Snow processes in bucket-type hydrological models – does increased realism lead to better simulations?

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HBV model - a typical bucket-type model

- Semi-distributed rainfall-runoff model
- Developed at SMHI, Sweden (Bergström, 1976; Lindström et al., 1996)
- Simple model structure
- Few model parameters (~10-15)
- Low data requirements
- Our version: ‘HBV light’

Seibert and Vis, 2012, HESS
Snow routine of the HBV model

• Threshold temperature $T_T$

• Degree-day method for snowmelt

$$M = C_{FMAX} (T - T_T) \quad [\text{mm d}^{-1}]$$

• Snow pack retains some melt water ($C_{WH}$, usually 0.1)

• This water can refreeze

$$M = C_{FR} C_{FMAX} (T_T - T) \quad [\text{mm h}^{-1}]$$

$C_{FR} = \sim 0.05 \ [-]$

Seibert and Vis, 2012, HESS
Can we improve the snow routine?

...while maintaining HBV’s characteristic simplicity and low data requirements.

Philosophy: which model will fly?
Should we improve the snow routine?

All models are wrong, but some are useful

(George Box)

Models that are less wrong, might be more useful
"Snow towers"

Freudiger et al., 2017, WIRES Water
Simple snow redistribution approach

Stahl et al. 2016&2017, KHR report

Figure modified from Stefanie Bittner, MSc thesis Uni Freiburg
Model improvement

No snow redistribution

Freudiger et al., 2017, WIRES Water

Observations

Simulations

With snow redistribution
Possible snow routine modifications
Possible snow routine modifications

- Precipitation
- Temperature
- Rain/snow partition
- Global radiation
- Threshold
- Degree-day factor
- Snowmelt
- Relative humidity
Temperature lapse rate

Rolland (2002)
Rain-snow partition

Froidurot et al., 2014

Magnusson (2014)
Rain-snow partition

Abrupt

Gradual
Degree-day factor

\[ M = C_0 \ (T - T_T) \]

\[ C_0(n) = C_0 \]

\[ C_0(n) = C_0 + \frac{1}{2} C_{0,i} \sin \frac{2\pi (n - 81)}{365} \]
Possible snow routine modifications

= 64 combinations
54 test catchments in Switzerland and the Czech Republic

Circle size ~ snow melt contribution (5 – 38 %)
Model setup

18 years of data
(2 y warming up, 8 y calibration, 8 y validation)

P, T and Q (daily data)

SWE: station data (for CH: interpolation by SLF, Tobias Jonas)

Evaluation:
NSE of $\log(Q)$ and SWE
A lot of model runs ...

64 Model modification combinations
54 Catchments
2 Objective functions
2 Time periods
10 Calibration trials, each with 3500 model runs

= almost 500 million model runs
Effect of single modifications

Example for one catchment (Allenbach)
Effect of a single modification for the different catchments

Variable DDF = improvement

More snow

Less snow

Large variability between catchments
Ranks of the modifications in the different catchments

Snow Calibration
Ranks of the modifications in the different catchments

Calibration

Validation

Snow

Runoff

Percentage of catchments [%]
Combination of modifications
Snow Calibration

Cumulative frequency ($R_W$)

Ranked model alternative
No clear improvements - Why?
Unce upon a time ...

Brugga catchment
(450 – 1400 m a.s.l.)

Uhlenbrook et al., 1999, HSJ
Effect of number of elevation zones

Uhlenbrook et al., 1999, HSJ

Brugga catchment (450 – 1400 m a.s.l.)
More catchments?

Other evaluation criteria?

Additional data for evaluation?

Other modifications?
Spatial distribution of snow cover

A

Homogeneous

B

Redistributed

C

Heavily redistributed

Snow melt runoff

Runoff

Time

Freudiger et al., 2017, WIRES Water
Thank you! – Questions?

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Seibert and Vis, 2012, HESS

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