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Soil Moisture Accounting for Nelson Churchill River Basin using HYPE

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01. Introduction

Hydrological models are important tools to analyse the cold regions processes, such as permafrost, seasonally frozen soil and snow cover, which are widely distributed across Canada. Improvement of the hydrological models to better represent the cold regions processes is one the core objective under Theme A2 of IMPC. In cold regions, frozen soil processes play a key role in generating the runoff by restricting the infiltration during the frozen state, and thawing during the melting phase. Therefore, the improvement of such processes can significantly boost the confidence in model projection for historical and climate change scenarios, and hence reduce the uncertainty associated with it.

Objectives:

- To improve the reliability of HYPE model to simulate soil moisture for NCRB, emphasizing on the frozen soil processes.
- To validate model results with observed soil temperature and soil moisture recorded at several locations within NCRB
- To investigate future climate change impacts on soil moisture and soil temperature using the improved HYPE-NCRB model, and their implications on the uncertainty associated with the projection of streamflow.

02. Study Area

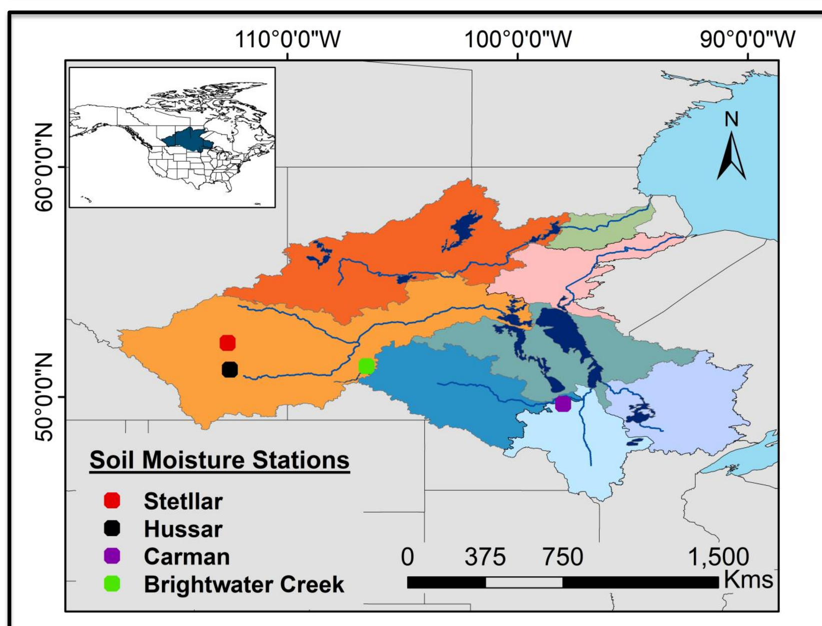

Fig 1 Study area with location of soil moisture monitoring stations within NCRB

- NCRB drains over 1.4 millions sq. km approximately (Fig 1).
- Recorded soil moisture data are available starting from 2013.
- Most stations record soil temperature and soil moisture at 20 cm depth, 50 cm depth and 100 cm depth from ground level.
- Hydro-GFD meteorological reanalysis dataset is used for model setup (Berg et al., 2018).

03. Soil Moisture Accounting in HYPE

- HYPE is a semi-distributed model discretized at sub-basin level.
- A sub-basin in HYPE is further divided into classes or SLCs (unique LULC - Soil combination), similar to HRUs (Hydrological Response Units).
- Soil routine in HYPE consists of up to three consecutive soil layers with soil depths given in meters (Fig 2).

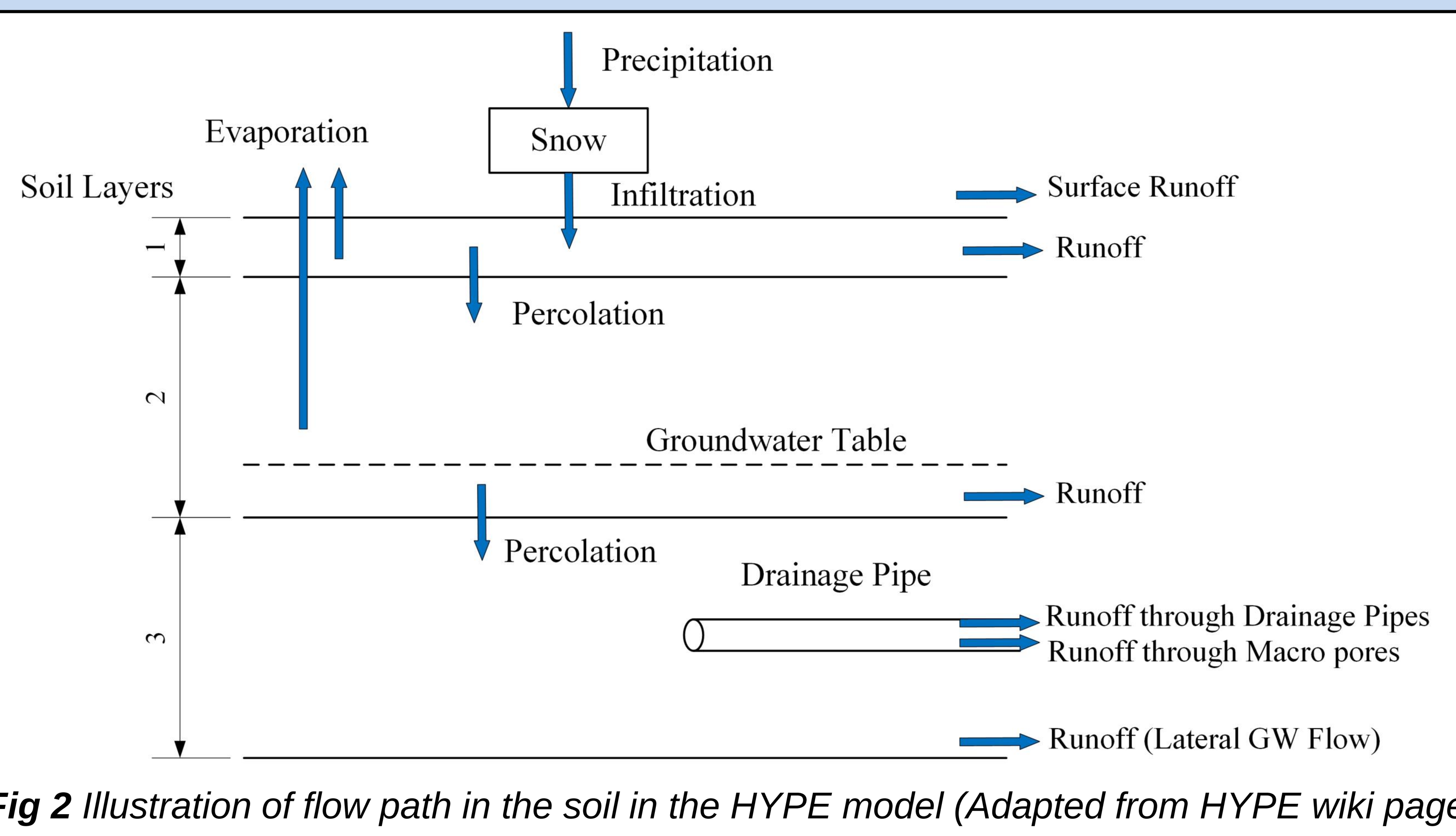

Fig 2 Illustration of flow path in the soil in the HYPE model (Adapted from HYPE wiki page)

- Infiltration in HYPE is calculated from the sum of rainfall and snowmelt.
- If ∑(rainfall+snowmelt) > infiltration capacity, a part of water will not infiltrate into the soil.
- The calculation of actual infiltration considers the effects of surface runoff, macro pore flow and frozen soil.

04. Frozen Soil Infiltration

- If soil temperature > 0°C, liqfrac(k) =1 (normal infiltration, soil water from all layers is available for runoff)
- If soil temperature < 0 °C, liquid water content is calculated based on freezing point depression equation (Clapp and Hornberger, 1978).

$$\theta_{l,max} = \theta_S \left(\frac{L_F (T_{freeze} - T_{soil})}{g T_{soil} \psi_S} \right)^{-1/b}$$

where, $\theta_{l,max}$ is the maximum volumetric liquid water content (m^3 m^{-3}), θ_S is the saturation volumetric water content or porosity (m^3 m^{-3}), LF is the latent heat of fusion (3.34 × 105 J kg^{-1}), T_{freeze} = 273.16 K, T_{soil} is soil layer temperature (K), g is gravitational acceleration (9.81 m s^{-2}), ψ_s is soil water potential at saturation (m), and b is the shape coefficient of the soil water potential-moisture curve (MacDonald et al., in revision).

05. Preliminary Results

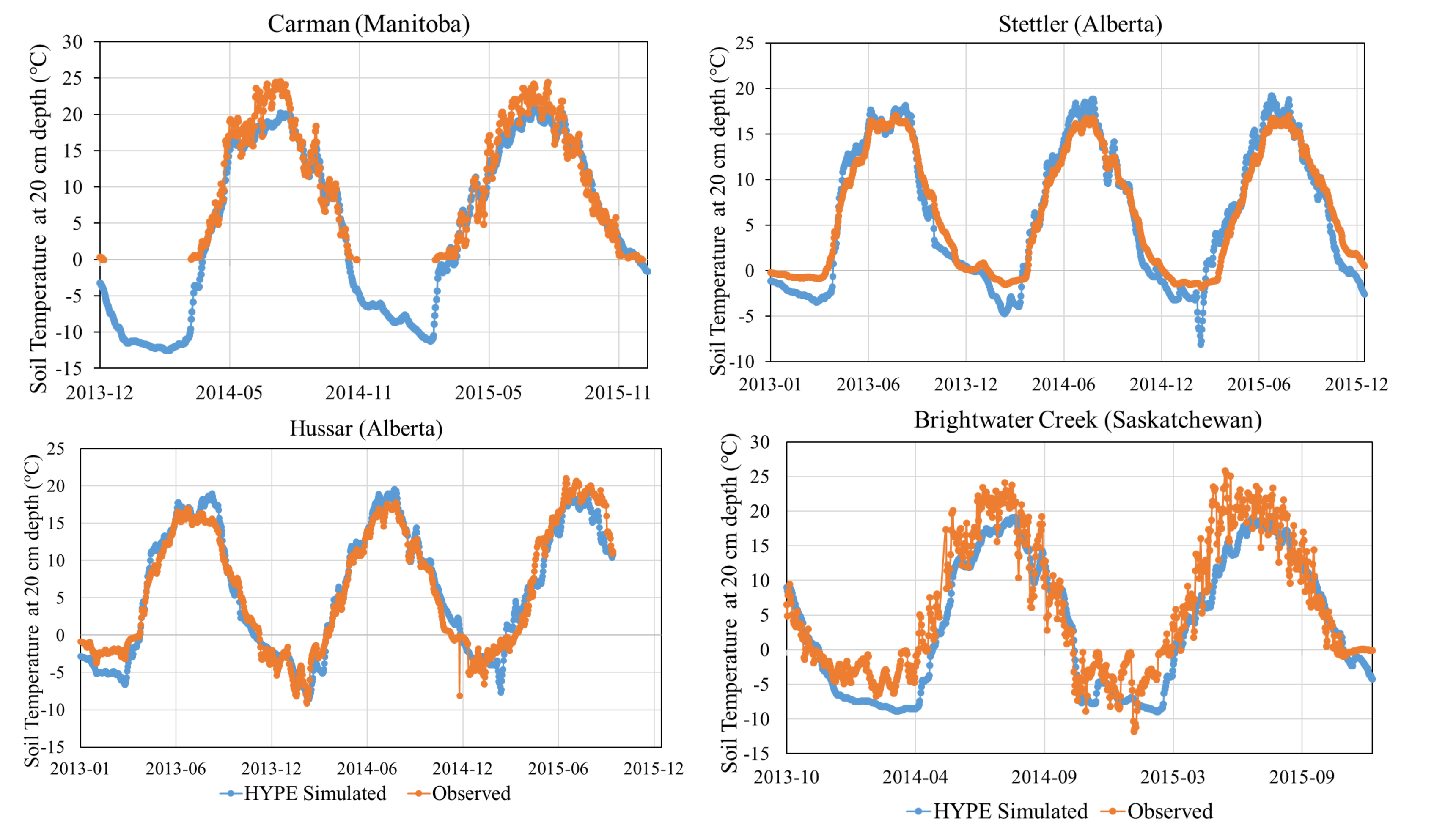

Fig 3 Simulated soil temperature vs observed soil temperature at several locations within NCRB at 20 cm depth.

- The simulated soil temperature from HYPE (20 cm depth) at different locations were validated with measured temperature (Fig 3).
- Soil temperature simulated in HYPE from 2013 to 2015, at 20 cm depth, matches well with the observed data for all the locations within NCRB.

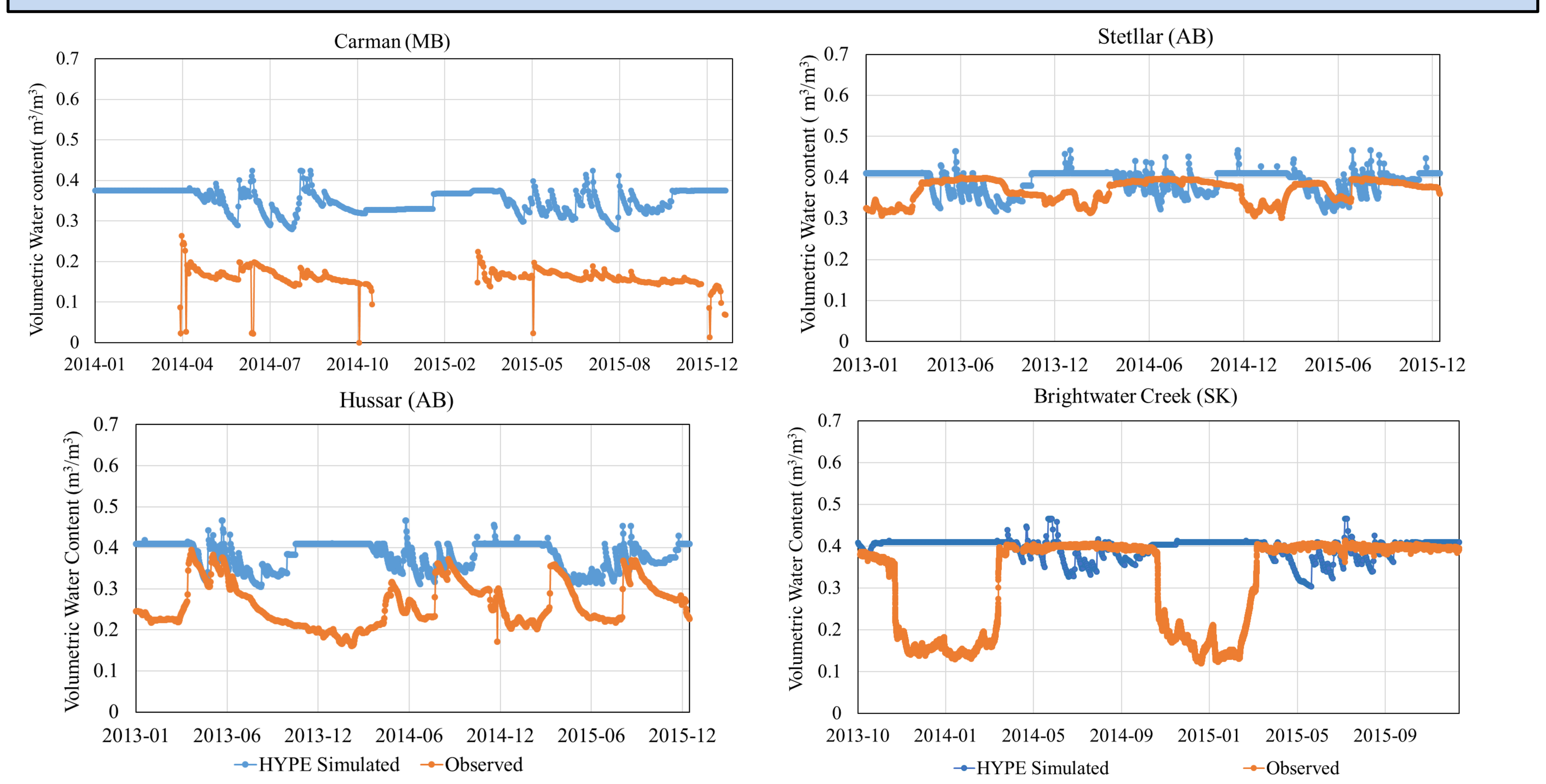

Fig 4 Simulated soil moisture vs observed soil moisture at several locations within NCRB at 20 cm depth.

- The soil moisture simulated by HYPE at 20 cm depth fails to capture the soil moisture during the winter months, when infiltration is low and soil moisture drops significantly (Fig 4).
- The simulated soil moisture is significantly higher and remains more or less constant during the freezing period.
- The results could be improved by integrating suitable frozen soil infiltration to limit the soil moisture during winter season, and further calibration of soil moisture parameters will be required.

06. Future work

- Improve HYPE-NCRB model to simulate the soil moisture more accurately, especially during winter.
- The frozen infiltration will be implemented layer by layer based on soil layer temperature.
- The progressive freezing and thawing of soil layers based on soil layer depth will be accounted.
- Analyze future climate change impacts on soil moisture and soil temperature using the improved HYPE-NCRB model, and analyze the uncertainty associated with it.

07. References & Acknowledgements

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