Impacts of evapotranspiration estimation on the hydrological modeling of a subarctic bog in northern Quebec, Canada

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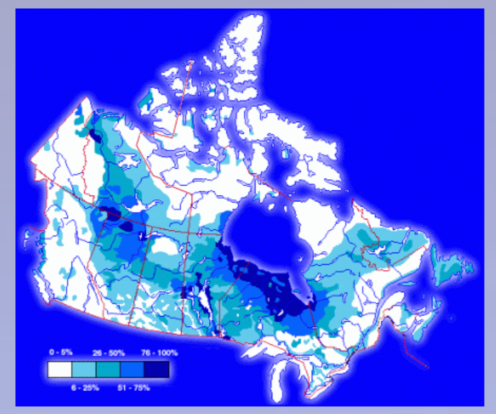
Introduction

Wetlands represent about 4% of the global emerged surface, and 60% of them are found in the northern boreal regions. Peatlands, a type of wetland, account for 10% to 20% of the overall boreal territory. The water budgets of boreal peatlands are of high importance to accurately model regional hydrological processes in nordic countries such as Canada, Finland or Russia. Unfortunately, data collected over this type of landscape are scarce, and when available, are usually basic. This implies that some processes have to be estimated, as is usually the case with evapotranspiration (*ET*).

Percentage cover of wetlands across Canada

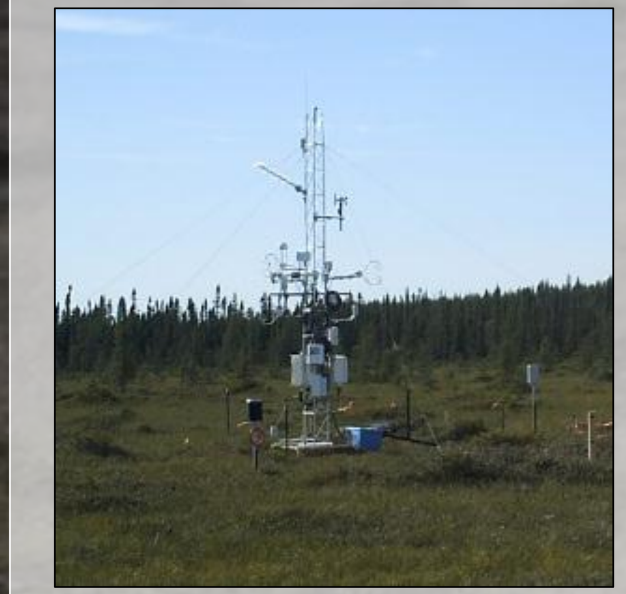


Atlas of Canada

Objectives

- Compare different models to estimate *ET*
- Describe energy and water budgets of boreal peatlands
- Assess the impact of the *ET* model on hydrological modeling

Study Site and Experimental Field Setup



Necopastic bog

Trapezoidal canal at the outlet of the bog

The site features (and measures):

- Eddy covariance setup: *ET* and sensible heat flux (*H*)
- Net radiometer: Net radiation (R_n)
- Soil heat flux plates: soil heat flux (*G*)
- Trapezoidal canal: Outgoing discharge (*Q*)
- Rain gauge: Precipitation (*P*)
- Level logger: Water table height (*dS*)
- Plus some basic meteorological instruments: wind speed, air temperature, air humidity, surface temperature, rainfall, etc.

Site's location

Energy Budget:

$$R_n = L_v ET + H + G + \text{Residual}$$

Hydrological Budget:

$$P = ET + Q + dS + \text{Residual}$$

Evapotranspiration Estimation Models

Penman (1948, 1963):

$$ET = \frac{\alpha}{L_v}\left[\frac{\Delta}{\Delta+\gamma}(R_n - G) + \frac{1}{\Delta+\gamma}E_A\right]$$

- Based on energy budget considerations
- Weighs available energy and atmospheric evaporative power
- Needs: R_n, *G*, T_a, *U*, air humidity and air pressure (for Δ and γ), plus vegetation characteristics to calculate roughness characteristics

Priestley-Taylor (1972):

$$ET = \frac{\alpha}{L_v}\left[\frac{\Delta}{\Delta+\gamma}(R_n - G)\right]$$

- Simplification of Penman's equation for wet surfaces
- Needs: R_n, *G*, T_a, air humidity and air pressure

Bulk-Transfer Approach (Brutsaert, 1982):

$$ET = C_E \rho U \left(q_{sfc} - q_a\right)$$

- Usually used over open water surfaces, but works well over boreal peatlands (Isabelle *et al.*, *J. Hydrometeorol.*, in press)
- C_E is a water vapor transfer coefficient obtained empirically or theoretically with measurement heights and surface roughness characteristics (for open water, C_E ~ 0.0012)
- Needs: T_a, T_{sfc}, *U*, air humidity and air pressure, plus vegetation characteristics for surface roughness

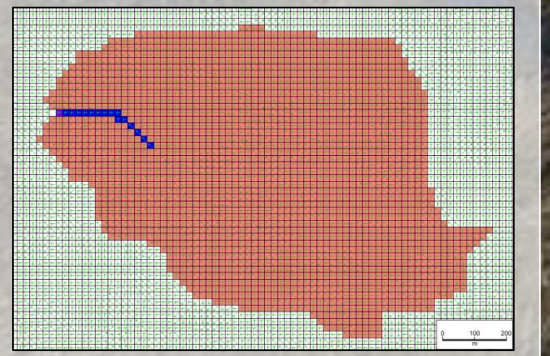
Hydro-Québec's Formula (Dionne *et al.*, 2008):

$$ET = \alpha 0{,}029718\left(T_{a,\max} - T_{a,\min}\right)\exp\left(0{,}0342\left(T_{a,\max} - T_{a,\min}\right) + 64\right)$$

- Empirical formulation
- Needs only air temperature

Hydrological Model : HYDROTEL

- Distributed hydrological model
- Coupled with a specialized GIS (PHYSITEL), which needs: digital elevation model, land-use and soil type grid
- PHYSITEL then creates homogeneous sub-basins (called RHHUs)
- HYDROTEL uses a cascade of hydrological sub-models to calculate streamflow on each RHHU
- Sub-model used:
  - **Interpolation of precipitation data**: Thiessen Polygons
  - **Snow cover estimation**: Mixed Approach (deg.day – energy balance)
  - **Evapotranspiration**: Input by user
  - **Vertical water balance**: Three layer vertical balance (for now)
  - **Overland and channel routing**: Kinematic Wave

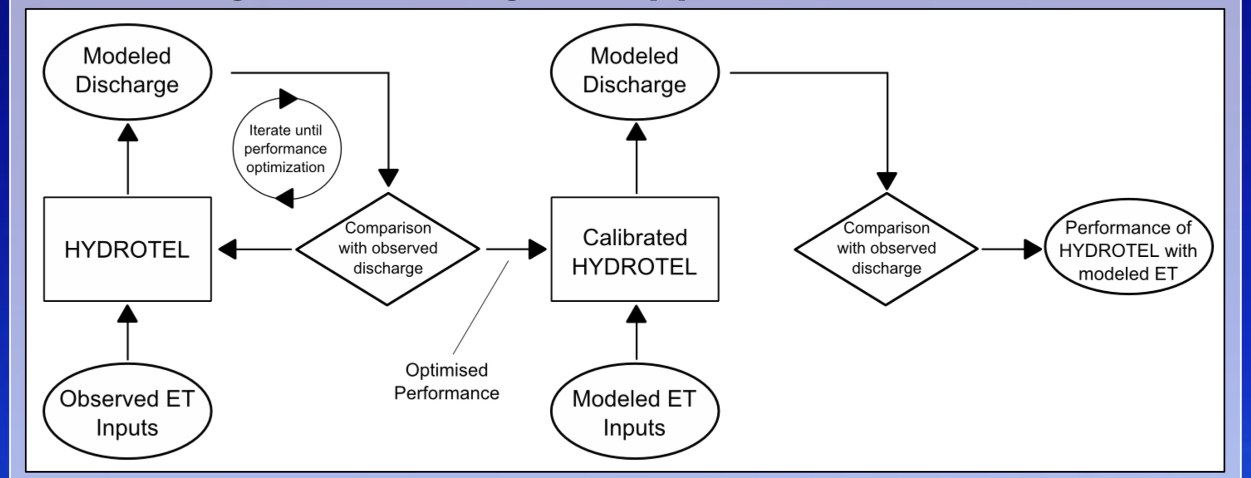


Necopastic bog single RHHU

Necopastic bog in HYDROTEL

- **Area**: 90 ha
- **Elevation**: 71 m ASL
- **Land-use**: Bog (31%), Forest (20%), Bare rock (17%), Burnt-over (11%), Fen (9%), Riparian vegetation (9%), Water (3%)
- **Soil type**: Combination of mostly clay and sandy loam (under ~2 m of peat)

Modeling Methodological Approach

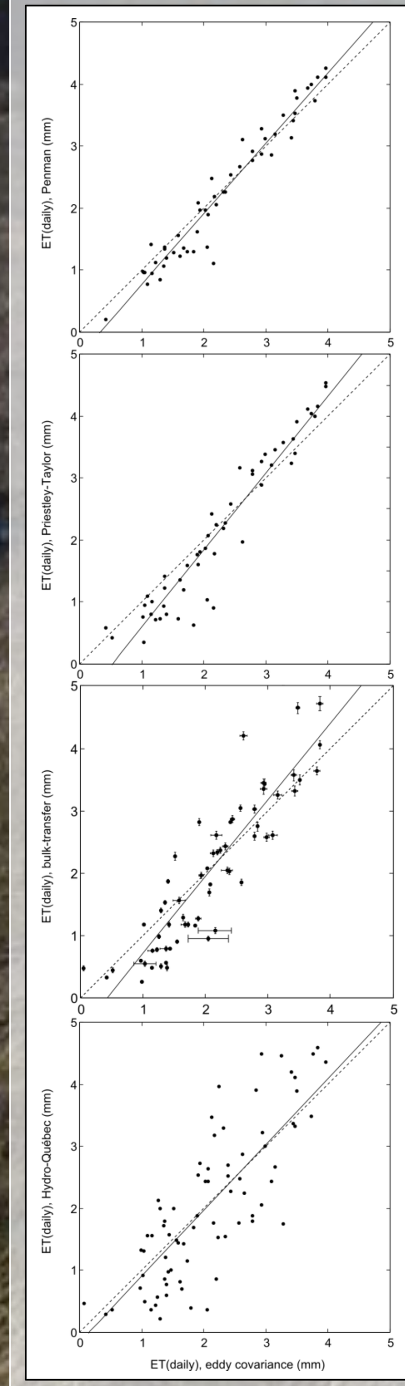


ET Models Calibration (*α* coefficients)

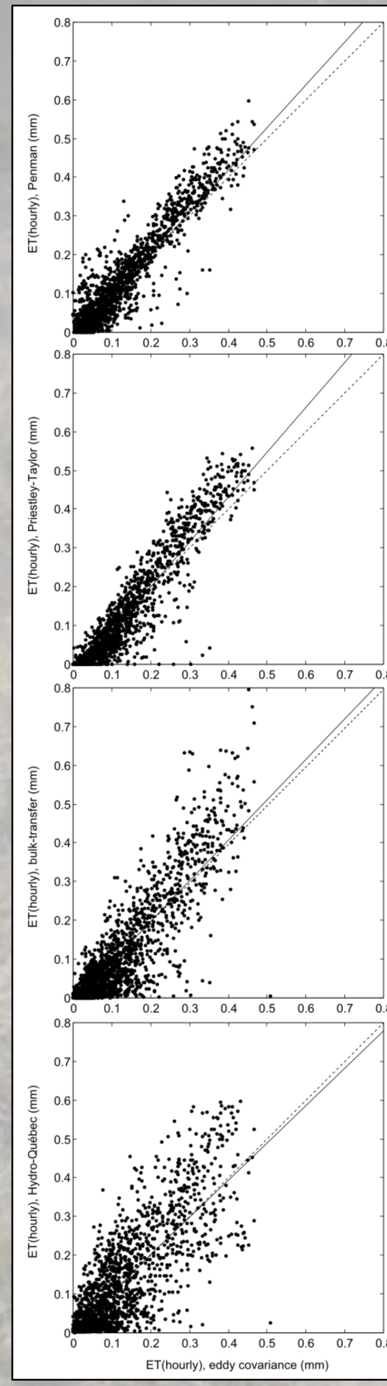
- Each evapotranspiration model has a coefficient of proportionality (*α*) to adjust from potential *ET* to actual *ET*
- *α* is calculated as the slope of a linear regression between modeled and observed *ET* values passing through the origin
- The Bulk-Transfer approach does not need this coefficient, it's adjustment being included in C_E

Results: Observed versus Estimated ET

Daily



Hourly



Penman

R^2 (daily) = 0.92
α (daily) = 0.58
R^2 (hourly) = 0.71
α (hourly) = 0.57

Priestley-Taylor

R^2 (daily) = 0.92
α (daily) = 0.86
R^2 (hourly) = 0.83
α (hourly) = 0.79

Bulk-Transfer

R^2 (daily) = 0.82
C_E (daily) = 0.00232
R^2 (hourly) = 0.74
C_E (hourly) = 0.00231

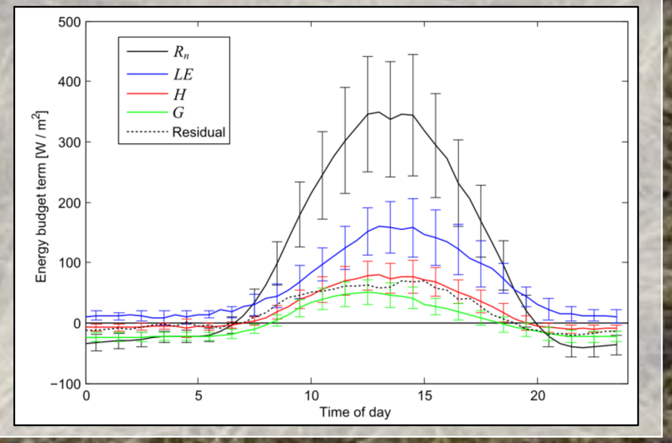
Hydro-Québec

R^2 (daily) = 0.66
α (daily) = 0.74
R^2 (hourly) = 0.66
α (hourly) = 0.88

Results: Energy budget

Mean Daily Energy Budget.

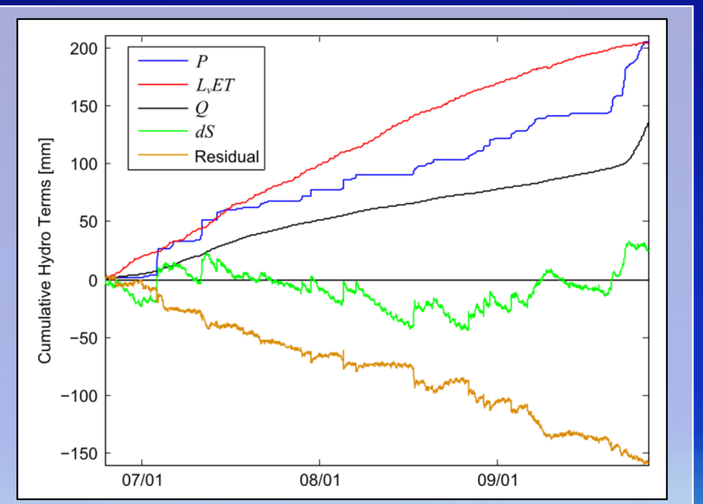
A positive residuals means there is a neglected sink of energy



Results: Water budget

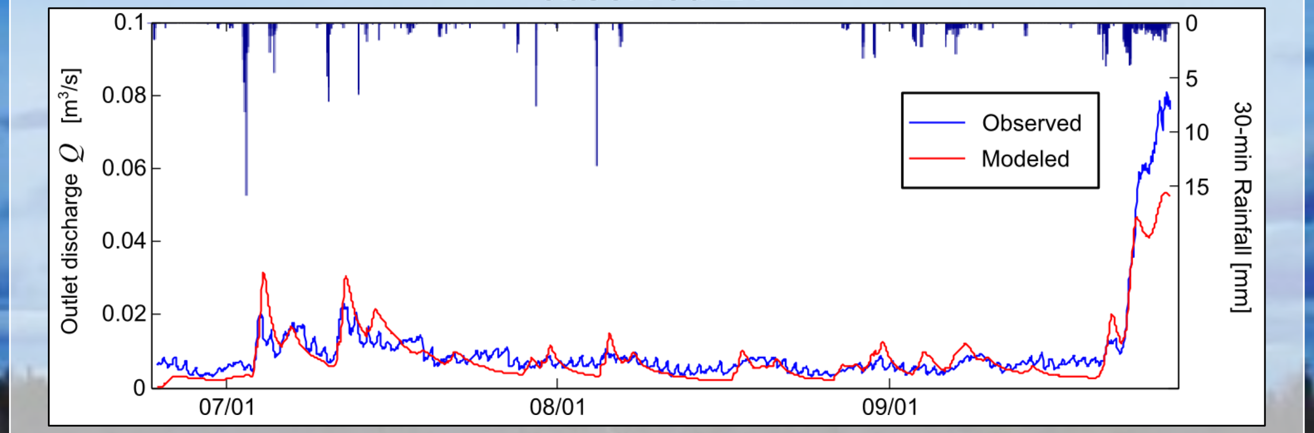
Cumulative Water Budget, for Summer 2012.

A negative residual means there is a neglected inflow to the sub-basin.



Results: Impact on Modeling Performances

Observed and modeled outlet discharge, hourly scale with observed *ET*



Performance metrics for various *ET* inputs

ET input	Normalized mean error		R^2		RMSE		Nash-Sutcliffe	
	Daily	Hourly	Daily	Hourly	Daily	Hourly	Daily	Hourly
Observed *ET*	0.2894	0.3079	0.8630	0.8421	0.0041	0.0049	0.8552	0.8160
Penman	0.2908	0.3062	0.8607	0.8375	0.0041	0.0049	0.8568	0.8194
Priestley-Taylor	0.2877	0.2999	0.8673	0.8551	0.0039	0.0044	0.8649	0.8503
Bulk-Transfer	0.2866	0.2960	0.8643	0.8614	0.0040	0.0044	0.8639	0.8539
Hydro-Québec	0.2950	0.3232	0.8430	0.8060	0.0043	0.0055	0.8368	0.7729

Conclusions

- Overall, the more input data a model requires, the more precise it becomes
- Such precision does not seem to transpose in a better performance in HYDROTEL
- On a **daily scale**, there is no significant difference in performance with changes of *ET* inputs
- On a **hourly** scale, only the Hydro-Quebec model causes a significant decrease in hydrological modeling performances

Perspectives

- Methodology used can be redone with upgrades of HYDROTEL that include special sub-models for wetland flow (these replace the three layer vertical balance sub-model)
- Same can be done with different definition of the *α* coefficients (fixed value from the literature, value based on cumulative summer *ET*, etc) to assess the performance a modeler without *ET* observations would obtain

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