*Middle States Geographer, 2015, 48: 41-47*

# THE SEASONALITY OF REGIONAL MAXIMUM TEMPERATURES ASSOCIATED WITH CHANGING SURFACE INSOLATION PENETRATION: A WESTERN NEW YORK CASE STUDY

Stephen Vermette[1] and Shannon Graves[2]
[1]Department of Geography & Planning
[2]Department of Earth Sciences & Science Education
SUNY Buffalo State
1300 Elmwood Avenue
Buffalo, NY 14222

***ABSTRACT:*** *Operational meteorologists in Western New York (WNY) have observed that modeled daily maximum temperatures for the month of April often under-predict reported daily maximum temperatures on dry sunny days. The hypothesis explored here is whether daily maximum temperatures on sunny dry ground days in the spring and fall months, when greater insolation reaching the surface and the dark color of the surface allow for greater absorption and heating when the forest floor and agricultural soils are most exposed, are greater than for summer months after green-up and before leaf-drop. Thirty years of data, taken from Local Climatological Data Monthly Summaries, were examined so that potential patterns could be seen in the data independent of the day-to-day variability of weather. To differentiate dry versus wet ground, a 'Dry-ground Day' (DGD) and 'Wet-ground Day' (WGD) index was developed. A positive difference (comparing DGD versus WGD conditions) in daily maximum temperatures were shown for all months. The month of April shows the greatest difference in daily maximum temperatures (mean of +4.6ºC) associated with DGDs, while July shows the least difference (mean of +2.3ºC). Collectively, summer (June through August) daily maximum temperature differences increased an average of 2.5ºC. This average increase in daily maximum temperature differences was heightened by about 1.8ºC (to 4.3ºC) and 1.4ºC (to 3.9ºC) in the spring and fall seasons, respectively. These finding are consistent with our hypothesis.*

***Keywords: d****aily maximum temperatures, temperature anomalies, seasons, insolation, western New York*

## INTRODUCTION

Upon reaching a surface, incoming solar radiation (insolation) is partitioned to heat the surface (sensible heat) and to evaporate moisture (latent heat) (Aguado and Burt, 2007). The degree of partitioning dictates, in part, the temperature of a surface and that of the air above it. A wet surface will partition some insolation to evaporate moisture, leaving less available for sensible heat used to warm the surface and air. This soil moisture-temperature coupling is well established (Seneviratne et al., 2010). In evaluating a regional climate model for southern Europe, Jaeger et al. (2009) show that most of the land-atmosphere coupling characteristics are consistent between observations and their regional models. Their analysis of the correlation between evapotranspiration and temperature similarly suggests a strong coupling between surface moisture, latent heat, sensible heat, and observed surface temperatures. Whan et al. (2015) demonstrated for regions of Europe that soil moisture influences the magnitude of temperature extremes, linking dry soils in Europe to hot temperature extremes.

Being aware of soil moisture-temperature coupling linking dry soils to heightened temperatures, operational meteorologists in Western New York (WNY) have observed that regional model temperatures for the month of April often under-predict daily maximum temperatures on dry sunny days. It was noted that once a 'green-up' (vegetation) occurred, this process ended (McLaughlin 2015). This supports the earlier research of Jaeger et al. (2009), who noted a tendency in their model for sensible heat to have a positive, and latent heat a negative, phase-shift error in the mean seasonal cycle. They attributed this phase-shift to their model onset of the vegetation period predicting too early in spring. They also noted that the phase-shift in sensible heat was much greater than for latent heat. In an assessment of daily temperature errors associated with single-station model output statistics (MOS), Taylor and Leslie (2005) noted that temperature forecast errors tend to be relatively small during the summer and comparatively large during the spring and fall transition seasons. They also noted that trends in temperature errors are inconsistent and rarely continue for more than two or three consecutive days.

In his initial explanation of the warming, McLaughlin (2015) attributed this warming to direct heating of soils and a surface absent of green (vegetation) to absorb the heat and use it as energy for plants. However, the efficiency of chlorophyll in converting sunlight to energy is in the range of only a few percent (Hall and Rao, 1999), thus the impact on maximum air temperatures due to its use by plants is minimal. In a station pairing (forested vs meadow), Henderson (2014) found no supporting evidence that the loss of chlorophyll in the forest canopy impacted the local energy budget, however, a temperature difference was noted after leaf drop.

An explanation for the green-up effect on daily maximum temperature, as described by McLaughlin (2015), may relate to the seasonal shading of a surface. In summer, a forest and an agricultural field shade the soils below them. The shading limits the amount of insolation reaching the forest floor or soil in a field, thus the heating of that surface is lessened. In the spring months, trees are not in leaf and crops have not yet sprouted in fields, allowing for more insolation to pass through the forest or field canopy onto the forest floor or agricultural soil. During the month of April, and early May, forest soils may become especially dry as root pressure – which draws water out of the soil – is triggered by the warming soils attributed, in part, to trees in early spring that do not shade the forest floor (Wilmot, 2011). Similarly, in the fall months, leaf drop and harvested fields allow for greater penetration of insolation (Figure 1). The greater insolation reaching the surface and the dark color of that surface (brown leaves and dark soils) allows for greater absorption and heating. Thus, it would be expected that the differences in daily maximum air temperatures during periods with sunny days and dry surfaces, as compared to periods with sunny days and wet surfaces, are greatest during the spring and fall months when the forest floor and soils are most exposed, and least during the summer months after vegetation and before leaf-drop. It is interesting to note that the inconsistency of model temperature errors - rarely continuing for more than two or three consecutive days - in the spring and fall months, as observed by Taylor and Leslie (2005), conforms to what might be the expected variability between sunny dry surface days, and sunny wet surface days, as described above.

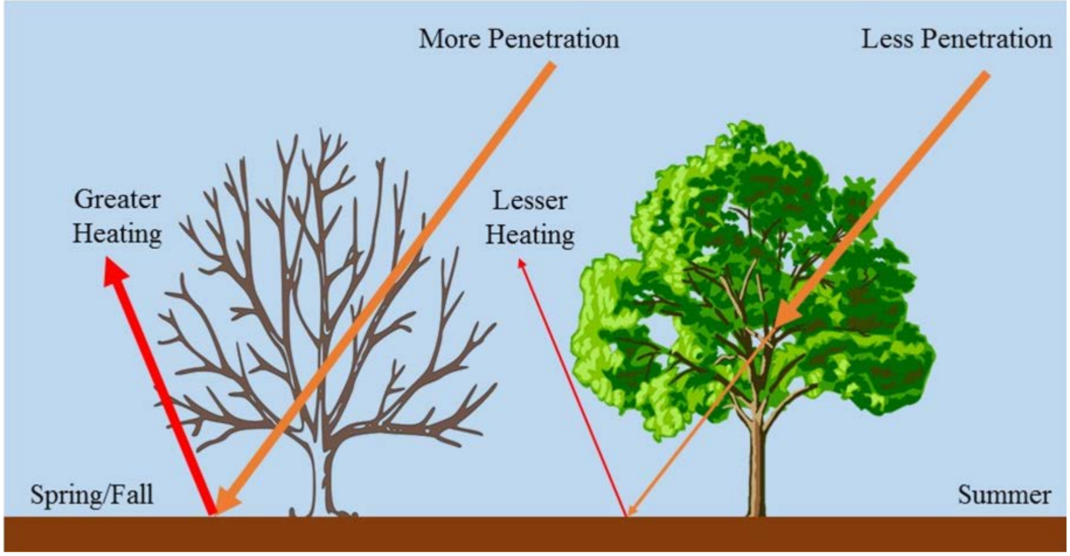

Figure 1. Varying insolation penetration by season.

If regional-scale forcing is to be attributed to the seasonality of land cover, specifically forest and farm, then the region studied must be dominated by this land cover. The WNY Regional Sustainability Plan (2013) reports that the combined acreage of agriculture and timberland accounts for 70% of the region's land cover. This acreage count is conservative as it does not include forested land that is not producing - or incapable of producing - industrial wood crops, or abandoned farmland left fallow.

Regional-scale forcing can be masked by local and micro-scale forcing at the point of measurement (a weather station). Adherence to World Meteorological Organization (WMO) guidelines on instrumentation and methods of observations are tailored to minimize these forcings (WMO, 2008). These guidelines include: air temperatures taken in an environmental screen, thermometers positioned 1.5 m above level ground, equipment located away from obstructions, and removed from nearby local topographic variations. Numerous examples of poorly-exposed sites, including Cooperative Observer (COOP) Program sites, exist in the literature (Mahmood, et al., 2006; Davey and

Pielke, 2005). It is critical to choose a weather station that is regionally representative, or more precisely, that is capable of detecting regional-scale forcing.

The question addressed in this study is whether there is evidence in the daily maximum temperature record, as obtained from a single weather station, of regional-scale forcing associated with seasonal changes in land cover. Specifically, the question is whether the differences in daily maximum air temperatures during periods with sunny days and dry surfaces, as compared to periods of sunny days and wet surfaces, are greatest during the spring and fall months when the forest floor and soils are most exposed, and least during the summer months after green-up and before leaf-drop.

## METHODOLOGY

Meteorological data for WNY were obtained from the Buffalo Niagara International Airport (KBUF). KBUF is a first order NWS site, the region's climate site, and conforms to WMO standards, minimizing local and micro-scale forcing to better detect regional-scale forcing. The KBUF site was moved 14 km inland from the Lake Erie coast in 1942. Analyses of post-1942 climate records by Quinn et al. (1982) and Vermette and Orengo (2006) concluded that the move of the NWS to its current location has resulted in loss of the lake effect seen in the post-1942 climate record, thus the site is more representative of the wider region. Quinn et al. (1982) found no statistical difference in temperatures between KBUF and the land-locked WNY community of Lockport, a further 30 km from KBUF.

Meteorological data for KBUF were taken from Local Climatological Data Monthly Summaries, as obtained from NOAA's National Centers for Environmental Information (NCEI). The 30 years of study chosen were from 1966 to 1996. These years were chosen because 1996 is the last year that the NCEI Monthly Summaries reported daily sunshine data. We chose to use the certified NCEI sunshine data, as opposed to a cloud cover surrogate approach that introduces its own set of errors (Perez et al., 2001; Belcher and DeGaetano, 2005).

A regional and climatological approach was taken for this study. The regional approach is to the extent that temperatures reported at KBUF were influenced by regional-scale forcing associated with seasonal changes in land cover; and climatological in that 30 years of data were used so that potential patterns could be seen in the data, independent of the day-to-day variability of weather.

To differentiate dry versus wet ground, a 'Dry-ground Day' (DGD) and 'Wet-ground Day' (WGD) index was developed. A DGD was defined as a day when no measureable precipitation was recorded on that day and on the two previous days, and the day experienced greater than 50% of maximum possible direct insolation (sunshine) received at KBUF, as measured by a Foster-Foskett sensor (Foster and Foskett, 1953). A WGD was defined as a day when no measureable precipitation was recorded on that day but measureable precipitation was recorded on the previous two days, and the day experienced greater than 50% sunshine. For both cases (DGD and WGD), the definition included the absence of a snowpack. The choice of two days for both DGDs and WGDs was somewhat arbitrary as there is no clear guidance as to when leaf litter or soil is dry or wet. The DGD and WGD index is more appropriately characterized as 'drier' (DGD) and 'wetter' (WGD). In addition, use of three- or four-day periods substantially limited the size of our data set.

Based on the definition criteria, individual DGDs and WGDs were identified in the monthly summaries. The daily maximum temperatures for each DGD and WGD day were recorded, summed for the month, and the difference between the two sums (DGD−WGD) was recorded as a monthly value. A 30-year mean of the differences (DGD−WGD for each month) was calculated for the summed monthly values, whereas individual monthly values were used to express variability. These steps were repeated for each of the 12 months, over the 30-year period.

## RESULTS AND DISCUSSION

The winter months of November through February were omitted from further study as less than half of the 30 years of data reported DGDs and WGDs. The absence of DGDs and WGDs can be attributed to the presence of a snowpack. The month of March included slightly more than 50% of DGDs and WGDs but, given that March is often defined as a winter month in WNY (McInerney and Vermette, 2008), it was also omitted from this study.

Monthly temperature mean differences and variability are shown in Figure 2. On average, all months exhibit positive daily maximum temperature differences (DGD–WGD), but the spring (April and May) and fall months (September and October) show a greater difference in average daily maximum temperatures than the summer months (June, July, and August). The month of April appears to show the greatest daily maximum temperature difference associated with DGDs (mean of +4.6ºC), while July shows the least difference (mean of +2.3ºC).

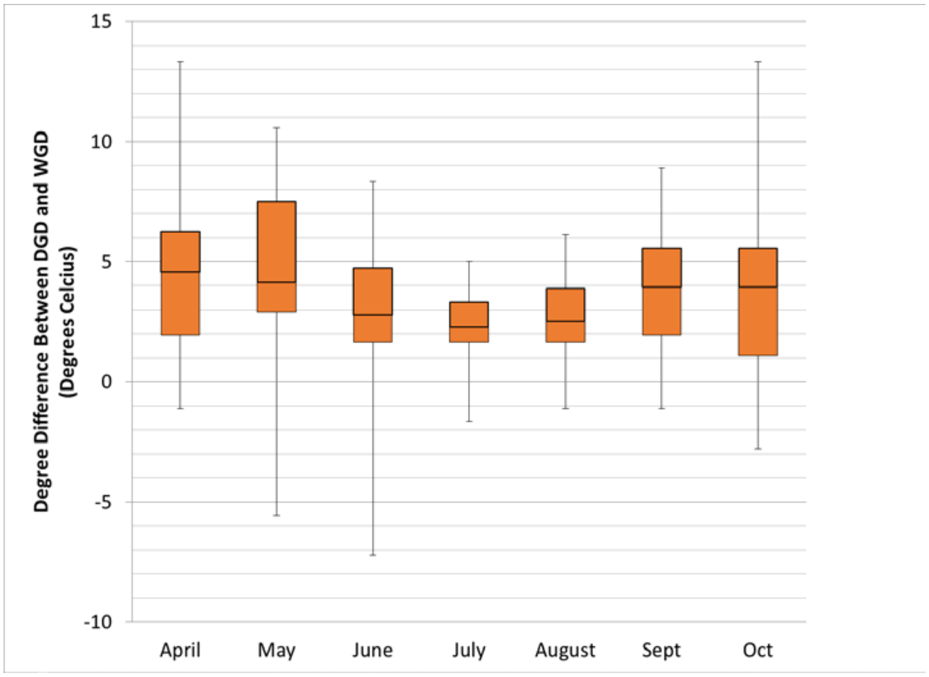

Figure 2. Monthly DGD−WGD daily maximum temperature differences (1966-1996). Shown are means, 25th and 75th percentiles, and extremes.

A Student's T-test was administered to determine if the monthly maximum daily temperature difference are significantly different from one another. Given that a P-value of <0.1 (90% confidence level) indicates a significant difference between months, the summer month temperature differences appear significantly different (many at or near the 95% confidence level) from that of the spring and fall months (Table 1). And the spring and fall months do not appear significantly different from one another.

Table 1: Student's T-test (P-values) comparing the significance of DGD−WGD monthly daily maximum temperature values (* denotes a significant difference, p <0.1).

| | May | Jun | Jul | Aug | Sep | Oct |
|---|---|---|---|---|---|---|
| Apr | 0.697 | 0.072* | 0.007* | 0.044* | 0.486 | 0.584 |
| May | | 0.219 | 0.052* | 0.091* | 0.858 | 0.876 |
| Jun | | | 0.444 | 0.091* | 0.858 | 0.876 |
| Jul | | | | 0.521 | 0.005* | 0.036* |
| Aug | | | | | 0.016* | 0.074* |
| Sep | | | | | | 0.998 |

Given the statistical separation between the months of June, July, and August from that of the other months, the months were grouped into seasons (Figure 3). As with Figure 2, the daily maximum temperature increase attributed to DGD is greatest in the spring and fall months and least in the summer. As expected, average daily maximum air temperatures were warmest on days with dry surfaces, as opposed to days with wet surfaces. Collectively, the summer months exhibit a mean daily maximum temperature difference of +2.5$^{o}$C. The spring season shows a greater difference in average daily maximum temperatures over that of the summer season, exhibiting a mean temperature difference of +4.3$^{o}$C. The mean difference between the two seasons (+1.8$^{o}$C), is consistent with a springtime lack of tree canopy and fallow agricultural fields. A similar case can be made for the fall season, although the difference between summer and fall is slightly less (+1.4$^{o}$C). The greater spring mean daily maximum temperature difference, as compared to that of the fall, may, in part, be attributed to the increased drying of early spring forested soils due to root pressure.

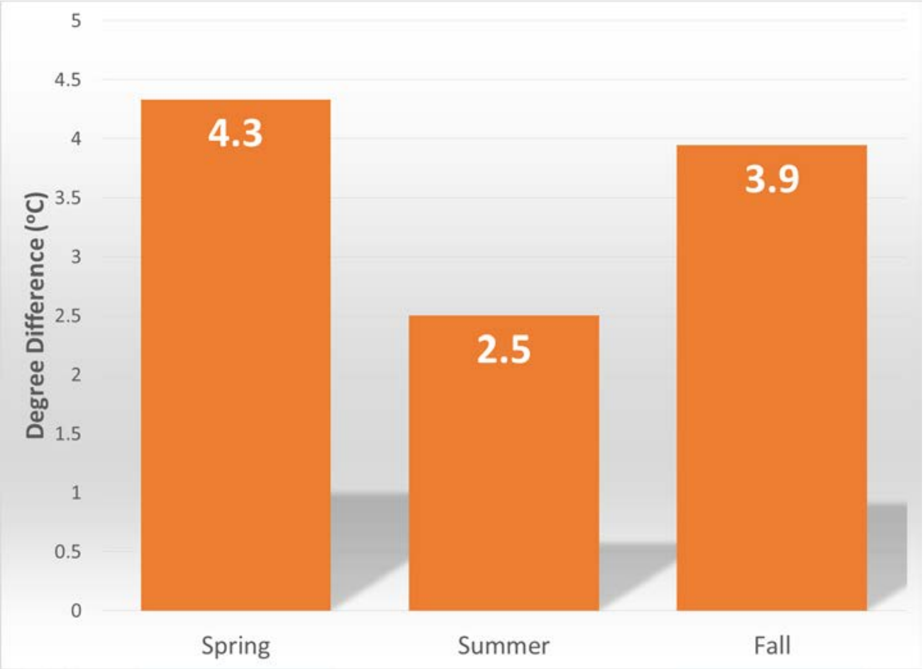

Figure 3: Seasonal mean DGD−WGD differences in daily maximum temperatures.

These finding are consistent with our hypothesis that during the spring and fall months the forest canopy and agricultural crops are absent or in flux, allowing insolation to warm the forest floor and agricultural soils, and ultimately heat the region's air to a greater extent than would occur during the summer season once there has been a green-up and this heating process ends.

## CONCLUSION

Building on observations that WNY regional model temperatures for the month of April often under-predict daily maximum temperatures on dry sunny days, a single-station climatological approach was undertaken to determine whether there is evidence of regional-scale forcing on daily maximum temperatures associated with seasonal changes in land cover. A positive difference (comparing DGD versus WGD conditions) in maximum temperatures was shown for all months, where the spring (April and May) and fall months (September and October) showed a greater difference than that of the summer months (June, July, and August). The month of April shows the greatest difference in daily maximum temperatures (mean of +4.6ºC) associated with DGDs, while July shows the least difference (mean of +2.3ºC). Collectively, summer (June through August) daily maximum temperature differences increased an average of 2.5ºC. This average increase in daily maximum temperature differences was heightened by about 1.8ºC (to 4.3ºC) and 1.4ºC (to 3.9ºC) in the spring and fall seasons, respectively. These finding are consistent with our hypothesis, that during the spring and fall months the forest canopy and agricultural crops are absent or in flux, allowing insolation to warm up the forest floor and agricultural soils, and ultimately heat the region's air to a greater extent than would occur during the summer season once there has been a green-up and this heating process ends.

The implications of this research apply to local weather forecasting – indicating that modeled daily maximum temperatures must be adjusted upwards based both on surface moisture and season. Implications of this research also apply to local climate change modeling, where seasonality must be factored in when considering the impact of soil moisture on air temperatures.

## ACKNOWLEDGEMENTS

The authors acknowledge the contribution of Steven McLaughlin (retired NWS forecaster) who first raised the issue. Our appreciation to the '4JR' team: Justin Blicharski, Jeremy Brant, Jacob Bajdas, James Hubacher and

Ronald Corp who completed the first exploratory work on this topic as part of an Applied Climatology (GEG 386) course at SUNY Buffalo State.

## REFERENCES

Aguado, E. and Burt, J.E. 2007. *Understanding Weather and Climate*, 4th Edition, Pearson Prentice Hall, Upper Saddle River, NJ.

Belcher, B.N. and DeGaetano, A.T. 2006. A revised Empirical Model to Estimate Solar Radiation Using Automated Surface Weather Observations. *Solar Energy* 81(3): 329-345.

Davey, C.A. and Pielke, R.A. 2005. Microclimate Exposures of Surface-based Weather Stations. *Bulletin of the American Meteorological Society* 86(4): 497-504.

Foster, N.B. and Foskett, L.W. 1953. A Photoelectric Sunshine Recorder. *Bulletin of the American Meteorological Society* 34: 212-215.

Hall, D. and Rao, K. 1999. *Photosynthesis*. Cambridge University Press, 6th Edition, Cambridge, UK.

Henderson, K. 2014. *Seasonality of Energy Budget Changes Associated with Decreased Chlorophyll Production by Trees during Autumn*. Presented at the Association of American Geographers Middle States Division Meeting, York, PA. October 24-25, 2014.

Jaeger, E.B., Stockli, R. and Seneviratne, S.I. 2009. Analysis of Planetary Boundary Layer Fluxes and Land-atmosphere Coupling in the Regional Climate Model CLM. *Journal of Geophysical Research* 114, D17106.

Mahmood, R., Foster, S.A., and Logan, D. 2006. The Geoprofile Metadata, Exposure of Instruments, and Measurement Bias in Climate Record Revisited. *International Journal of Climatology* 26: 1091-1124.

McInerney, T. and Vermette, S. 2008. Development of a Severe Winter Index: Buffalo, New York. *The Geographical Bulletin* 49 (1): 47-55.

McLaughlin, S., 2015. Personal Communication.

Perez, R., Bonaventura-Sparagna, J.A., Kmiecik, M., George, R., Renne, D., 2001. Cloud cover reporting bias at major airports. In: *Proceedings of the American Solar Energy Society Annual Conference*, 2001.

Quinn, F. H., Assel, R. A., and Gaskill, D.W. 1982. An Evaluation of the Impact of the Niagara Ice Boom on the Air Temperature Regime at Buffalo, New York. *Journal of Applied Meteorology* 21(3): 342-349.

Seneviratne, S.I., Corti, T., Davin, E.L., Hirschi, M. Jaeger, E.B., Lehner, I., Orlowsky, B., and Teuling, A.J. 2010. Investigating Soil Moisture-climate Interactions in a Changing Climate: A Review. *Earth Science Reviews* 99: 125-161.

Taylor, A.A. and Leslie, L. 2005. A Single-station Approach to Model Output Statistics Temperature Forecast Error Assessment. *Weather and Forecasting* 20: 1006-1020.

Vermette, S.J. and Orengo, E. 2006. A Re-examination of Buffalo's Lost Lake Effect. *Geographical Bulletin* 48 (2): 97-108.

Whan, K., Zsheischler, J., Orth, R., Shongwe, M., Rahimi, M., Asare, E.O., and Seneviratne, S.I. 2015. Impact of Soil Moisture on Extreme Maximum Temperatures in Europe. *Weather and Climate Extremes* 9: 57-67.

Wilmot, T. 2011. Root Pressure in Trees: A Spring Phenomenon. *Farming – The Journal of Northeast Agriculture* 14 (5): 48-49.

Western New York Regional Sustainability Plan 2013. WNY Regional Economic Development Council and One Region Forward: http://uploads.oneregionforward.org/content/uploads/2013/06/Western-New-York-Regional-Sustainability-Plan.pdf

World Meteorological Organization (WMO), 2008. *Guide to Meteorological Instruments and Methods of Observation.* WMO, No. 8 (7th Edition). Secretariat of the World Meteorological Organization, Geneva, Switzerland.