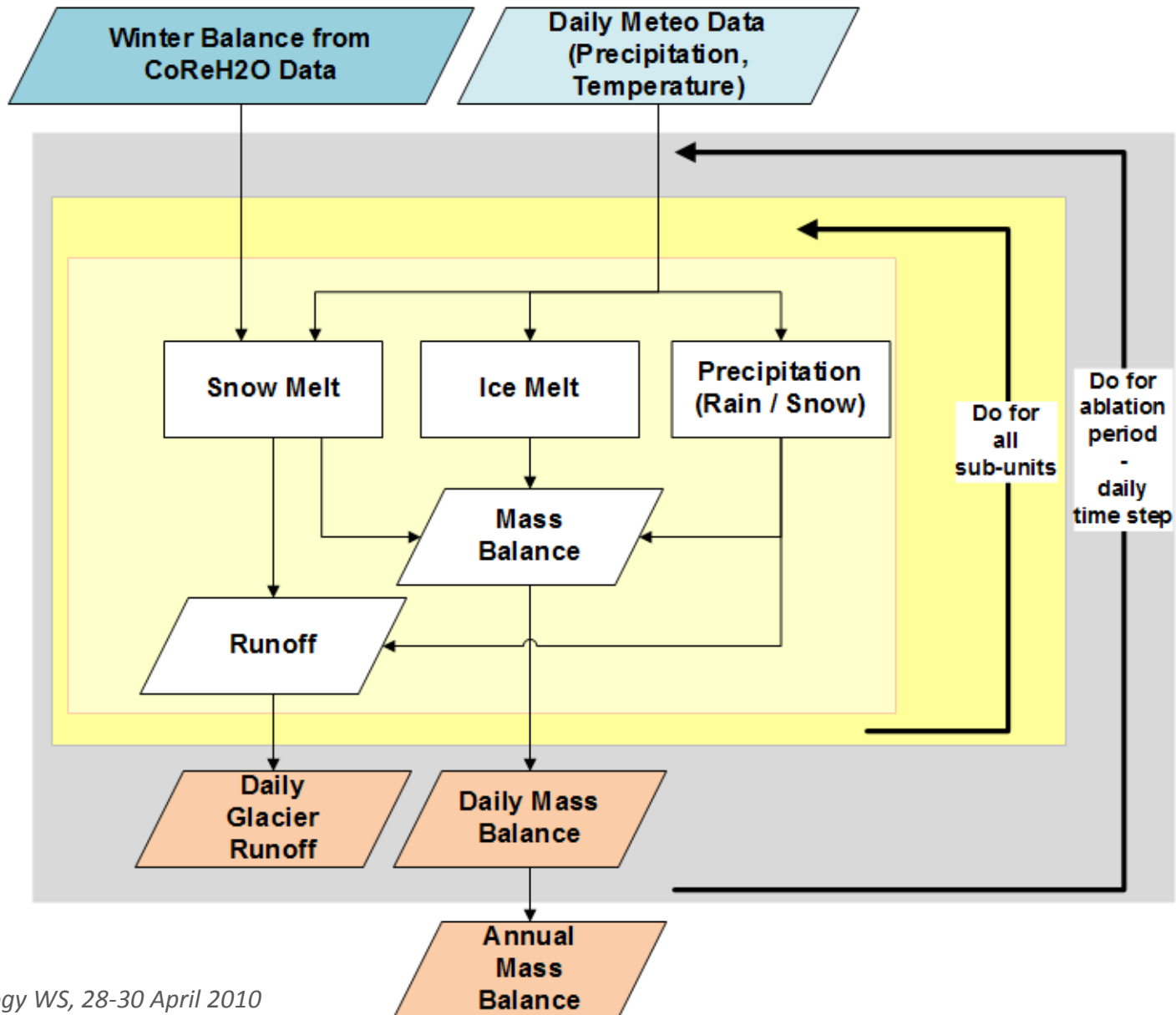
Computed Mass Balance Storglombreen 2002

measurements by M. Jackson, NVE

Estimation of winter snow accumulation by iterative matching of modelled and satellite–observed time evolution of snow/ice area extent

Use of CoReH2O retrieved Snow Accumulation

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- A semi-distributed model has been developed for computing glacier mass balance from meteorological data and time series of spatially detailed snow / ice maps derived from satellite data. The model was applied and validated for glaciers in the Alps and in Norway.

- The estimation of the winter snow accumulation was identified as the main uncertainty for computing annual mass balance.

- The accumulation estimate can be improved iteratively by using time series of snow/ice area extent from satellite data. Close time series of satellite images throughout the ablation period are needed.

- Spatially detailed data on snow accumulation would significantly improve glacier mass balance modelling in remote regions. Such measurements are addressed by CoReH20.