Climate-Change Effects on Groundwater Recharge in the Prairies

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Research motivations and objectives

- There is a need to understand the response of prairie hydrological processes to climate change and their influence on groundwater recharge.
- The Versatile Soil Moisture Budget (VSMB) model was used to investigate hydrological process under the present climate (2006-2015). Moreover, the Weather Research and Forecasting (WRF) model outputs with 4 km resolution for the present climate and pseudo-global warming (PGW) conditions were used to model the future changes in hydrological processes in 2091-2100.
- The objective of this study is to understand how can the changes in precipitation phase and air temperature, and soil moisture and temperatures affect evapotranspiration, freeze-thaw, runoff, and groundwater recharge in the prairies using the Spyhill site near Calgary (Fig.1).

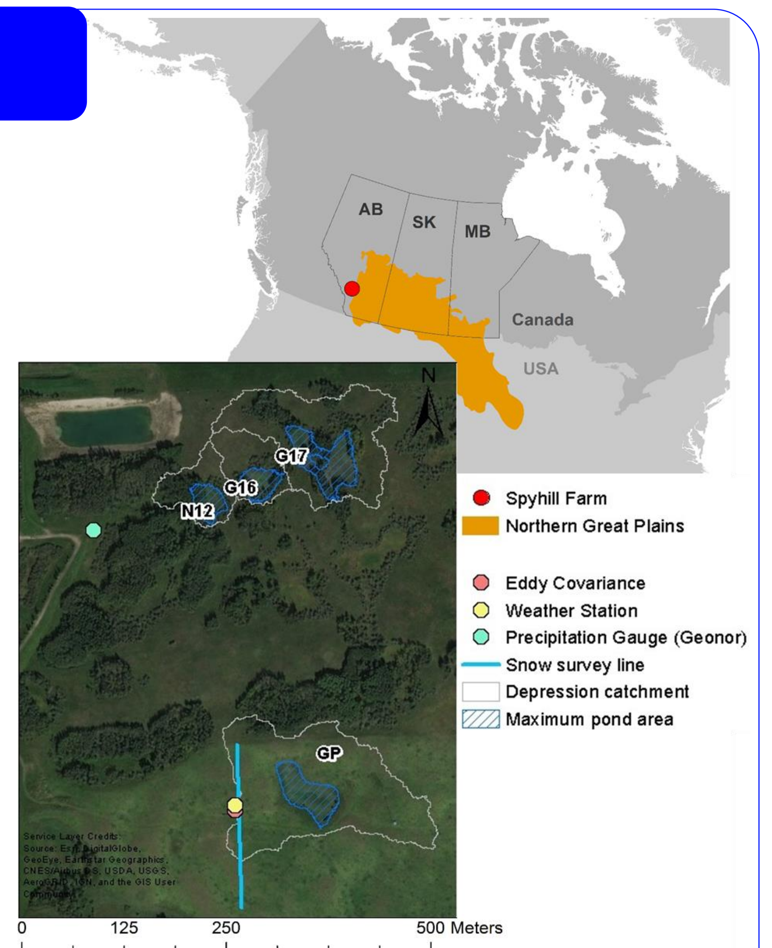

Figure 1 – Satellite graphs for Spyhill site, including the location of selected depressions (GP, N12, G16 and G17) and instrumentations.

Assessment of the model performance

➢ Groundwater recharge model

The VSMB calculates soil water balance on a daily basis for seven soil layers (five for depression) with thicknesses ranging between 0.05 m and 2.0 m (Fig. 2). Depression-focussed groundwater recharge is estimated using the VSMB Depression-Upland System (VSMB-DUS), which couples vertical soil water balances of depression and upland simulated by the VSMB, via lateral runoff from uplands to a depression.

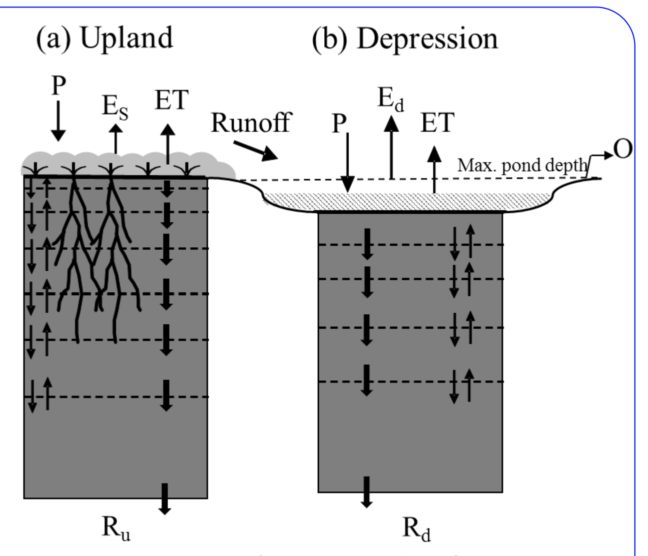

Figure 2 – Conceptual framework of VSMB-DUS model

➢ Evaluation of the potential evapotranspiration output of VSMB

- ➢ Preliminary simulations showed that calculated potential evapotranspiration (PET) is relatively insensitive to climate warming, as its temperature dependence is only reflected in changes in the slope of saturation vapour pressure – temperature curve. Therefore, an option was added in this study to define PET using the Penman-Monteith equation.
- ➢ Compared to observed data, simulated E captured the seasonality of vapour flux reasonably well (Fig. 4a), and had a MBE of 0.089 mm d^{-1} and RMSE of 0.71 mm d^{-1} (Fig. 4b).

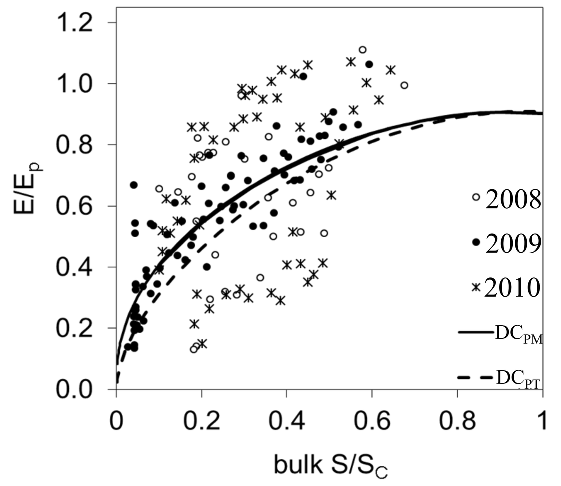

Figure 3 – The optimized drying curve (DC_{PM}) and the default drying curve (DC_{PT})

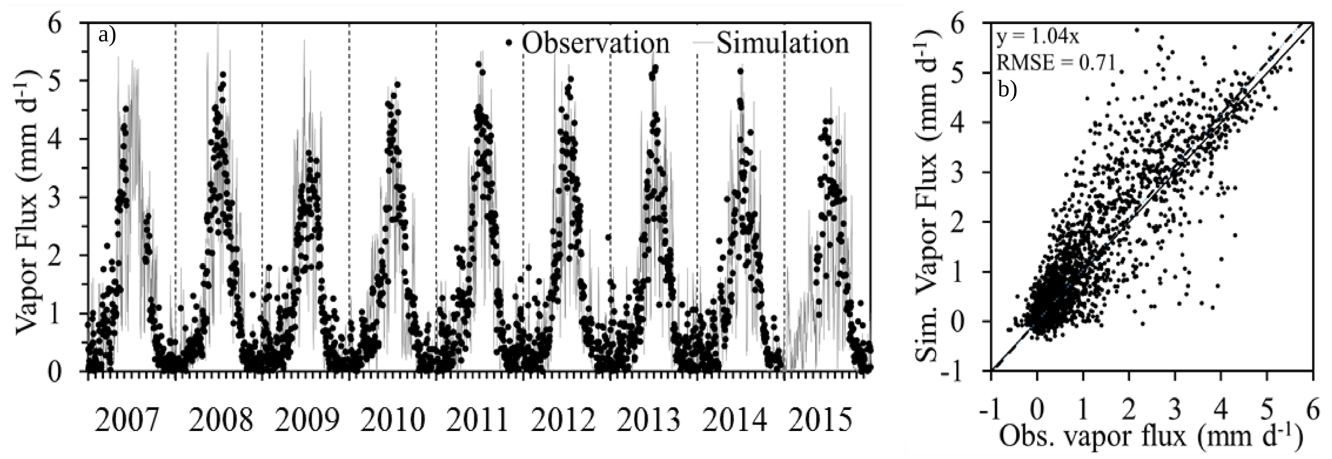

Figure 4 – Black dots represents observations and gray line represents simulations by the VSMB model during (2007-2015). The right panel (b) shows scatter plot of the observed and simulated vapor fluxes.

➢ Upland model outputs compared to observations

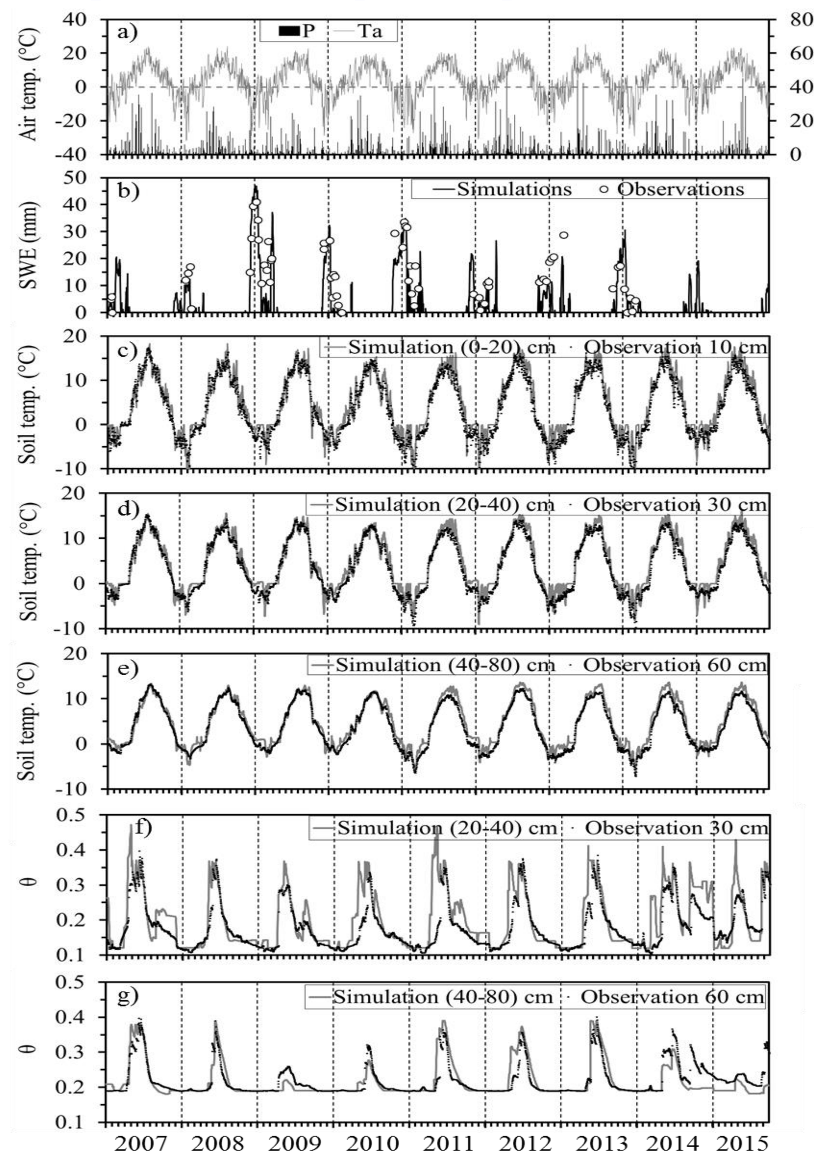

Figure 5 – (a) Observed daily precipitation (P) and mean daily air temperature (Ta), (b) observed and simulated snow water equivalent (SWE), (c, d & e) soil temperatures 10, 30 and 60 cm below the ground surface, (f & g) soil liquid water content 30 and 60 cm below ground surface in the Spyhill site during the simulation period (2006-2015).

➢ Depression model outputs compared to observations

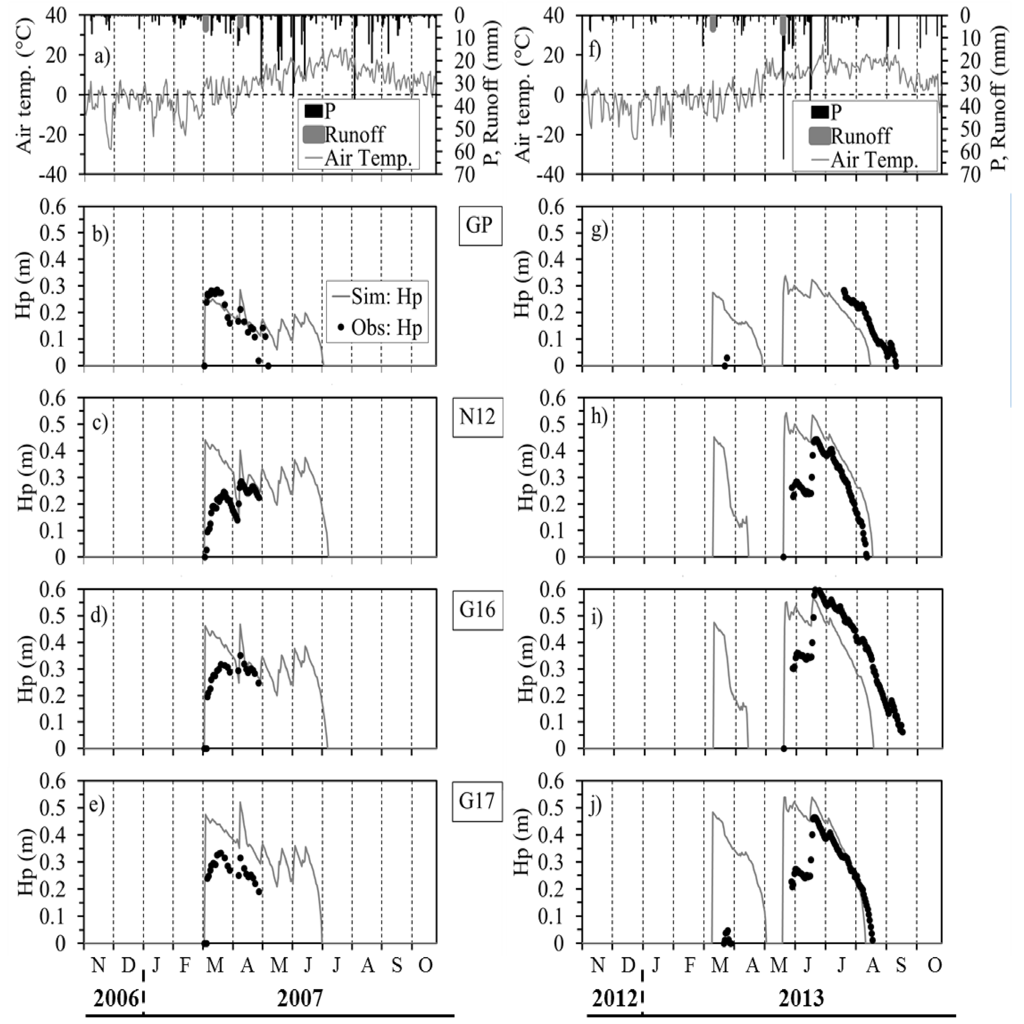

Figure 6 – Values of key variables for 2007-2007 (left) and 2012-2013 (right) seasons. (a) Observed precipitation, simulated runoff, and air temperature for 2006-2007. (f) Same variables for 2012-2013. (b)-(e) Pond water levels (Hp) for depressions GP, N12, G16 and G17. (g)-(j) Same variables for 2012-2013.

Hydrological changes under pseudo-global warming conditions (WRF, VSMB simulations)

Precipitation and air temperature was monitored in the present climate (2006-2015) and compared to PGW under the RCP8.5 scenario for 2091-2100 (Fig.7). Climate model outputs were bias-corrected using Spyhill observations (Fig.8).

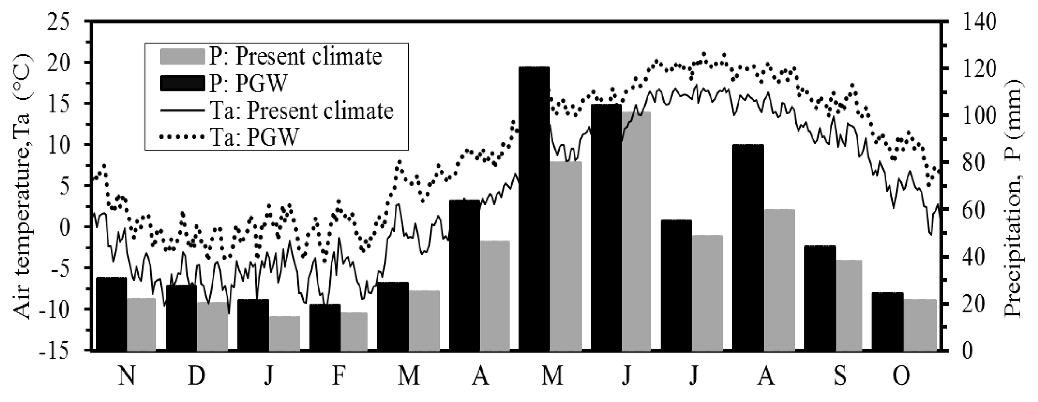

Figure 7 – The annual cycle of mean monthly precipitation and mean daily air temperature over 2006-2015 under present climate, observed in the Spyhill site and simulated by WRF model under PGW scenario for 2091-2100.

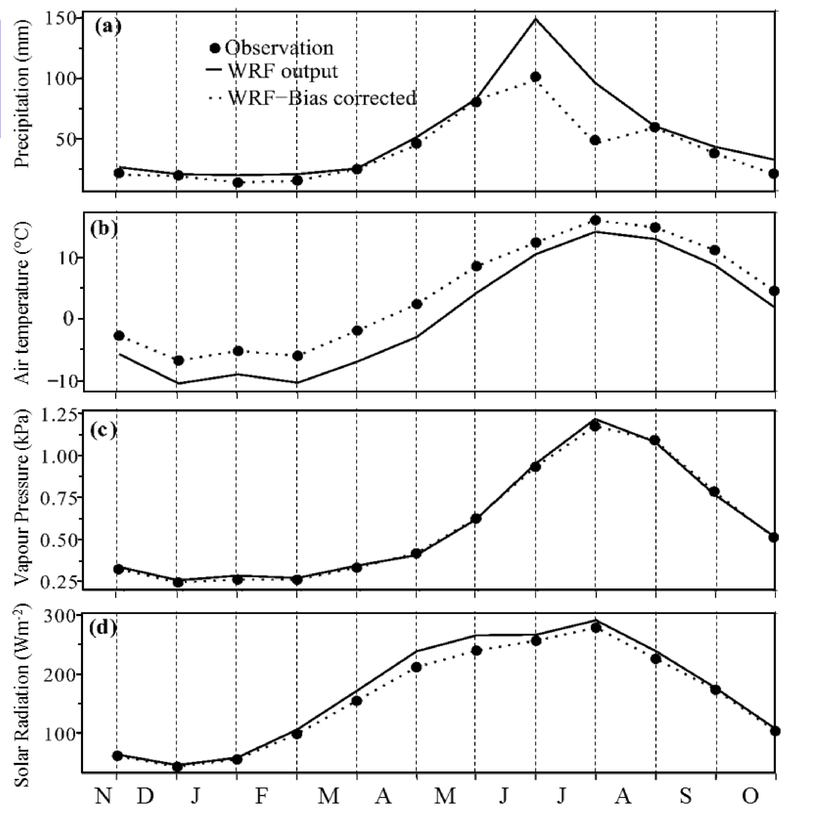

Figure 8 – The annual cycle of precipitation, air temperature, vapour pressure and solar radiation simulated by WRF model and measured at the Spyhill site. There are wet and cold biases between the WRF model outputs and observations that were corrected by multivariate quantile mapping.

➢ Soil temperature changes with PGW

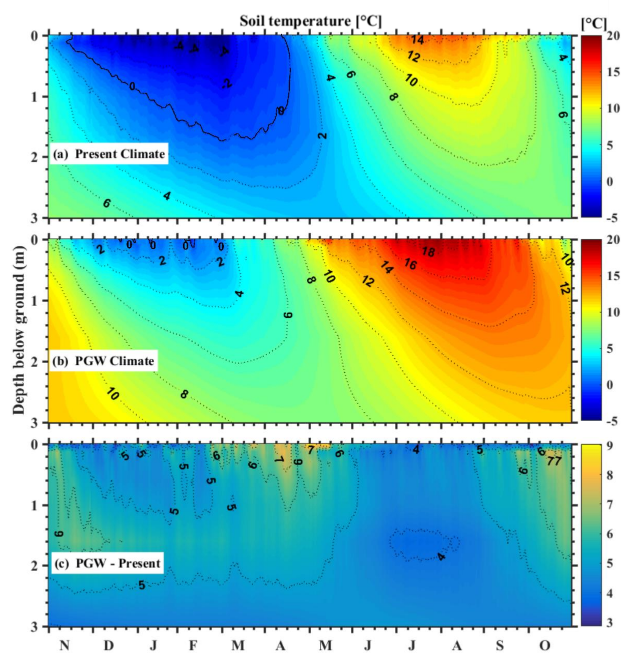

Figure 9 – The annual cycle of the soil temperature in °C with soil depth in the Spyhill site under (a) present climate (2006-2015), (b) PGW conditions (2091-2100), and (c) changes between the present and PGW climates.

➢ Total water content changes with PGW

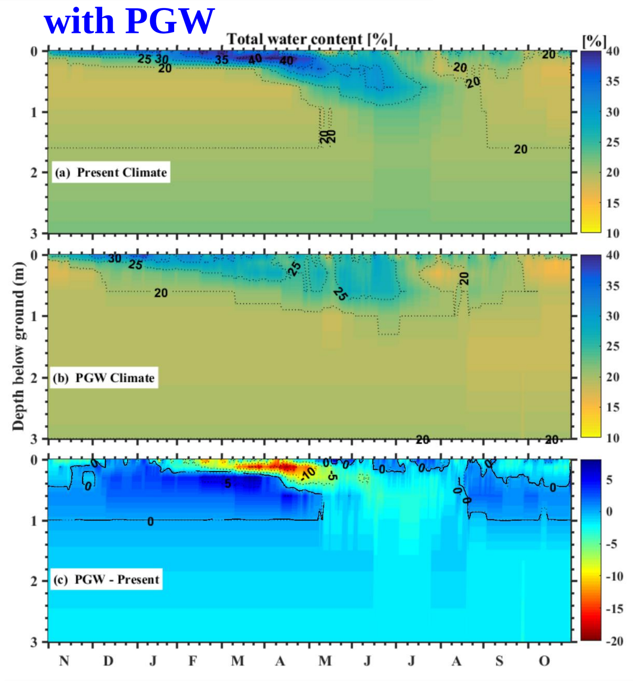

Figure 10 – The annual cycle of the total soil water content in m^3 m^{-3} with soil depth in the Spyhill site in the under (a) present climate (2006-2015), (b) PGW conditions (2091-2100), and (c) changes between the present and PGW climates.

➢ SWE changes with PGW

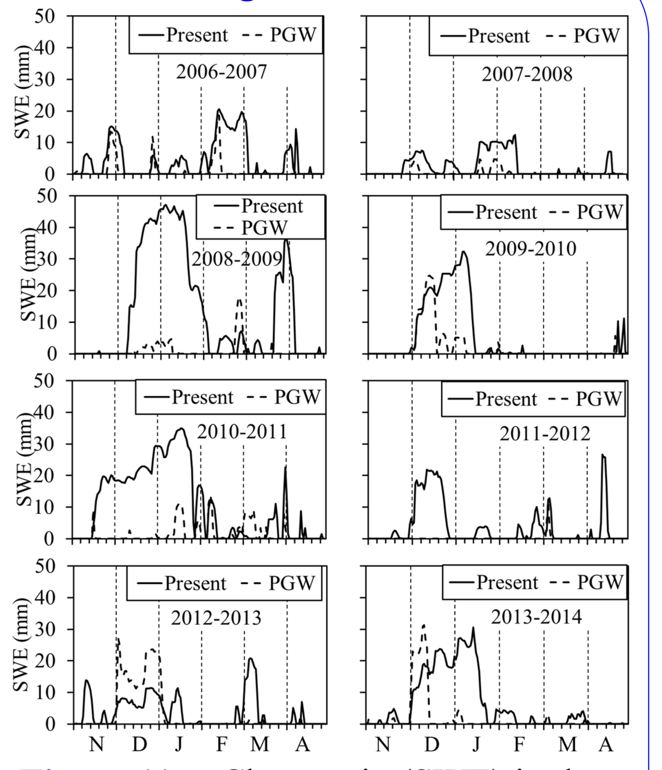

Figure 11 – Changes in (SWE) in the Spyhill site under the present (2006-2015) and the PGW (2091-2100) conditions. Note that 2091 in the PGW corresponds to 2006 in the present

➢ Changes in recharge under PGW

Under the PGW scenario, an increase in air temperature (Fig. 7) results in an increased the prominence of rainfall over snowfall and decreased the soil frost. Soil temperature and moisture (Figs. 9 and 10) and SWE (Fig. 11) are affected as well. **The annual runoff amount decreases from 7.1 mm under the present climate to 5.5 mm under PGW.** All these factors influence the groundwater recharge to occur earlier in the year due to the early snowmelt occurrence (December–February), with a lower amount of recharge due to the reduction of annual runoff rate. **Average recharge rate decreases from 4.9 mm y^{-1} in the present climate to reach a 3.6 mm y^{-1}under PGW scenario (Fig. 12).**

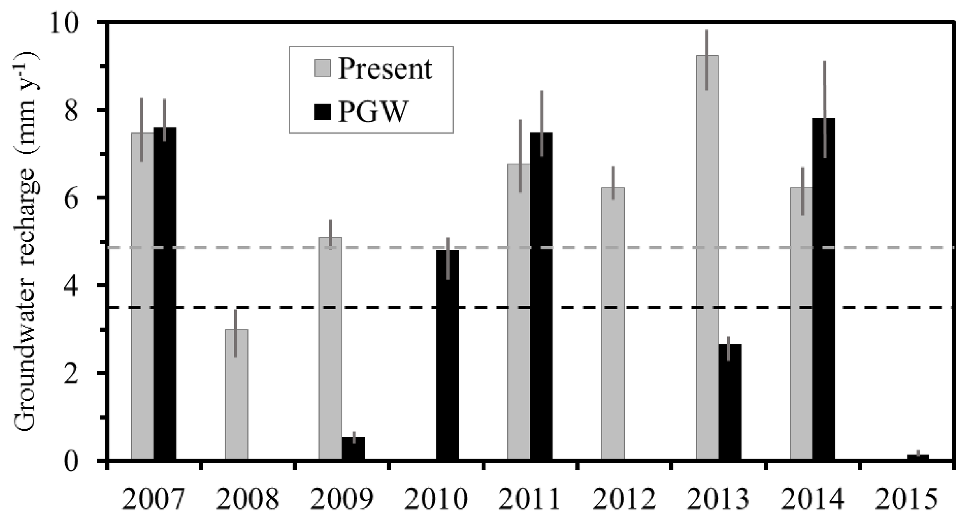

Figure 12 – Groundwater recharge estimated from four depressions (GP, N12, G16, G17) under the present climate and the PGW scenario. Each bar indicates the average value of four depressions with a line showing the range of values. The dotted lines show the average value for the nine hydrological years (2007-2015 for the present and 2092-2100 for the PGW).

Conclusions

- Hydrological response of a grassland site was assessed in the present climate (2006-2015) and compared to pseudo global warming under the RCP8.5 scenario for 2091-2100.
- Air temperature will increase, and precipitation patterns and soil temperature and moisture will change.
- The hydrology of the grassland site will shift to a regime with less surface runoff and groundwater recharge in the PGW climate compared to the present climate.