World Academy of Science, Engineering and Technology
International Journal of Geological and Environmental Engineering
Vol:3, No:9, 2009

# Simulating climate change (temperature and soil moisture) in a mixed-deciduous forest, Ontario, Canada

David Goldblum and Lesley S. Rigg



*Abstract*— To simulate expected climate change, we implemented a two-factor (temperature and soil moisture) field design in a forest in Ontario, Canada. To manipulate moisture input, we erected rain-exclusion structures. Under each structure, plots were watered with one of three treatments and thermally controlled with three heat treatments to simulate changes in air temperature and rainfall based on the climate model (GCM) predictions for the study area. Environmental conditions (including untreated controls) were monitored tracking air temperature, soil temperature, soil moisture, and photosynthetically active radiation. We measured rainfall and relative humidity at the site outside the rain-exclusion structures. Analyses of environmental conditions demonstrates that the temperature manipulation was most effective at maintaining target temperature during the early part of the growing season, but it was more difficult to keep the warmest treatment at 5º C above ambient by late summer. Target moisture regimes were generally achieved however incoming solar radiation was slightly attenuated by the structures.

***Keywords—*** *Acer saccharum,* climate change, forest, environmental manipulation

## I. Introduction

The impact that anthropogenic climate change might have on plant communities has become a focus of much ecological research over the past decade. Numerous studies of vegetation response to climate change over the past 20 years have demonstrated significant shifts (mostly elevational, but also latitudinal) in species range limits. Latitudinal shifts are harder to detect as temperature changes are more subtle. In both cases however, the magnitude of temperature changes have been relatively minor over the past 20-30 years, and in many ecosystems recent changes are well below those predicted from general circulation models (GCMs) for the coming century. Thus, to best evaluate how plants might respond to climate change predicted for the next 100 years, climate change simulation experiments may play an important role. Heating experiments can be either passive (open-top greenhouse chambers) or active (heaters). While open-top chambers are simple to erect, temperatures are difficult to regulate. A handful of studies (e.g. [1] – [8]) have successfully manipulated air temperature in field environments to assess the impact that warmer climates might have on plant communities. However, a significant drawback of experimental heating using suspended heatlamps or open-top chambers (as used by many research teams) is that soil moisture tends to decrease under constant heating, which may confound attempts to ascertain a plant's ability to acclimatize to temperature [5]. While this decrease in soil moisture is a real phenomenon that follows from warming, it may not reflect future climate conditions given the potential for increased rainfall during certain months of the growing season, as is the case in our study area. Given the projected climate change in our study area, our design allowed us to closely control both temperature *and* soil moisture. As part of a larger study on the likely impact of climate change on forests of central Ontario, we established a field design which allows us to actively manipulate temperature and moisture regimes. This paper describes the degree to which our field design achieved the intended goal of simulating climate conditions modeled for the 2080s.

David Goldblum is with the Department of Geography, Northern Illinois University; DeKalb, IL 60115, USA (815-753-6839; fax: 815-753-6872; e-mail: dgoldblum@niu.edu). Author for correspondence.

Lesley S. Rigg is with the Department of Geography, Northern Illinois University; DeKalb, IL 60115, USA (815-753-6838; fax: 815-753-6872; e-mail: lrigg@niu.edu).

Funding for the project is through a NSF grant to LSR and DG.

## II. Study area

This research was conducted in Ontario, Canada within Lake Superior Provincial Park (LSPP), [47°45'N, 84°54'W]. The park is located at the ecotone between the deciduous forest (found to the south) and boreal forest (dominant from the study area north) on the northeastern shore of Lake Superior, approximately 300 – 400 m above sea level [9] – [11]. Several conifers, including white spruce (*Picea glauca*) and short-lived balsam fir (*Abies balsamea*) dominate the valley bottoms in the southern portions of the ecotone, in addition to dominating all topographic locations in the northern portions of the ecotone [9] – [11]. As a result of this, the dominant deciduous species, sugar maple (*Acer saccharum*), and less abundant yellow birch (*Betula alleghaniensis*) become increasingly restricted to the upland areas, and are generally found nowhere else [11] – [12]. Balsam fir and the other coniferous species are most abundant in the valleys between the sugar maple dominated uplands. While balsam fir and white spruce occur sporadically on the uplands, sugar maple is never found in the valley bottoms [9] – [11]. Less dominant species occurring within the study area include northern white-cedar (*Thuja occidentalis*), tamarack

(*Larix laricina*), red maple (*Acer rubrum*), trembling aspen (*Populus tremuloides*), and red pine (*Pinus resinosa*) [11].

On the uplands, little soil development has occurred; therefore most of the plants growing in these areas are rooted in the surface organic material that is covering the rocky surface below [12]. The pH ranges from 3.7 to 4.4 in the areas in which mineral soil is present [10]. Tree falls are frequent within the study site and tree growth as well as turnover are relatively rapid [12].

The study area is an approximately 40 m x 40 m area 5 km south of the sugar maple northern limit in LSPP. Previous stand structure analysis [10] at the site indicated a total tree (>5 cm diameter at breast height [dbh]) density of 1175 trees/ha, comprised of 1125 sugar maple per hectare and white birch and yellow birch each at 25 trees/ha. The only tree seedlings (<30 cm ht.) and saplings (>30 cm ht, <5 cm dbh) in the study site are sugar maple with a seedling density of 29.9/$m^2$, and a relatively high sapling density of 1.0/$m^2$.

The weather station in Wawa, Ontario (25 km north of the study plot) maintains the closest weather records to the study area [11] – [12]. According to Environment Canada [13], Wawa has a mean January temperature of -14.8 °C (std. dev. = 3.2) and a mean August temperature of 14.9 °C (std. dev. = 1.6). The annual average rainfall in Wawa is 727.4 mm, while the annual average snowfall is 328.6 mm, with the largest average snow depth occurring in February (67 cm)

To fully capture the range of expected environmental changes, we implemented a fixed two-factor (air temperature and moisture) split-plot field design with repeat measures. To manipulate rainfall input, we erected 15 open-sided polythene-topped rain-exclusion structures (1 x 2 m) to shelter the soil surface below which contained three 50 cm x 75 cm sub-plots. The one meter tall structures (resembling six-legged tables) were constructed of PVC plumbing pipes. Wide-mesh chicken wire on the top provided the support for greenhouse film (rated to transmit 91% of direct sunlight). The sub-plots were 15 cm in from edges with 10 cm spacing between plots. In order to minimize blockage of direct solar radiation, the rain-exclusion structures were situated with the long axis aligned west-east, so that mid-morning through mid-afternoon sun reaches the back of the plots passing through as little of the rain-exclusion canopy as possible. Additionally, we established four uncovered control plots, mixed in with the treatment plots, each with three sub-plots.

Under each rain-exclusion structure, plots were watered manually (eight times per month) with one of three treatments: 1) “Average” – 1961-1990 average Wawa, Ontario rainfall, 2) “Wet” – 20% greater than “average” treatment, and 3) “Dry” – 20% less than “average” treatment. Water application amounts were adjusted for each of the growing season months (May – August) in order to track seasonal precipitation patterns. Control plots received natural rainfall.

Seedling plots were also manipulated to simulate changes in ambient air temperature. Given the Canadian Regional Climate Model (CRCM) predictions for the study area [14], we established three heat treatments. Operating 24 hours/day, from May 24 – August 16, 2008 we powered a 165 cm long infrared heater (Kalglo Electronics Co., Inc.; Bethlehem. PA, USA: Model MRM-1215) from the underside of each rain-exclusion structure, approximately 85 cm above the soil surface. Five of the plots were unheated and therefore experienced ambient air temperatures (hereafter 0º C), but contained dummy infrared heaters as a methodological control. Five structures were maintained at 5º C above ambient both day and night and five were maintained at 2.5 º C above ambient both day and night.

Environmental conditions under each rain-exclusion structure and within the four controls were monitored every 30 minutes (from May 24 – August 16, 2008) with a Decagon EM50 data logger which tracked air temperature (25 cm above the soil surface), soil temperature (three probes – one in each sub-plot), soil moisture (three probes – one in each sub-plot), and photosynthetically active radiation (PAR) (one sensor). Additionally, we measured rainfall (one sensor) and relative humidity (two sensors) at the site outside the rain exclusion structures.

## III. Results

*Soil temperature*

Average growing season soil temperature was 13.6 °C in the 0 °C plots, 16.1 °C in the 2.5 °C plots, and 18.8 °C in the 5 °C plots (Figure 1A). The mean temperature in the unheated control plots was 13.5 °C (Figure 1B). Therefore the heat treatments were 0.1 °C, 2.6 °C, and 5.3 °C above ambient. Soil temperature differences by moisture treatment were more pronounced in the warmer treatments (Figure 1A), but no pattern is evident.

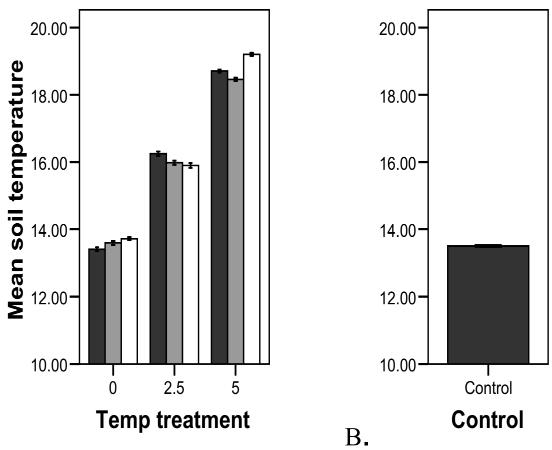
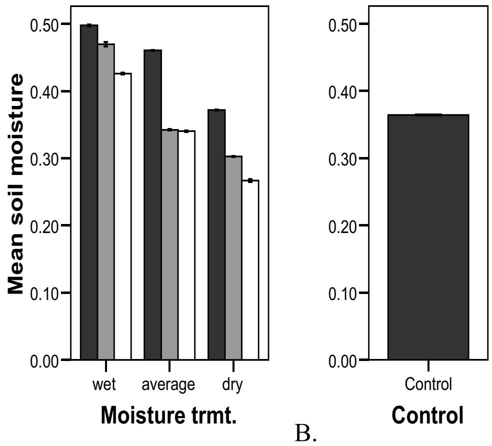



Fig. 1. A) Soil temperature (°C) by temperature treatment (shading of bars represent moisture treatment; black = wet, grey = average, white = dry). Error bars represent 95% confidence intervals. B) Control represent plots without rain exclusion structures

*Soil Moisture*

Average growing season soil moisture was 0.302 ($m^3/m^3$ VWC) in the dry plots, 0.358 in the average plots, and 0.429 in the wet plots (Figure 2A). The mean soil moisture in the control (natural rainfall) plots was 0.364 (Figure 2B). Therefore, the dry, average, and wet moisture treatments were -17%, -1.6% °C, and 18% below/above natural. Soil moisture differences based on temperature treatment exhibit no clear pattern of difference (Figure 2A), but the warmer treatments tend to show slightly less variability in soil moisture likely due to enhanced evaporation.




A. B.

Fig. 2. A) Soil moisture ($m^3/m^3$ VWC) by moisture treatment (shading of bars represent temperature treatment; black = 0 °C, grey = 2.5 °C, white = 5 °C). Error bars represent 95% confidence intervals. B) Control represent plots without rain exclusion structures.

*PAR (Photosynthetically active radiation)*

A primary objective of the environmental manipulation was to alter soil moisture and temperature while minimally altering other environmental parameters (i.e., light levels). Of the four uncovered control plots only plots two contained PAR sensors. Mean midday PAR (measured from 11am – 1pm) differed significantly (ANOVA; $p<0.0001$) but a post-hoc Scheffé failed to distinguish the plots into groups (Figure 3A), however a post-hoc Tukey identified differences. Mean daily PAR (sunrise to sunset) differed significantly ($p<0.001$) between plots (Figure 3B), yet the post-hoc Scheffé test identified two broad groups with significant overlap.

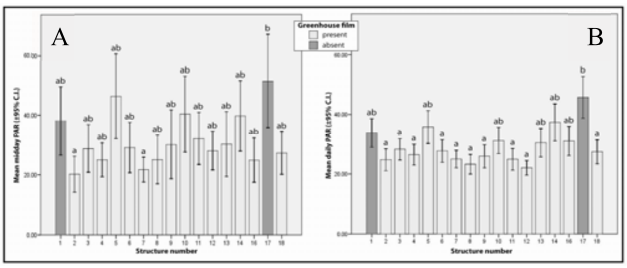



Fig. 3. A) Mean midday light levels (left) and B) mean daily light levels (photosynthetically active radiation; μmol $m^{-2}s^{-1}$) (right) for all plots (presence of greenhouse film is indicated with light bar shading). Error bars represent 95% confidence intervals. Letters indicate statistical grouping based on two ANOVAs (midday light levels and mean daily light levels) with post-hoc Scheffé tests.

*Air temperature*

As mentioned above, the primary objective of the heat treatments was to elevate air (and soil) temperature by 2.5 and 5 °C. Mean maximum air temperature (measured from 14 - 16 h) differed significantly across the structures (ANOVA; $p < 0.001$, post-hoc Scheffé test), with no overlap between treatments (Figure 4). The open structures were significantly cooler (mean = 16.6 °C), then the unheated plots (mean = 19.8 °C), the 2.5 °C plots (mean = 21.3 °C) and the 5 °C plots (23.2 °C). Mean minimum air temperature (measured from 2 - 4 h) differed significantly (ANOVA; $p<0.001$) between heat treatments, but there was no difference between control and 0 °C plots (Figure 5). The unheated (mean = 11.4 °C) and open plots (mean = 11.8 °C) were statistically similar, while the 2.5 °C plots (mean = 12.8 °C) were warmer than the control and unheated plots and the 5 °C plots (mean = 14.8 °C) were statistically warmer than all treatments. Mean daily air temperature (24 h average) differed significantly (ANOVA; $p<0.0001$) between treatments (Figure 6). Overall there was no statistical difference between the unheated (mean = 15.3 °C) and open plots (mean = 14.9 °C), while the 2.5 °C (mean = 16.9 °C) treatments were statistically warmer than the control and unheated plots and the 5 °C (mean = 18.9 °C) plots were significantly warmer than the other treatments. Daily air temperature range (daily maximum – daily minimum temperature) differed significantly (ANOVA; $p<0.0001$) between treatments (Figure 7). The control treatment had significantly lower range (mean = 4.81 °C) than the covered heat treatment plots (mean = 8.47 °C), including the 0 °C treatment.

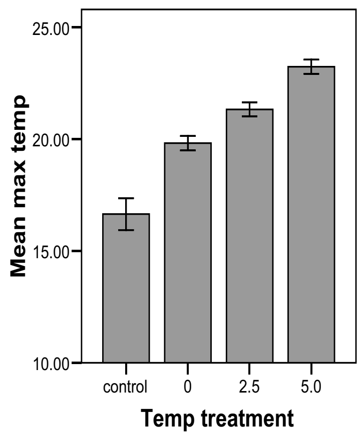



Fig. 4. Mean maximum air temperature (°C) under structures, measured between 14 - 16 h. Error bars represent 95% confidence intervals.

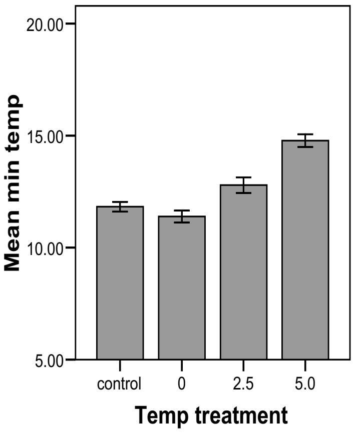



Fig. 5. Mean minimum air temperature (°C) under structures, measured from 2 - 4 h. Error bars represent 95% confidence intervals.

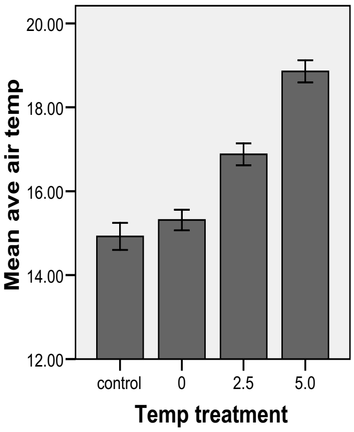



Fig. 6. Mean daily air temperature (°C) under structures. Error bars represent 95% confidence intervals.

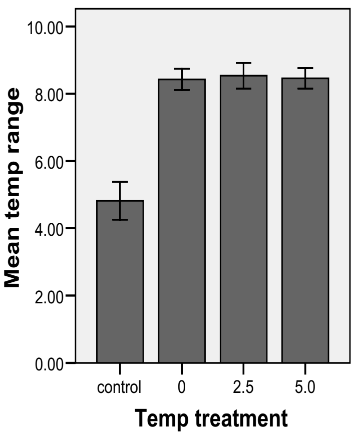



Fig. 7. Mean daily air temperature range (°C) under structures. Error bars represent 95% confidence intervals.



## IV. Discussion

Based on soil temperature measurements during the growing season, the objective of elevating ambient temperature by 0 °C, 2.5 °C, and 5 °C was largely achieved. Similarly, the objective of altering soil moisture by decreasing and increasing soil moisture by 20% was largely attained. Overall, as was the case with soil temperature, the heat treatments generally achieved the desired goal in elevating air temperature. The change in maximum temperatures was somewhat complicated by the structure design. The unheated structures were significantly warmer than ambient (control treatments) conditions likely due to inhibition of outgoing longwave radiation. The heat treatments surpassed the intended temperature increase when daily maximum temperatures were considered. The differential in daily minimum temperatures for the 2.5 °C plots were 1.4 °C above ambient, while the temperatures increase in the 5 °C plots was 2.4 °C above ambient. Overall, the change in average air temperature was 2 °C for the 2.5 °C plots, and 4 °C for the 5 °C plots, reasonably close to the experimental objective. Likely due to an increase in daily maximum temperatures, the daily temperature range for all the structure plots was greater than the uncovered plots.

While there were certainly complications due to the field methodology, the field design proved to be an effective way to simulate climate change. The goal of excluding natural rainfall in order to control moisture in the plots comes necessarily with slight decreases in incoming radiation given the greenhouse film topping the structures. While the attenuation of incoming radiation could readily be mitigated by increasing structure height (allowing unimpeded direct radiation to reach the entire area beneath the structures) it would increase the likelihood of rainfall penetrating laterally under windy conditions which would make accurately controlling soil moisture nearly impossible.

## V. Conclusion

In general the primary objectives of the manipulation were met indicating the described method of environmental manipulation may be successful in other ecosystems. Soil temperature and soil moisture generally differed from ambient conditions to the targeted levels, and ambient light levels were only slightly lower than ambient incoming PAR. Air temperature differences generally tracked the desired changes, but due to surface turbulence and likely interference with outgoing radiation, air temperature differentials were somewhat inconsistent and daily temperature range exceeded natural conditions.

## ACKNOWLEDGMENT

The authors would like to thank the following students for assistance in the field: Valarie Arkell, Christine Carrier, Josh Halpern-Givens, Ian Kenny, Matthew Kwit, Alicia Lisowski, and Shannon McCarragher. Krista Kennett and Matthew Kwit provided assistance with data analysis. Funding for this project was provided by the National Science Foundation (BCS-0724256).

## REFERENCES

[1] J. Harte and R. Shaw. "Shifting dominance within a montane vegetation community: results of a climate-warming experiment," *Science,* Vol.. 267, pp. 876-880, February 10, 1995.

[2] J. Harte *et al.* "Shifting dominance within a montane vegetation community: results of a climate-warming experiment," *Ecological Applications*, Vol. 51, pp. 132-150, 1995.

[3] F.S. Chapin III and G.R. Shaver. "Physiological and growth responses of arctic plants to a field experiment simulating climatic change," *Ecology*, Vol. 77, pp. 822-840, 1996.

[4] N. Edwards and R. J. Norby. "Below-ground respiratory responses of sugar maple and red maple saplings to atmospheric $CO_2$ enrichment and elevated air temperature," *Plant and Soil*, Vol. 206, pp. 85-97, 1999.

[5] C. A. Gunderson, R. J. Norby, and S.D. Wullschleger. "Acclimation of photosynthesis and respiration to simulated climatic warming in northern and southern populations of *Acer saccharum*: laboratory and field evidence," *Tree Physiology*, Vol. 20, pp. 87-96, 2000.

[6] M.V, Price and M.N. Waser. "Responses of subalpine meadow vegetation to four years of experimental warming," *Ecological Applications*, Vol. 10, pp. 811-823. 2000.

[7] R.J. Norby, J.S. Hartz-Rubin, and M.J. Vergbrugge. "Phenological responses in maple to experimental atmospheric warming and $CO_2$ enrichment," *Global Change Biology*, Vol. 9, pp. 1792-1801. 2003

[8] S. Wan, R.J. Norby, K.S. Pregitzer, J. Ledford, and E.G. O'Neill. "$CO_2$ enrichment and warming of the atmosphere enhance both productivity and mortality of maple tree fine roots," *New Phytologist*. Vol. 162, pp. 437-446. 2004.

[9] N. Barras and M. Kellman. "The supply of regeneration micro-sites and segregation of tree species in a hardwood/boreal forest transition," *Journal of Biogeography*. Vol. 25, pp. 871-881. 1998.

[10] D. Goldblum and L.S. Rigg. "Age structure and regeneration dynamics of sugar maple at the deciduous/boreal forest ecotone, Ontario, Canada," *Physical Geography*, Vol. 23, pp. 115-129. 2002.

[11] D. Goldblum and L.S. Rigg. "Tree growth response to climate change at the deciduous/boreal forest ecotone, Ontario, Canada," *Canadian Journal of Forest Research.* Vol. 35, pp. 2709-2718. 2005.

[12] M. Kellman. Sugar maple (*Acer saccharum* Marsh.) establishment in boreal forest: the results of a transplantation experiment. *Journal of Biogeography*. Vol. 31, pp. 1515-1522. 2004.

[13] Environment Canada. Canadian climate normals or averages 1971-2000.Available:http://climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html. 2002.

[14] D.A. Plummer *et al*. "Climate and climate change over North America as simulated by the Canadian RCM," *Journal of Climate*. Vol. 19, pp. 3112-3132. 2006.

**David Goldblum**. B.S., UCLA, Los Angeles, CA USA 1988, M.A. University of Colorado, Boulder, CO, USA 1990, Ph.D. University of Colorado, Boulder, CO, 1994. All degrees are in geography.
He is currently an assistant professor at Northern Illinois University in the Department of Geography.

**Lesley S. Rigg**. B.S., York University, North York, Ontario, CANADA 1992, M.A. University of Colorado, Boulder, CO, USA 1994, Ph.D. University of Melbourne, Melbourne, AUSTRALIA 1998. All degrees are in geography.
She is currently an associate professor at Northern Illinois University in the Department of Geography.