STREAM WATER TEMPERATURE MODELING UNDER CLIMATE CHANGE SCENARIOS

STREAM WATER TEMPERATURE AND WATER / AIR TEMPERATURE RELATIONSHIPS

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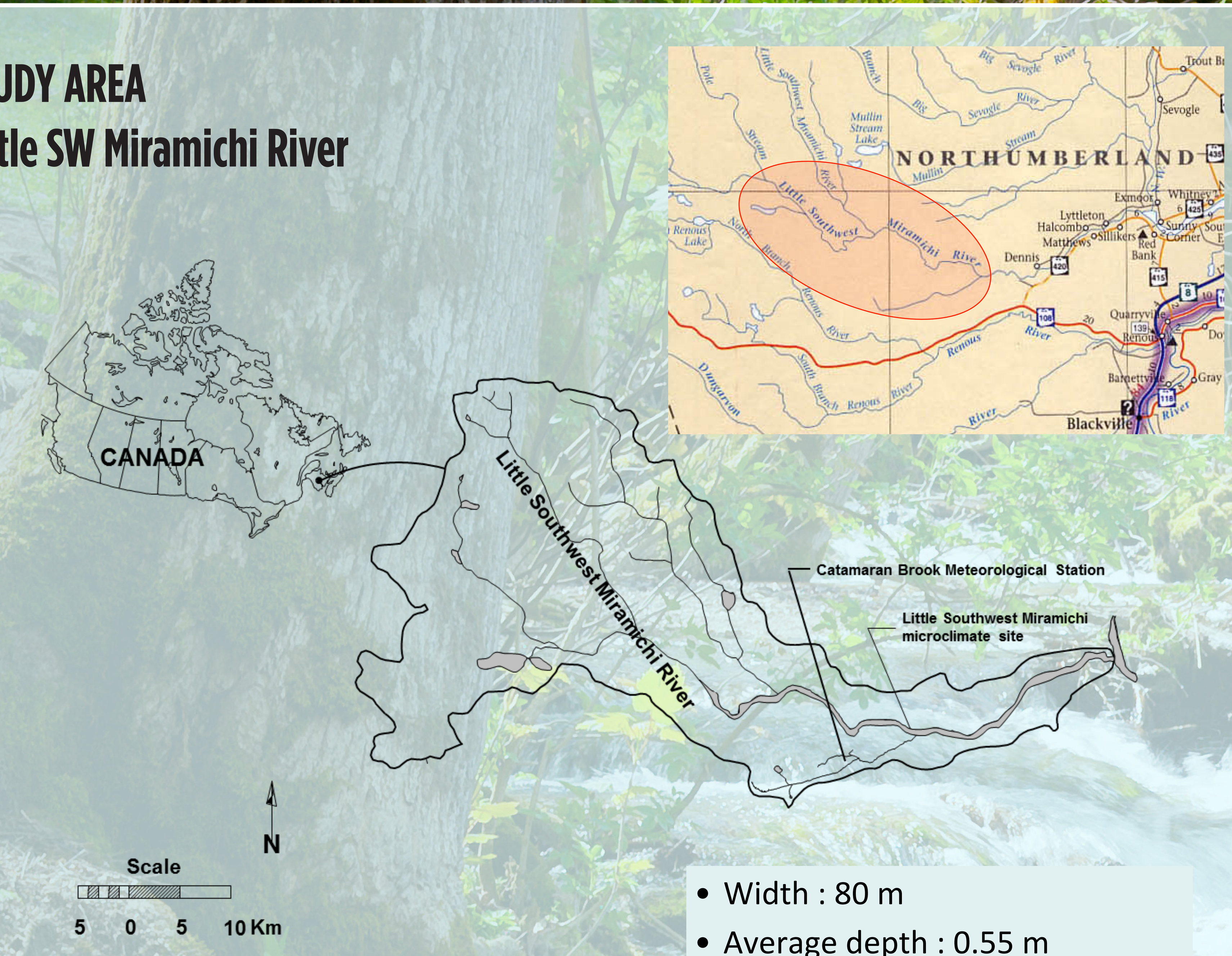
ABSTRACT

Stream water temperature is a very important parameter when assessing aquatic ecosystem dynamics. For instance, cold-water fishes such as salmon can be adversely affected by maximum summer temperatures or by those exaggerated by land-use activities such as deforestation. The present study deals with the modelling of stream water temperatures by means of Stochastic Models (SM1 & SM2) and two intelligent algorithms such as genetic programming (GP) and polynomial neural networks (PNN) to relate air and water temperatures in Little SW Miramichi River, New Brunswick. The results indicated that it was possible to predict daily mean and maximum stream temperatures using air temperatures and that the four models produced similar results in predicting these temperatures. The root mean square error (RSME) varied between 1.51°C and 1.77°C on an annual basis from 1990 to 2010. Of the four models, the SM1 (Multiple Regression) and PNN were preferred based on performance and simplicity in development.

STUDY AREA

Little SW Miramichi River



- Width : 80 m
- Average depth : 0.55 m
- Drainage area : 1340 km^2
- Mean annual flow : 32.5 m^3/s

STREAM TEMPERATURE MODELING

t : day of year (100 … 320, july 1=182)
c : vector of real constants
{+,-,*,÷} : operators used
T, Tmn, Tmx : mean, min, max air temperatures
Tw : water temperature
TA : annual component
Rw, Ra : water & air temperature residuals

Stochastic Models (SM1 & SM2)

$$Tw(t) = TA(t) + Rw(t)$$

$$TA(t) = a + b\sin\left(\frac{2\pi}{365}(t - t_0)\right)$$

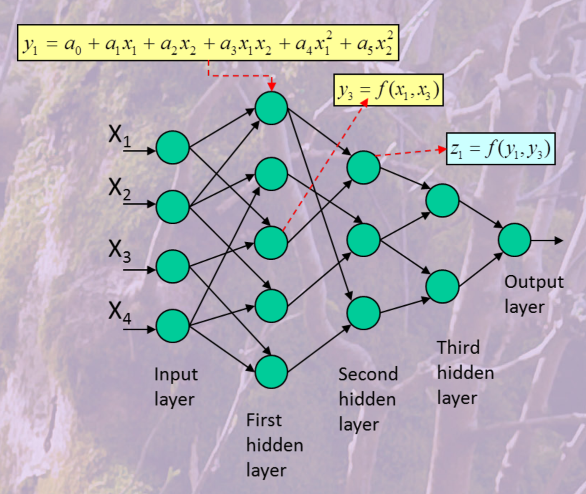
SM1 (MultipleR) $Rw(t) = b_1 Ra(t) + b_2 Ra(t-1) + b_3 Ra(t-2)$

SM2 (Markov) $Rw(t) = A_1 Rw(t-1) + A_2 Rw(t-2) + K\,Ra(t)$

Polynomial Neural Network (PNN)

Input Layer → Output L.

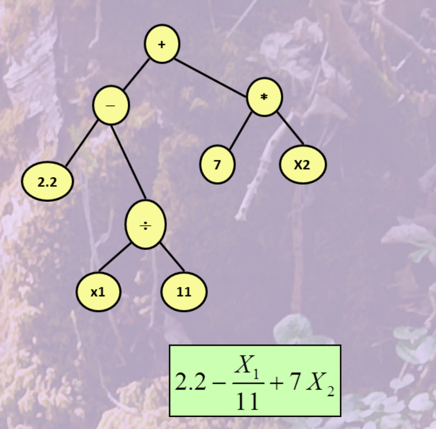
$$\begin{Bmatrix} t \\ T(t), T(t-1), T(t-2) \\ Tmx(t), Tmx(t-1), Tmx(t-2) \\ Tmn(t), Tmn(t-1), Tmn(t-2) \end{Bmatrix} \Rightarrow \begin{Bmatrix} Tw^{mean} \\ or \\ Tw^{\max} \end{Bmatrix}$$



Genetic Programming (GP)

Input Layer → Output L.

$$\begin{Bmatrix} t, \bar{c}, \{+,-,*,\div\} \\ T(t), T(t-1), T(t-2) \\ Tmx(t), Tmx(t-1), Tmx(t-2) \\ Tmn(t), Tmn(t-1), Tmn(t-2) \end{Bmatrix} \Rightarrow \begin{Bmatrix} Tw^{mean} \\ or \\ Tw^{\max} \end{Bmatrix}$$



RESULTS

Model results for the estimation of mean water temperatures

	Periods	RMSE	R^2
GP	Train (1992-96)	1.67	0.937
	Valid (2000-04)	1.55	0.953
	Test (2005-10)	1.77	0.926
PNN	Train (1992-04)	1.28	0.963
	Test (2005-10)	1.58	0.946
SM1	Calibr. (1992-04)	1.33	0.962
	Test (2005-10)	1.51	0.947
SM2	Calibr. (1992-04)	1.53	0.946
	Test (2005-10)	1.68	0.938

Model results for the estimation of maximum water temperatures

	Periods	RMSE	R^2
GP	Train (1992-96)	1.29	0.960
	Valid (2000-04)	1.93	0.937
	Test (2005-10)	2.24	0.909
PNN	Train (1992-04)	1.76	0.944
	Test (2005-10)	2.02	0.926
SM1	Calibr. (1992-04)	1.73	0.942
	Test (2005-10)	2.00	0.933
SM2	Calibr. (1992-04)	1.80	0.936
	Test (2005-10)	2.00	0.932

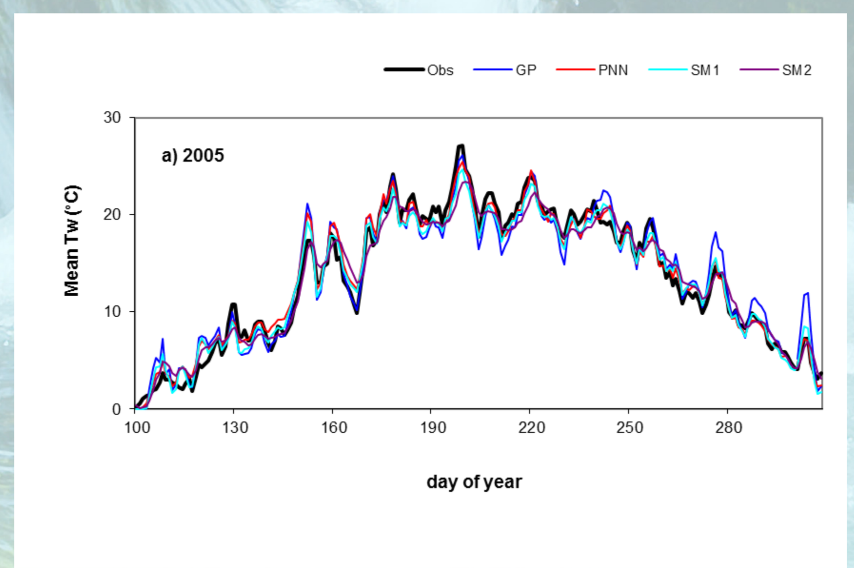
Note: In the case of PNN, the training data set was also used for cross-validation (5-fold)

CONCLUSIONS

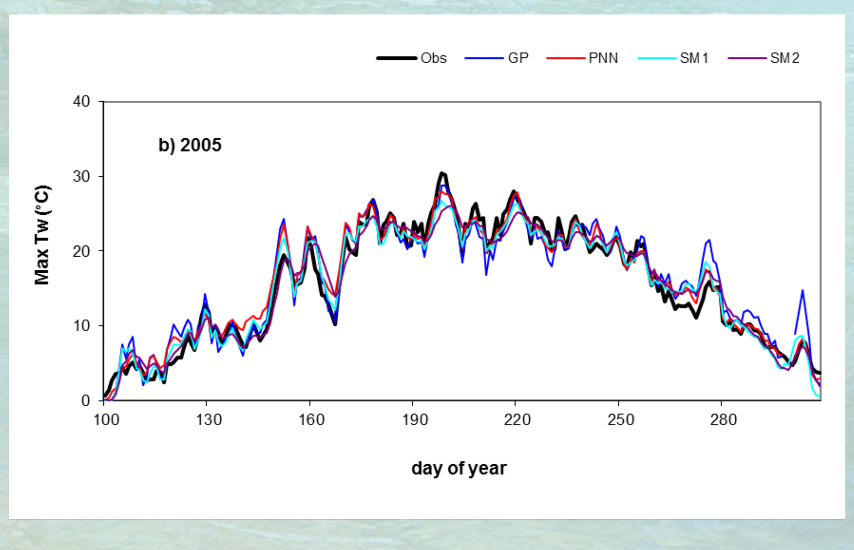
- All modeling approaches may be used to model stream water temperatures with Root Mean Square Errors (RMSE) generally less than 2.0°C.
- Intelligent algorithms such as GP and PNN were able to closely follow the behaviour of stream water temperatures by providing simple equations which can be readily incorporated into any programming environment.

OUTPUT EXAMPLES

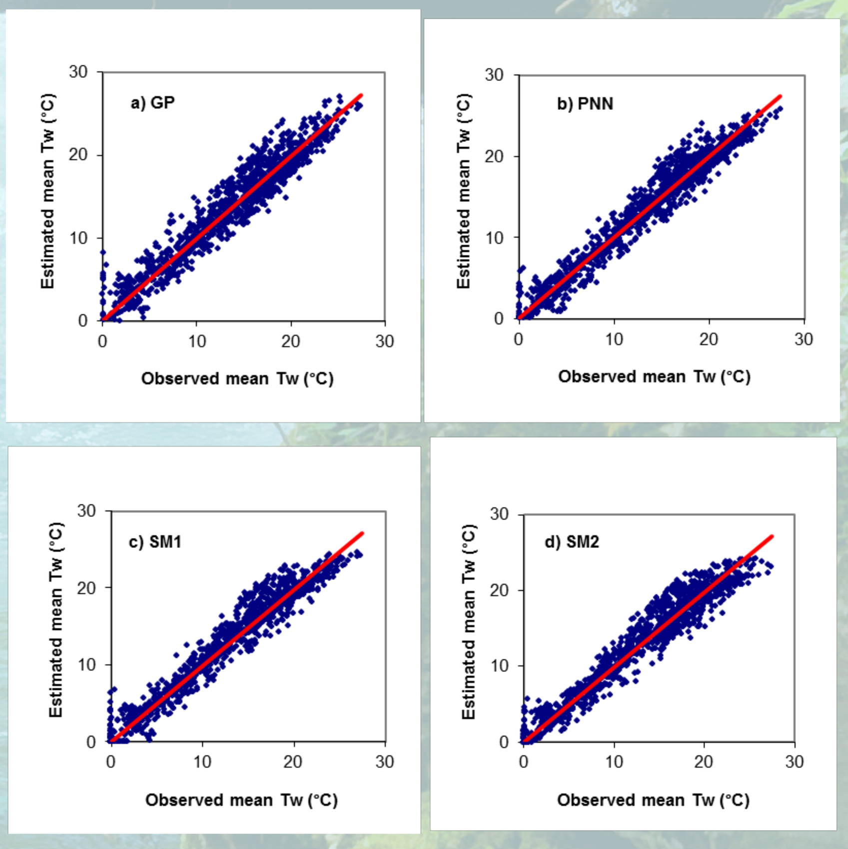
Mean water temperatures for year 2005



Maximum water temperatures for year 2010



Comparison between observed and estimated mean water temperature for the test set (2005-2010) using a) GP b) PNN c) SM1 d) SM2



GP output for mean water temperature

$$T_w(t) = -\frac{1}{t^4}0.19085\left(198.24 + 3.2635\,T(t-1) + 1.6318\,Tmn(t-1) + T(t)\right)^4 + 0.45515\,T(t) + 0.22839\,T(t-2) + 0.36733\,T(t-1) + 1.2353$$

PNN output for maximum water temperature

$$T_w^{\max}(t) = 0.9709A - 0.0735A^2 - 0.3653B + 0.1129AB - 0.0378B^2 + 0.3691C$$

$$A = -33.33 + 0.4328t - 0.0010t^2 + 0.2095T(t) + 0.0162T(t)^2 + 0.1880T(t-1) - 0.0191T(t)T(t-1) + 0.0128T(t-1)^2$$

$$B = -38.91 + 0.4986t - 0.0012t^2 + 0.0501Tmx(t) + 0.0115Tmx(t)^2 - 0.0097Tmx(t-1) + 0.0002t\,Tmx(t-1) - 0.0118Tmx(t)Tmx(t-1) + 0.0119Tmx(t-1)^2$$

$$C = -33.39 + 0.4267t - 0.0010t^2 + 0.1771T(t-2) - 0.0002t\,T(t-2) + 0.0033T(t-2)^2 + 0.0792Tmx(t) + 0.0002t\,Tmx(t) + 0.0029T(t-2)Tmx(t) + 0.0059Tmx(t)^2$$

t : day of year (100..320)
Tw : water temperature
T : mean air temperature
Tmn : minimum air temperature
Tmx : maximum air temperature