The relative importance of biophysical and meteorological effects on growing season surface available energy partitioning at high-altitude wetlands in Canadian Rocky Mountain

Hydrometeorology Research Group
University of Waterloo

Yi Wang[1](y3445wan@uwaterloo.ca), Mazda Kompanizare[2], Adam Green[1], Rich Petrone[1]

1. Department of Geography and Environmental Management, University of Waterloo.
2. Global Institute for Water Security, University of Saskatchewan.

1. Introduction

- The balance of the earth's energy components, including terrestrial net radiation (Rn) and its partitioning into ground heat (G), sensible (H) and latent heat (LE) fluxes, impacts the global climate system and hydrological cycle.
- Mechanistic understanding on how the biophysical factors (i.e., vegetation and underlying soil) and the meteorological factors affect the available energy partitioning (A) into H and LE are still lacking.
- Assumptions (i.e., linearity and independence of explanatory variables) of the commonly used methods (e.g., linear regression) that quantify the relative importance of biophysical and meteorological controls on energy partitioning may not always hold true, which cause considerable uncertainties.
- Ground observations on surface energy partitioning in high-elevation ecosystems are insufficient, and these ecosystems are vulnerable to climate change.

2. Objectives

- To develop a more comprehensive sensitivity analysis which takes the indirect linkages between environmental variables into account.
- To quantify the relative importance of biophysical and meteorological controls on available energy partitioning, in terms of the Bowen ratio (β = H/LE), in three representative high-elevation wetlands in Kananaskis, Canada.

3. Study Site

Table 1. Elevations of the study sites and the mean daily climatic conditions during the daytime period of the study sites in the growing seasons of 2018 and 2019

Study sites	Elevation (m)	Temperature (◦C)	Rn ($W\,m^{-2}$)	VPD (kPa)	Wind speed ($m\,s^{-1}$)
Sibbald fen	1,475	18.7	399.05	1.4	1.6
Burstall marsh	1,900	16.6	371.45	1.2	2.9
Bonsai meadow	2,100	16.2	331.35	1.1	1.6

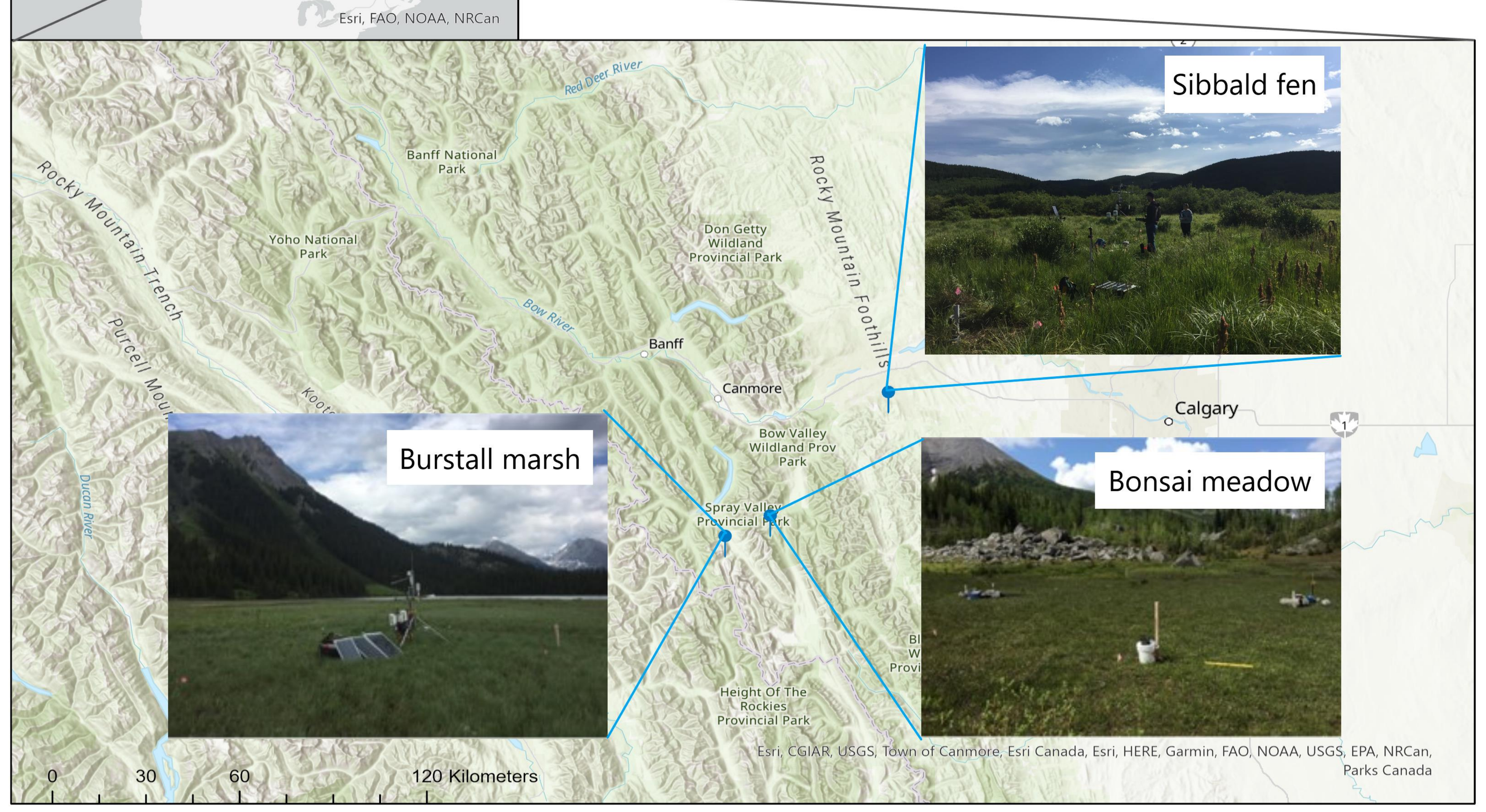

Figure 1. Study sites and their climatic conditions during the study period.

4. Methods

- **Measurements at each site**
  (1) Energy fluxes: the eddy covariance system
  (2) Climatic variables: the climate station
  (3) Soil moisture: volumetric water content probes at two depths (20 and 40 cm)
  (4) Vegetation survey
- **Quantifying the biophysical and meteorological controls based on the sensitivity analysis**
  The changes in response variable (y) as a result of a unit change in the explanatory variable (x_i):

$$S_{x_i\_y} = \lim_{x_i \to 0}\left(\frac{\Delta y/y}{\Delta x_i/x_i}\right) = \frac{dy}{dx_i}\cdot\frac{x_i}{y} \quad \text{(Eq 1)}$$

- **Interactions of explanatory variables of β**
  (1) Penman-Monteith approximation (Wilson et al., 2002):

$$\beta = \frac{1+\left(\frac{r_s}{r_a}\right)-\left(\frac{r_i}{r_a}\right)}{\frac{\Delta}{\gamma}+\frac{r_i}{r_a}} \quad \text{(Eq 2)}$$

Where, r_s, r_a and r_i are surface resistance, aerodynamic resistance, and climatological resistance, respectively ($s\,m^{-1}$); Δ is the slope of the relation between saturation vapor pressure and temperature; and γ is the psychrometric constant (kPa $^oC^{-1}$).

(2) An empirical model on the responses of canopy conductance to VPD (Oren et al., 1999):

$$g_c = g_{c,ref}[1 - m \times ln(VPD)] \quad \text{(Eq 3)}$$

Where, gc is the canopy conductance ($m\,s^{-1}$), $g_{c,ref}$ is a reference canopy conductance rate ($m\,s^{-1}$) at VPD = 1 (kPa), and a, b and m are fitted parameters.

(3) Interactions of environmental variables in determining β:

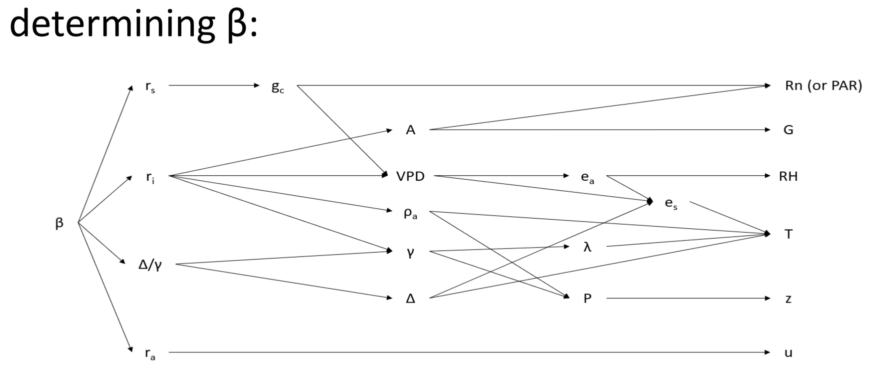

Figure 2. Tree diagram based on the chain rule.
Where, A is the available energy (W m-2); ρ_a is the density of air (kg m^{-3}); e_o is saturation vapor pressure (KPa); e_a is actual vapor pressure (KPa); λ is latent heat of vaporization (kJ kg^{-1}); P is atmospheric pressure (KPa); z is the elevation (m); and u is the wind speed ($m\,s^{-1}$).

- **Separating biophysical and meteorological controls on β, according to the T-Scenario, the Rn –Scenario and the RH-Scenario:**

Taking the T-Scenario as an example:

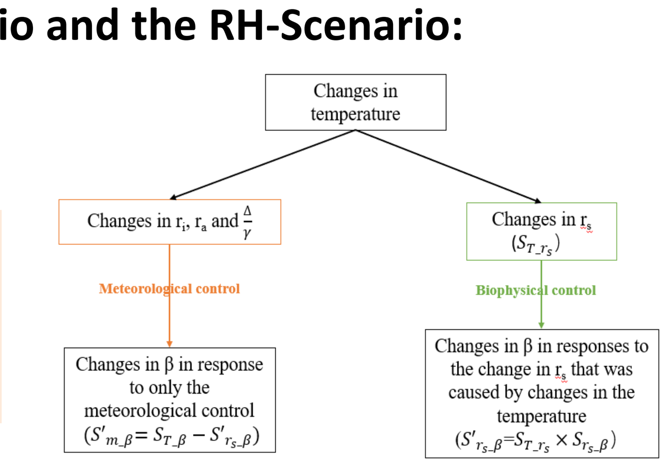

Figure 3. Separating the biophysical and meteorological controls on β based on the T-Scenario

5. Results

- **The relative importance of biophysical and meteorological effects on β**

The magnitude of the meteorological control on β was significantly larger than that of the biophysical control under the Rn- and T-Scenarios (both p<0.001), but not under the RH-Scenario.

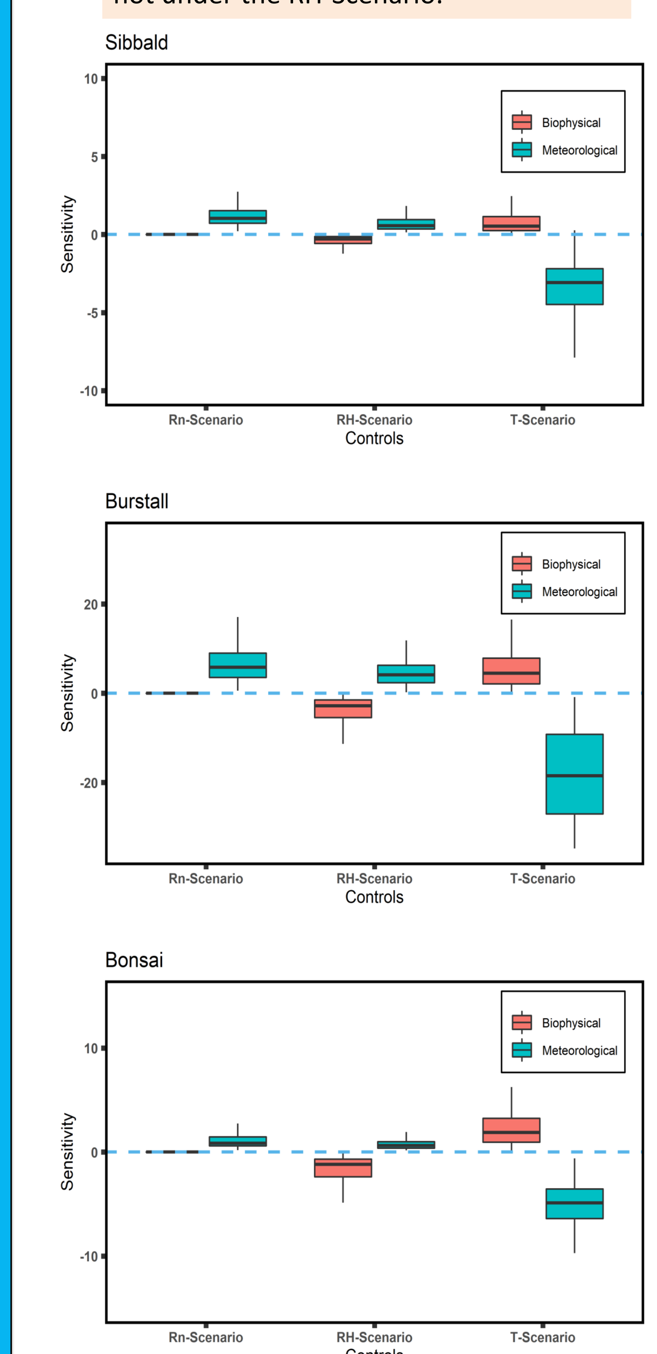

Figure 4. Sensitivity of β to the biophysical and meteorological controls under the Rn-Scenario, RH-Scenario and T-Scenario at Sibbald, Burstall and Bonsai.

- **The sensitivity of β to climatic variables**

β was most sensitive to T (all p<0.001), but the sensitivities of β to the Rn, wind speed and RH varied with sites.

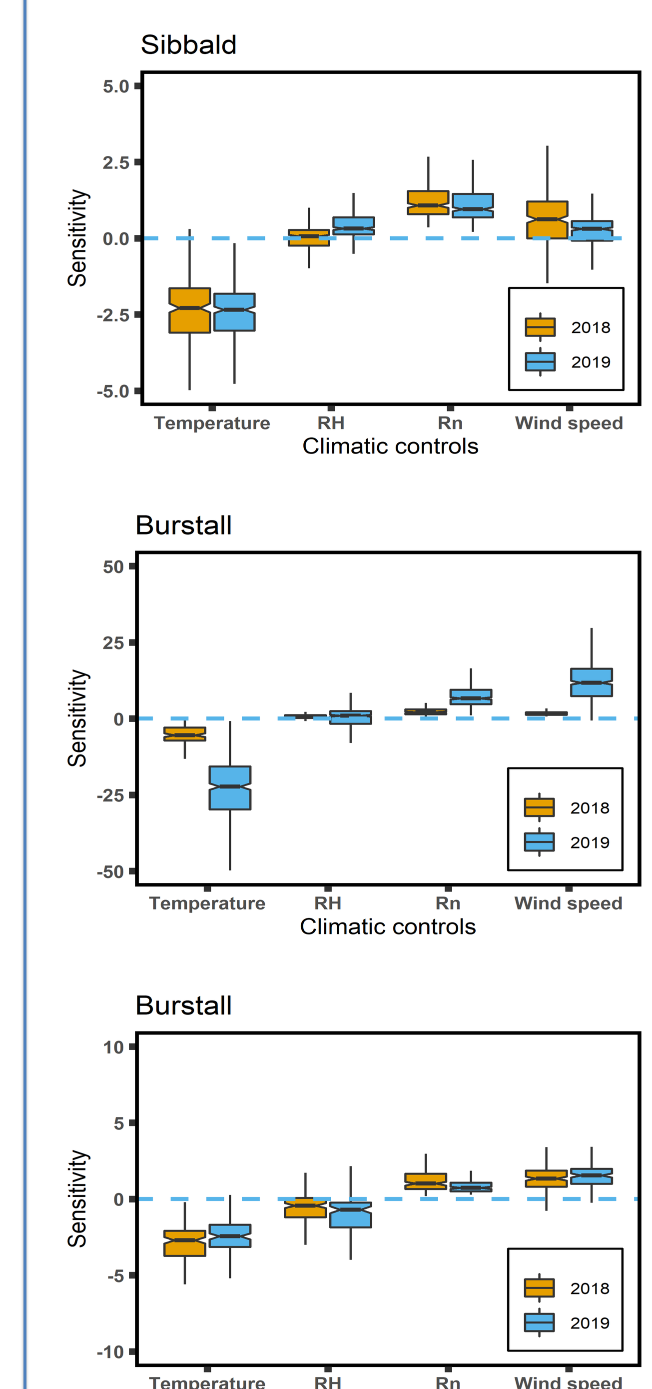

Figure 5. The sensitivity of β to temperature, relative humidity (RH), net radiation (Rn) and Wind speed at Sibbald, Burstall and Bonsai during the growing season of 2018 and 2019.

- **The effects of soil moisture on the biophysical and meteorological controls**

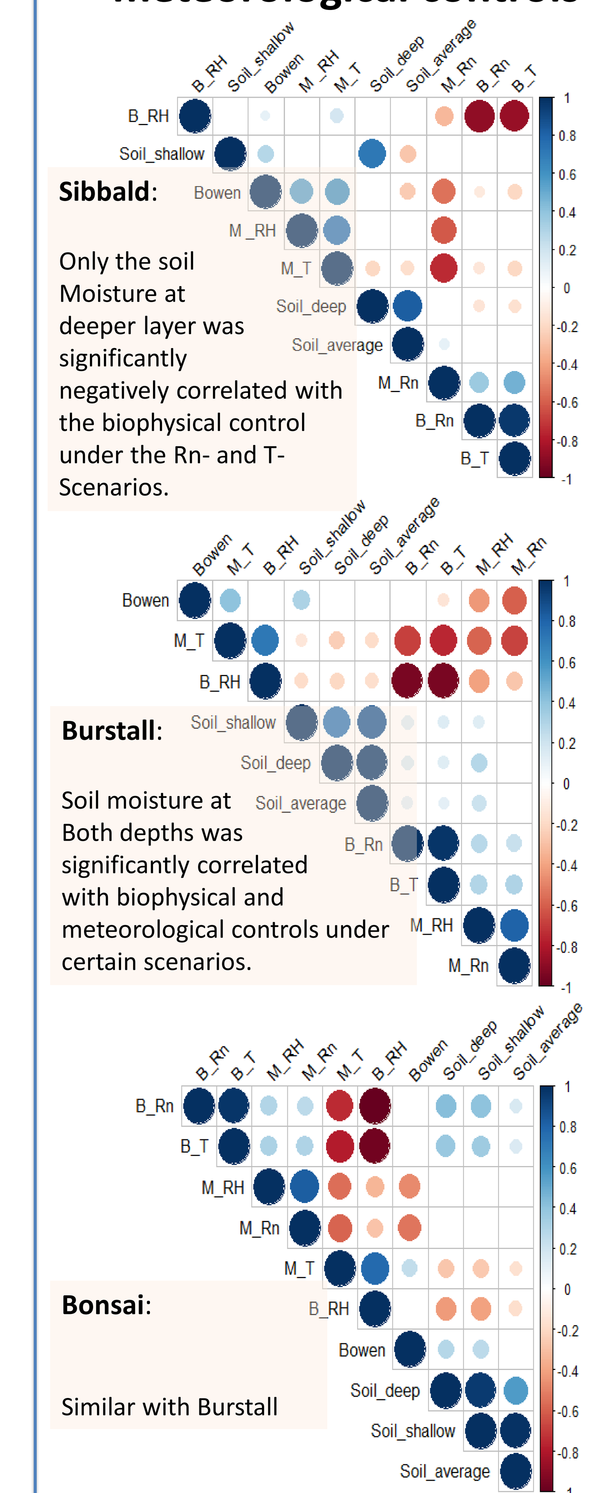

Figure 6. Correlations between soil moisture at 20 cm (Soil_shallow) and 40 cm (Soil_deep) depths and biophysical and meteorological controls under the three scenarios (the type of the control is indicated as B_Scenario or M_Scenario).

6. Discussion & Conclusions

- In our study sites, surface available energy partitioning was more influenced by the meteorological control than by the biophysical control, but the latter may become as important as the meteorological control when there is an abrupt change in air humidity.
- The effects of soil moisture at different depths on the biophysical and meteorological controls varied with scenarios and sites, which requires further investigation to improve our understanding on the role of soil moisture on the land-atmosphere coupling.
- The high sensitivity of the available energy partitioning to temperature suggests that the energy balance, and subsequent water and carbon processes may be significantly impacted by warming in the high-elevation wetland ecosystems.

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