Snow hydrology in Slovakia

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(G. Babiaková, Z. Kostka, J. Parajka, M. Danko, P. Krajči)

Tále, 15 February 2016

Snow hydrology

- Snow has manifold effects on nature and human society
- Transporation, economical activities, ecobiological aspects, hazard (avalanches), arts, etc.
- Snow hydrology – role of snow cover in hydrological cycle - accumulation, melt, effects on runoff formation (minimum, maximum), operational hydrology

Geography Compass 5/4 (2011): 200–218, 10.1111/j.1749-8198.2011.00412.x

Snow Hydrology in Central Europe

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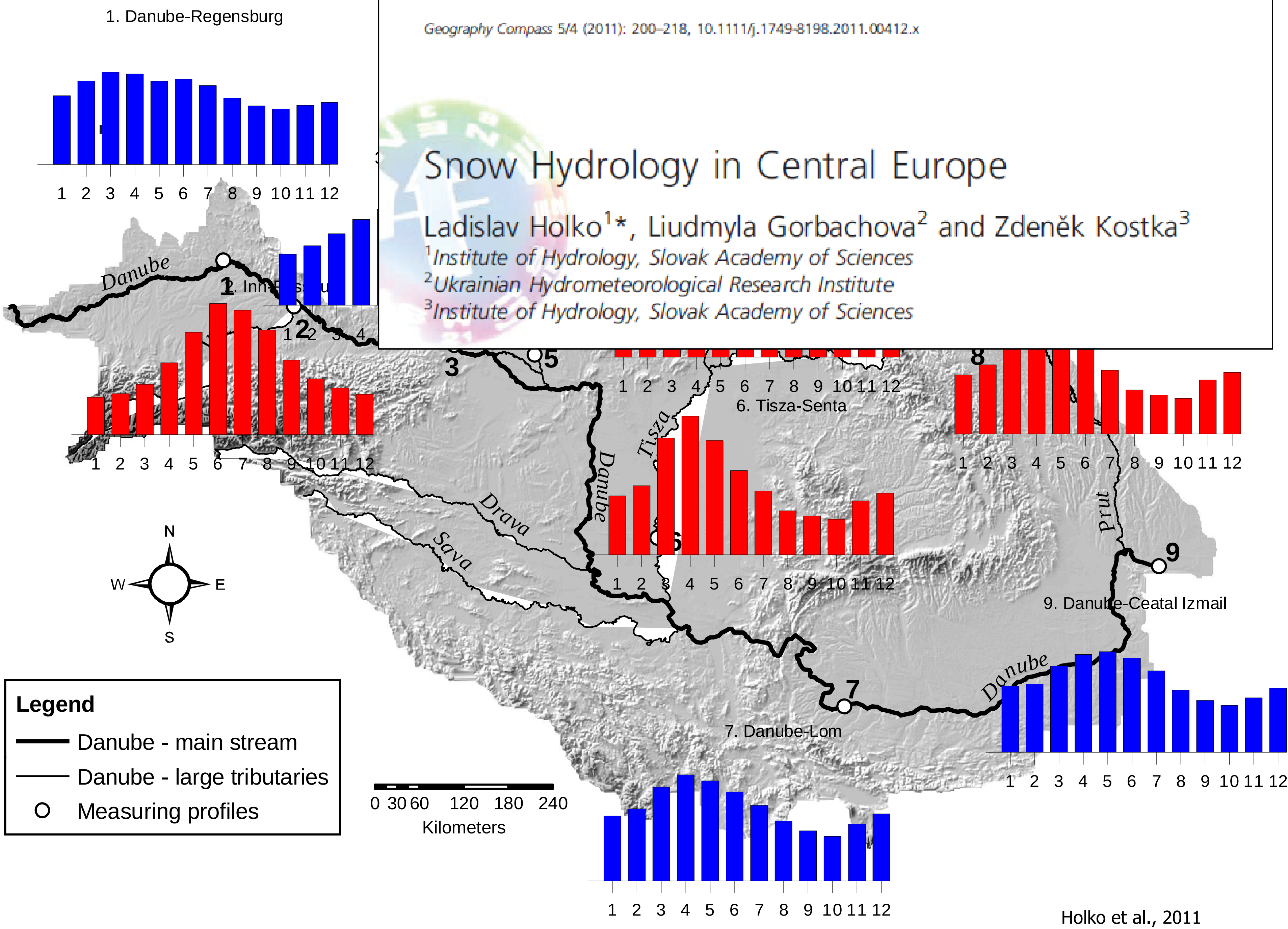
[3]Institute of Hydrology, Slovak Academy of Sciences



Holko et al., 2011

Presentation outline

- History of snow measurements in Slovakia
- Some measured data and equipment
- Role of snow in catchment hydrology (northern Slovakia)
- Snow accumulation and melt modelling

History of snow measurements

- First measurements related to snow are known since the end of the 18th or beginning of the 19th centuries
- regular measurement of snow characteristics started with the establishment of national hydrometeorological services in the 19th century

History of snow measurements

- Kotlyakov - Russia became the motherland of the snow cover studies founded by the geographer and meteorologist A. Voyeikov in the 1880’ who was the first who quantified the impact of snow cover on climate by comparing the data from snow covered and snowless stations.

History of snow measurements

- Kuusisto - the role of snowmelt as a contributor to spring floods was discussed in studies carried out at the Academy of Turku in the 18th century.

History of snow measurements in Slovakia

- In Slovakia (Austro-Hungarian monarchy) the days with snow and the depth of the new snow were recorded in the 1850′ and 1870;, respectively
- regular measurement of total snow depth started in 1921 (Czechoslovak hydro-meteorological service)

Not yet snow hydrology

Snow hydrology research in Slovakia

- Snow hydrology started in the 1960′ by research conduced at IH SAS
- Later, SHMI started to organize snow course measurements in several mountain catchment to know the volume of water stored in the snow before the snowmelt for forecasting purposes
- Snow course measurements by the foresters (university research) started in the last decade

SUMMARY REPORT
OF THE
SNOW INVESTIGATIONS

SNOW HYDROLOGY

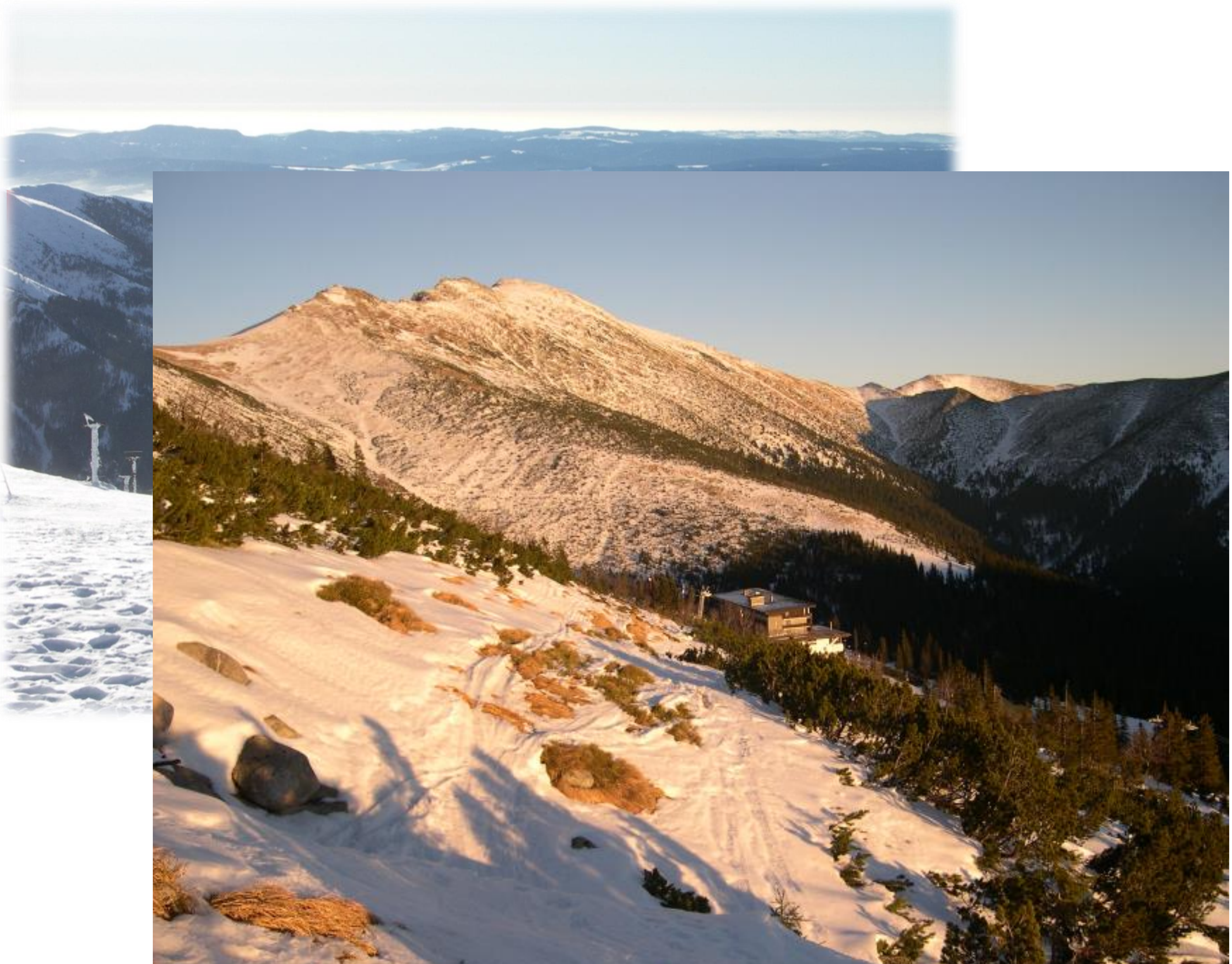
NORTH PACIFIC DIVISION
CORPS OF ENGINEERS, U.S. ARMY
PORTLAND, OREGON
30 JUNE 1956

П П Кузьмин

ПРОЦЕСС ТАЯНИЯ СНЕЖНОГО ПОКРОВА

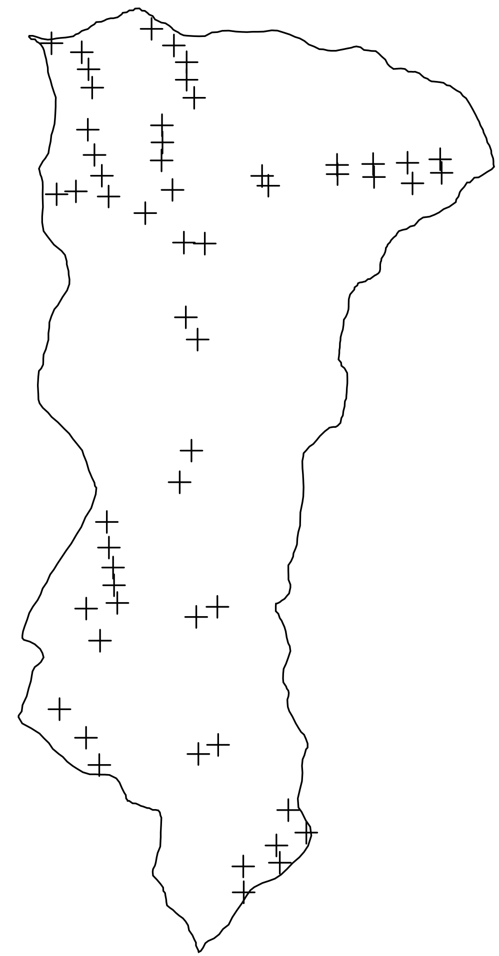
Гидрометеоиздат
1961

Martinec, J. (1960). The degree-day factor for snowmelt-runoff forecasting. In *Proceedings General Assembly of Helsinki*, Commission on Surface Waters, IASH Publ. 51, pp. 468–77.

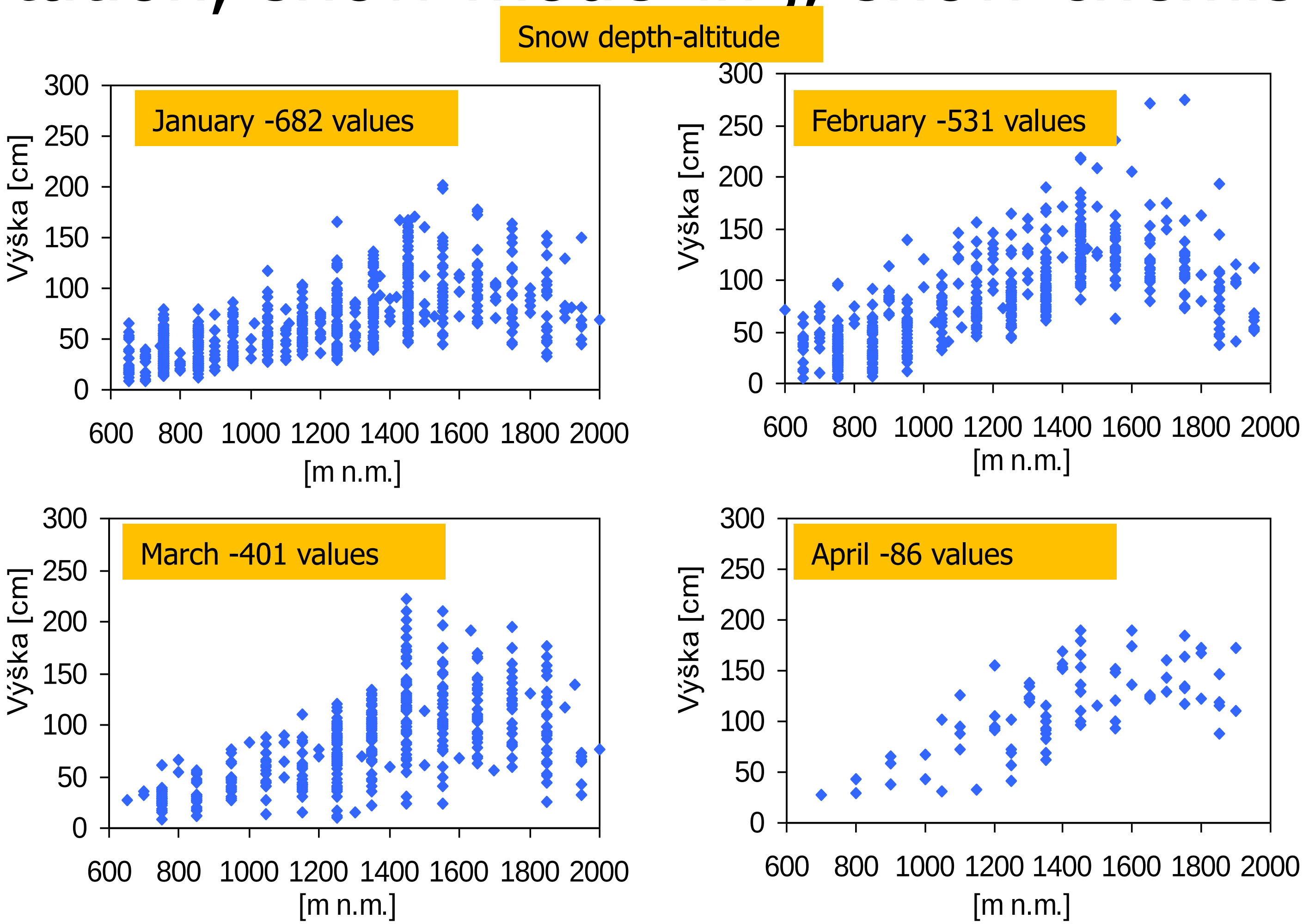


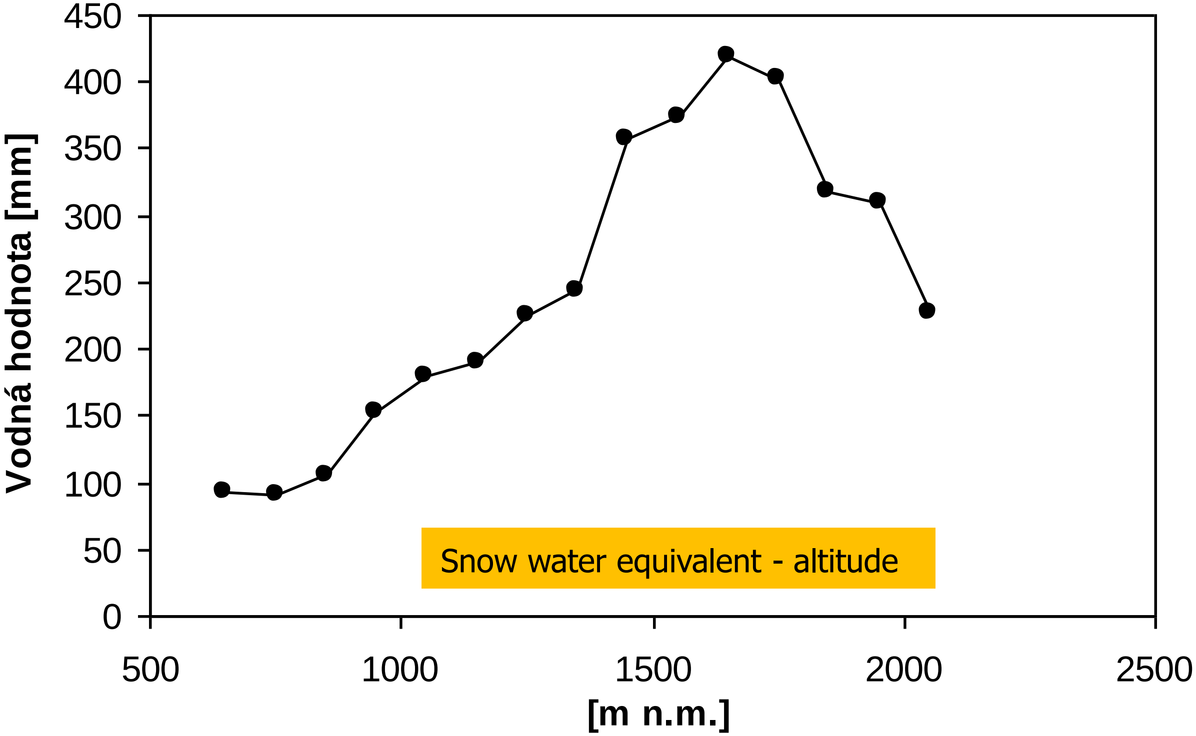
Bystrianka catchment

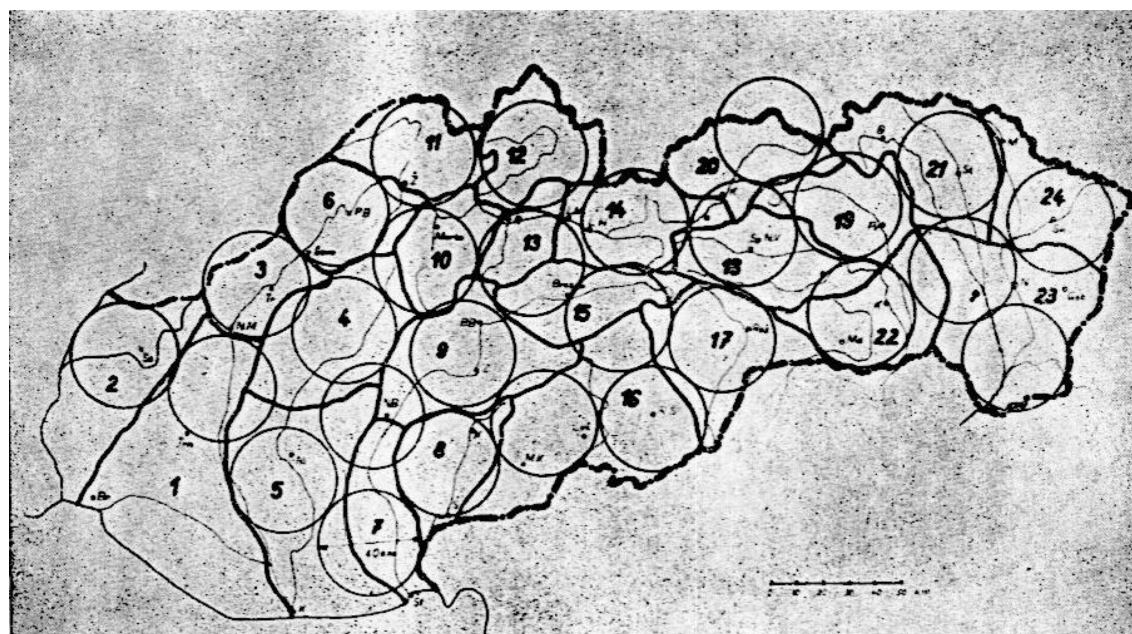
- 23 km^2, 700-2043 m a.s.l.
- March 1963 – January 1992
- 21-38 snow courses



- methodology of measurements, errors of equipment, remote sensing, variability of snow characteristics, relationship with vegetation, snow modelling, snow chemistry




Vodná hodnota [mm]
450
400
350
300
250
200
150
100
50
0
500
1000
1500
2000
2500
[m n.m.]
Snow water equivalent - altitude


1
2
3
4
5
6
7
8
9
10
11
12
13
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16
17
18
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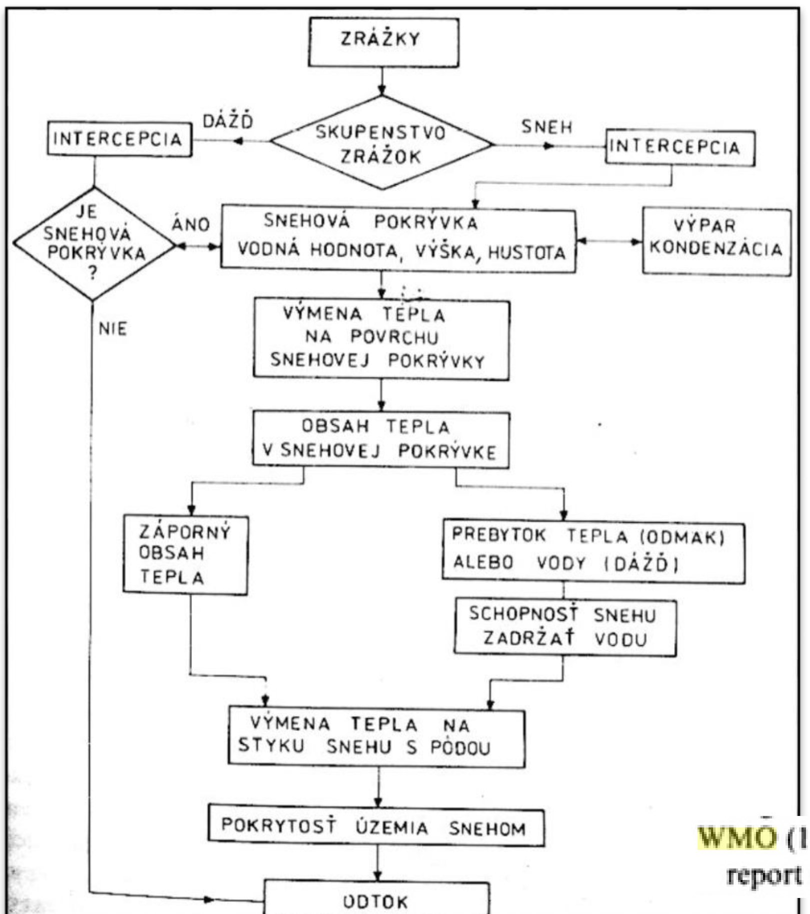
21
22
23
24

- methodology of measurements, remote sensing, variability of snow characteristics, relationship with vegetation, snow modeling, snow chemistry



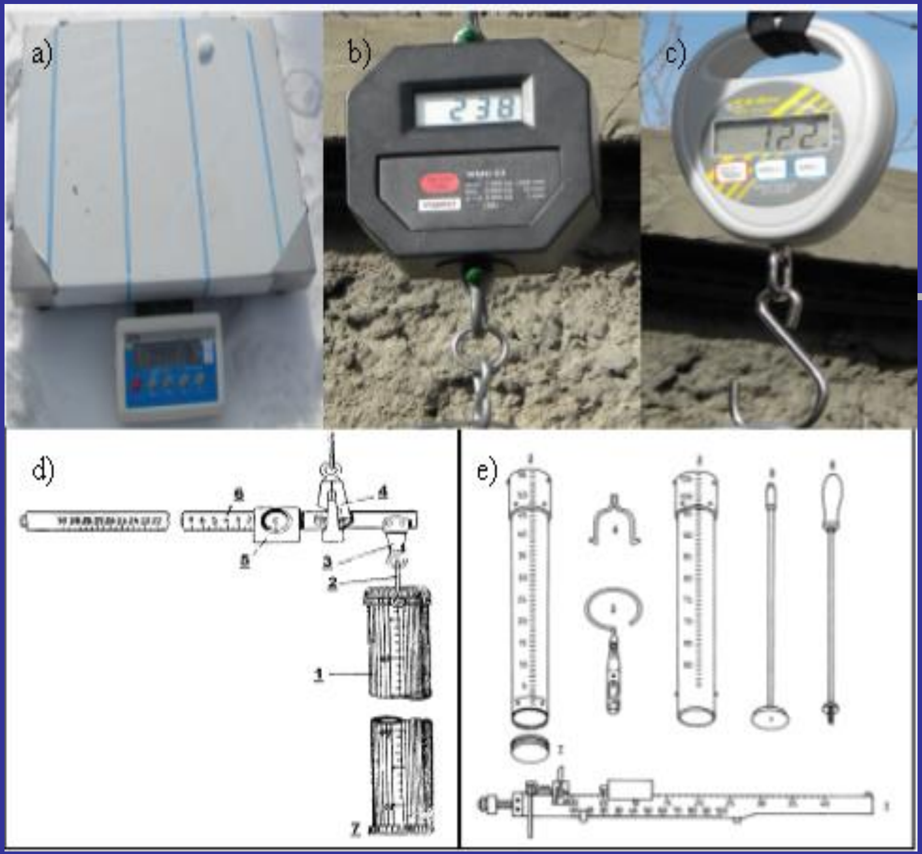
WMO (19
report r

Credit G. Babiakova

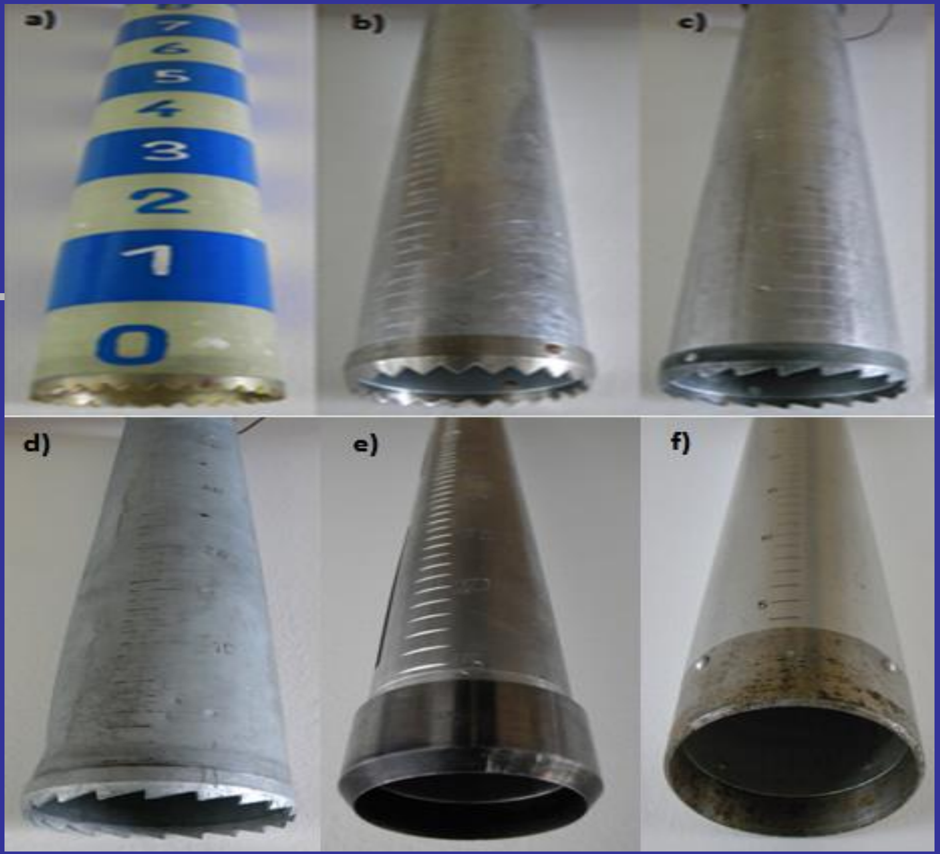
WMO operational hydrology
ation, Geneva.







Snow scales – varying construction and accuracy

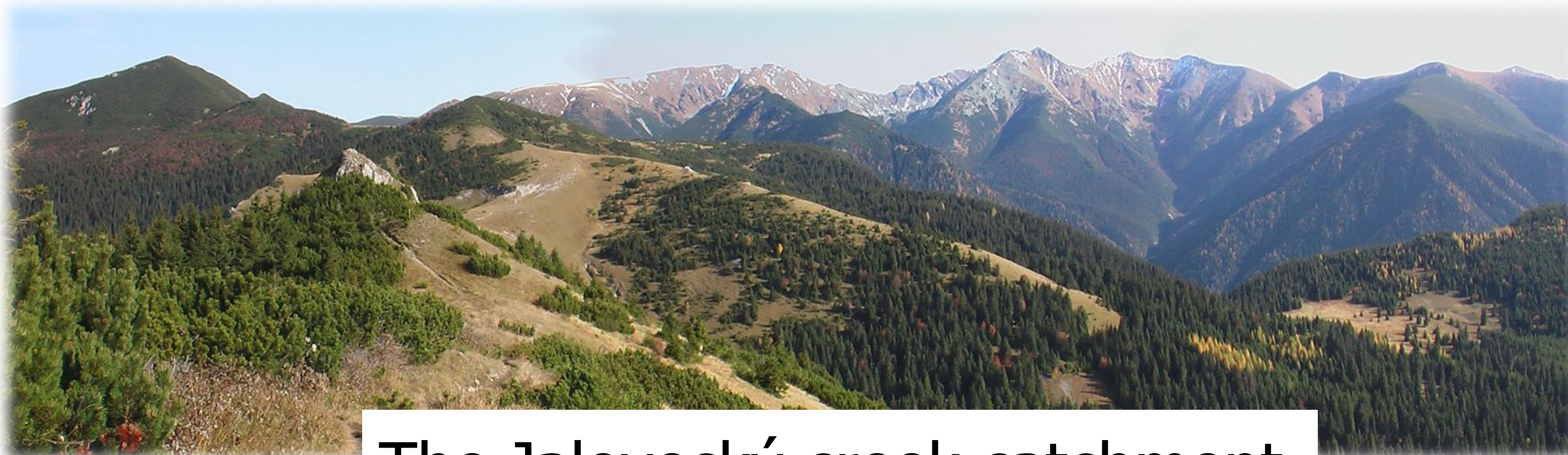


Snow tubes – different material and end

Credit M. Hribik


9
8
7
6
5
4
3
2

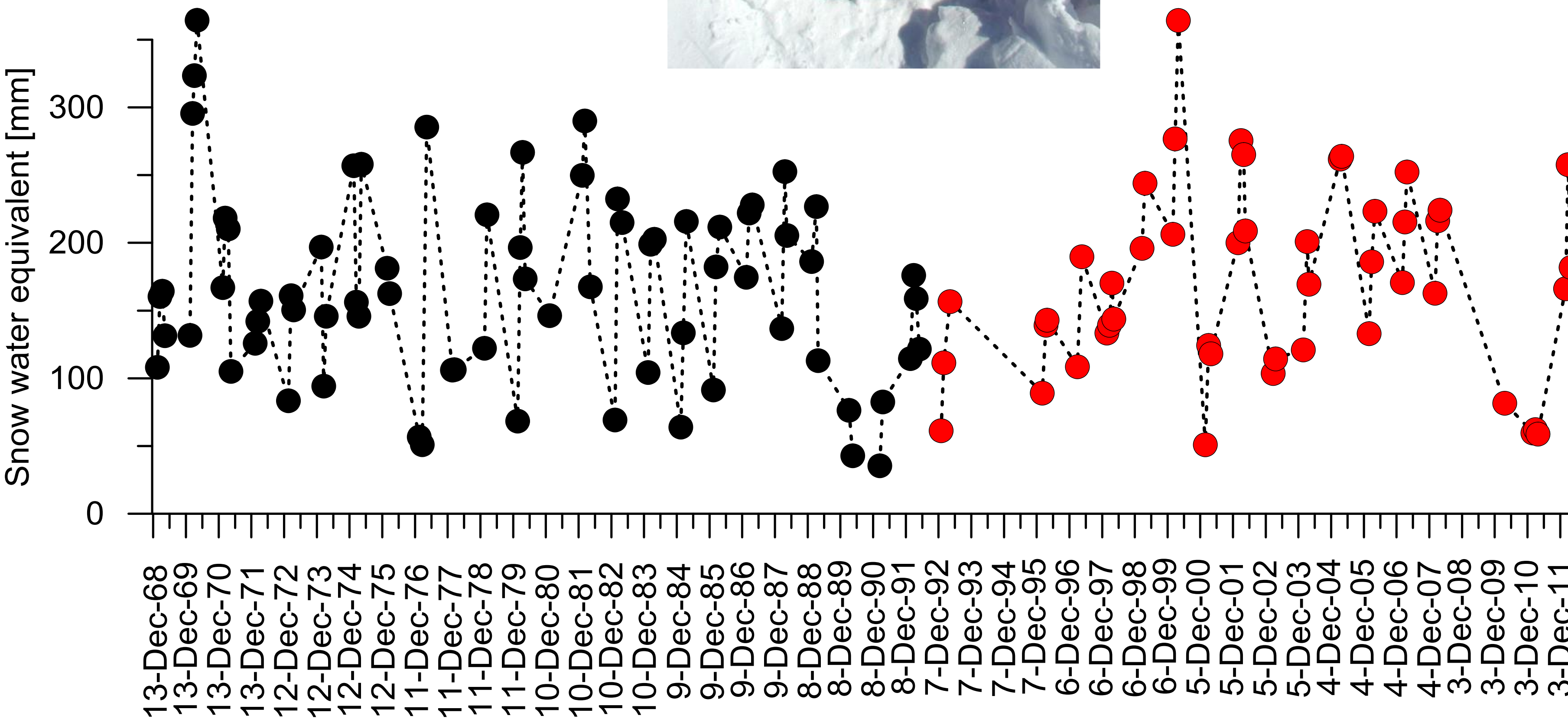

ELAN
ATOMIC



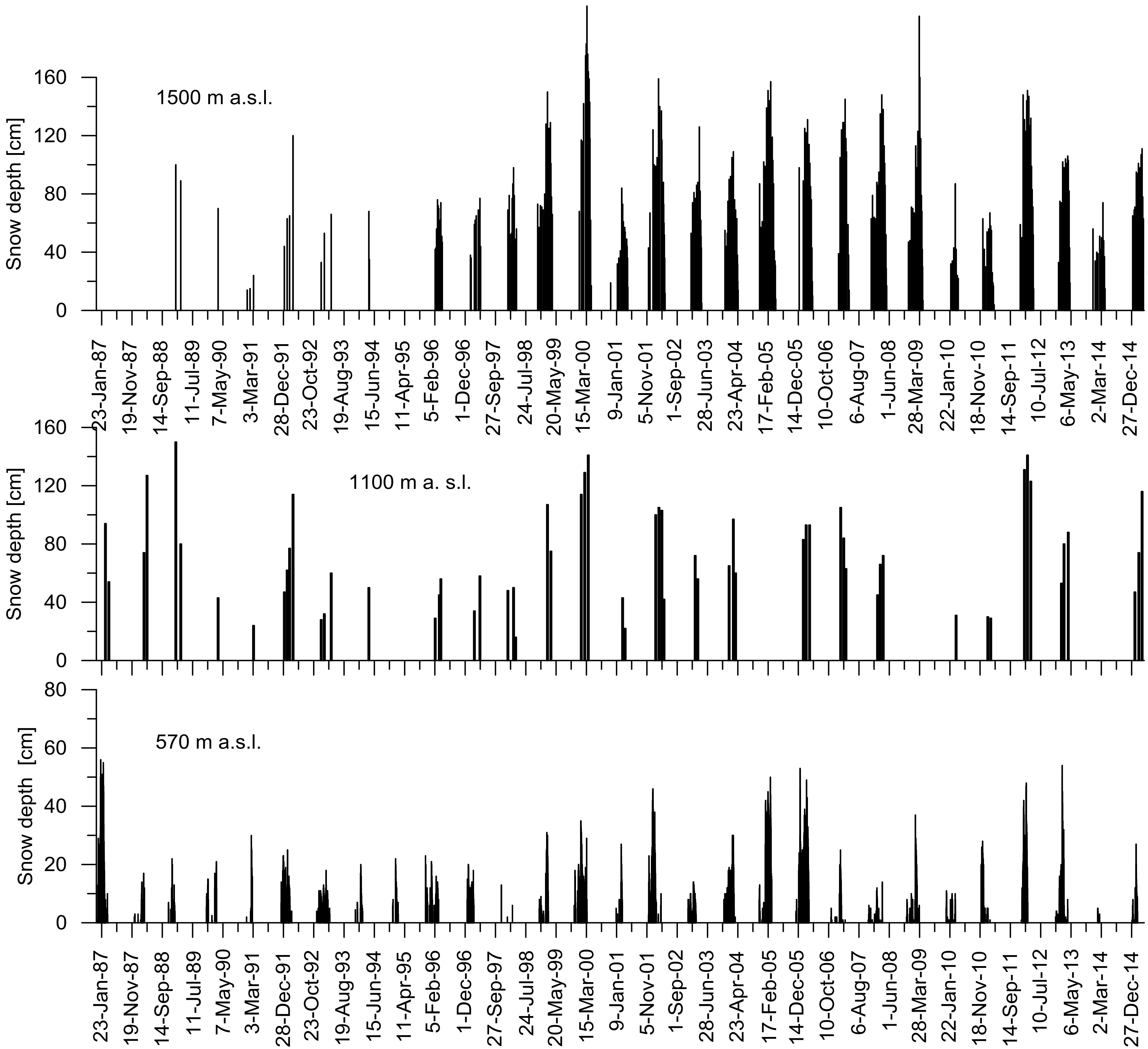
The Jalovecký creek catchment

Area 22 km^2, 820-2178 m a.s.l., since 1986
hydrological cycle in mountains

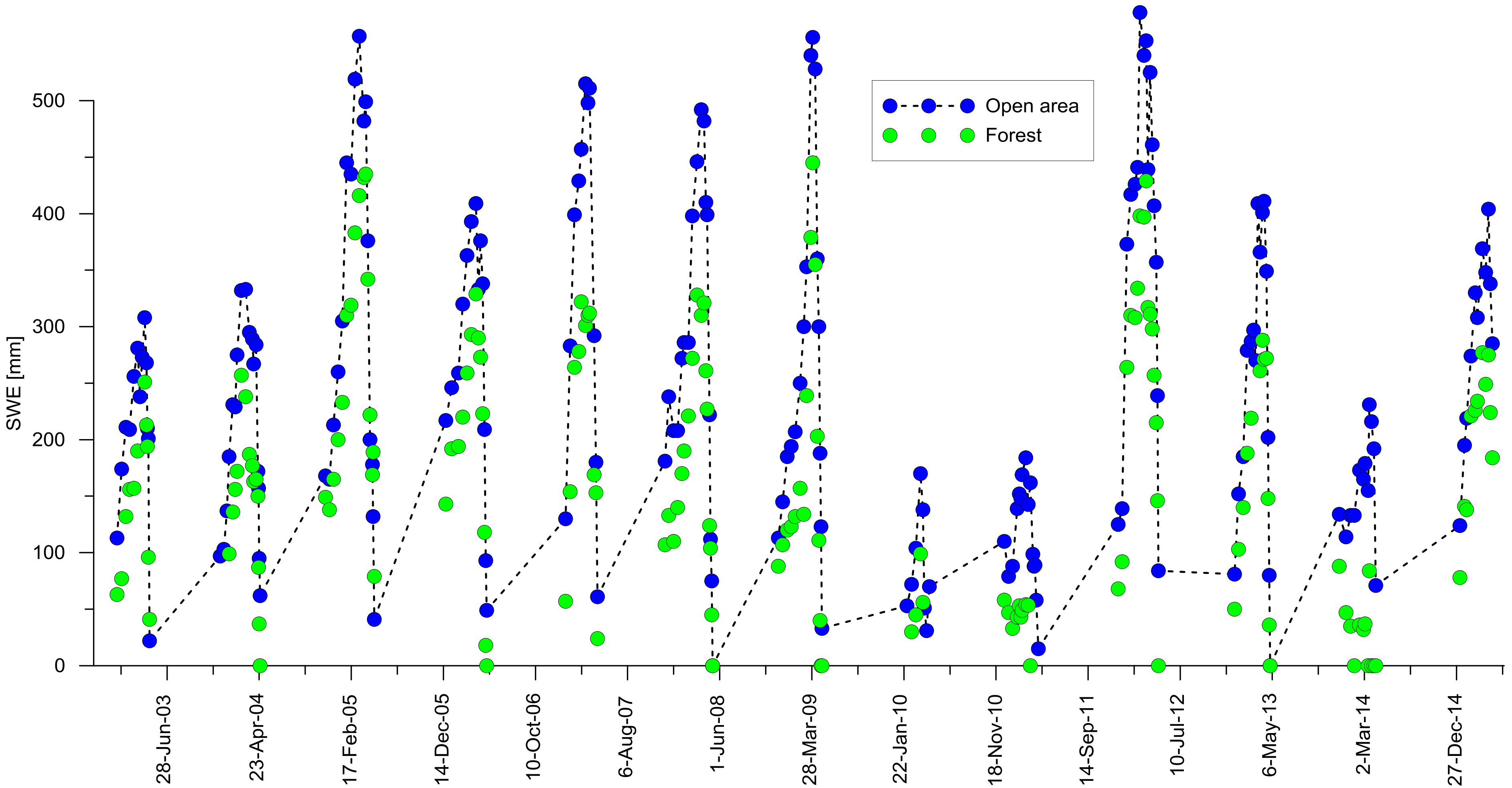
Extrapolation of SWE for Bystrianka



Mountain and foothill parts


1500 m a.s.l.
1100 m a. s.l.
570 m a.s.l.
Snow depth [cm]
Snow depth [cm]
Snow depth [cm]
0
40
80
120
160
20
60
23-Jan-87
19-Nov-87
14-Sep-88
11-Jul-89
7-May-90
3-Mar-91
28-Dec-91
23-Oct-92
19-Aug-93
15-Jun-94
11-Apr-95
5-Feb-96
1-Dec-96
27-Sep-97
24-Jul-98
20-May-99
15-Mar-00
9-Jan-01
5-Nov-01
1-Sep-02
28-Jun-03
23-Apr-04
17-Feb-05
14-Dec-05
10-Oct-06
6-Aug-07
1-Jun-08
28-Mar-09
22-Jan-10
18-Nov-10
14-Sep-11
10-Jul-12
6-May-13
2-Mar-14
27-Dec-14

The most detailed
measurements
are conducted
at 1500 m a.s.l.

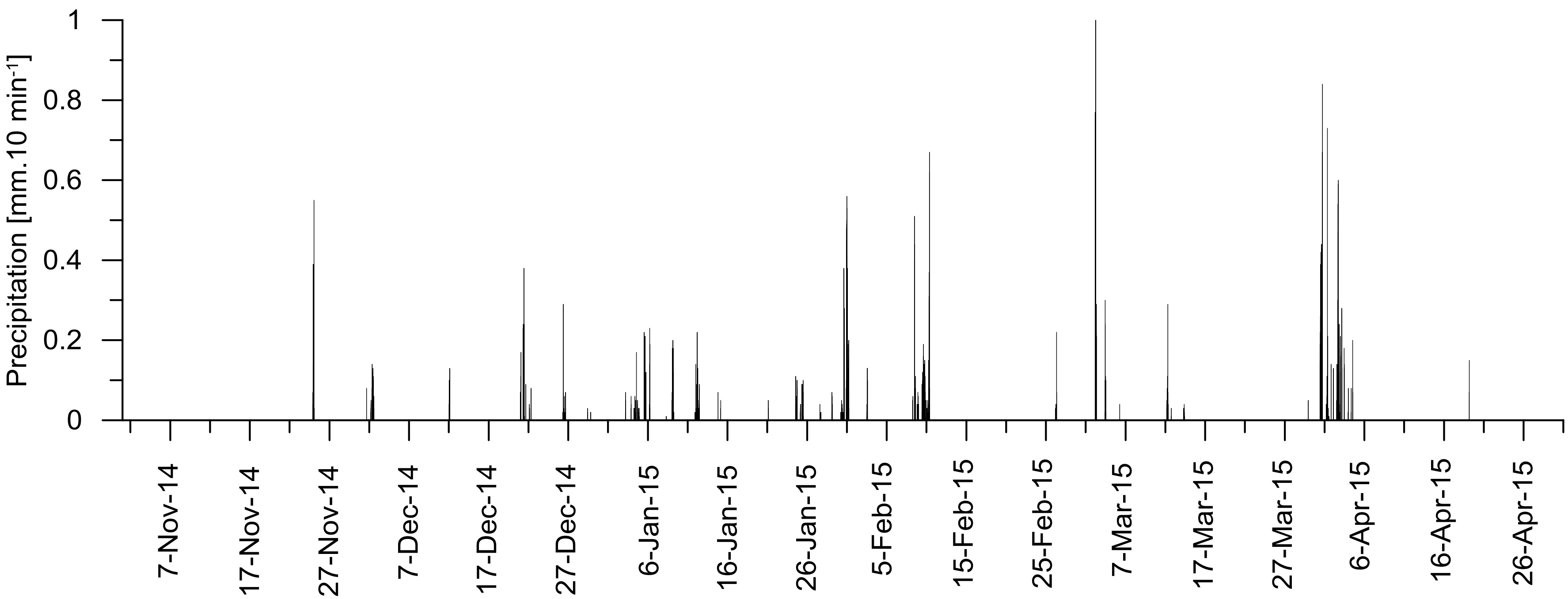


Snow water equivalent in open area and forest

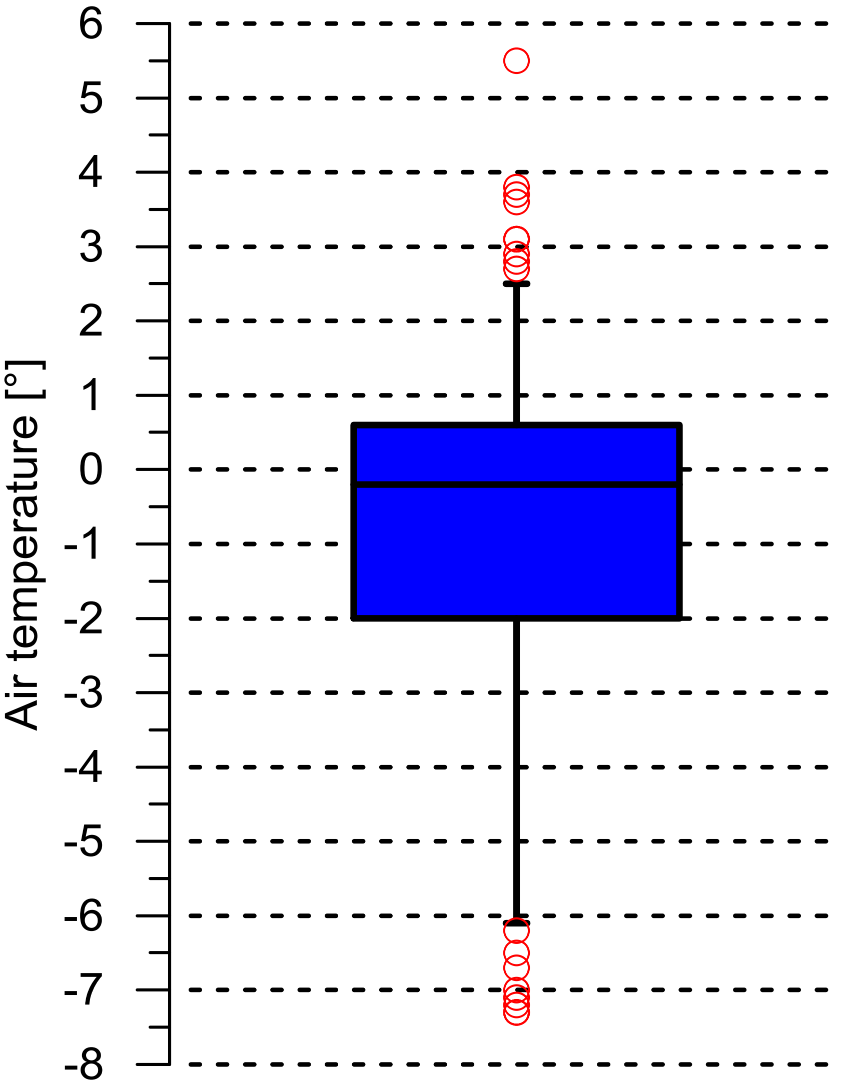
Disdrometer (Ott Parsivel)

needs 220 V

Occurrence of snowfall



Disdrometer (Ott Parsivel)

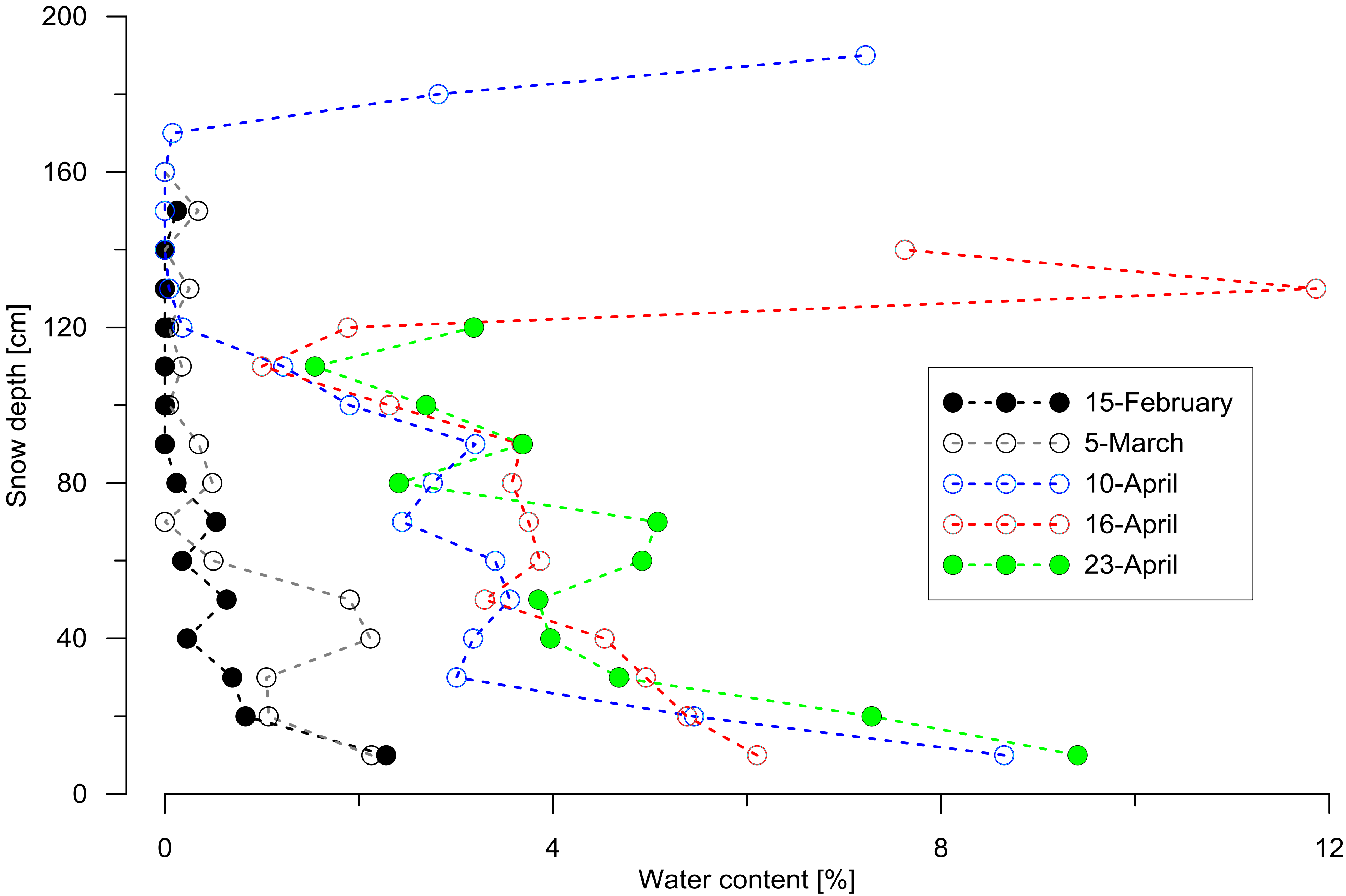


Air temperature during snowfall

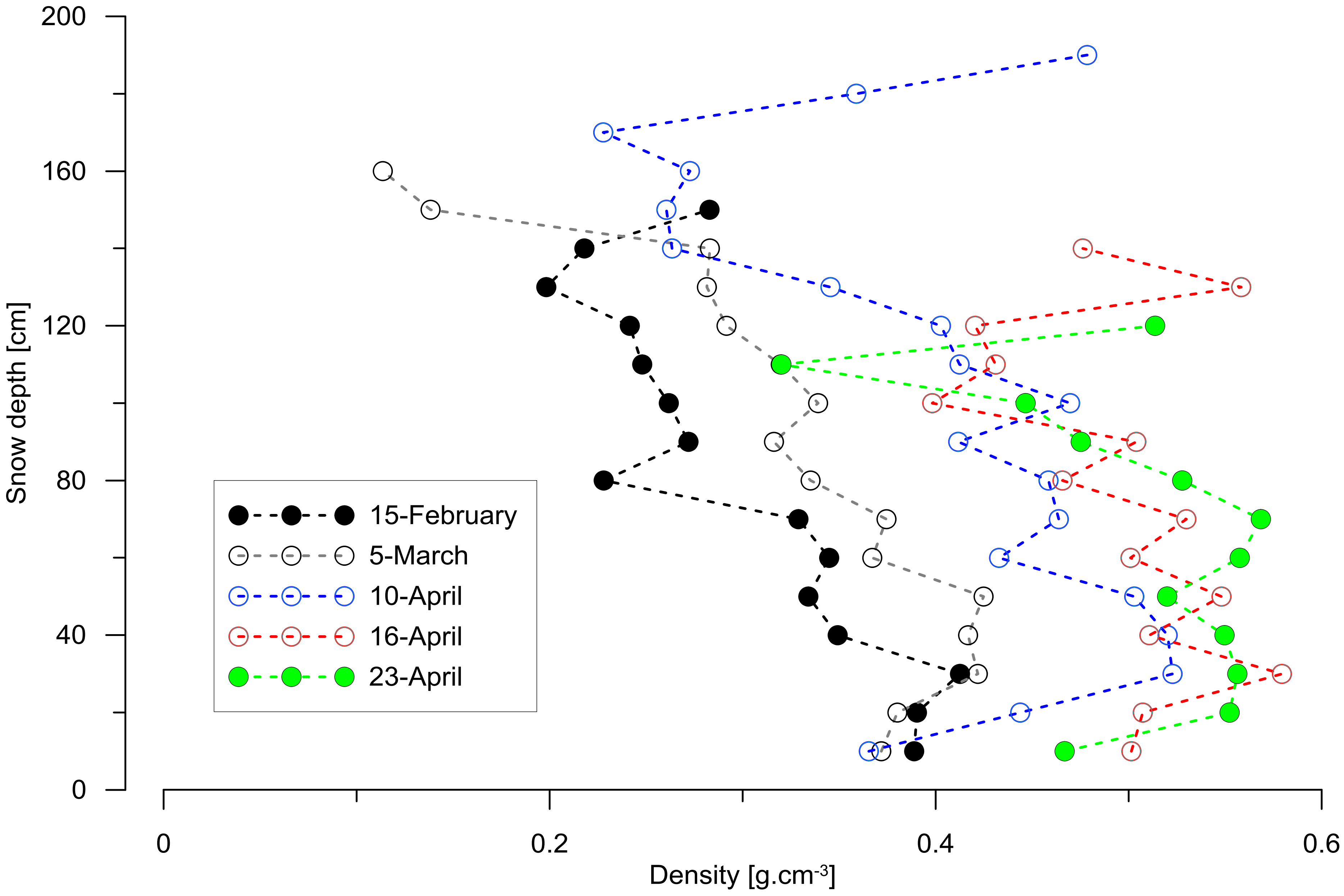
An important threshold parameter in snow accumulation modelling

Analogically, the air temperature during rainfall may be analysed

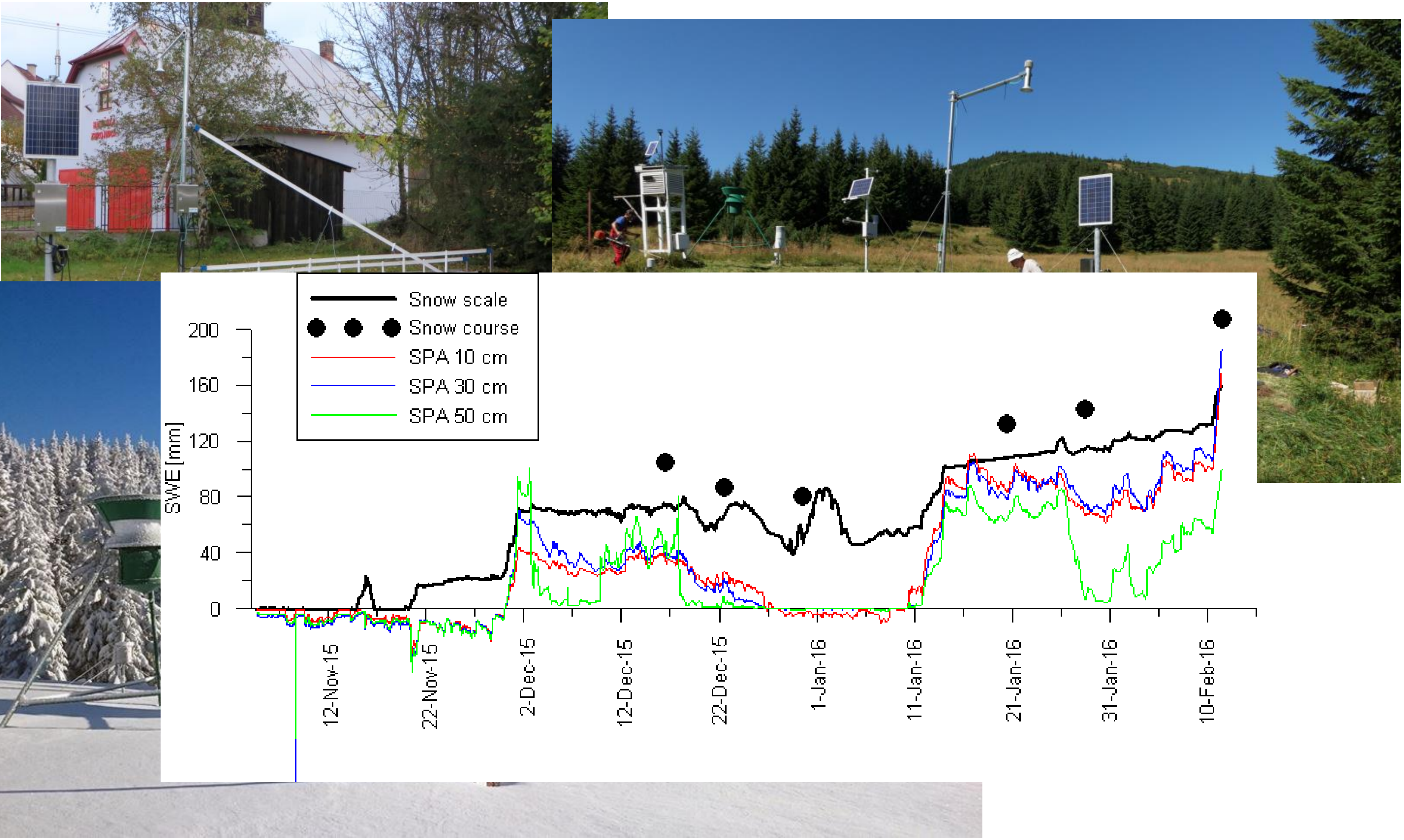
Snow water content and density (Toikka Snow Fork)
2015



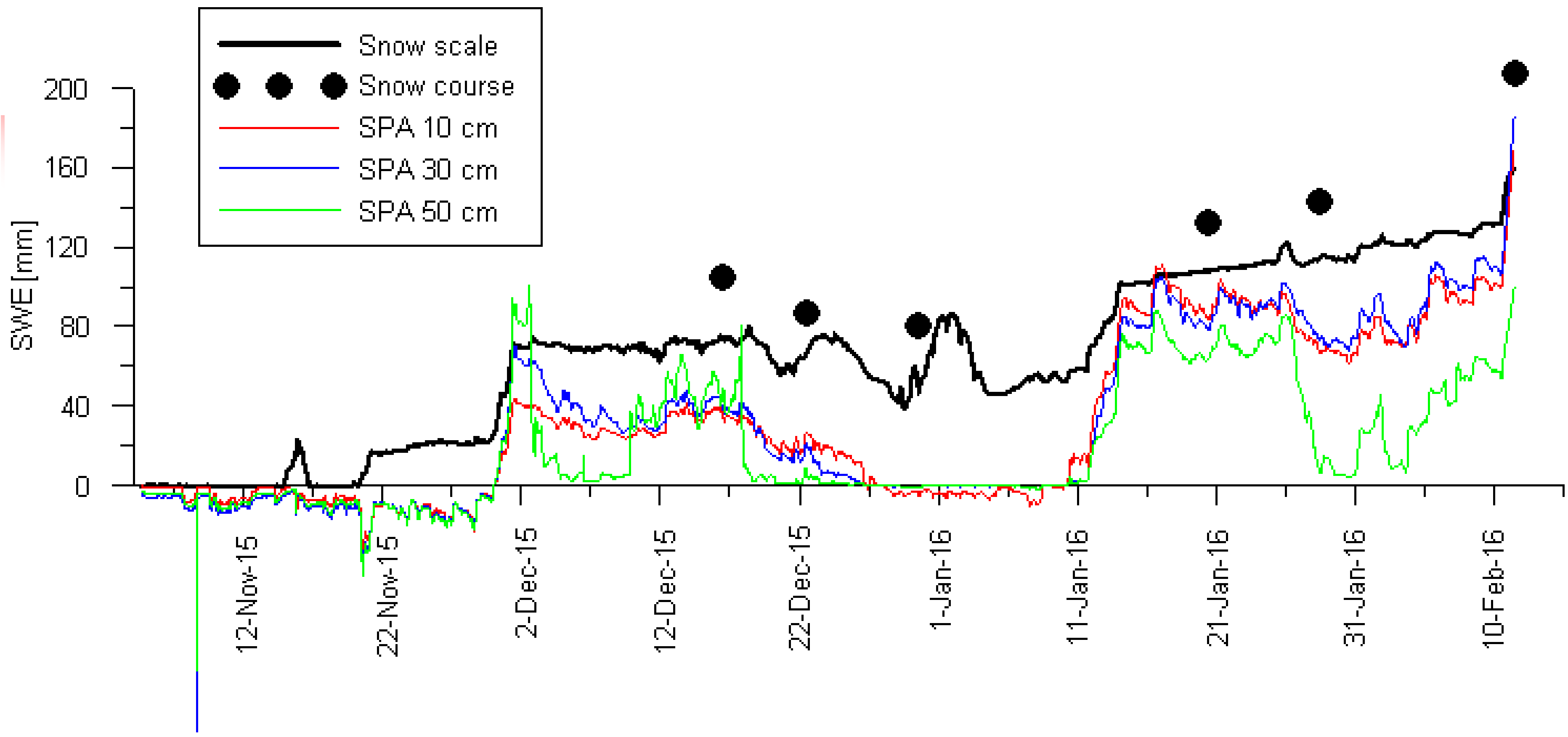
200
160
120
80
40
0
Snow depth [cm]
0
4
8
12
Water content [%]
15-February
5-March
10-April
16-April
23-April



200
160
120
80
40
0
Snow depth [cm]
0
0.2
0.4
0.6
Density [g.cm-3]
15-February
5-March
10-April
16-April
23-April

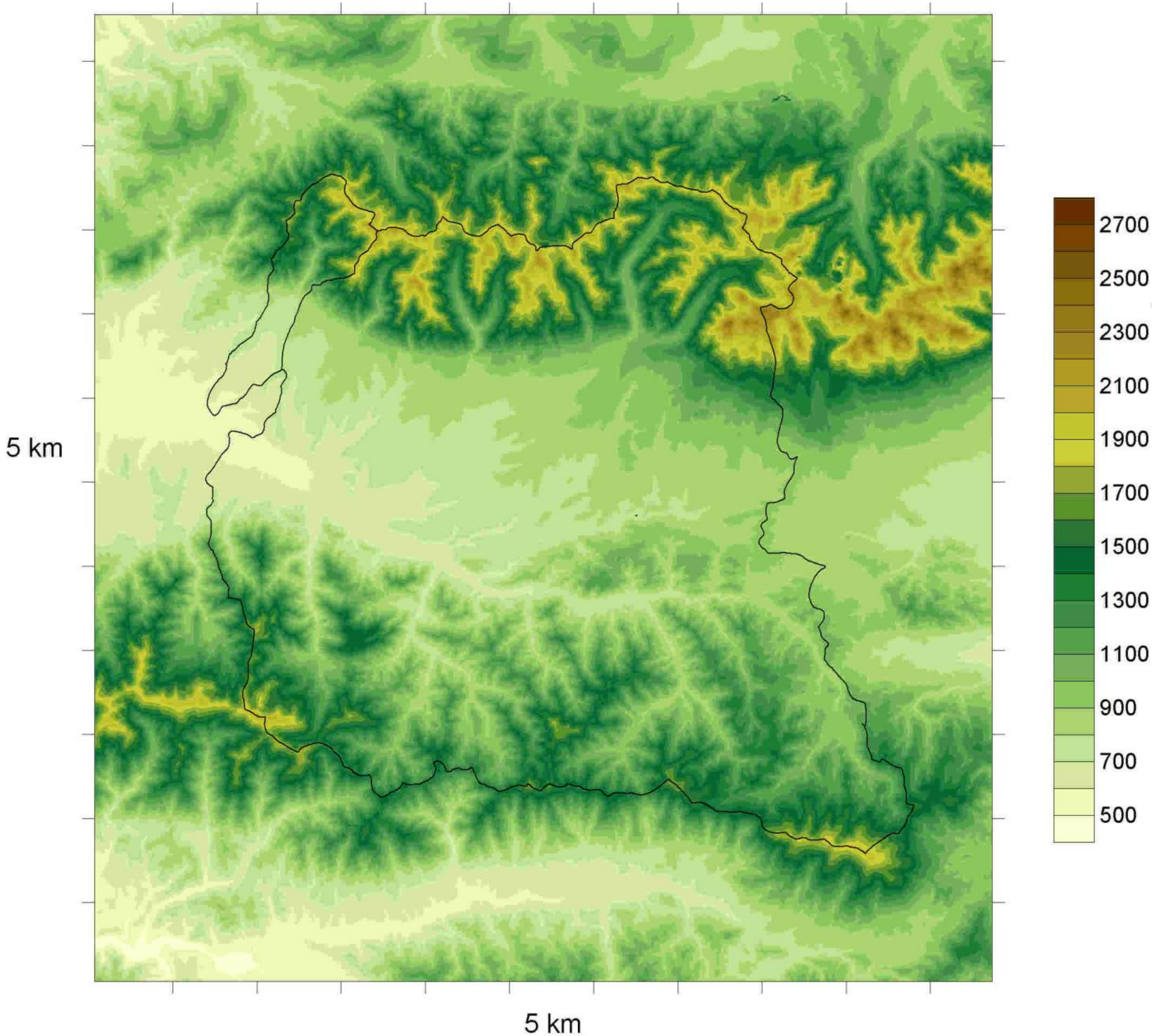


Snow scale and SPA sensors – Sommer; snow depth, water equivalent, density, ice and water contents in layers



Comparison of manual and automatic measurements

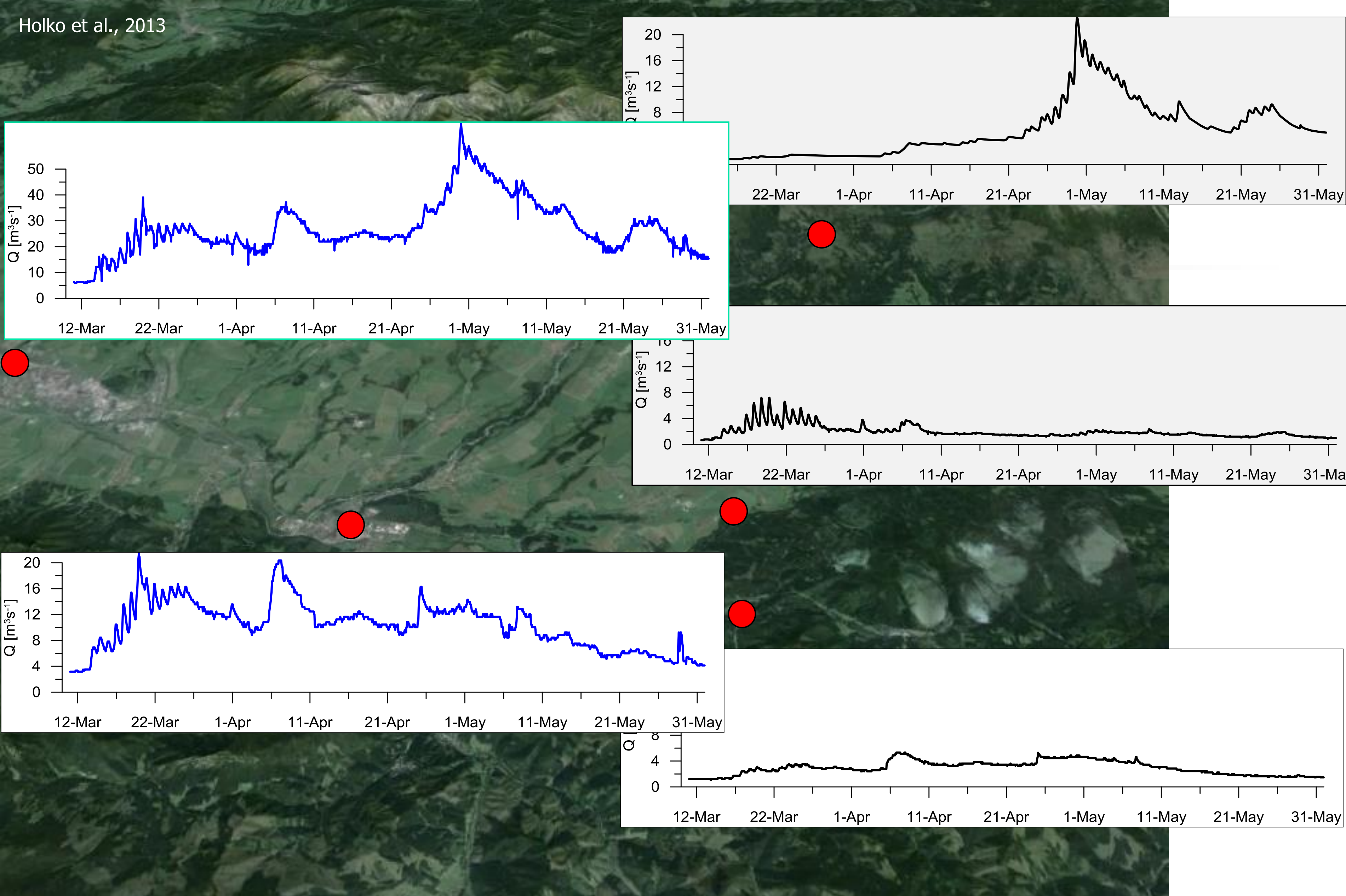
The role of snow in hydrology of the highest part of the Carpathians



Váh river

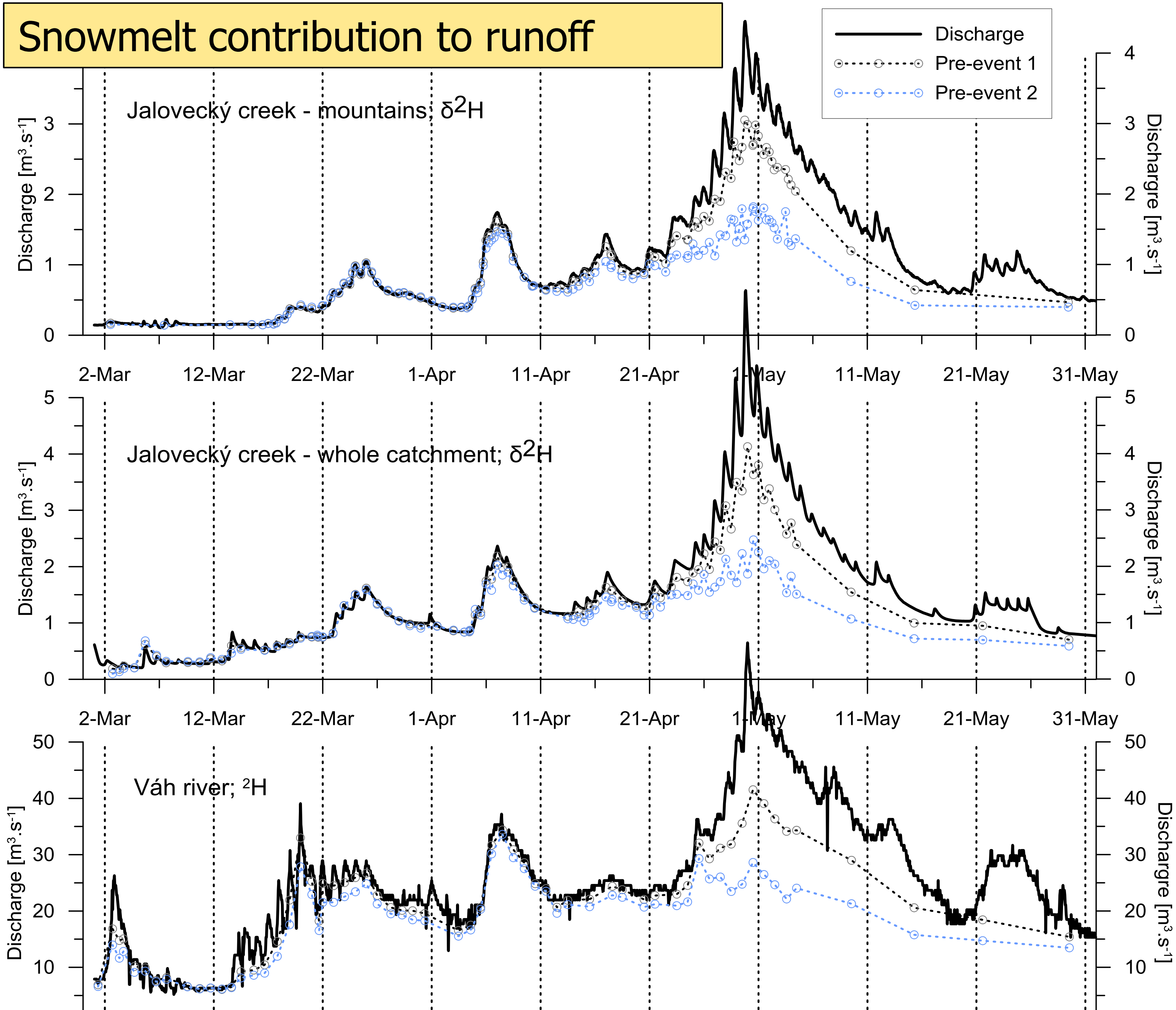
Area 1100 km2
560-2494 m a.sl.
Mountain ranges in the north and ion the south

Spring discharge timing in a river basin



Different runoff variability in subcatchments

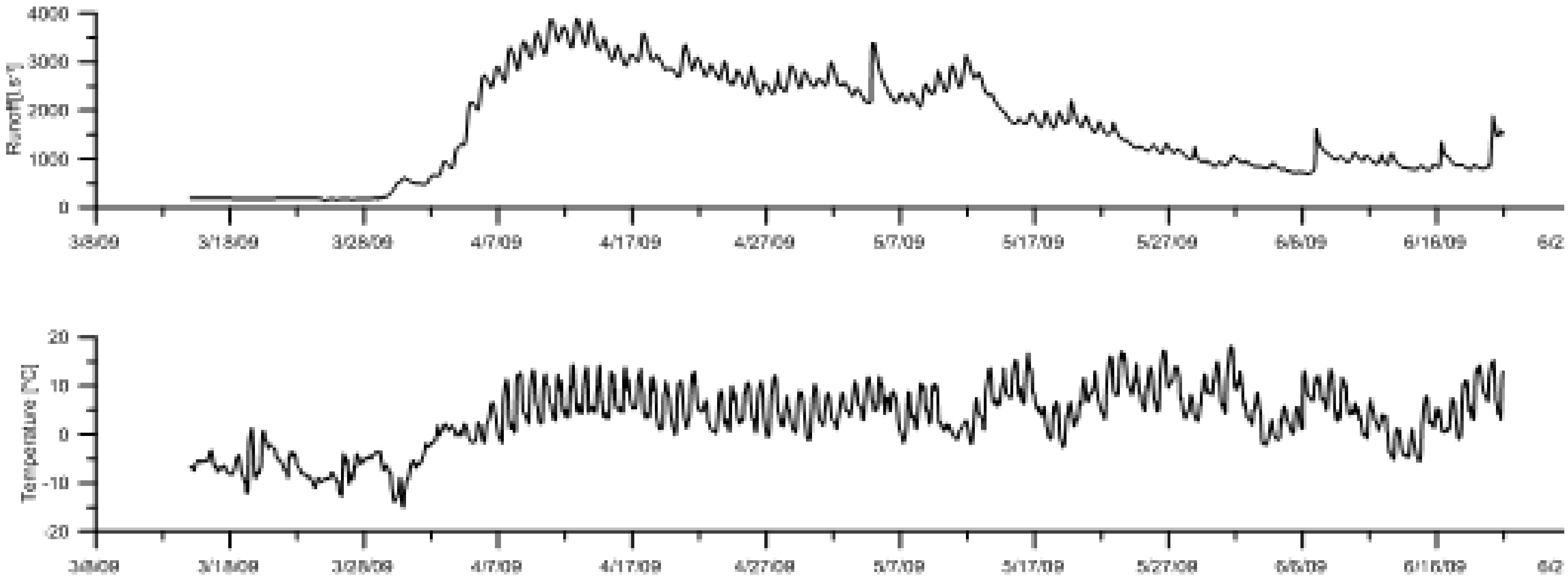
Snowmelt contribution to runoff



Holko et al., 2013

Runoff during the first snowmelt events contains very little snowmelt water

How long is snowmelt water ”visible” in the catchment?

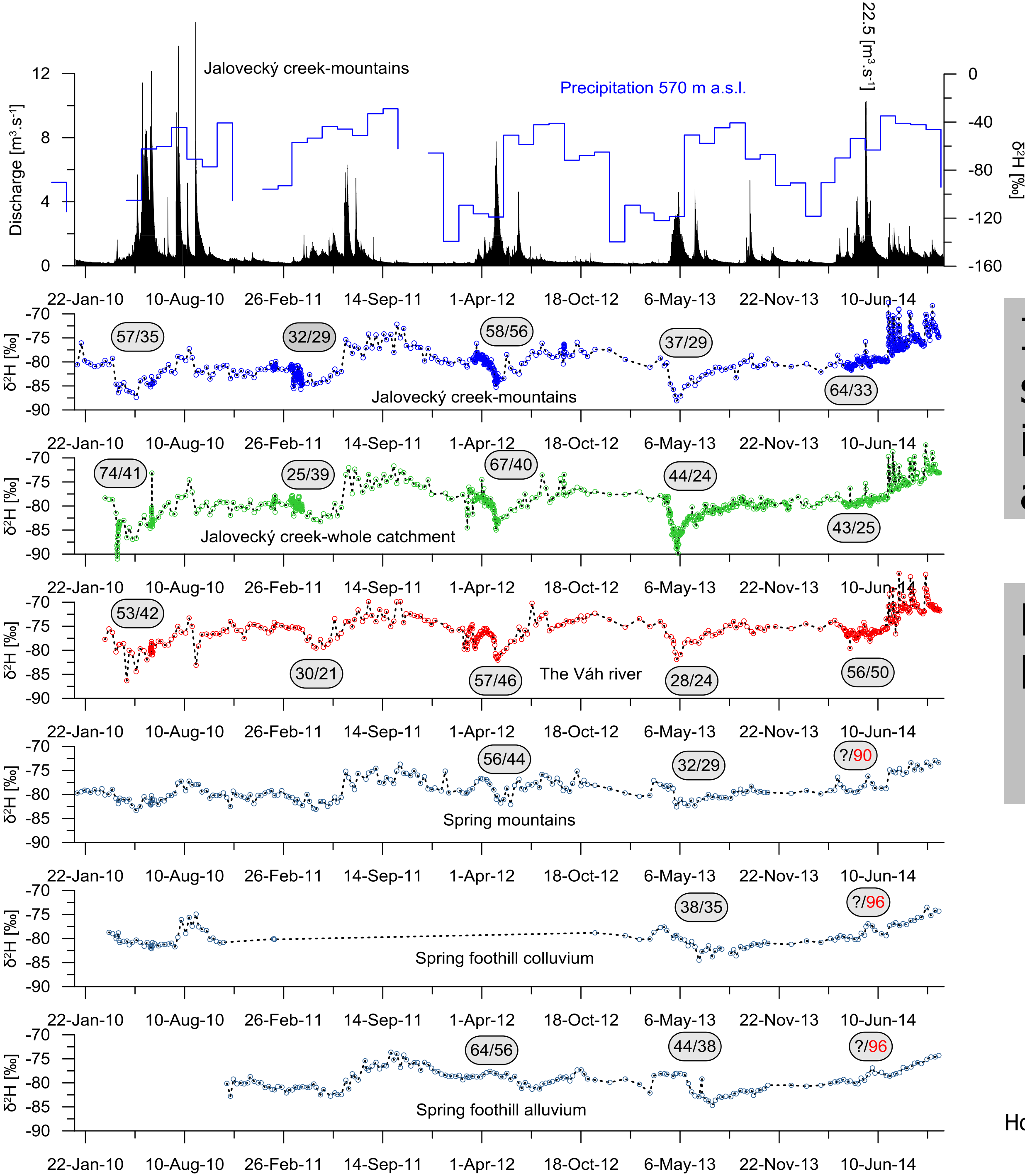


Catchment scale, diurnal runoff variability

Hourly data 1988-2011, small mountain catchment, granite, gneiss (22 km^2)

Influence of snow is visible for about 96 days on average

Isotopic approach

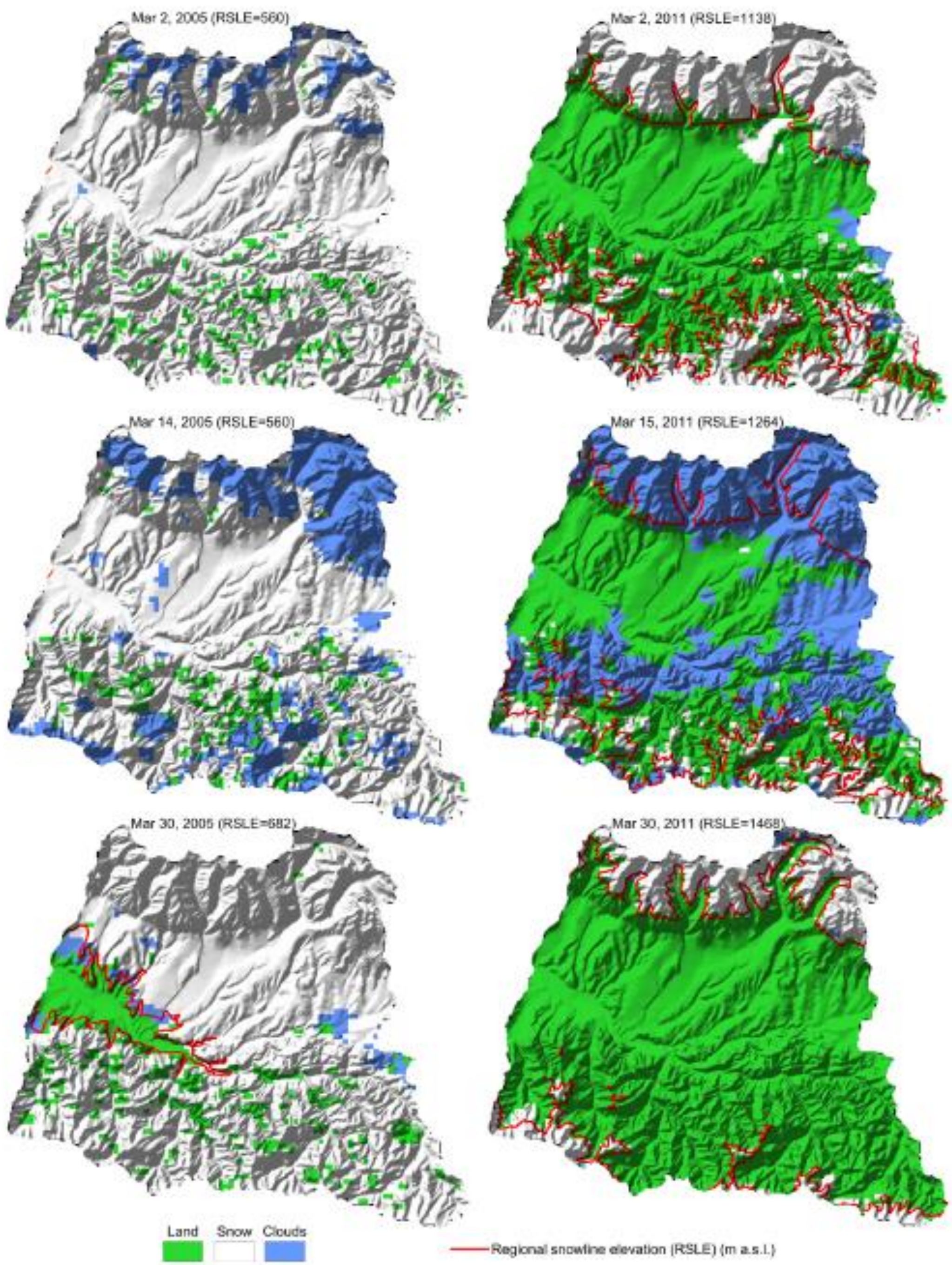


Isotopically light snowmelt water is visible in the streams approximately until June

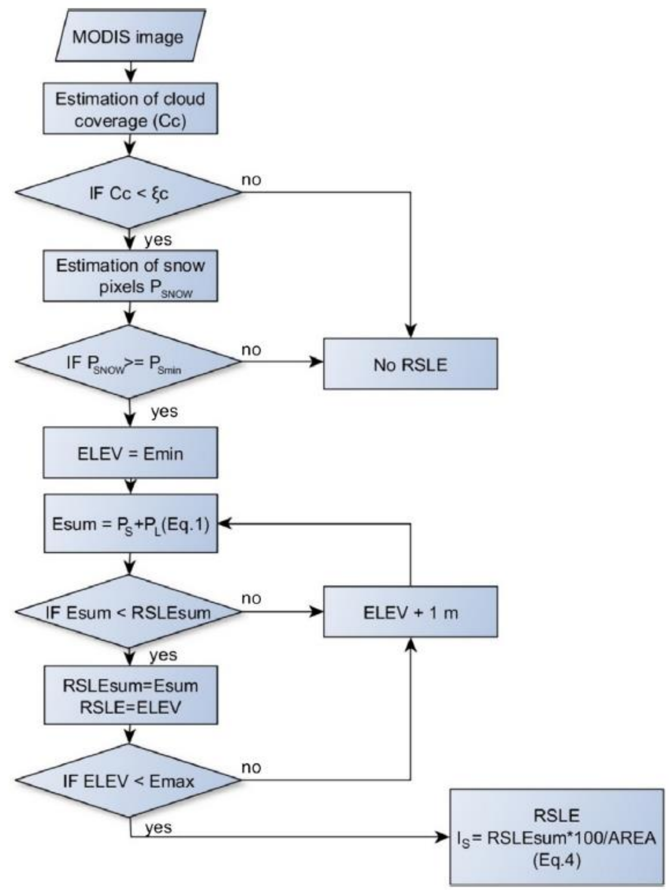
Mean transit times vary between 0.7 and 3 years

Holko et al., in print

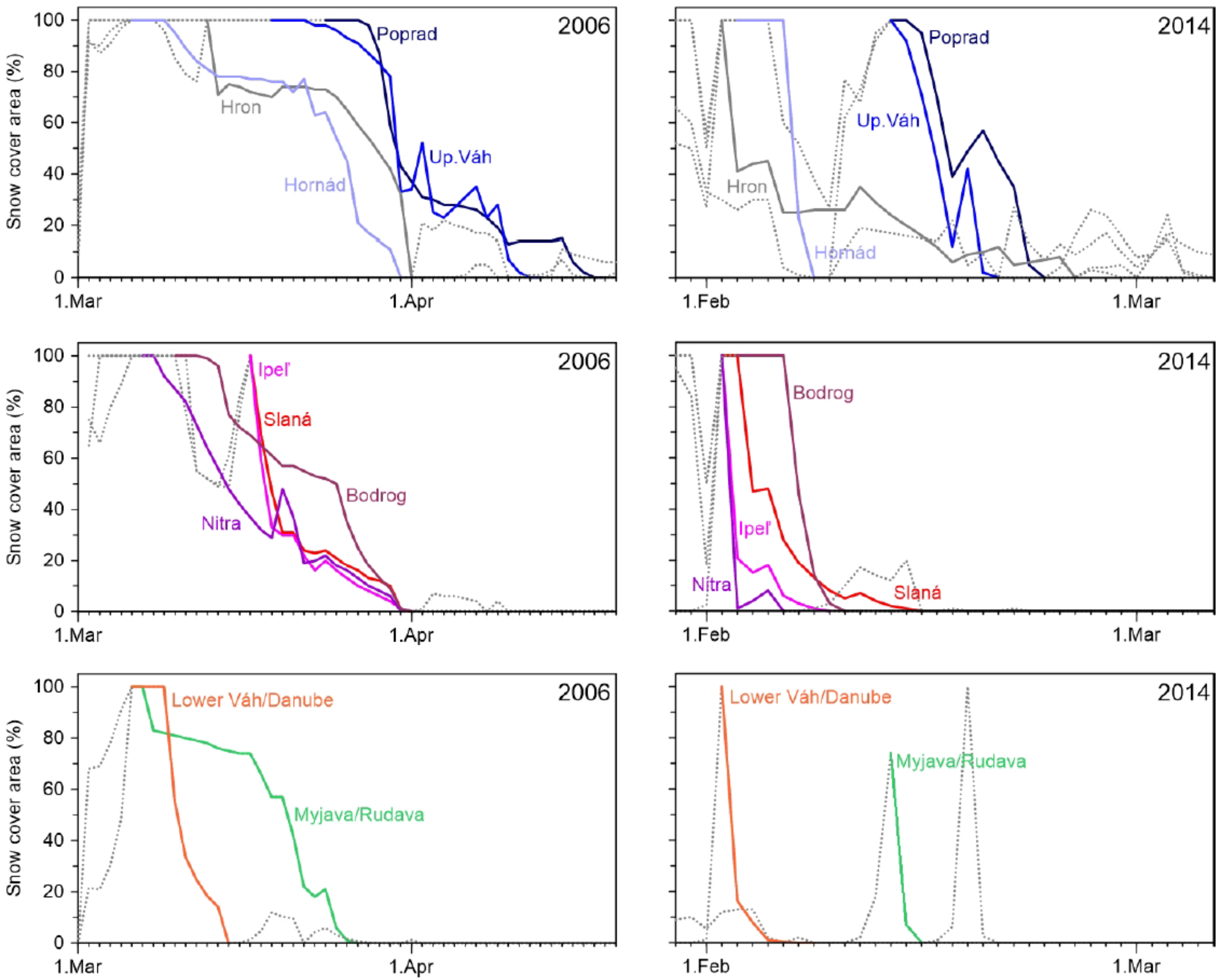
Snow line estimation for data from remote sensing



$$F(\mathrm{RSLE}) = P_S(\mathrm{RSLE}) + P_L(\mathrm{RSLE})$$



Krajči et al., 2014



Krajči et al., 2016

Snow depletion curves for the Slovak river basins

Snow accumulation and melt modelling

- Objective – simulation of the snow water equivalent to know the timing and amount of water from melting snow entering catchment or an aquifer
- Basic principles of snow accumulation and melt, and thus also the SWE simulation were elaborated about 50 years ago (US Army Corps of Engineers, 1956, 1960; Kuz'min, 1957, 1960, 1961).

Snow accumulation and melt modelling

- Snow accumulation is usually simulated using the air temperature to discriminate between liquid and solid precipitation

Disdrometer data useful

$$P_{snow} = \frac{T_{R/S} + T_{trans} - T}{2\,T_{trans}}$$

Schulla, 2012

- P_{Snow} - fraction of snow on the total precipitation (0..1), *T - air temperature [°C]*, $T_{R/S}$ - temperature, at which 50 % of precipitation is falling as snow [°C], T_{trans} -½ of the temperature-transition range from snow to rain [K]

Snow accumulation and melt modelling

- Snow melt can be simulated either by a more complex energy balance model or by a simpler index model
- Index models – e.g. the temperature-index (degree-day model)

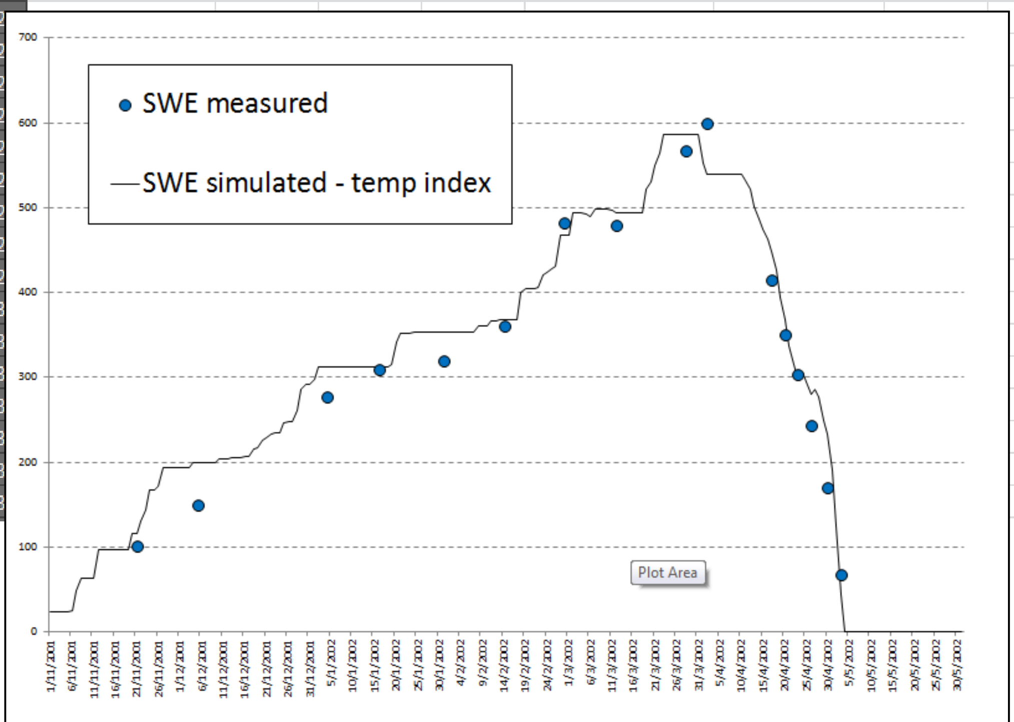
$$M = c_0 . (T - T_{o,m})$$

- C_o – degree-day factor [mm.°C^{-1}.day^{-1}]

Date	Preci	Tempx	C0 - DDF	SWE_Measured	SWE_simulated
1-Nov-01	23.6	0.10	0.00		23.6
2-Nov-01	0.0	-3.67	0.00		23.6
3-Nov-01	0.0	-1.73	0.00		23.6
4-Nov-01	0.0	-0.69	0.00		23.6
5-Nov-01	0.0	-2.06	0.00		23.6
6-Nov-01	0.9	-3.35	0.00		24.5
7-Nov-01	23.6	-0.94	0.00		48.1
8-Nov-01	15.4	0.17	0.00		63.5
9-Nov-01	0.0	-3.60	0.00		63.5
10-Nov-01	0.0	-6.44	0.00		63.5
11-Nov-01	0.0	-4.71	0.00		63.5
12-Nov-01	34.0	-0.65	0.00		97.5
13-Nov-01	0.0	-2.15	0.00		97.5
14-Nov-01	0.0	-6.17	0.00		97.5
15-Nov-01	0.0	-6.02	0.00		97.5
16-Nov-01	0.0	-4.56	0.00		97.5
17-Nov-01	0.0	-4.44	0.00		97.5
18-Nov-01	0.0	-3.10	0.00		97.5
19-Nov-01	0.0	-3.35	0.00		97.5

Parameters		
Trs	1	temperature limit for rain (Grad Celsius)
Ttrans	0	transient zone for rain-snow (T0R +- this range)
T0m	0	temperature limit snow melt
C1		degree-day-factor without wind consideration mm/(d*C)
C2		degree-day-factor considering wind mm/(d*C*m/s)
crfr		coefficient for refreezing
cwh		storage capacity of the snow for water (relative part)
RMF		radiation melt factor mm/d/C comb. method
C0	variabilne	temperature dependent melt factor mm/C/day

Altitude [m]	
hM	1500

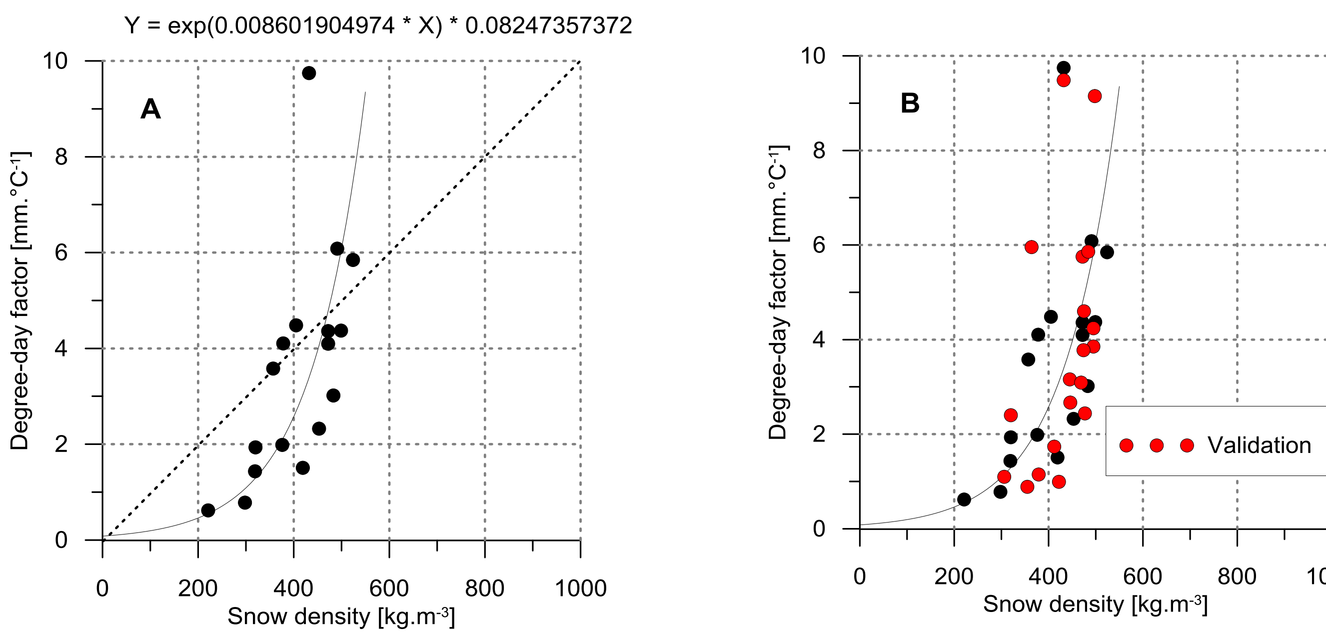


Run the temperature-index model

Snow accumulation and melt modelling

- How to determine the degree-day factor?
- Martinec (1960)

$c_o = c.D$, $c = 1.1$, D-snow density



Holko et al., 2012

Energy-based models

• calculate the energy balance of the snowpack
(net radiation, sensible heat, latent heat, condensation/sublimation, rain, conduction)

• UEB (Utah Energy Based snow accumulation and melt model); snowpack is characterised by two main state variables:

$$\frac{dU}{dt} = Q_{sn} + Q_{li} + Q_p + Q_g - Q_{le} + Q_h + Q_e - Q_m$$

$$\frac{dW}{dt} = P_r + P_s - M_r - E$$

U – energy content, W-water equivalence

Snow accumulation and melt modelling

$M = M_R + M_S + M_E + M_P$

M_R radiation melt [mm], M_S melt by sensible heat [mm], M_E melt by latent heat [mm], M_P melt by import of energy by precipitation [mm]

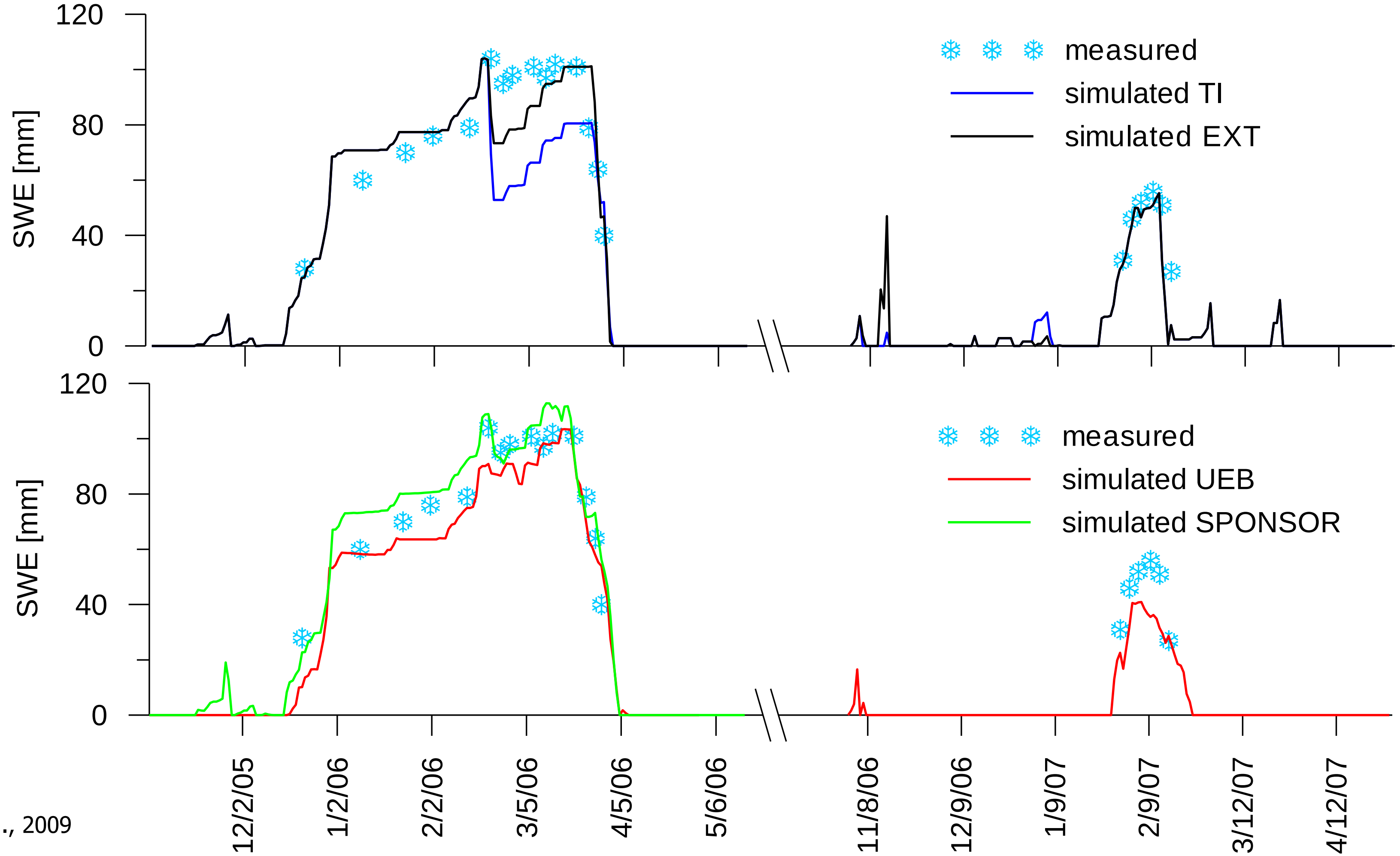
$$M_R = 1.2 \cdot T$$
$$M_S = (c_1 \cdot c_2 \cdot u) \cdot (T - T0,m)$$
$$M_E = (c_1 \cdot c_2 \cdot u) \cdot (E - 6.11/gamma)$$
$$M_P = 0.0125 \cdot P \cdot T$$

Snow accumulation and melt modelling

- Schulla, J. (2012): Model Description WaSiM
- U.S. Army Corps of Engineers (1998): Runoff from snowmelt
- Melloh, R.A. (1999): A Synopsis and Comparison of Selected Snowmelt Algorithms
- Tarboton, D., Luce, D. (1996): Utah Energy Balance Snow Accumulation and Melt Model (UEB). Computer model technical description and users guide. Utah State University and USDA Forest Service, 39 pp.

Index - or energy-based model?

Index - or energy-based model?



Holko et al., 2009

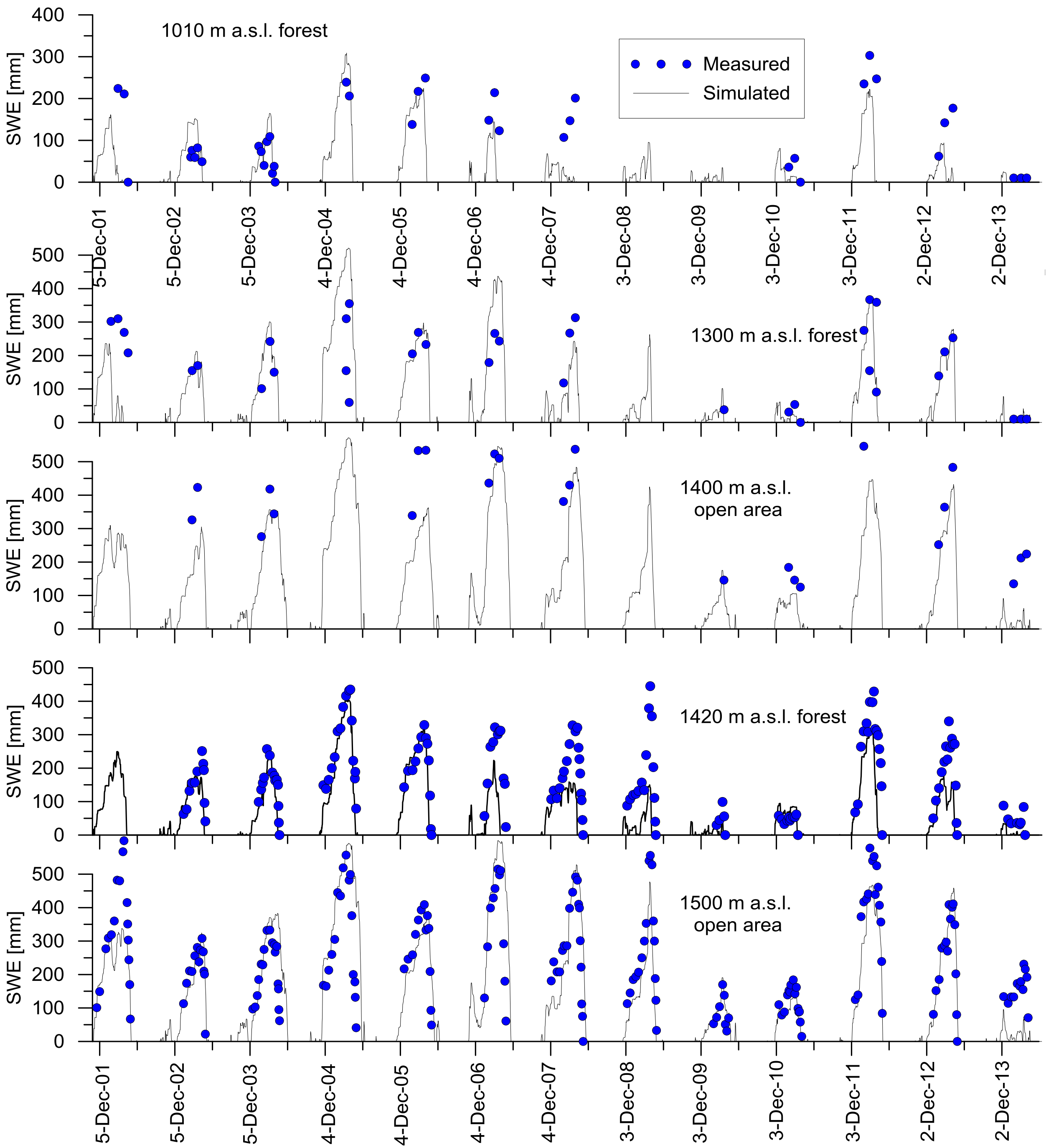
Index - or energy-based model?

- all models provided similar simulated SWE (comparable with measurements)
- in other words – every model could have been calibrated so, that the results were reasonable
- it means that even the simple degree day can give reasonable estimates of SWE – *this is well known*

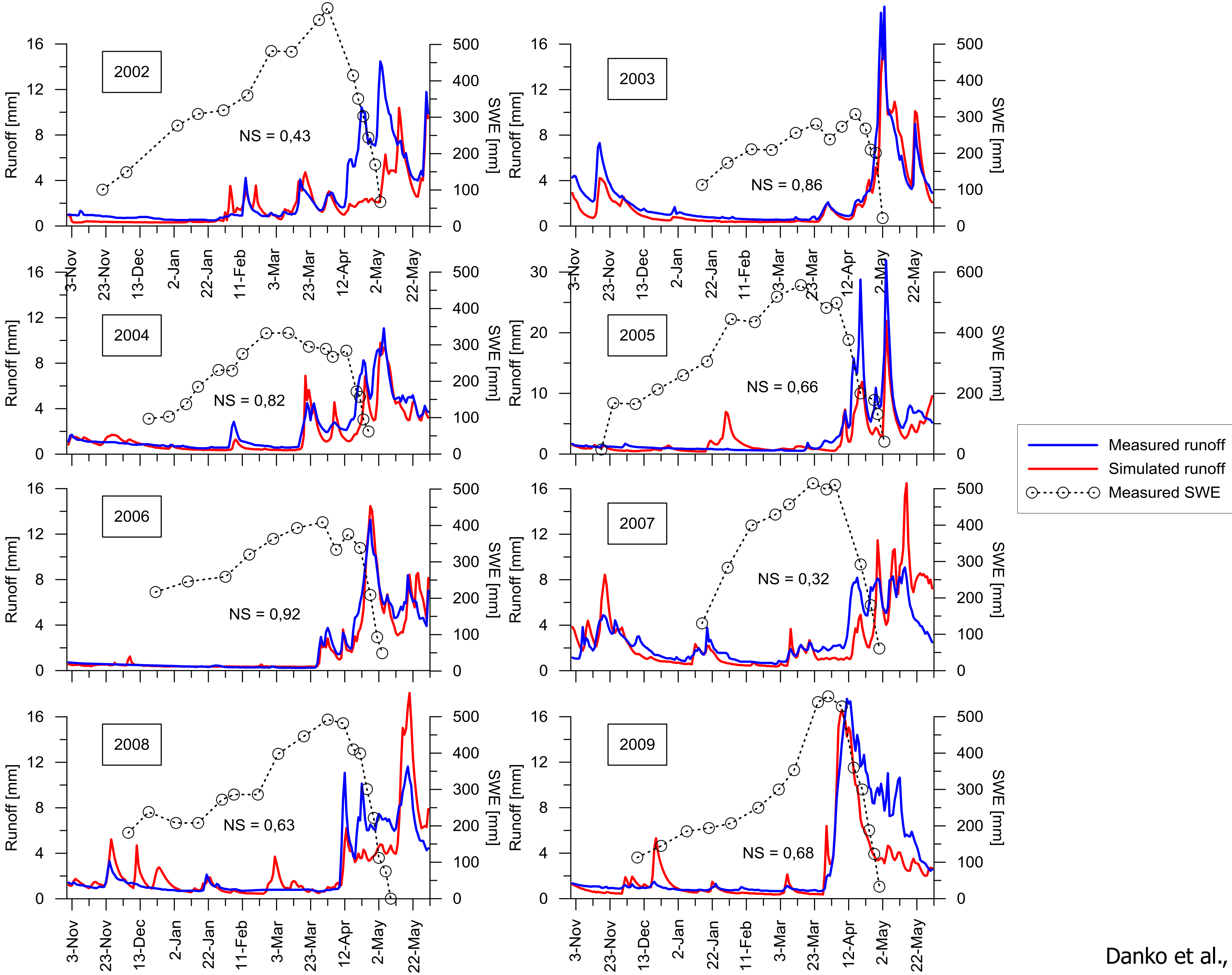
Index - or energy-based model?

- However, the energy-based models (even the simpler ones such as the EXT), which are not much more demanding from the point of view of the necessary input data can simulate the short snowmelt events better than the index models
- The energy-based models can simulate other snow characteristics (e.g. snow depth, surface snow temperature, snowpack temperature, …), too

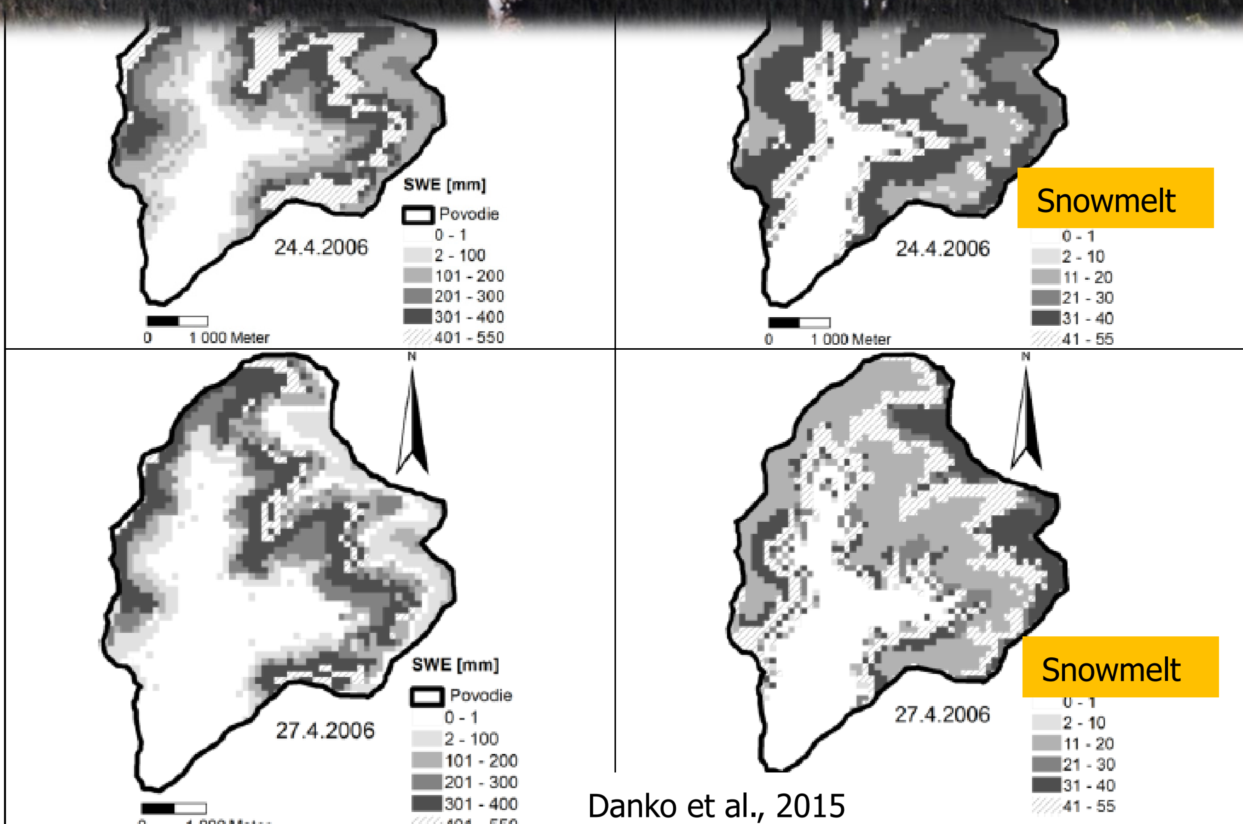
SWE simulation for different sites Mike SHE (degree-day)



Danko et al., 2015



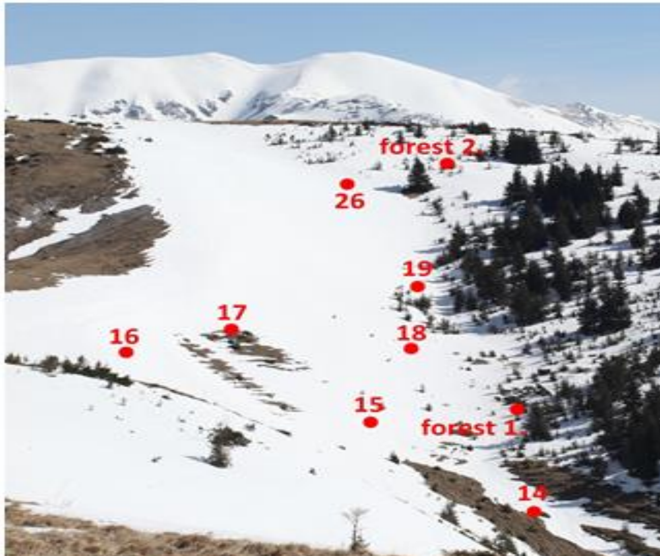
Danko et al., 2015

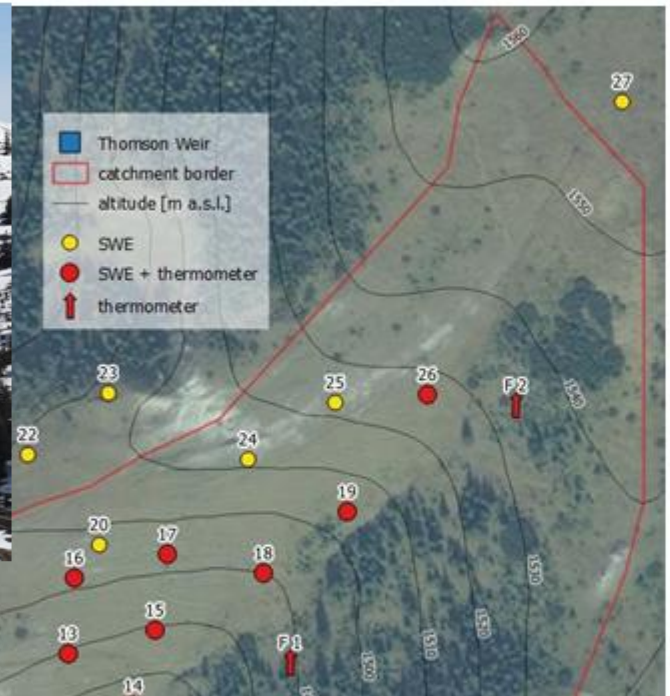


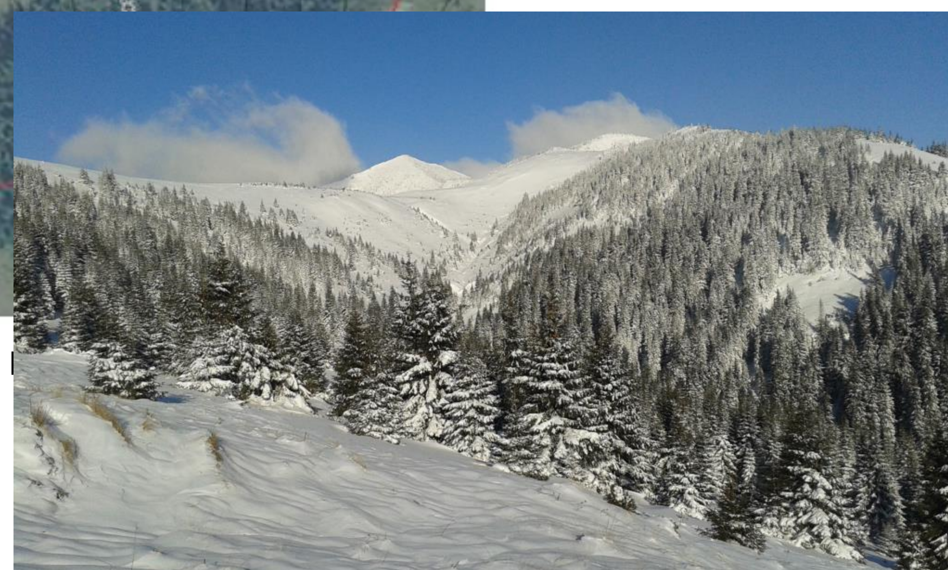
Danko et al., 2015

Good SWE simulation at points does not guarantee accurate catchment runoff simulation and spatial distribution of snow

Importance of distributed data on input precipitation

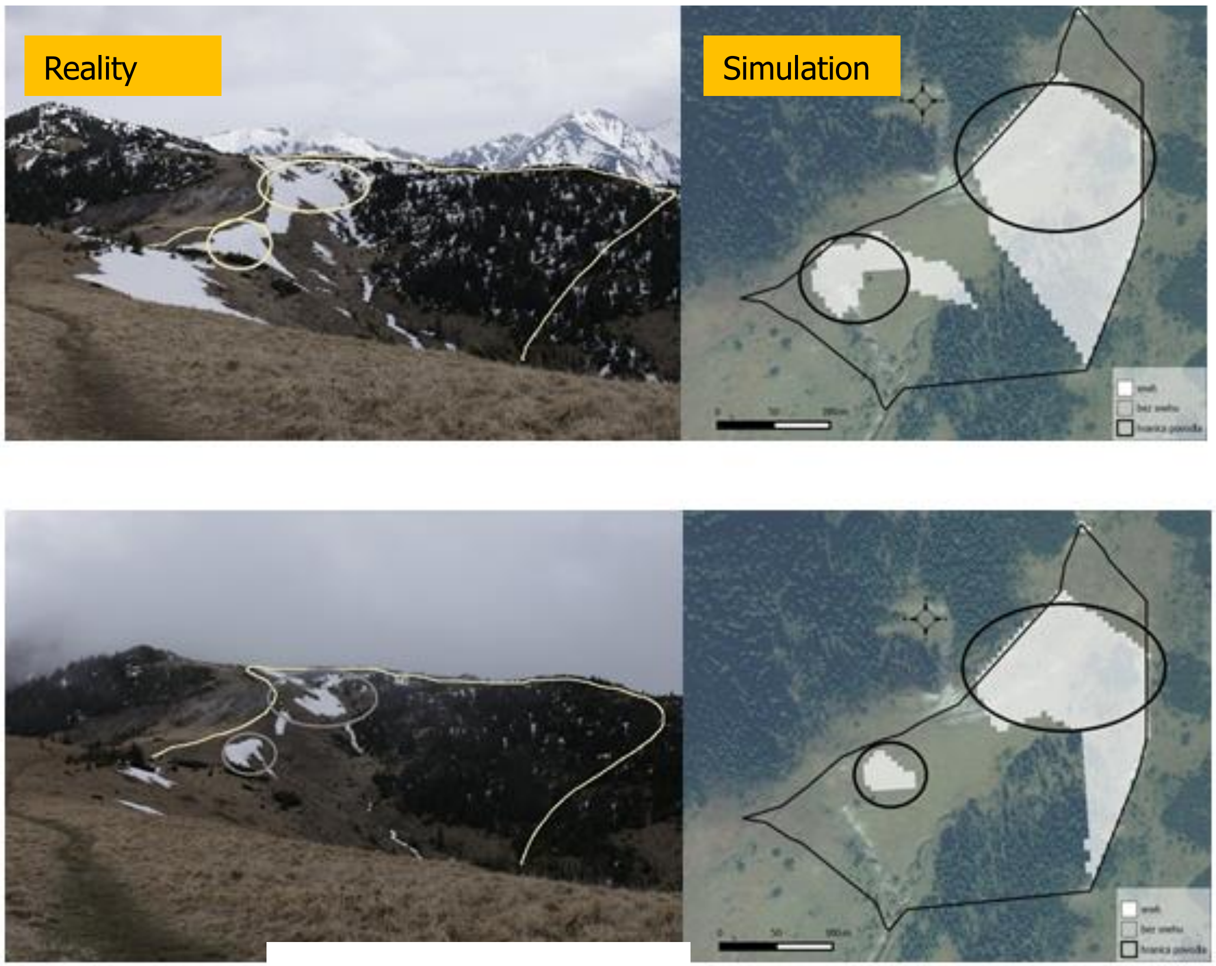




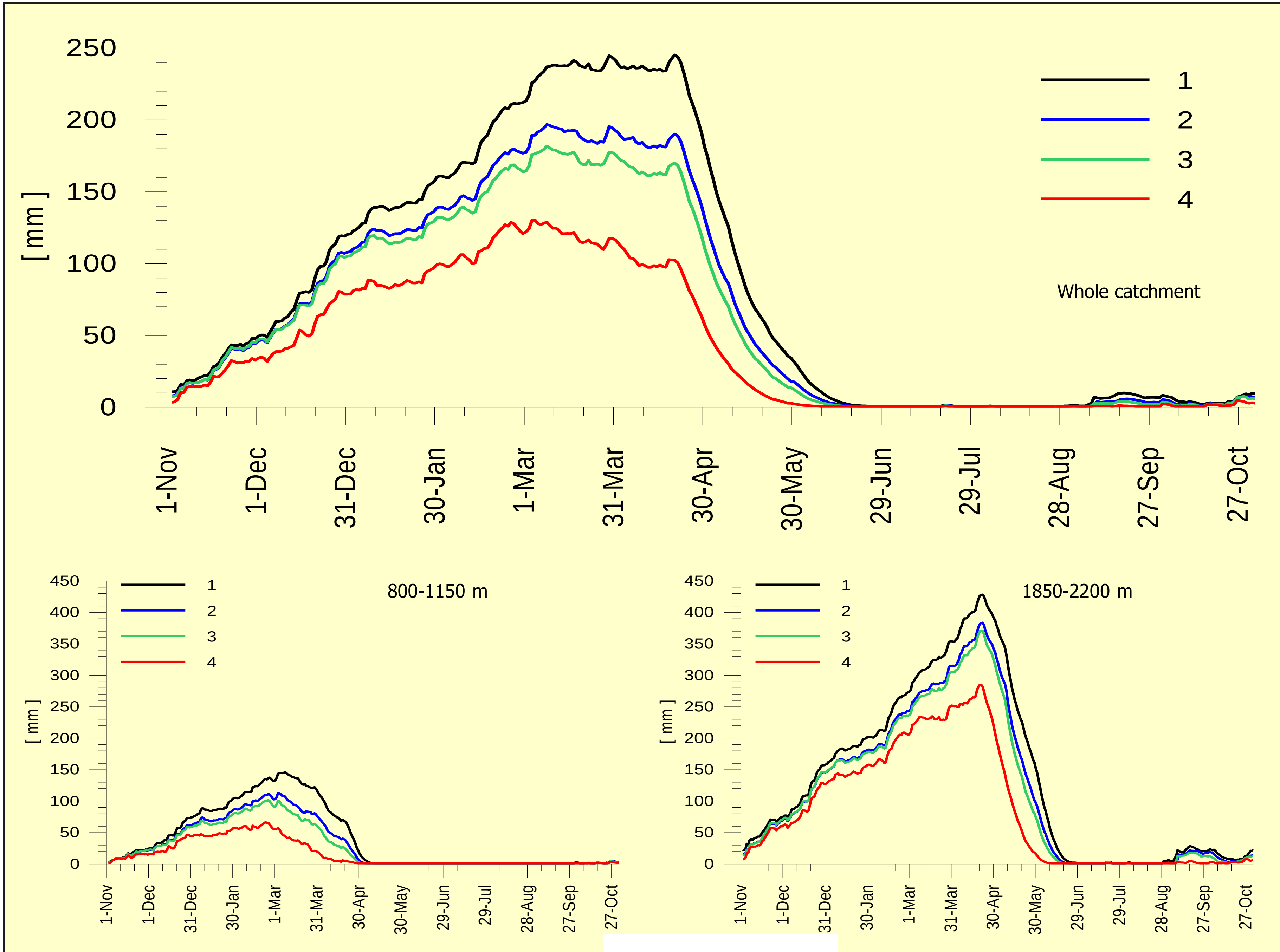


Snow gauges, snow lysimeters, ground surface thermometers

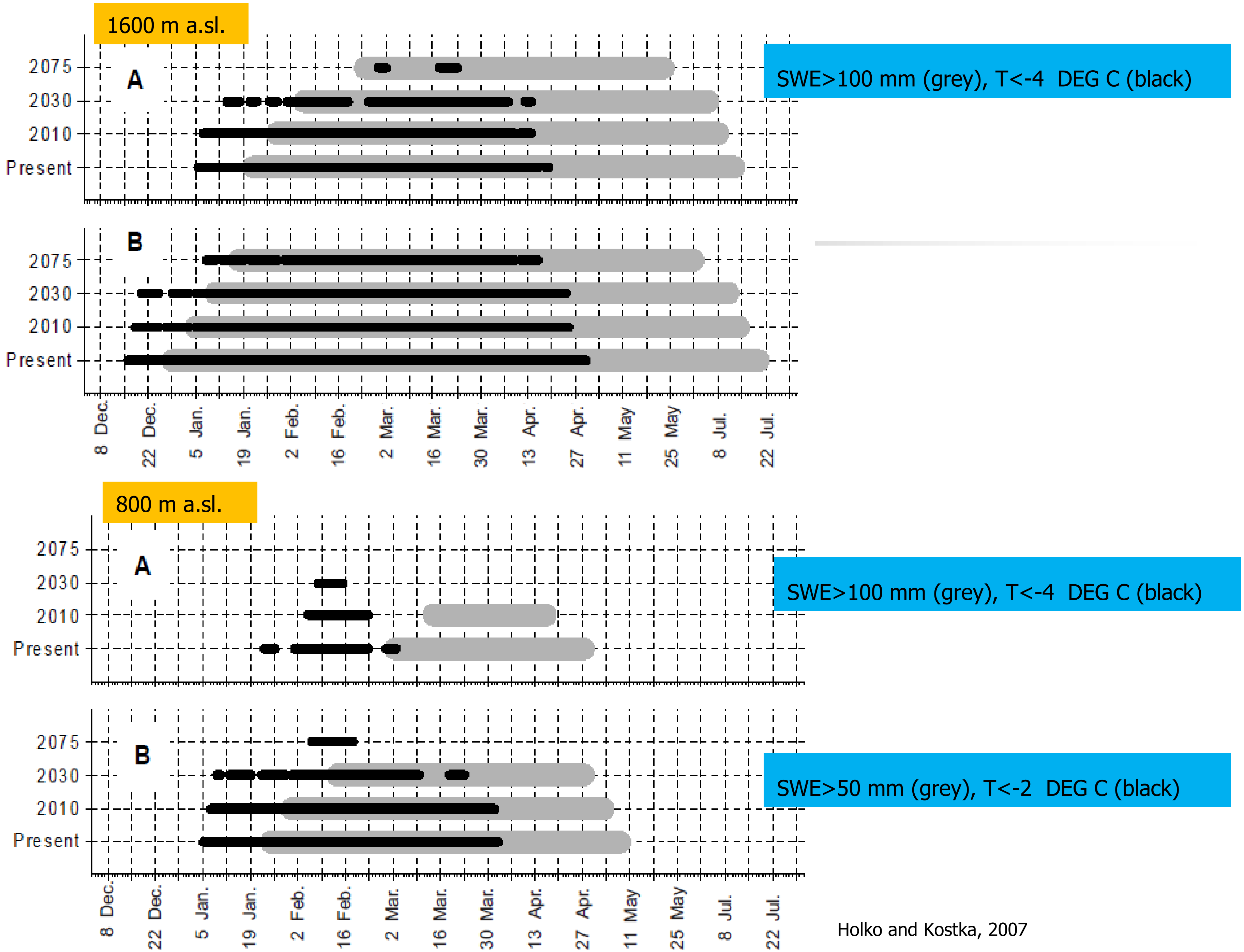
- SWE at points and catchment discharge were simulated acceptably
- Spatial distirbution of snow relfected the method of precipitation extrapolation



Krajči et al, in preparation



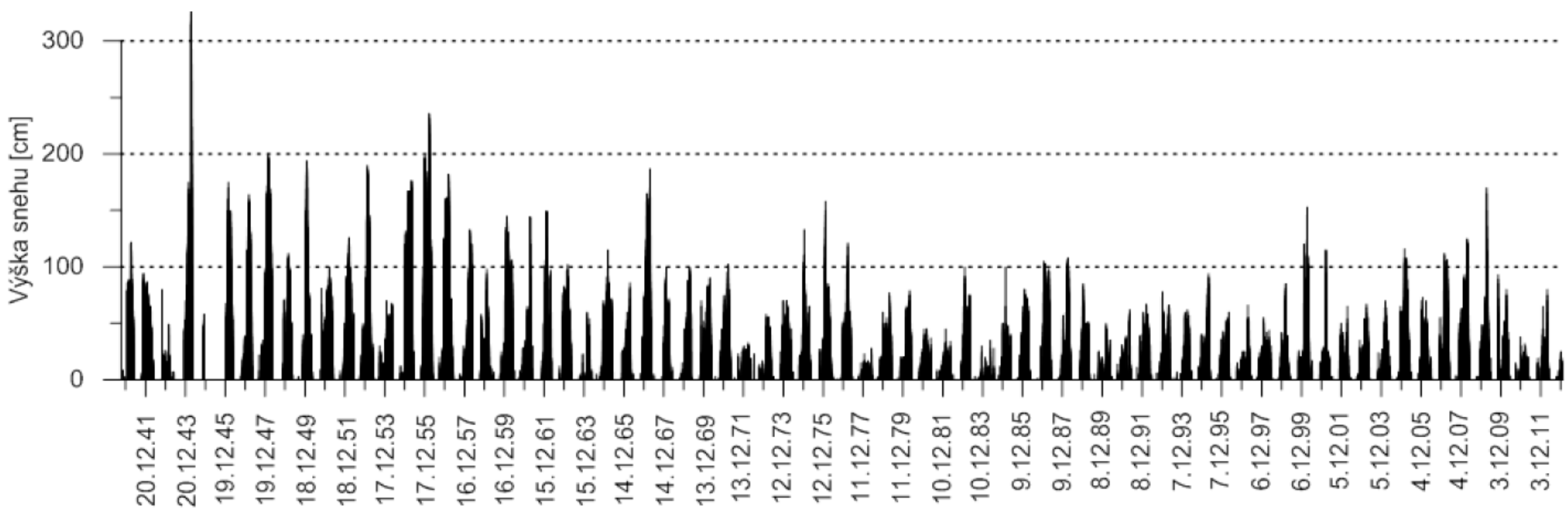
Kostka and Holko, 2000



Holko and Kostka, 2007

Abegg, 2006


1769 m a s.l.
Bičárová, 2013


Výška snehu [cm]
300
200
100
0
20.12.41
20.12.43
19.12.45
19.12.47
18.12.49
18.12.51
17.12.53
17.12.55
16.12.57
16.12.59
15.12.61
15.12.63
14.12.65
14.12.67
13.12.69
13.12.71
12.12.73
12.12.75
11.12.77
11.12.79
10.12.81
10.12.83
9.12.85
9.12.87
8.12.89
8.12.91
7.12.93
7.12.95
6.12.97
6.12.99
5.12.01
5.12.03
4.12.05
4.12.07
3.12.09
3.12.11

Conclusions

- Snow hydrology research has a long tradition in Slovakia
- Research results are applied in operational hydrology
- Although the frequency of snow-poor winters since the 2010 is high, we had similar periods in the past
- Snow cover will probably remain an important component of water balance in the highest part of the Carpathians

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