DAILY SNOW ACCUMULATION AND MELTING (SAM)

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Introduction

Snow accumulation and melting are two very complicated physical processes that for practical purposes (mostly for flood prediction and water resources estimation) were simplified. Frames for simplification are given by availability of initial data. There are usually air temperature, precipitation and snow depth available for the assessment. You are lucky if you have measurements of snow density. I have some: Ontario Power Generation for flood control makes snow measurements twice a month and publicizes them on the website.

My concept for empirical estimation of daily snow accumulation and melting is the following: physical transformation of snow that is important from hydrological point of view can be indicated by snow density and retention capacity changing. Snow density changes from 0.03- 0.1 g/cub.cm for newly fallen snow to 0.3 - 0.45 g/cub.cm for ripe, old snow. Retention capacity changes in opposite direction: from 55% for newly falling to 5 - 15% for ripe snow. Releasing of melted water from snow happens, when density is higher than 0.3 g/cub.cm (300 kg/cub.m) and amount of liquid water excesses 10%. My first step is to find empirical equations for total snow density changing.

There is one model description below: “adjusted”, - in which the discrepancy of hourly air temperature during a day may condition the snow accumulation under the positive daily average and the melting processes under the negative daily average. There is one more open condition in this model: the density threshold for melted water releasing from snowpack is variable, not just 0.3 g/cub.m.

“Simplified” model has invariable thresholds.

“Retention” model doesn’t operate with snow density at all and it is not developed enough to analyze the results.

1. Finding of basic equations for snow density (new snow, aging snow)

The temperature is of great significance for the type of ice crystal that is formed; the snowflakes that are formed will therefore look different at different temperatures. Cold, newly-fallen snow forms a light, porous layer, while damp snow forms a more compact layer (Gray, 1970, Bruce & Clark, 1966, B.Raab, H.Vedin, 1995, Dunn & Colohan, 1999).

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Snow density of different type of snow (tabl.1).

Type of snow	Kg/m³, Raab& Vedin, 1995	gm/cm³, D.M. Gray, 1970
Very loose new snow	< 30	0.01 - 0.03
Newly-fallen dry snow	30 - 100	0.07 - 0.19
Wet, new snow	100 - 200	
Wind-packed snow	200	0.2 - 0.35
Packed late-winter snow	200 - 300	0.4 - 0.55
Thawing snow in spring	>400	0.6 - 0.7

1.1 New snow

Density of newly-fallen snow is the exponential function of temperature (Gray, Kongoly, Raab & Vedin, Kuzmin) and wind (Bruce & Clark, Kuzmin, Bogoslovsky), but I don't have wind as input. To take it into account the initial snow density was accepted very close to upper limit for newly-fallen snow - 0.08. The same number was accepted by Bruce & Clark, 1966 and Currie, 1947 for northern areas of Canada (Kongoly starts from 50 kg/m3 or 0.05 g/cm3).

For estimation of density of newly-fallen snow the observation data for two Canadian sites (Beverly Swamp and Aguasabon watershed) and one Estonian (Tooma Bog Station) were used.

The curve for Aguasabon and Tooma can be described as following

$Sn = 0.09 + 1/(2-T)^4$ for $T <= 0^oC$ (1)

$Sn = 0.03T+0.163$ for $3 > T > 0$ (2)

Where T is a daily air temperature and Sn is the snow density of newly-fallen snow in gm/cm³. Snow falls and snow pack can be found at positive daily temperatures as well, especially with wind. I accepted +3 due to snow density for newly-fallen snow is around 0.5 according to (2) that is the upper limit for density caused by climate condition (air temperature) (Kuzmin, 1961, Raab & Vedin). Critical air temperatures for snow foundation and melting have different intervals and depend on climatic and geomorfological conditions of area (Kongoly, WMO n 168).

1.2 Old snow

As soon as snow lays on the ground its density goes up due to its own weight, wind, temperature and humidity fluctuations, precipitation (snow and rain) and melting (J.P.Bruce, R.Clark, 1966, B. Bogoslovsky et., 1984). The factors which cause the density of the snowpack to change are the following (Gray, 1970):

1. Heat exchange resulting from convection, condensation-sublimation, radiation, and heat flow from the ground.
2. The pressure of the overlying snow.
3. Wind.
4. Temperature and water variations within the pack.
5. Percolation of melted water.

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Snow pack has layer structure. Each layer has different snow density. Southern areas have much more "organized" consequence of the layers order due to better condition for snow melting. Snow density of each layer grows from the top to the bottom. Lowest layers have density 400-500 kg/m3. This is density of snow transformation into firn (ice) (Gray, 1970, Kotlyakov, 1984). Northern areas have more complicated structure due to better conditions for snow to stay.
Velocity of snow density changing with age is described very differently and it is different under unlike conditions. In the model, the differentiation was only done between the last snow fall and the previous snow pack as a whole.

As a function of air temperature and precipitation, the aging can be described as the following

Air temperature < 0:

Daily growth of	Sd	= Sd-1*(0.001 T + 1.025)	if no precipitation	(3)
	Sd	= (Sw-1*Sd-1 + P*Sn)/Sw	if P > 0	(4)
Air temperature > 0:				
	Sd	= Sd-1*(0.03T + 1.02), but it cannot excess 0.5		(5)

where Sd-1 is snow density of snow in previous day, Sw-1 and Sw are water equivalent in snow pack in previous and current day.

2. Snow melting

Snow melting calculation was done using a formula of the U.S. Army Corps of Engineers (1956) that gave satisfactory result for Canada (R. Brown, 1997) :

$$M = K[(1.88 + 0.007R)*1.8T + 1.27],\ T>0 \qquad (6)$$

where M - snowmelt water (mm/day)
K - locally-calibrated snowmelt factor
T - mean daily air temperature, C°
R - mean daily rainfall, mm

I put different K for spring and autumn to take into account the difference in soil temperature. The air temperature threshold for beginning of melting t can vary as well. So, I have used this variations as well:

$$M = Ki[(1.88 + 0.007R)*1.8*(T+t) + 1.27] \qquad (7)$$

3. Water content of snow pack

To calculate water content in snow pack the following conditions were established:

1. the variable snow density threshold (from 0 to 0.3) under which melted water either released or stayed in the pack

2. the temperature and pack size under which the evaporation (sublimation) Es from snow surface is noticeable (T < -10 and snow depth > 15 cm):

$$Es = 0.0051T^2 + 0.0147T \quad (8)$$

This empirical formula was obtained based on precipitation free cold periods, when snow pack changes his depth under two main processes: sublimation and density increase.

4. Results

All described above equations and conditions of their activation were used in the model of snow accumulation and melting SAM. The model was created in Excel spreadsheet. For several sets of data the model was calibrated and the best coefficient between calculated and obtained depths of snow pack revealed the final set of variable parameters in each case.
Some of results are presented on fig 1 for Canadian site and on fig.2 for Estonian site. It is too early to make a conclusion, because these estimations are not finished: there is no estimation of released water, which can be related with flow from examined watershed and entire water balance of the watershed.

Still, for some professionals it may be interesting.

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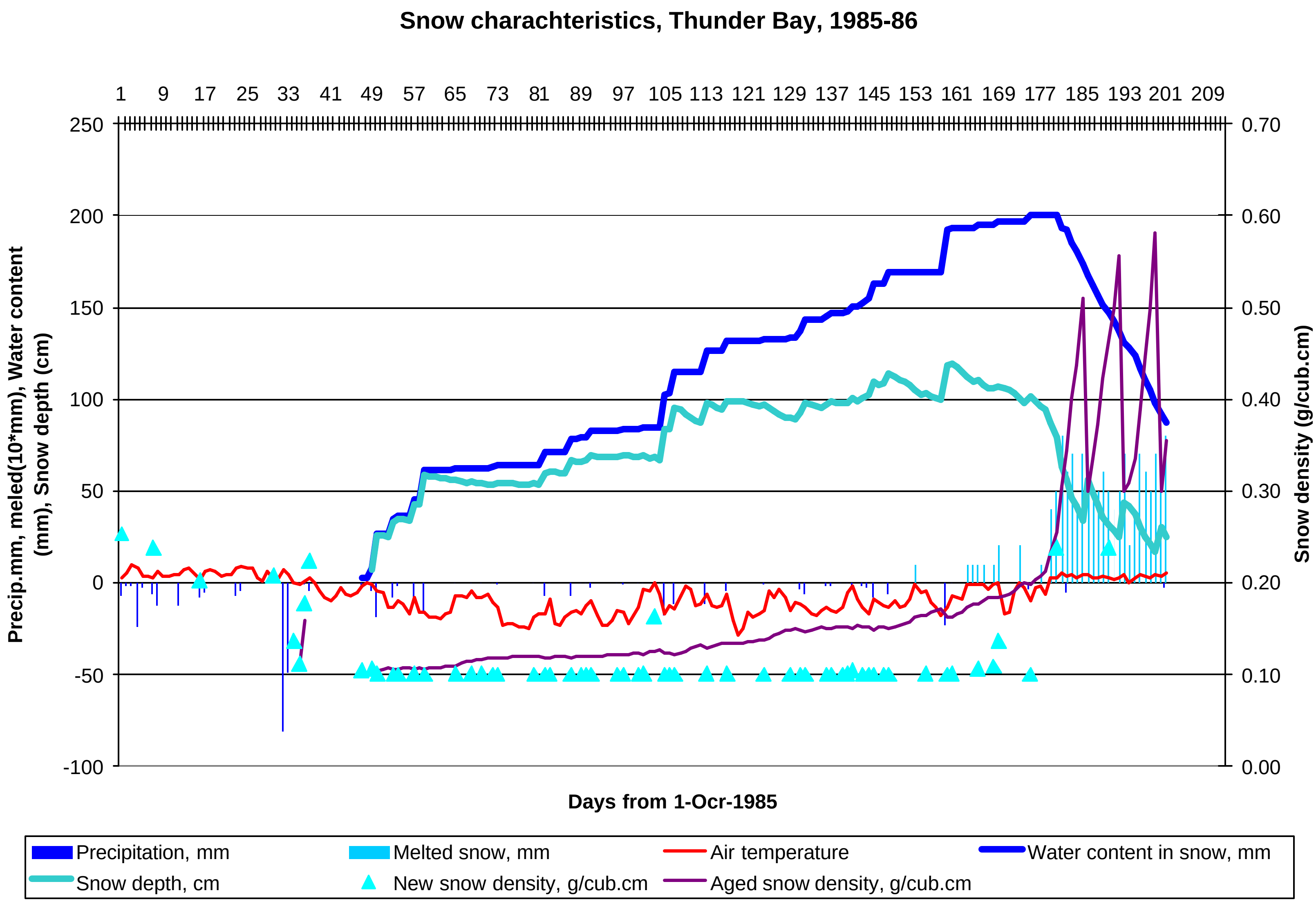
Daily snow accumulation and melting



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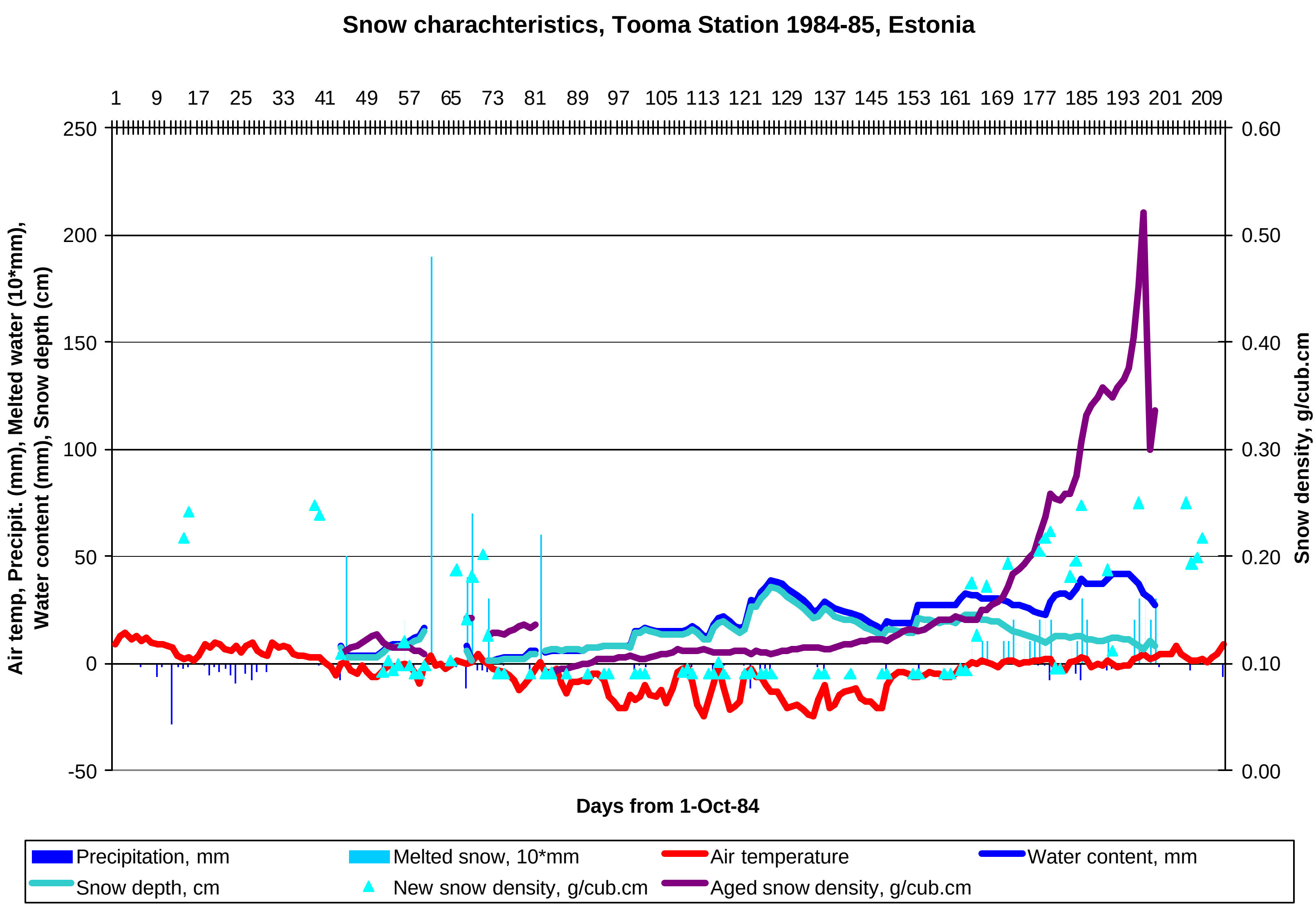

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