Comparison of two approaches to simulate soil water dynamics in the permafrost landscapes

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1. Introduction

Almost one-third of the land is covered by permafrost. Still more is seasonally frozen ground. For these environments melting of snowcover is the main hydrological event during the year. Infiltration of snowmelt into frozen ground and formation of surface flow are critical hydrological processes. But the problem of proper parameterization and accurate modelling of spring hydrological events still exists.

2.Goal

to compare two different approaches in modelling of infiltration into frozen ground and formation of surface flow as a result of snowmelt by the example of two slopes in Canadian environments.

3. Cold Regions Hydrological Model [1]

The soils are divided into restricted, limited, and unlimited classes according to its infiltration characteristics. When limited, infiltration is governed primarily by the snow-cover water equivalent (SWE) and the frozen water content of the top 40 cm of soil.

$$INF \quad C \quad S_0^{2.92} \; (1 \quad S_I)^{1.64} \; \left(\frac{273.15 \quad T_I}{273.15} \right)^{0.45} \; t_0^{0.44}$$

C is a coefficient, S_0 is the surface saturation ($mm^3 mm^3$), S_I is the average soil saturation (water + ice) of 0-40 cm soil at the start of infiltration ($mm^3 mm^3$), T_I is the average temperature of 0-40 soil layer at start of infiltration (K), t_0 is the infiltration opportunity time (h)

Difference between snowmelt water and infiltration is assumed to be surface flow

4. Hydrograph Model [2]

The snowmelt (or rainfall) intensity serves as an argument which together with the maximum possible infiltration rate (that is infiltration coefficient f_0) determines the relative size of infiltration area. It is assumed that the increment of the infiltration area corresponding to an increment of snowmelt intensity i decreases proportionally to this area. Then it follows that the intensity of surface flow q is determined by equation:

$$q \quad i \quad f \quad i \quad f_0 1 \quad \exp(\quad i / f_0)$$

Accounting for the first physical equation the probabilistic average of random process such as the difference between the rainfall intensity and infiltration is calculated as

$$\mathrm{M}\,q \quad \int_0 \quad i \quad f_0 1 \quad \exp \quad i / f_0 \quad i \; di \quad 1/ f_0 \quad 1$$

where, $i \; t \quad i \; t \; / I$ is snowmelt intensity, $I \quad 1/T \int_0^T i \; t \; dt$ is the mean snowmelt intensity for the period of snowmelt T. The distribution law of is represented by an exponential distribution: $i \quad 1/I \exp \quad i / I$ and $i \quad \exp \quad i$. Herein, the asterisk notation (*) along with any argument indicates that the last is divided by I. Finally,

$$\mathrm{M}\,q \quad I^2 / I \quad f_0$$

Then the value of surface flow formation H_q during the period T is the following:

$$\mathrm{H}_q \quad H^2 / H \quad f_0 T$$

where H is the snowmelt (rainfall) depth, and equals IT.

Simultaneously with water balance the heat dynamics calculations of soil stratum are conducted allowing for the account of solid and liquid moisture ratio and its affect on infiltration rates: $f^* = f_0(1 - S_i)^n$

n is a coefficient, S_I is the ice content of a layer ($mm^3 mm^3$), f^* - infiltration coefficient in frozen soil. n changes: 4 – sand, 5 – loam sand, 6 – loam, 7 - clay

5. Study area

Granger basin, 6 km^2 (60°32N, 135°18W)
Wolf Creek research basin, Yukon Territory, Canada

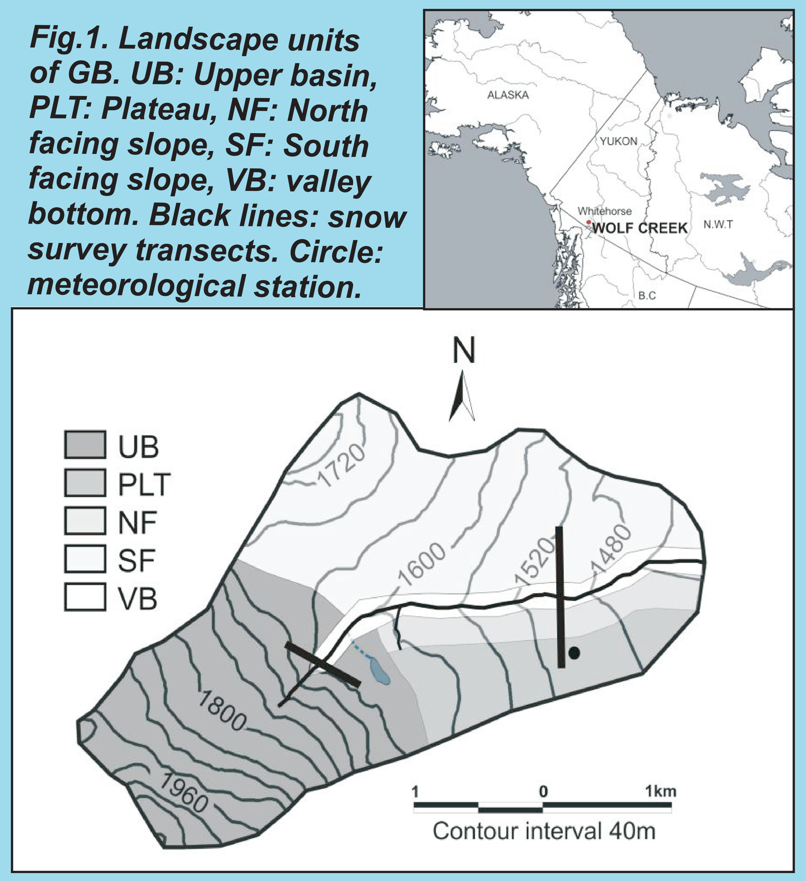

Fig.1. Landscape units of GB. UB: Upper basin, PLT: Plateau, NF: North facing slope, SF: South facing slope, VB: valley bottom. Black lines: our survey transects. Circle: meteorological station.

- elevation from 1310 to 2250 m a.s.l.
- subarctic continental climate
- mean annual January and July temperatures are -21°C and +15°C
- mean annual precipitation is 350 mm
- zone of discontinuous permafrost
- shrub tundra

Table 1. Physiographic characteristics of North facing and South-facing slopes *(sh - shrubs, gr - grass, bg - bare ground)*

Landscape unit	Elevation Type (m)	Vegetation Type	Vegetation cover (%)			Soil type
			sh	gr	bg	
North facing slope (NF)	1350 - 1460	mix-shrubs (0.3-1m)	78	17	5	thick organic layer (0.25m) + mineral
South facing slope (SF)	1350 - 1760	mix-shrubs (0.3-1m)	74	20	6	organic layer (0.12m) + mineral

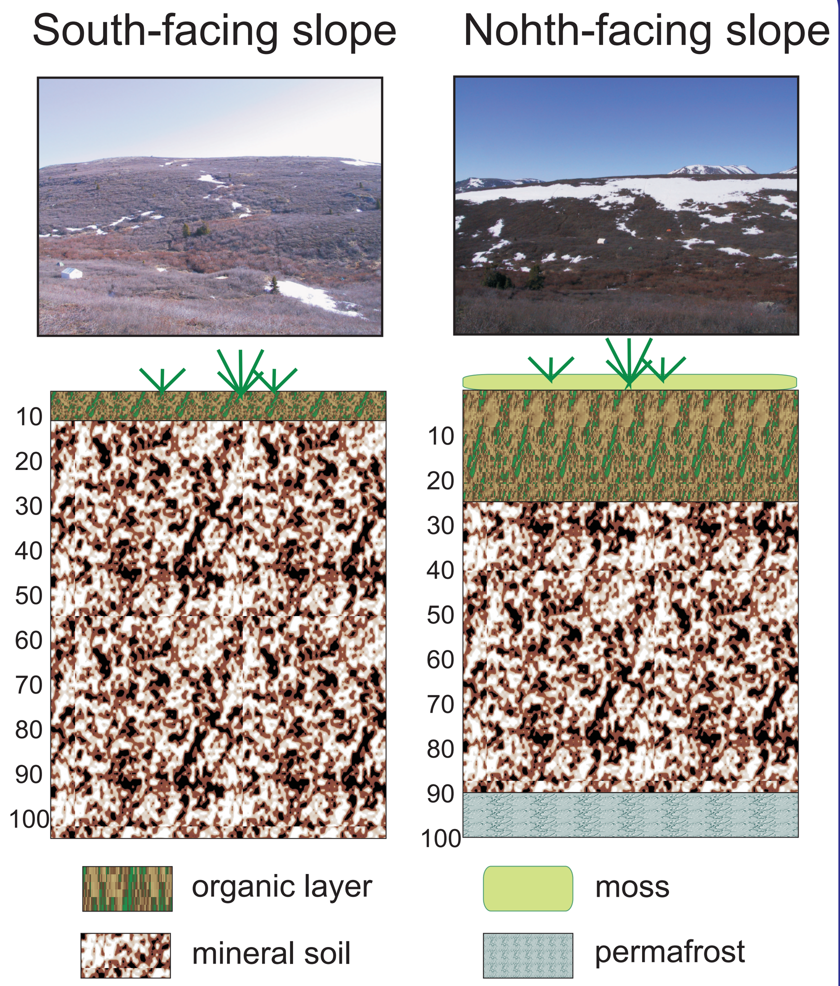

Fig.2. Soil profiles of north-facing and south-facing slopes

6.Comparison of process simulations by the Hydrograph and CRHM models

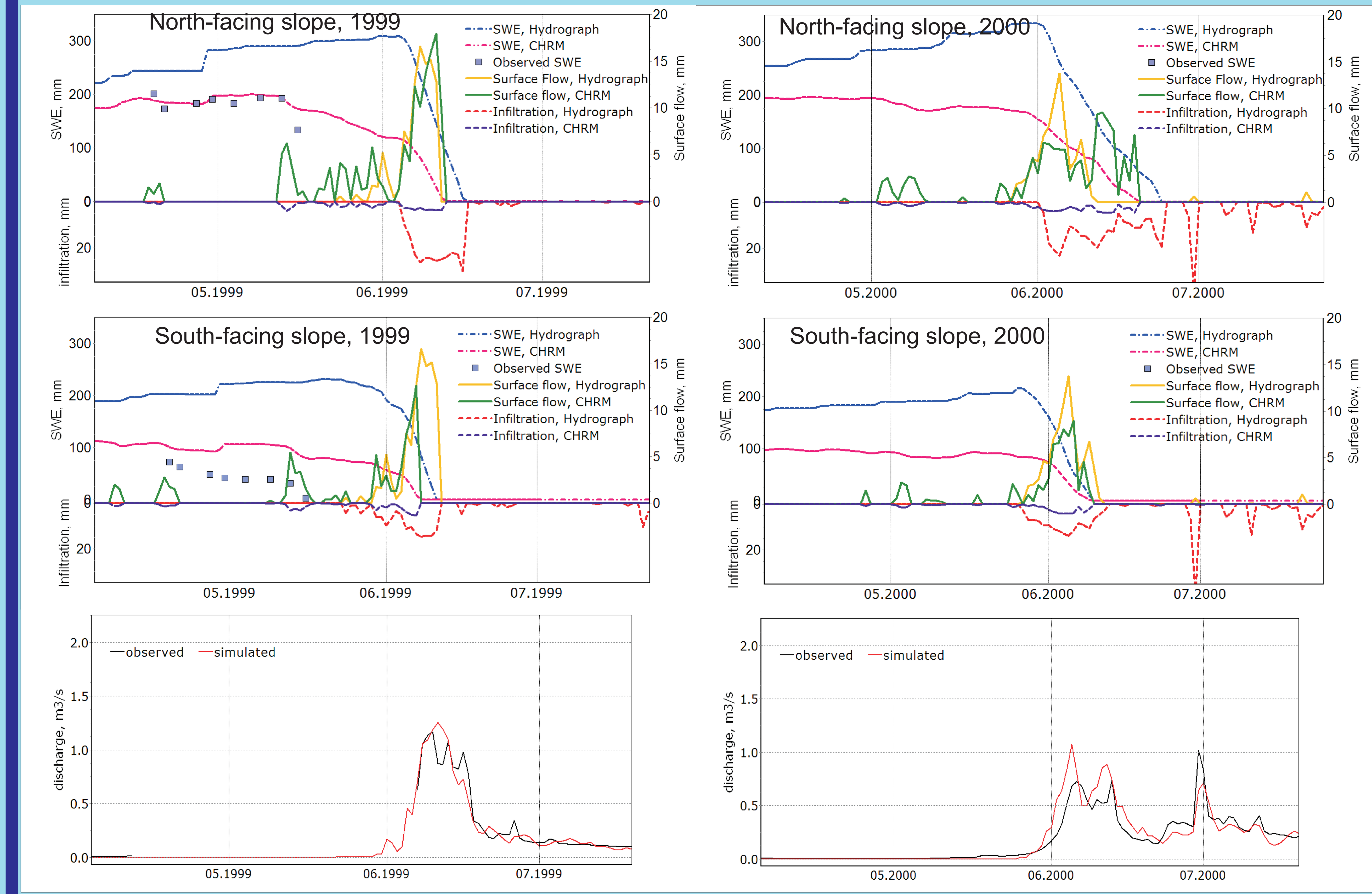

Fig.3. Calculated according to CRHM and Hydrograph models snowmelt, infiltration and surface runoff. Observed and calculated according to the Hydrograph model runoff. Snowmelt period 1999 and 2000.

7.Summary

1) Comparison of two approaches is complicated by not equal input rates of snowmelt. CRHM includes physically-based snow blowing model while the Hydrograph model accounts for snow redistribution only statistically.

2) The rates of simulated surface flow by both models matches quite satisfactory by absolute values as well as peaks timing. Although Hydrograph model frozen soil infiltration rates are always higher than for CRHM.

3) Deficiency of the Hydrograph model approach is the necessity to calibrate the infiltration coefficient by runoff if its observed values are not available.

4) Deficiency of CRHM approach is the necessity to make double loop in simulations to obtain the infiltration opportunity time.

5) Interesting conclusion is that the simulations results by empirically estimated CRHM equation are in a good coincidence with those calculated using conceptual approach of the Hydrograph model.

8.References

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2) Vinogradov, Y. B., Semenova, O. M. and Vinogradova, T. A. (2010) An approach to the scaling problem in hydrological modelling: the deterministic modelling hydrological system. Hydrol. Process., n/a. doi: 10.1002/hyp.7901

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