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Improving hydrological simulations in the Prairies using in-situ soil moisture information

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INTRODUCTION

- Traditionally, hydrological models are only trained to accurately reproduce the streamflow regime without considering other hydrological state variables such as soil moisture and evapotranspiration.
- Limited studies have been performed on constraining the state variables, which may provide large degree of freedom, resulting in equifinality and poor model performance.
- In this study, a multi-objective optimization approach is adopted, and both streamflow and soil moisture data are calibrated simultaneously for an experiment study basin in the Saskatchewan Prairies in western Canada.
- The novelty of this study is to improve the model predictive abilities in a Prairie basin that comprises variable contributing areas with thousands of shallow wetlands that only drain in wet period.

STUDY BASIN

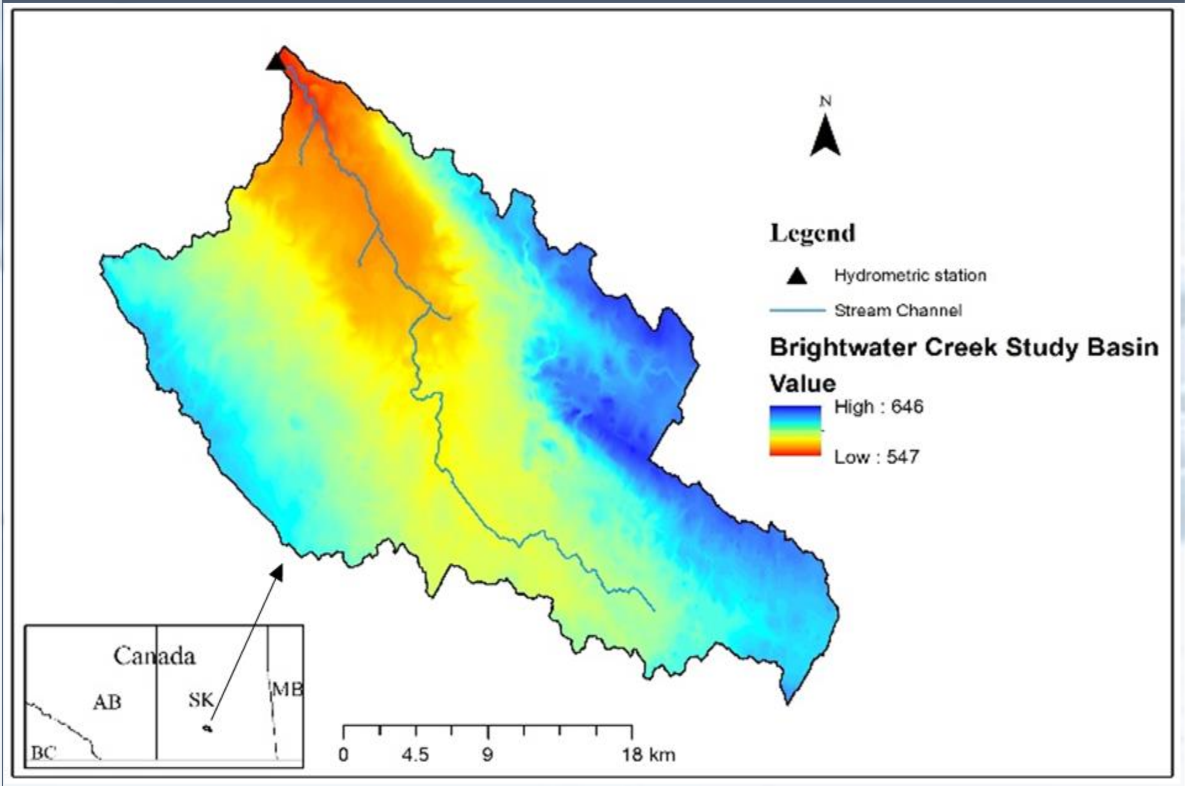

Fig 1. Brightwater Creek (BWC) Basin

- **Gross Drainage Area:** 864 km^2
- **Contributing Drainage Area:** 193 km^2
- **Mean annual precipitation:** 330 mm (2009-2014)
- **Land cover:** Predominantly cropland (cereals, oilseeds), patches of native grasses (wheatgrass, needle grass)
- **Soil Texture:** Loam to clay loam

METHODOLOGY

Hydrological model:

- MESH- PDMROF, a physically-based hydrological and land-surface model[1,2]
- PDMROF uses the concept of the Probability Distributed Model[3] to parsimoniously represent the runoff and storage in the Prairies.

Data required:

- Meteorological forcing data
- Soil moisture, evapotranspiration and hydrometric data

Model calibration:

- OSTRICH[4], a model–independent and multi-algorithm optimization program was used.
- Parallel Dynamically Dimensioned Search (PDDS) algorithm[5] for single objective optimization.
- ParaPADDS algorithm[6] for multi-objective optimization.

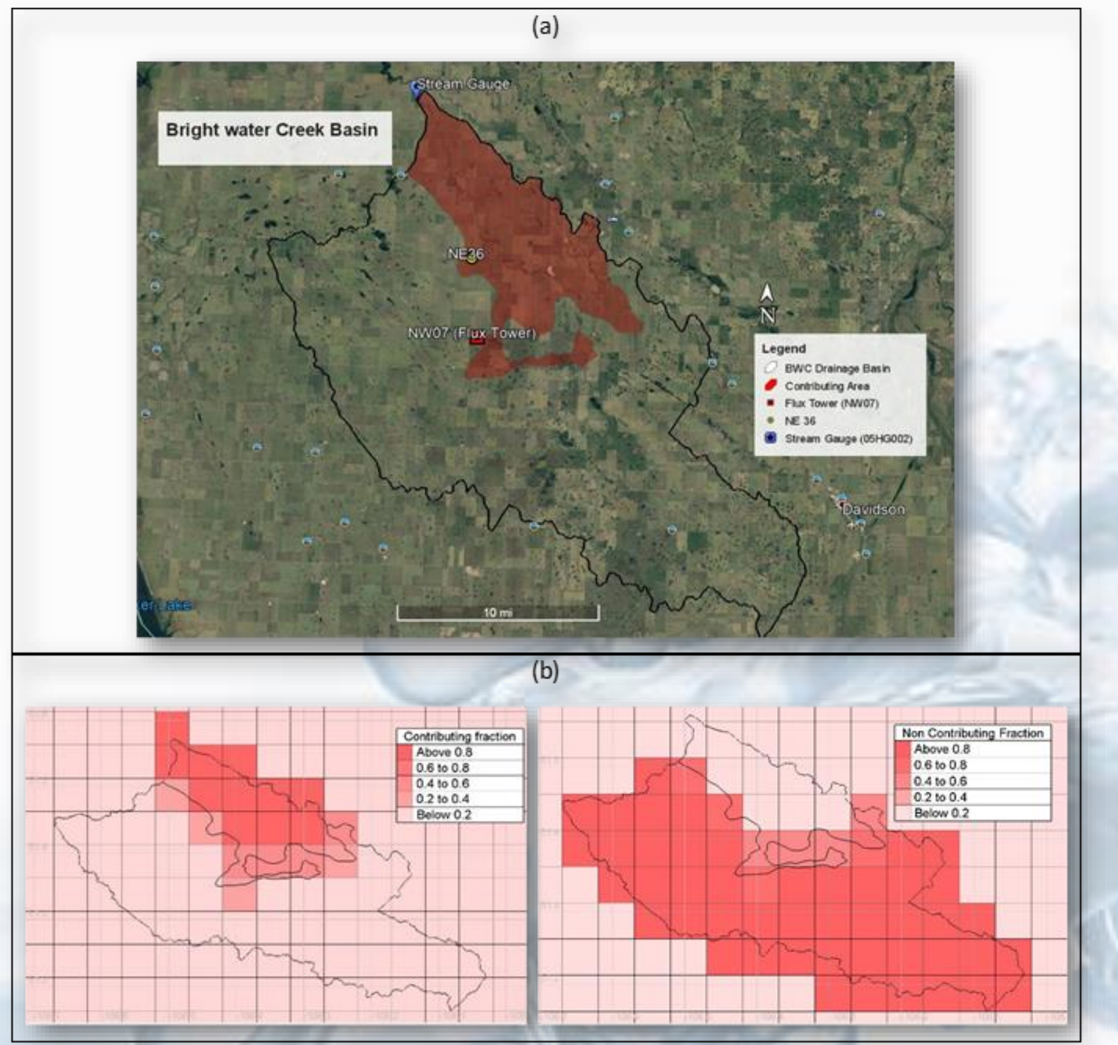

Fig 2. The study site. a) BWC Basin with tipping bucket station locations b) GRU delineation for contributing and non-contributing in Green Kenue for MESH

RESULTS

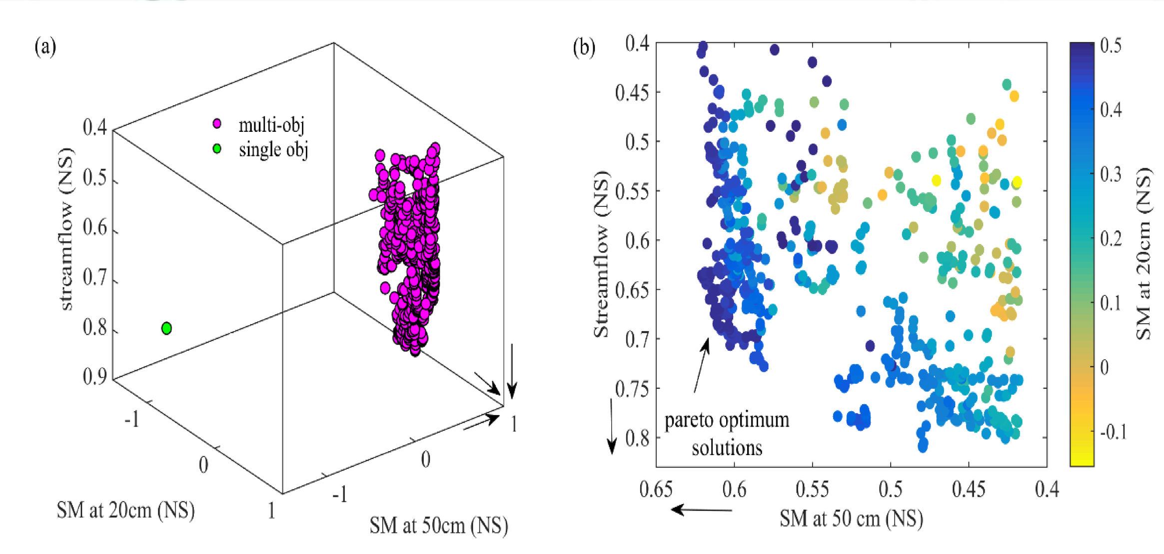

Fig 3. Result of model calibration with single and multi objective calibration (a) Full 3D Pareto runs (b) Two dimensional projection of Pareto runs from multi-objective calibration and the selected Pareto optimum solutions

The single objective calibration with streamflow resulted in higher NSE i.e.0.78 in the calibration period, but had lower NSE values of -1.58 and -1.721 for soil moisture at 20 cm and 50 cm depths, respectively. In contrast, the pareto optimum solution using multi-objective calibration resulted in higher NSE for streamflow [0.74-0.75], and soil moisture (20 cm [0.30-0.41] and 50 cm [0.42-0.53]).

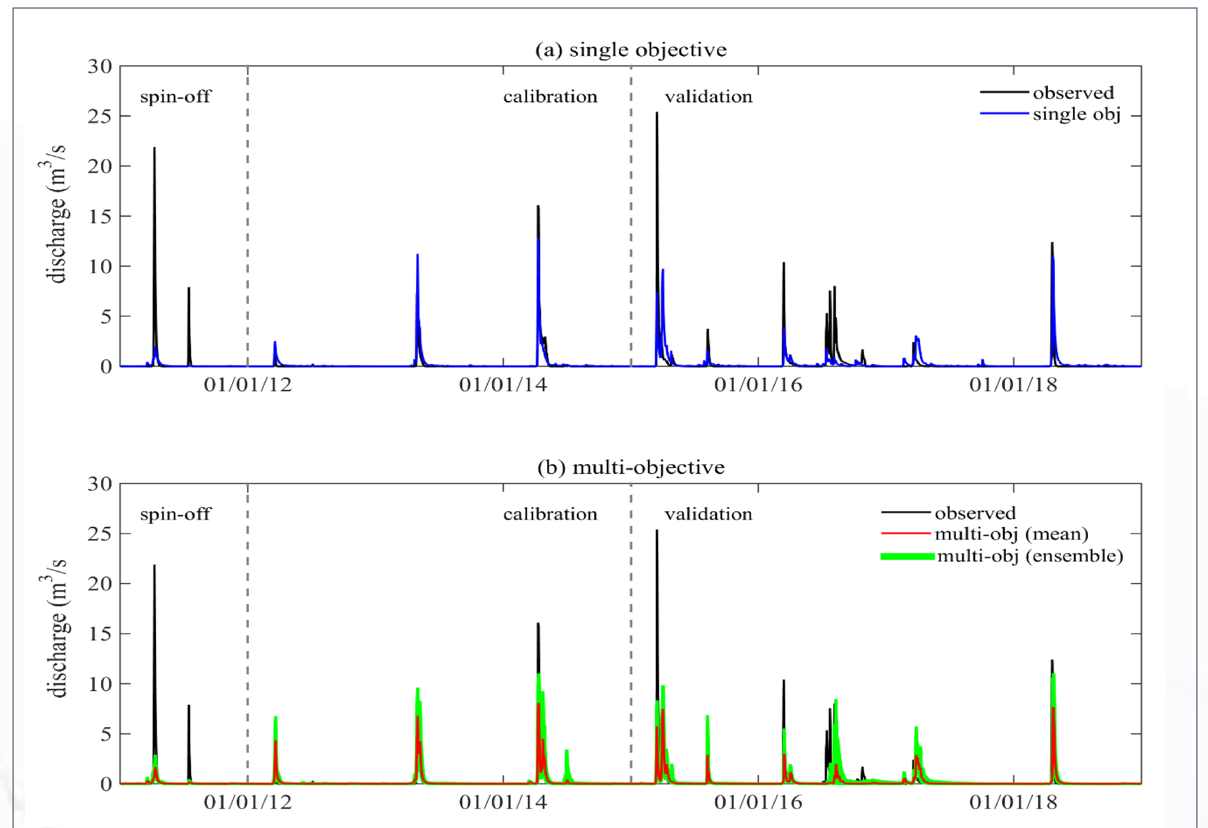

Fig 4. Observed and simulated streamflow at BWC

The single objective calibration of streamflow resulted the NSE of 0.78 and 0.49 for calibration and validation, respectively. Whereas, the multi-objective calibration produces a mean ensemble of streamflow of NSE 0.72 and 0.48 for calibration and validation, respectively.

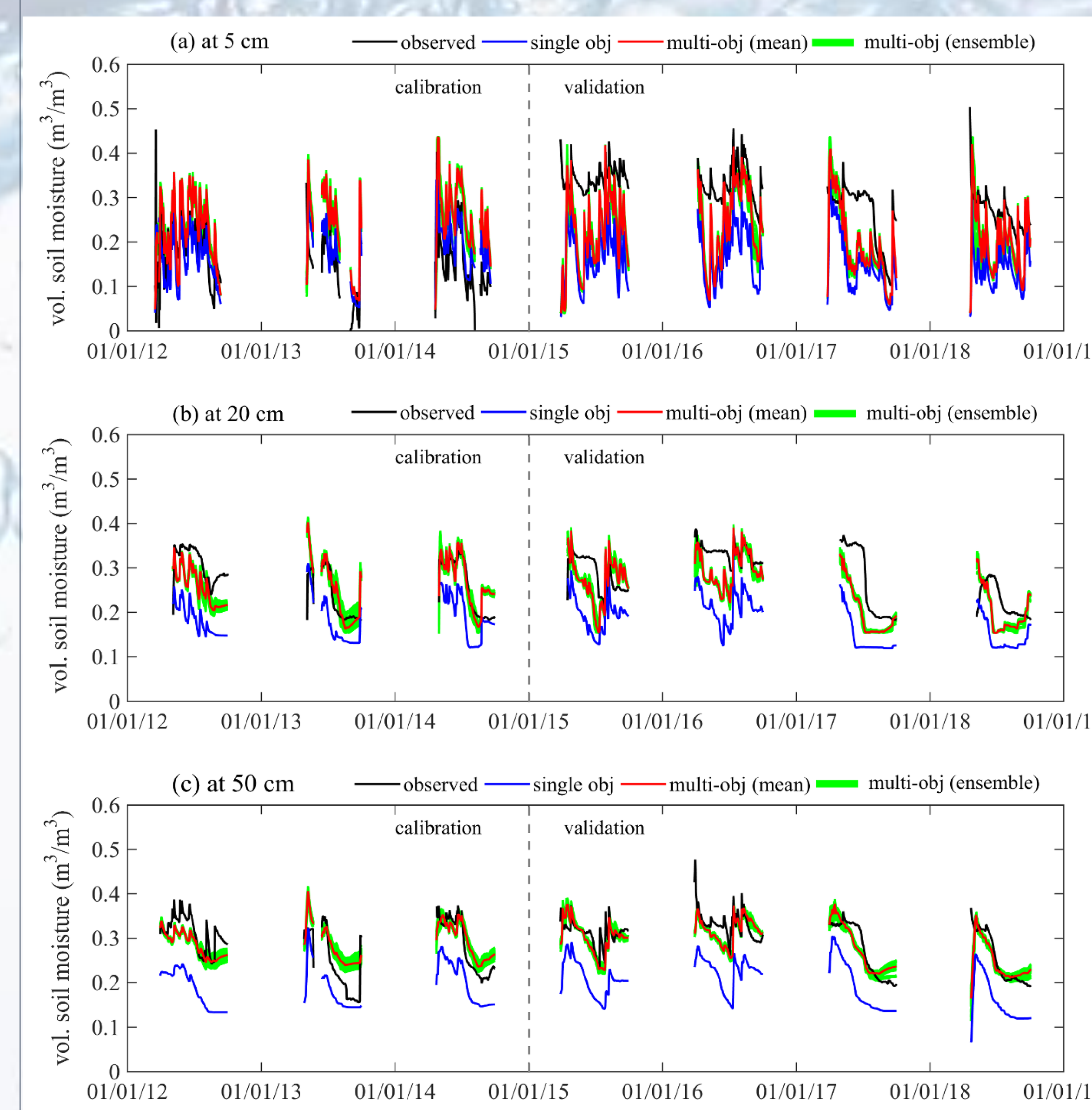

Fig 5. Observed and simulated soil moisture at NE36 station

Statistics	Single objective calibration (5 cm)	Mean Multi-objective calibration (5 cm)	Single objective calibration (20 cm)	Mean Multi-objective calibration (20 cm)	Single objective calibration (50 cm)	Mean Multi-objective calibration (50 cm)
NSE	-0.169 (-6.103)	-0.10 (-1.78)	-1.58 (-6.103)	0.44 (0.251)	-1.721 (-2.580)	0.562 (0.655)

Table 1: Statistics of soil moisture calibration (within parentheses are the values from model validation)

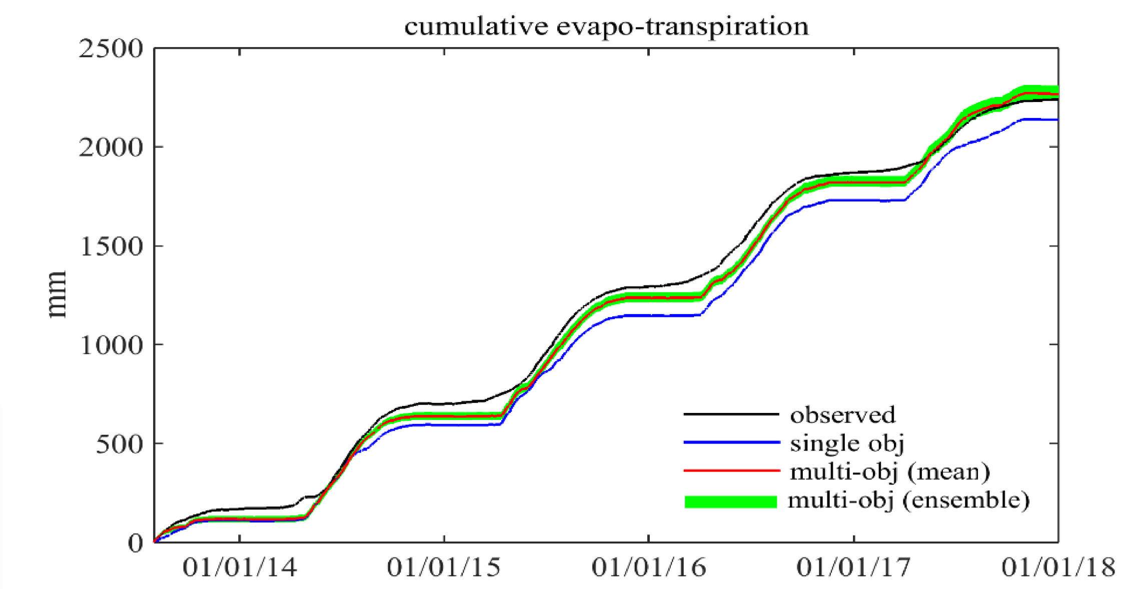

Fig 6. Observed and simulated Evapotranspiration at BWC

The cumulative observed ET at the end of 2017 was 2239 mm with 2266 mm from the mean of multi-objective ensemble and 2135 mm from the single objective. The single objective calibration resulted in underestimation of ET, whereas addition of the soil moisture as an objective function, improved the simulation of ET.

CONCLUSION

- The study demonstrates that, single objective calibration performed against only streamflow can fairly mimic the streamflow hydrograph but does not yield realistic estimation of other fluxes such as evapotranspiration and soil moisture (especially in deeper soil layers).
- The results also show that multi-objective calibration reduces uncertainty in the model parameters and improves the model performance in simulating deeper layer soil moisture and ET without significantly deteriorating the accuracy of the streamflow.
- Although the study was performed on a small experiment basin, the results are promising and further experiments and studies are required to upscale the study to other large Prairie basins.

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