Estimation of dynamic storage across northern catchments

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Background

The volume of water stored within a catchment and its partitioning between the snowpack, soil moisture, groundwater, vegetation and surface water characterize the state of the hydrologic system and regulate streamflow responses. While storage is relatively straightforward to conceptualize and define, it is difficult to measure. Thus, although the important role of storage is widely recognized, the spatial distribution of storage within catchments is usually unknown and the dynamics are not completely understood; particularly in northern snow-influenced regions. This study is part of the ERC funded VeWa project (Vegetation effects on Water flow and mixing in high-latitude ecosystems, led by D. Tetzlaff), which aims to improve our understanding of the role of vegetation in the partitioning of water along a cross-regional gradient.

Objective

To compare the distribution and dynamics of storage across a transect of 5 northern catchments with varying snow influence using a hydrological model.

Figure 1. Locations of the five VeWa catchments.

Data and approach

- Five catchments (Fig. 1): Wolf Creek (Canada, 7.6 km^2, P = 472 mm y^{-1}, annual mean T = -2°C), Krycklan (Sweden, 0.5 km^2, P = 637 mm y^{-1}, annual mean T = 1.8°C), Dorset (Canada, 1.2 km^2, P = 1023 mm y^{-1} , annual mean T = 4.8°C), Girnock (Scotland, 30 km^2, P = 1000 mm y^{-1}, annual mean T = 6.6°C), Dry Creek (US, 28 km^2, P = 653 mm y^{-1}, annual mean T = 9°C)
- Sites cover range of climates, with contrasting snow influence and flow regimes (Fig. 2)
- Long-term time series of observed precipitation, temperature and runoff (length time series ranges from 11 to 27 years), Thorntwaite method for PET
- HBV-light model applied to all sites (Seibert & Vis, 2012)
- Initial analysis used basic model structure; 1 vegetation zone, 1 elevation zone
- 1 million Monte Carlo runs, 100 best parameter sets selected based on Nash-Sutcliffe efficiency (NS), 20 best parameter sets used for storage simulation

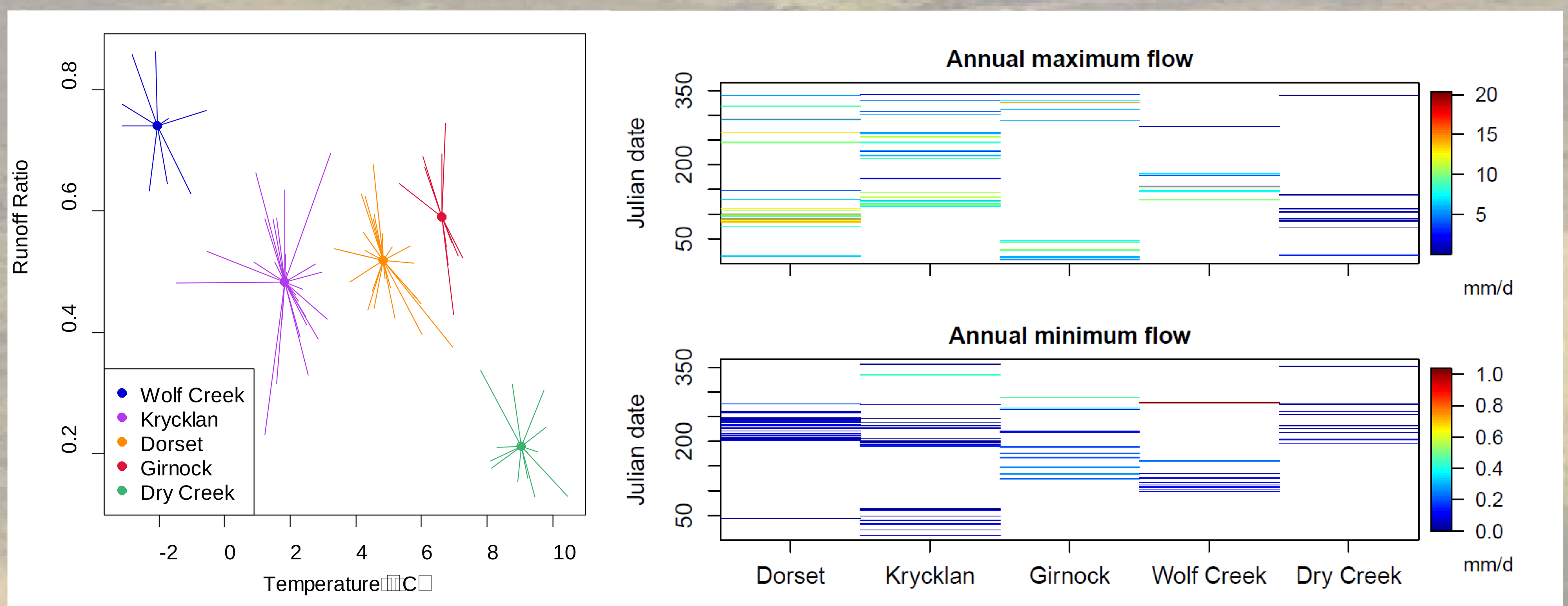

Figure 2. Comparison catchments based on observations. *Left)* Mean annual temperature versus mean annual runoff ratio. *Right)* Timing and magnitude of annual maximum and minimum flows.

Results

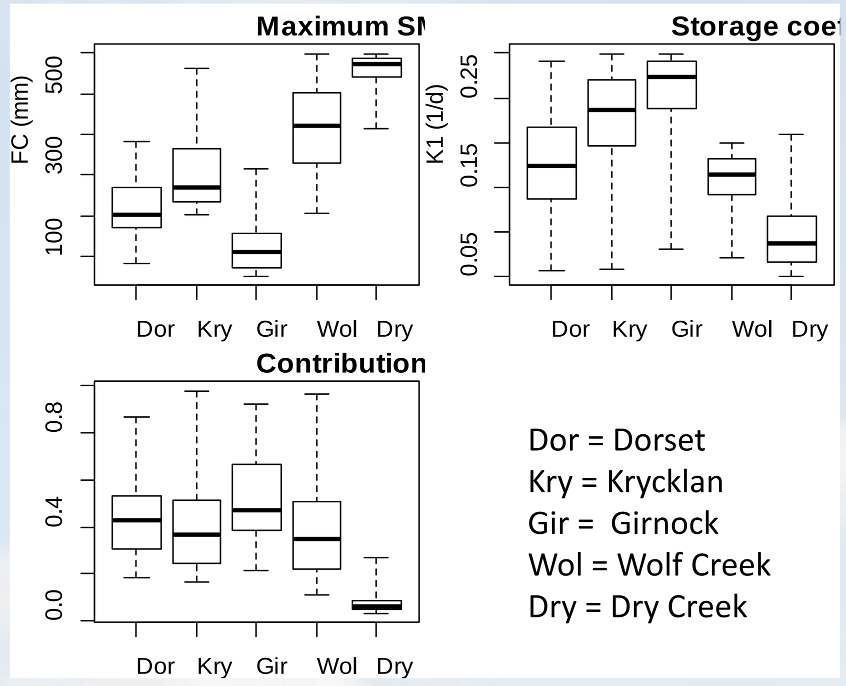

Figure 3. Range of selected parameters from retained 100 best parameter sets.

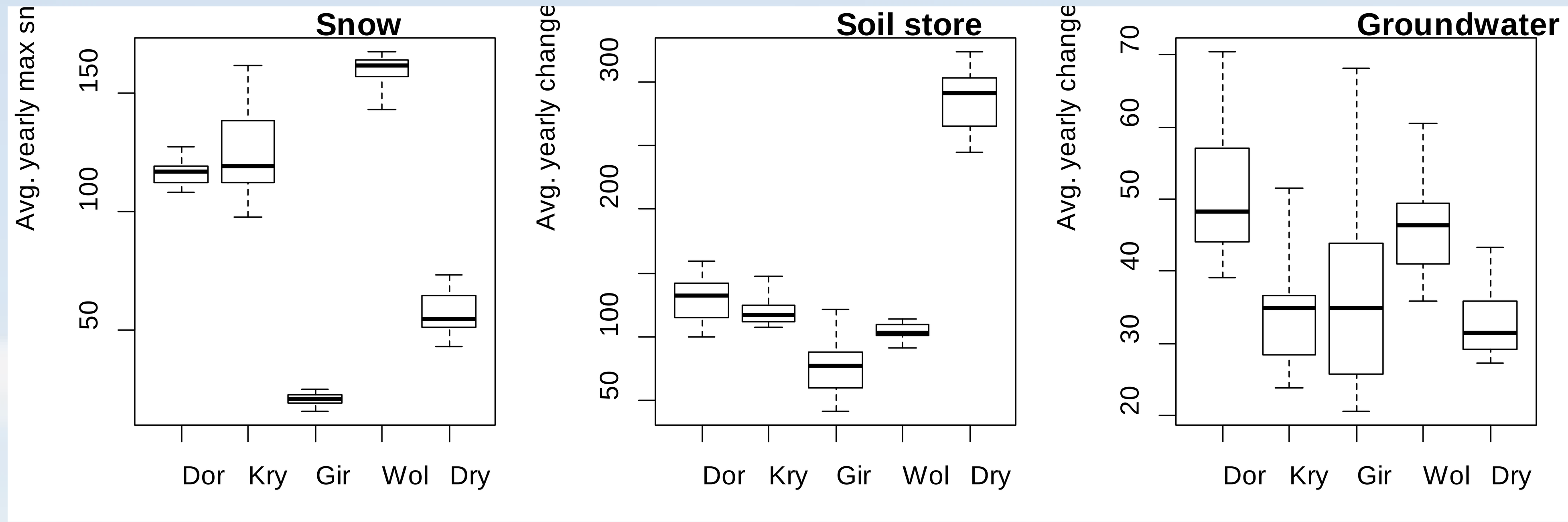

Figure 4. Range in storage values over 20 model runs. From left to right: Mean annual snowpack, mean annual change in soil moisture store, mean annual change in groundwater stores.

- Performance for initial models was reasonable, mean NS was >0.6 for Dorset, Krycklan and Girnock, but only ±0.5 for Wolf Creek and Dry Creek. The lower efficiency for Wolf Creek is mainly due to difficulties measuring winter low flows when the stream is frozen. For Dry Creek the initial model structure might be too simple given the large elevation differences and associated vegetation distributions.
- The parameter ranges reflect the catchment responses. Dry Creek is the most attenuated, with greater ET, high soil storage, and a low contribution of upper groundwater (i.e. high contribution lower groundwater), whereas Girnock has a fast response and shows lower soil storage and more rapid groundwater responses (Figs. 3 and 5). These two catchments had the lowest snow influences.
- Low flows were not well simulated in Krycklan, Wolf Creek, and Dry Creek, though annual melt events were reproduced quite well.
- Snow dynamics were well captured by the model with the largest snow packs at Wolf Creek, Krycklan and Dorset (Figs. 4 and 5).
- All catchments showed larger changes in the soil moisture store than in the groundwater stores (Figs. 4 and 5).
- The uncertainty in storage values for the different model runs was large. However, for the soil moisture store all model runs showed similar dynamics. The dynamics in the groundwater stores changed between model runs, especially in the Girnock (Fig. 5).

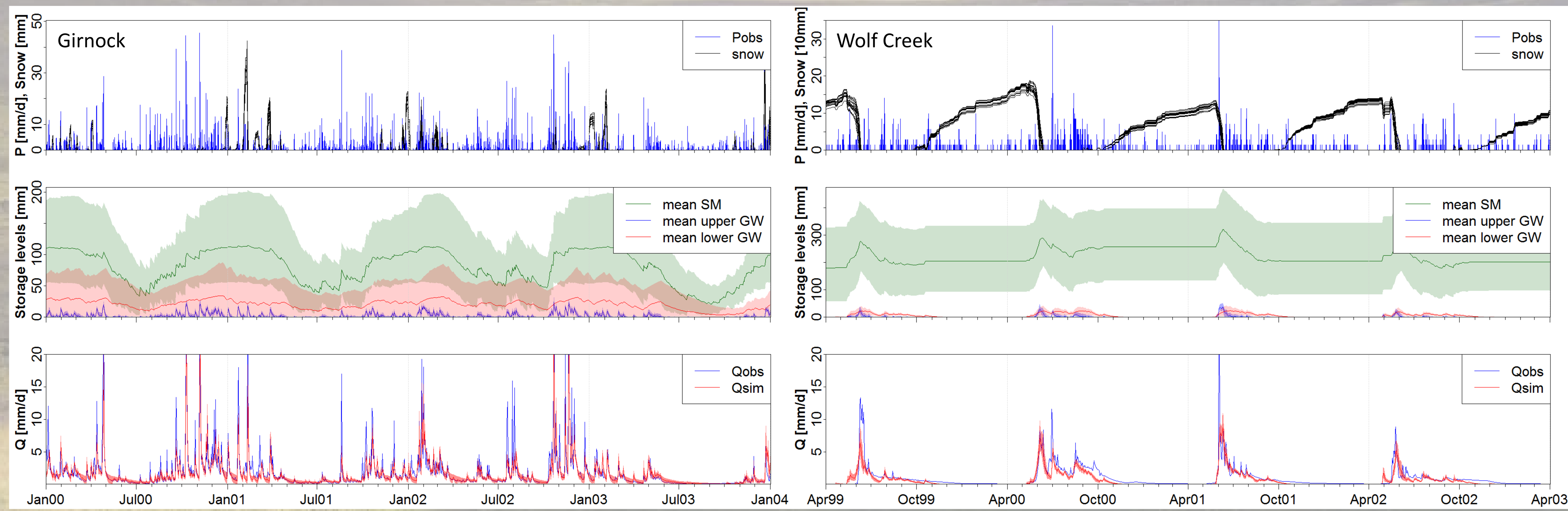

Figure 5. Examples of 4-year time series of model results for Girnock (left) and Wolf Creek (right). *Top row)* Observed precipitation and modelled snow, *middle row)* Storage levels, lines are means from 20 model runs, the coloured band indicates the range, *bottom row)* Observed and simulated discharge.

Conclusions

- The simple model application is a useful first step as a learning framework to understand storage dynamics.
- Differences in storage dynamics reflect the hydroclimate with a strong snow influence, and the amount and timing of snowmelt.
- Improved simulations and reduced uncertainty are likely if field data are used to constrain parameters and more complex model structures are implemented.

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VeWa project

Seibert, J. and Vis, M. J. P. (2012) Teaching hydrological modeling with a user-friendly catchment-runoff-model software package, *Hydrol. Earth Syst. Sci.*, 16, 3315-3325, doi:10.5194/hess-16-3315-2012.

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