The Cooling and Heating Impacts of a Lake and a Nearby Wetland Under Current and Changing Climate

Henrique Vieira[1] and Ali Nazemi[1]

[1]Concordia University

November 26, 2022

Abstract

Understanding the effect of different landscapes on local temperature is important for understanding land-atmospheric interactions, and is a critical step toward an informed urban design under a changing climate. This presentation considers Lake Memphremagog, a transboundary water body between Quebec and Vermont, along with one of its adjacent wetlands as a test bed to study the impact of different water bodies on regulating the local temperature. We use the data from two identical climate stations to study hourly temperature, absolute and relative humidity as well as incoming and outgoing radiation components along with vapour pressure deficit at the lake and wetland. We benchmark the temperature measurements in these two sites with the data gauged in an Environment and Climate Change Canada's weather station located between the two sites. Using a systematic analysis, we account for the cooling and heating impacts of the lake and the wetland and demonstrate their underlying causes. We show that during the growing season and at the daily scale, the cooling impacts of the wetland can cancel out the heating impacts of the lake. This is not the case during day times, in which the lake acts as a sink of heat, while the wetland is the source. We show that the cooling and heating effects of the considered lake-wetland duo can be described by the daily temperature statistics (i.e. average, minimum, maximum and range) at the benchmark weather station. This provides an opportunity to create stochastic models for retrospective and prospective projections of cooling and heating impacts of this lake-wetland duo under current and future climate.

The Cooling and Heating Impacts of a Lake and a Nearby Marsh Under Current and Changing Conditions

Henrique Vieira and Ali Nazemi, PhD
Concordia University, Montréal, Québec, Canada

Planet Earth by Wider Embraces is licensed under CC BY-SA-NC

"Nature based solutions are a vital complement to decarbonization, reducing climate change risks and establishing climate resilient societies" (UN Global Compact)

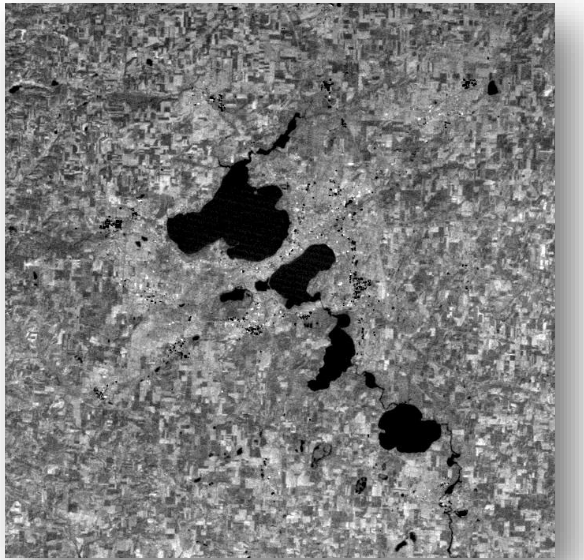
Nature based solutions are already in place or being legally implemented in several countries, so their effects must be well understood

Quebec's Bill 132: An Act respecting the conservation of wetlands and bodies of water

The literature is asking for studies on the thermal effects of water bodies

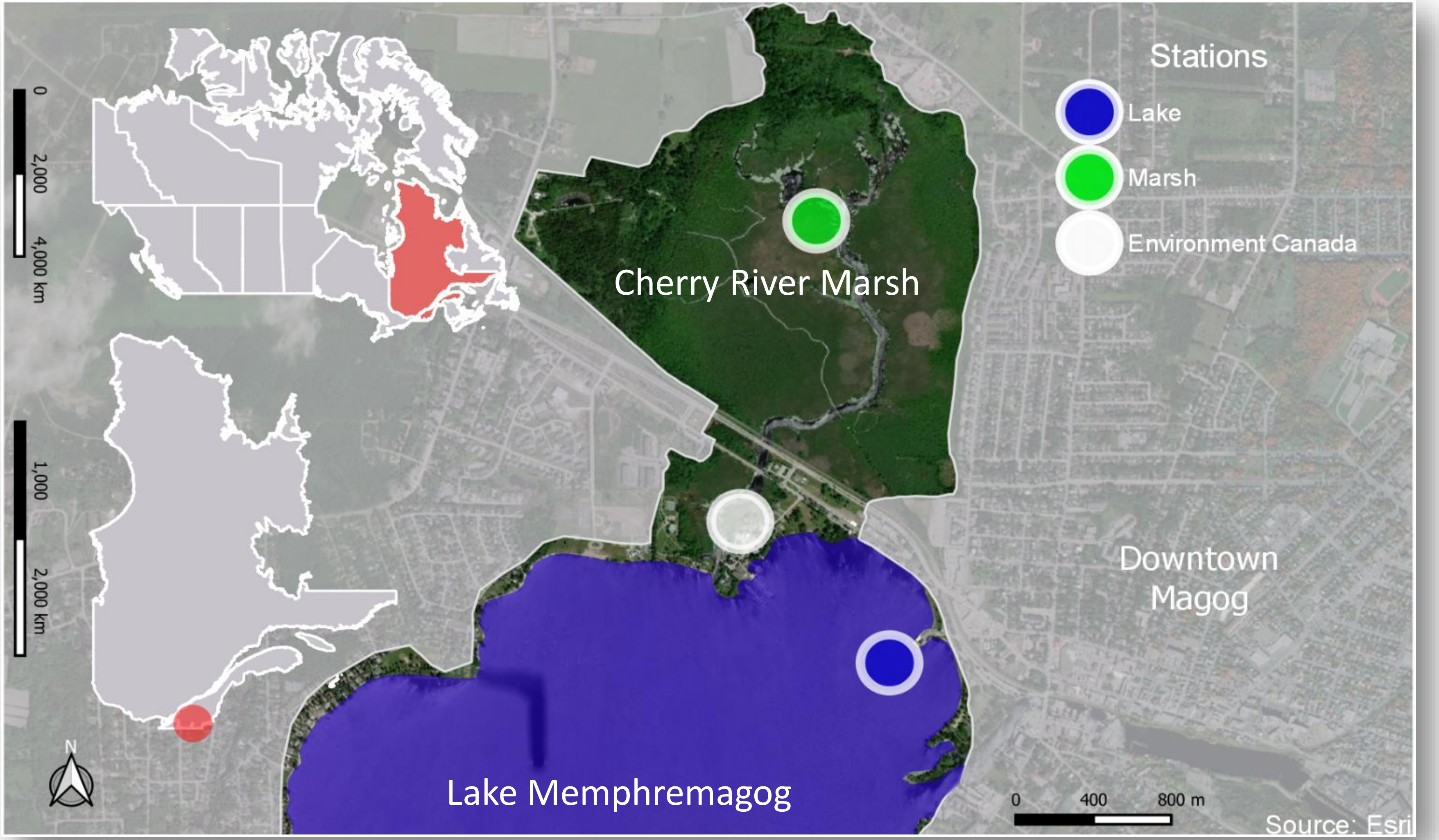
Howard, 1833:
Comparing urban and rural temperatures

Oke, 1991:
Thermal properties and evapotranspiration strongly affect surface energy balance



Coutts, 2013:
Water bodies received less attention
Lack of station data

Study area: a strategic location for water resources research



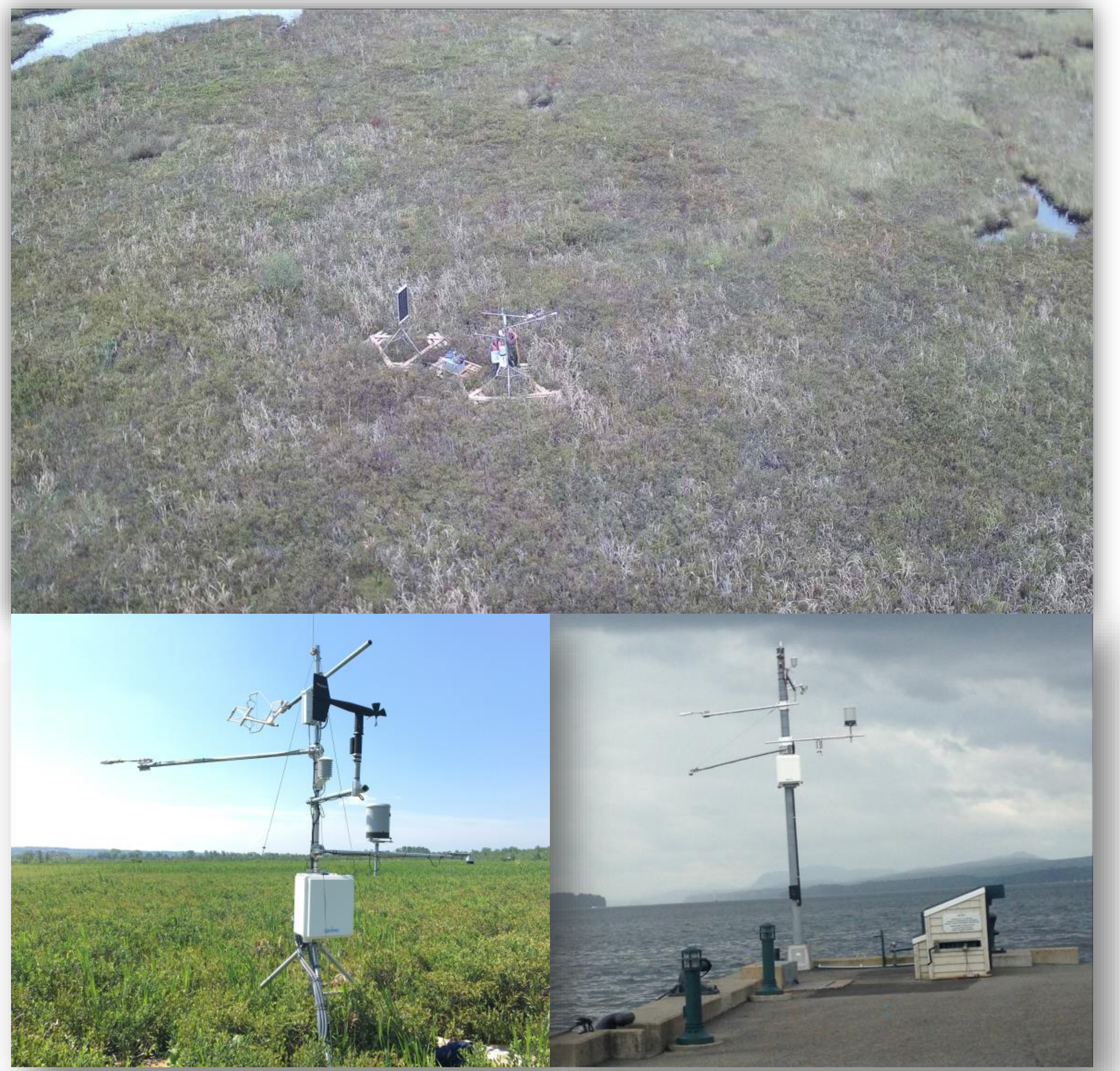
Marais de la Rivière aux Cerises

Memphrémagog Conservation inc.

Study area

Data Collection (30 min):

- Temperature
- Relative humidity
- Wind speed and direction
- Precipitation
- Radiation components
- Surface level
- Evapotranspiration*



1. To quantify the heating and cooling impacts...

Compute Net Degree Hour Difference (NDHD; daily scale):

$$NDHD_{day} = \sum_{day} (T_{marsh/lake,\, hour} - T_{ECCC,\, hour})$$

2. To understand the microclimatological differences between the marsh and the lake...

Compute differences

1. Time scales: daily, weekly and monthly
2. Variables: temperature, net radiation, absolute humidity and vapor pressure deficit as proxies of thermal properties and evapotranspiration
3. Times of the day: full days, days and nights

e.g. Air temperature difference in the marsh: $\Delta T_a = T_{a,marsh} - T_{a,lake}$

3. To model the heating and cooling impacts…

Develop monthly copula models* to represent NDHD as a function of air temperature (min, max, mean or range)

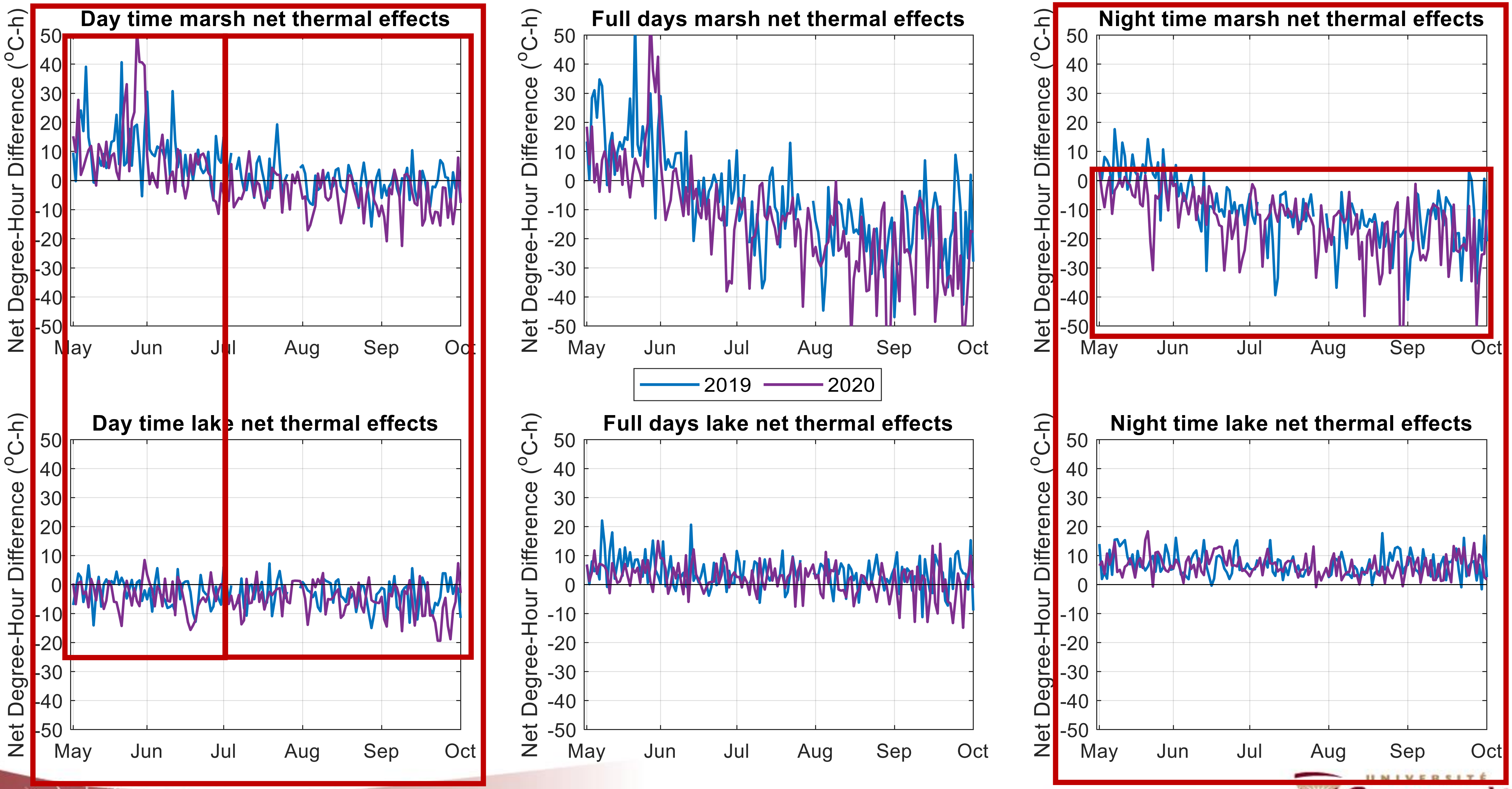
1. Select best predictor using Mann-Kendall's dependence test to assess the statistical significance (*p*-value) and strength of the dependencies (τ)

2. Select and use the best copula family (Frank, Gaussian, Student or Clayton)

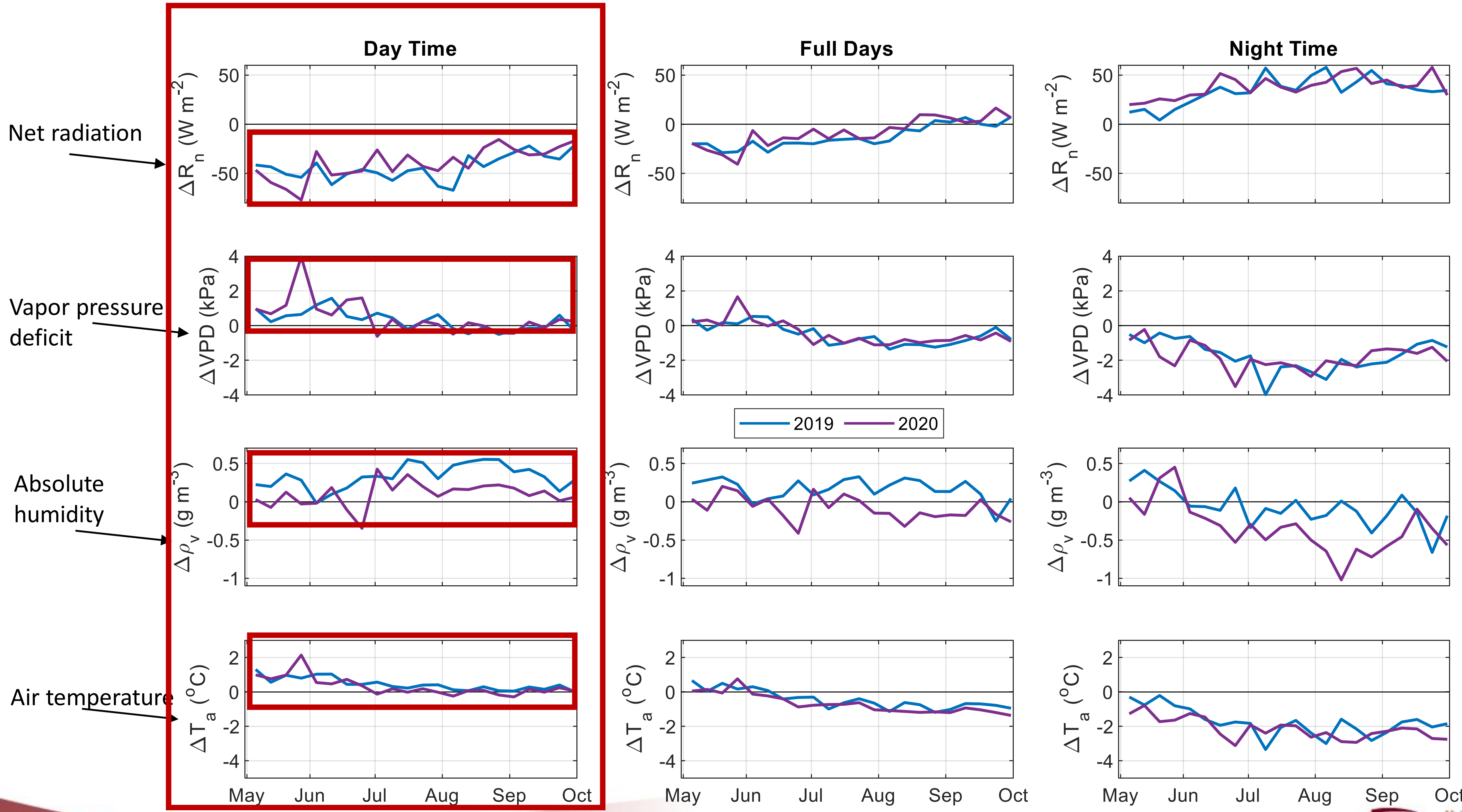
3. Generate NDHD based on different changes to temperature using the monthly copulas (sensitivity analysis)

*Genest, C., & Favre, A.-C. (2007). Everything you always wanted to know about copula modeling but were afraid to ask. *Journal of Hydrologic Engineering*, *12*(4), 347–368.

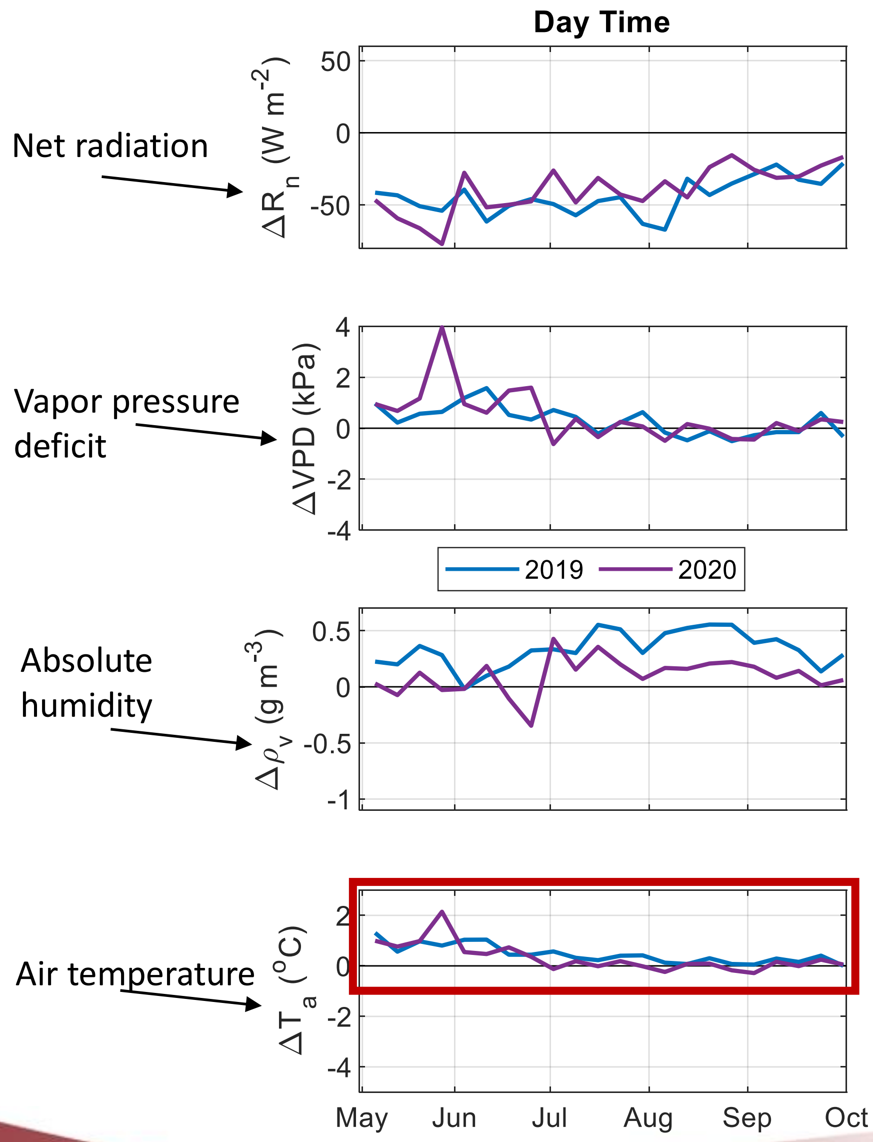
Net thermal effects of the marsh and lake on the reference station (daily)

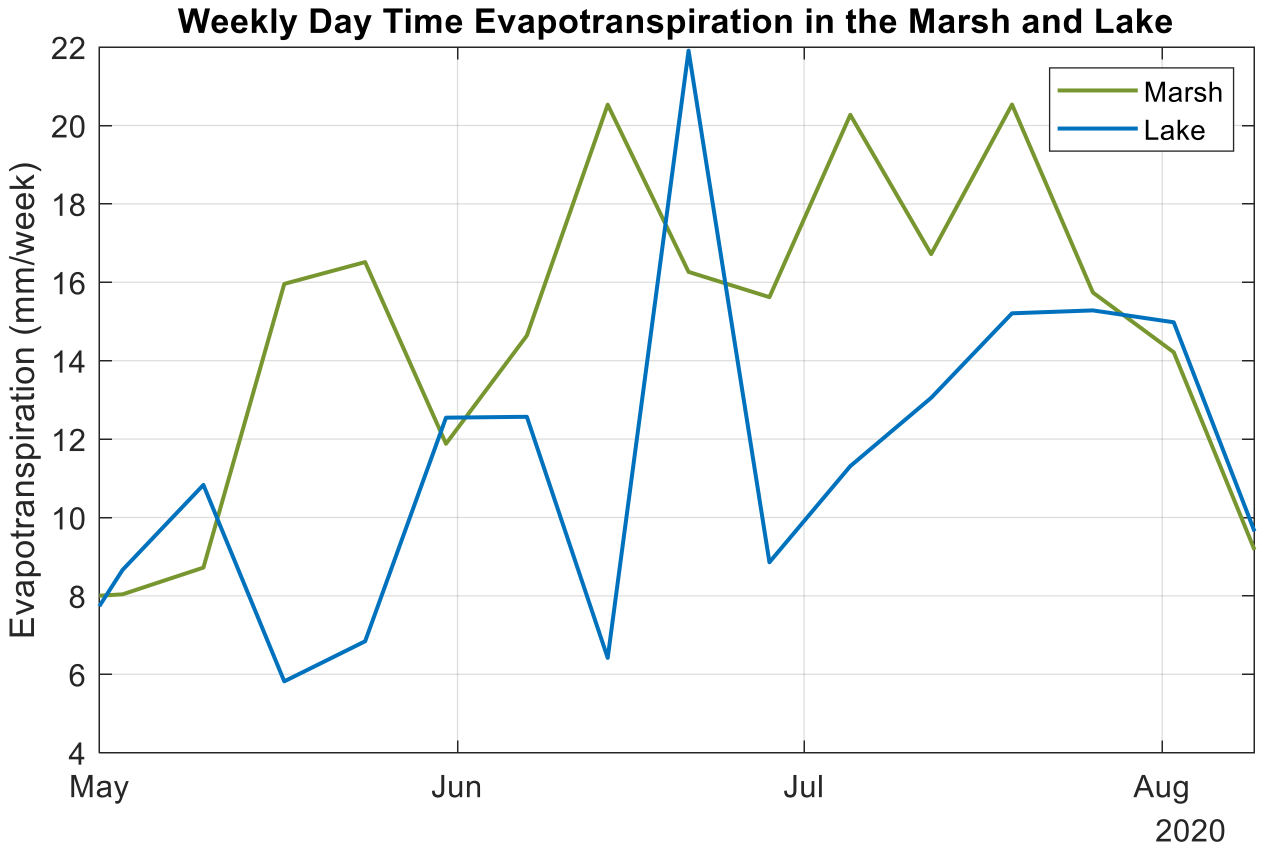


Weekly difference between variables of interest in the marsh and the lake (Δ: marsh-lake)

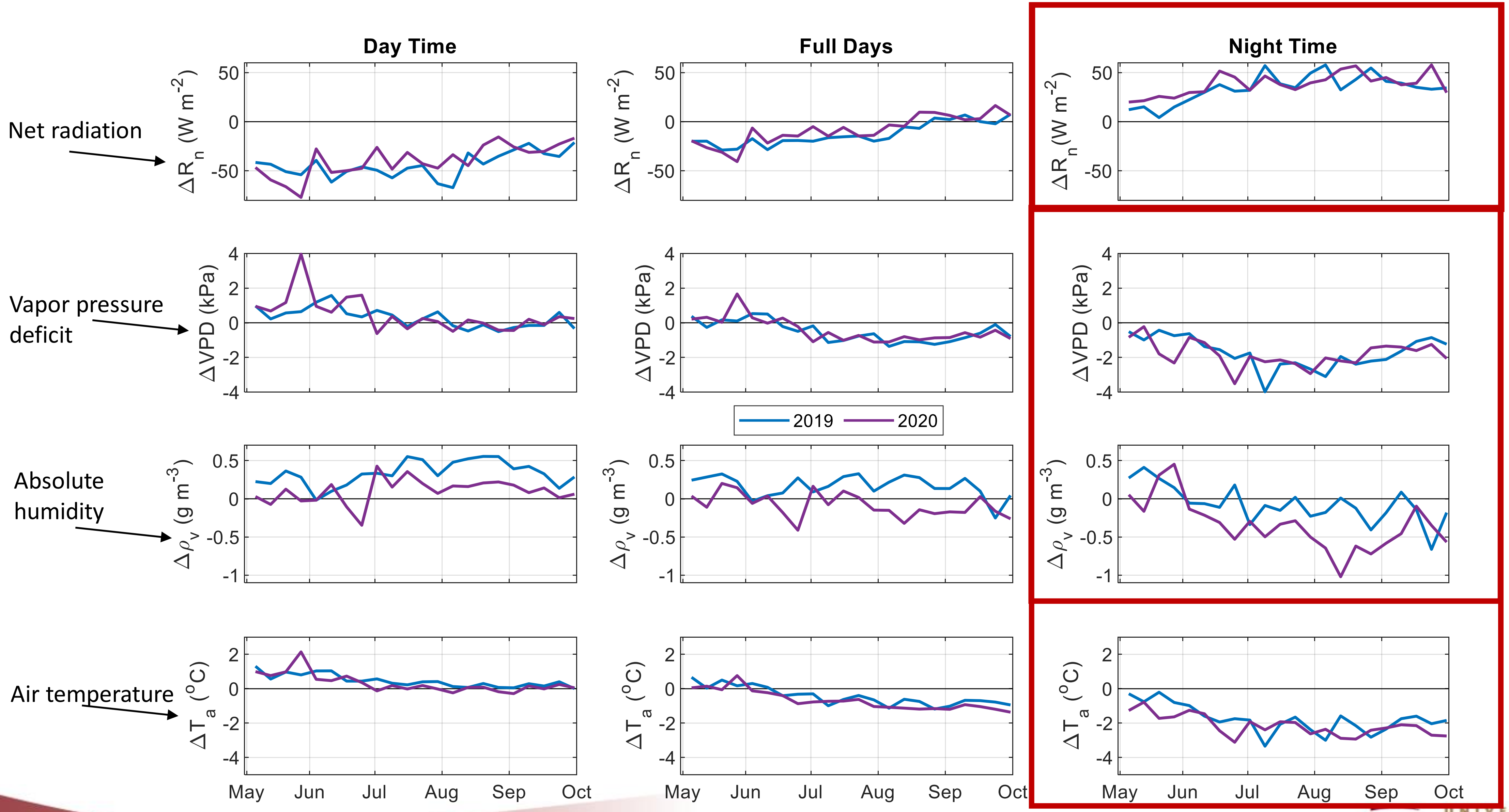


Weekly difference between variables of interest in the marsh and the lake (Δ: marsh-lake)

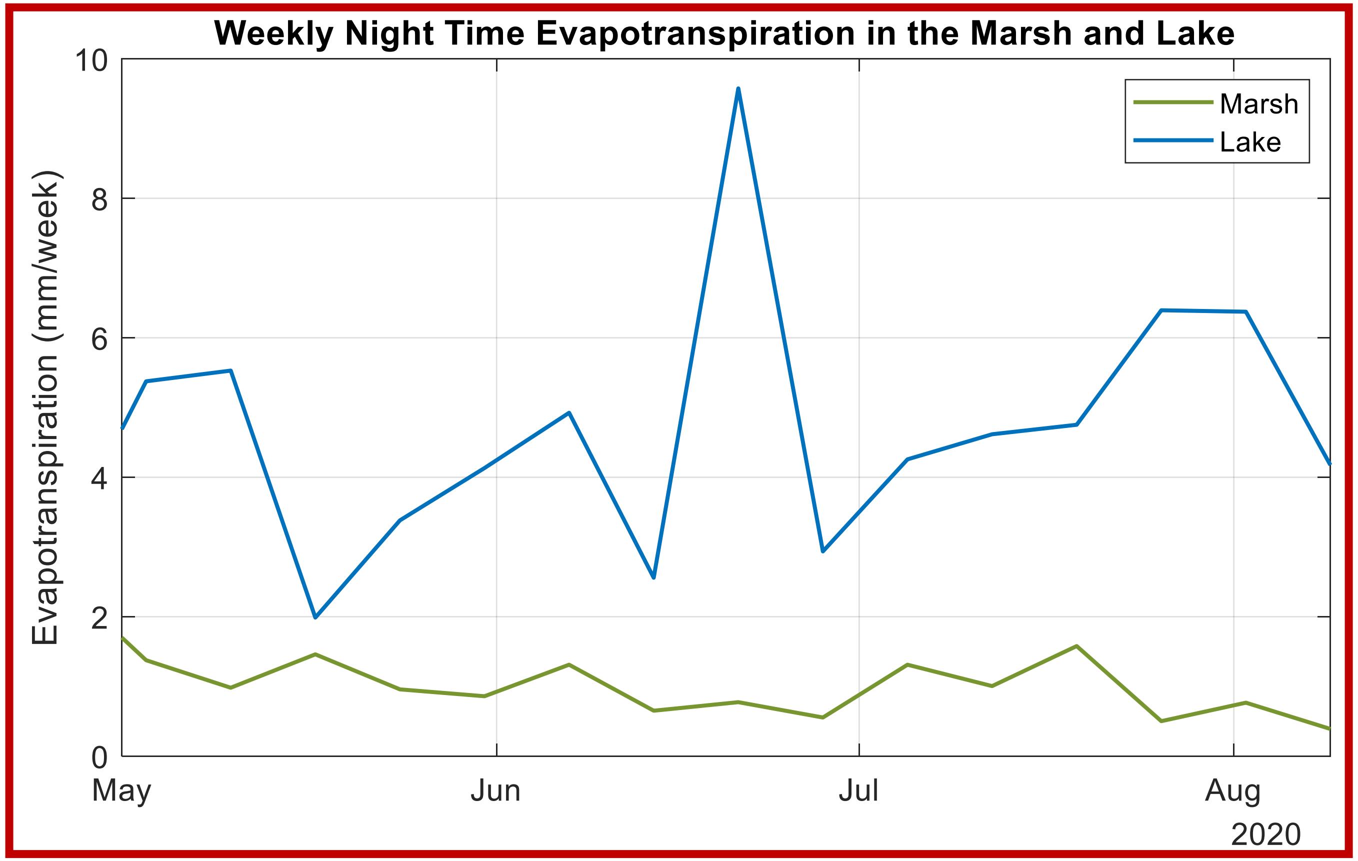


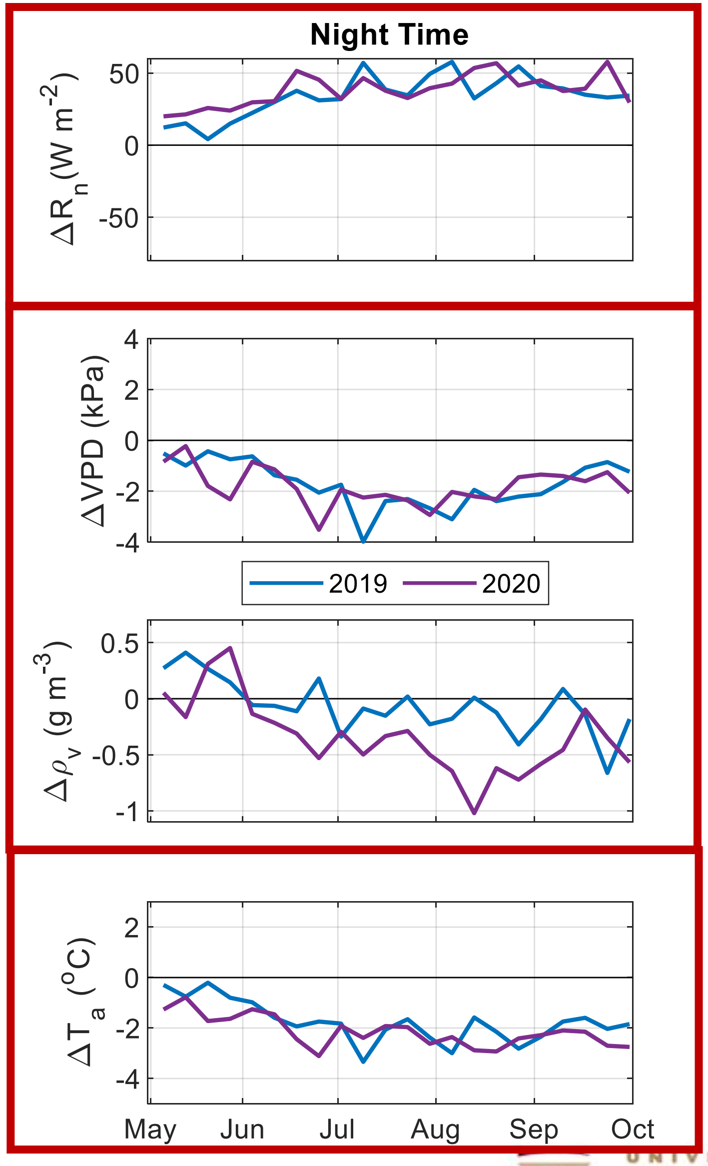


Weekly difference between variables of interest in the marsh and the lake (Δ: marsh-lake)

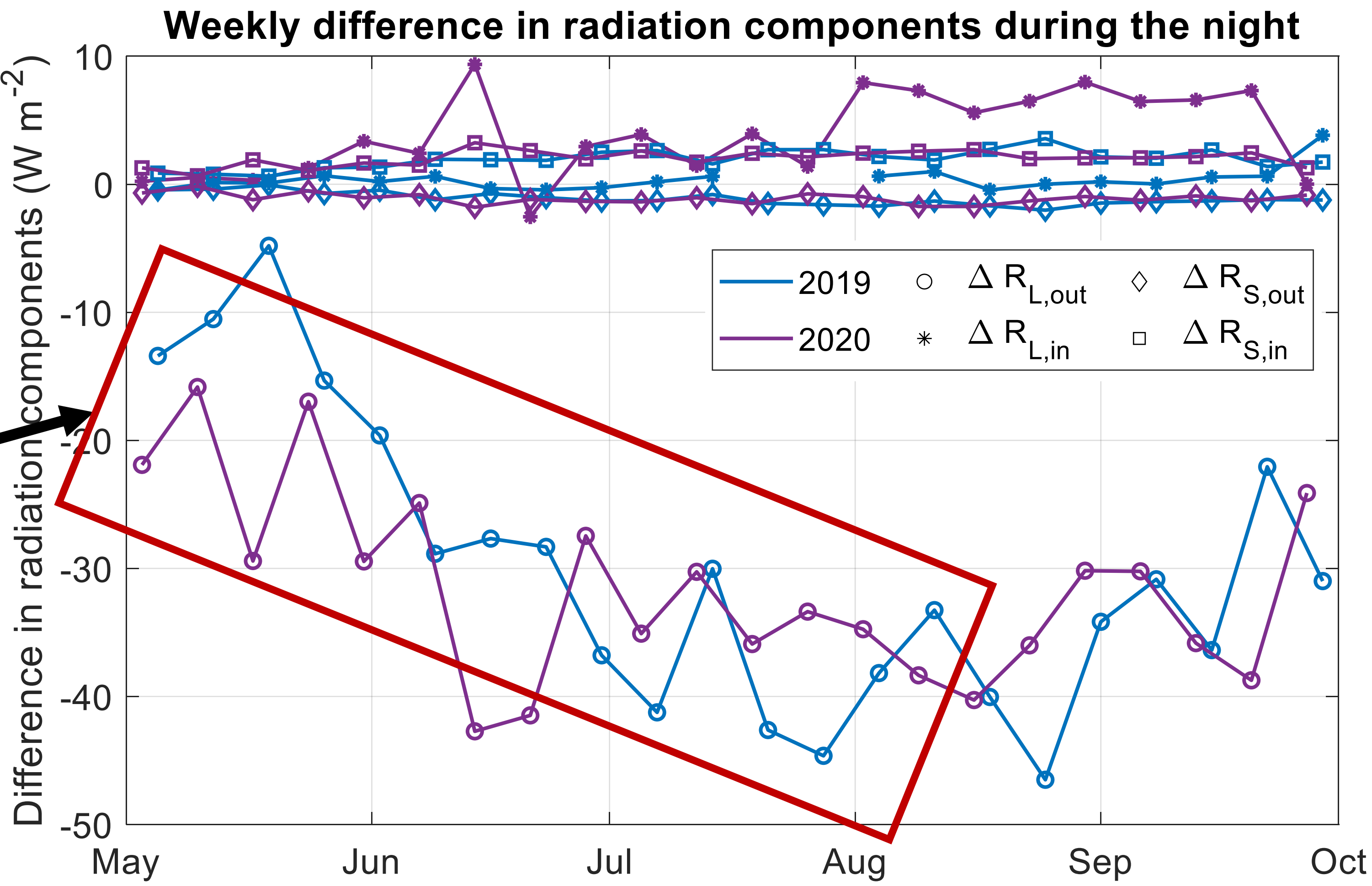


Weekly difference between variables of interest in the marsh and the lake (Δ: marsh-lake)



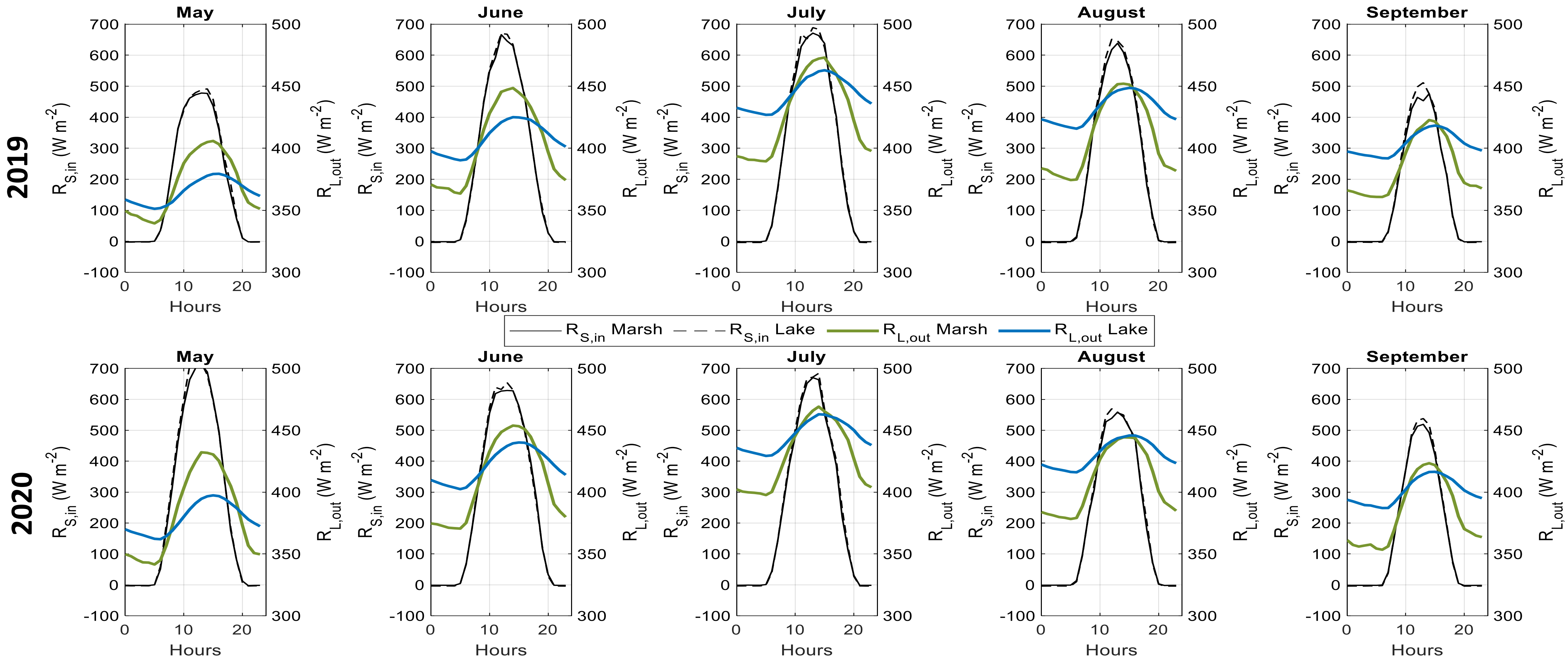


Negative trend: increasing outgoing longwave radiation in the lake



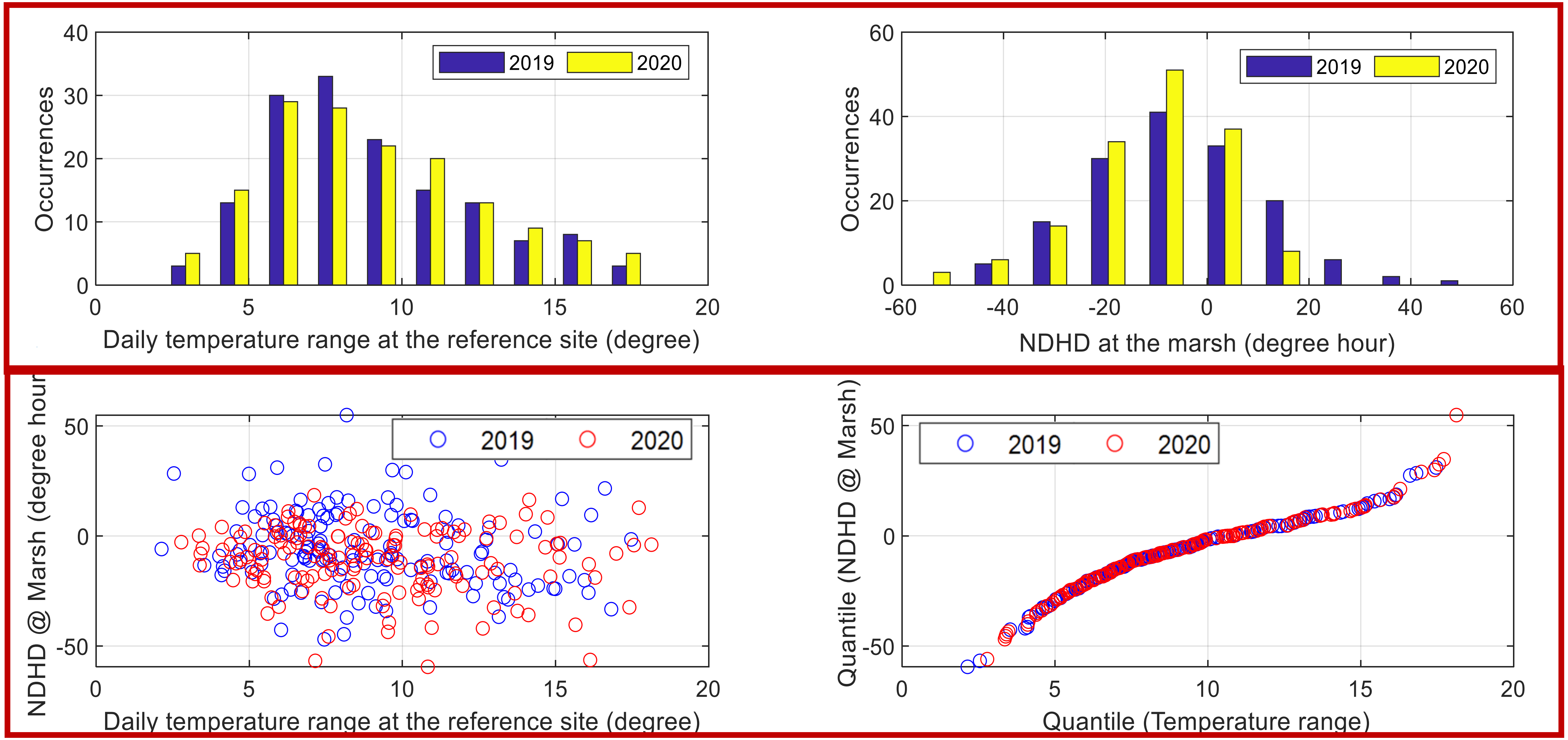
As the growing season peaks, the lake has more stored heat than the marsh

Hourly averages of incoming shortwave and outgoing longwave radiation show higher thermal inertia and slower radiative responses in the lake

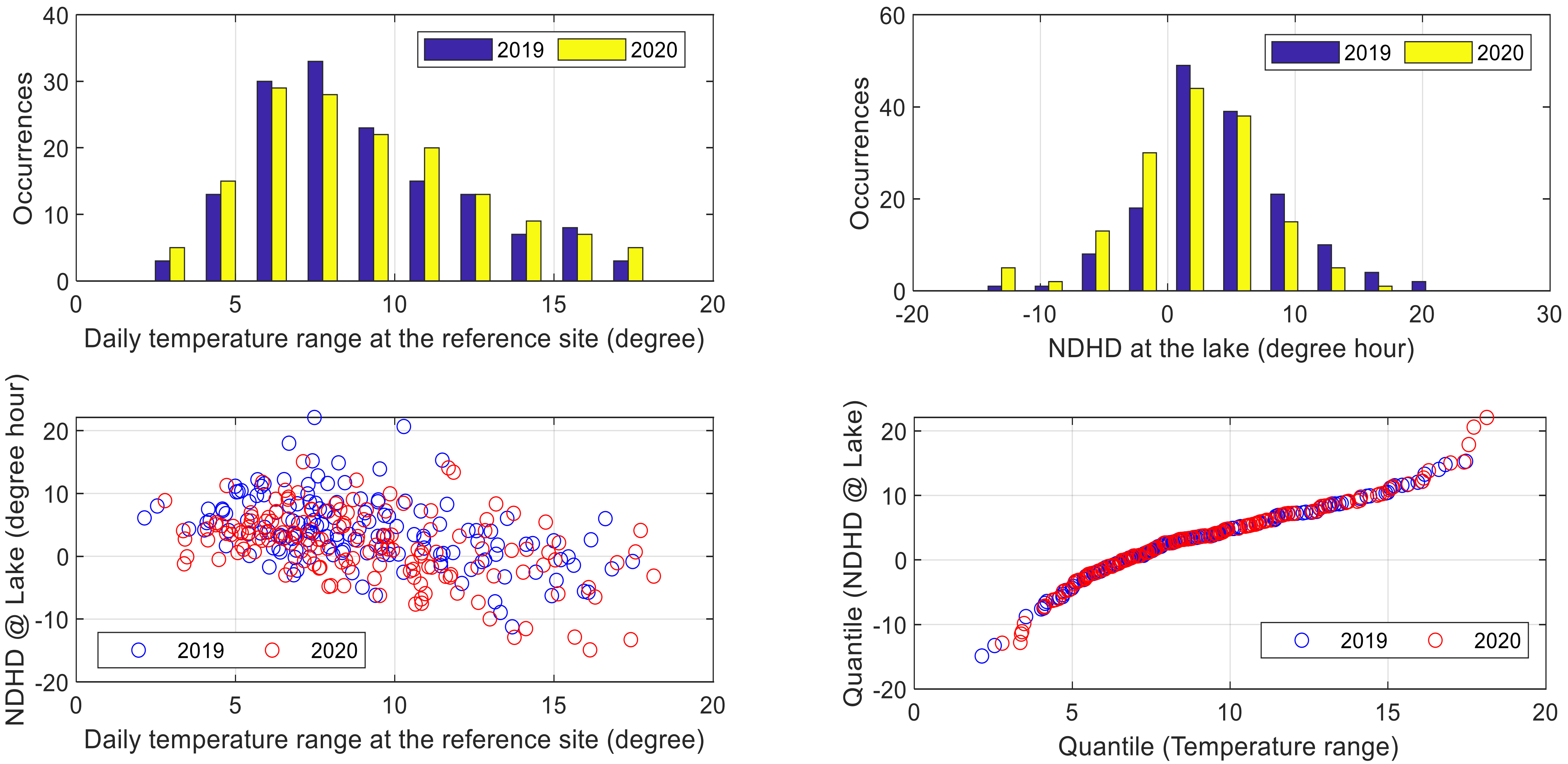


May-to-September hourly seasonality of $R_{S,in}$ (incoming shortwave) and $R_{L,out}$ (outgoing longwave)

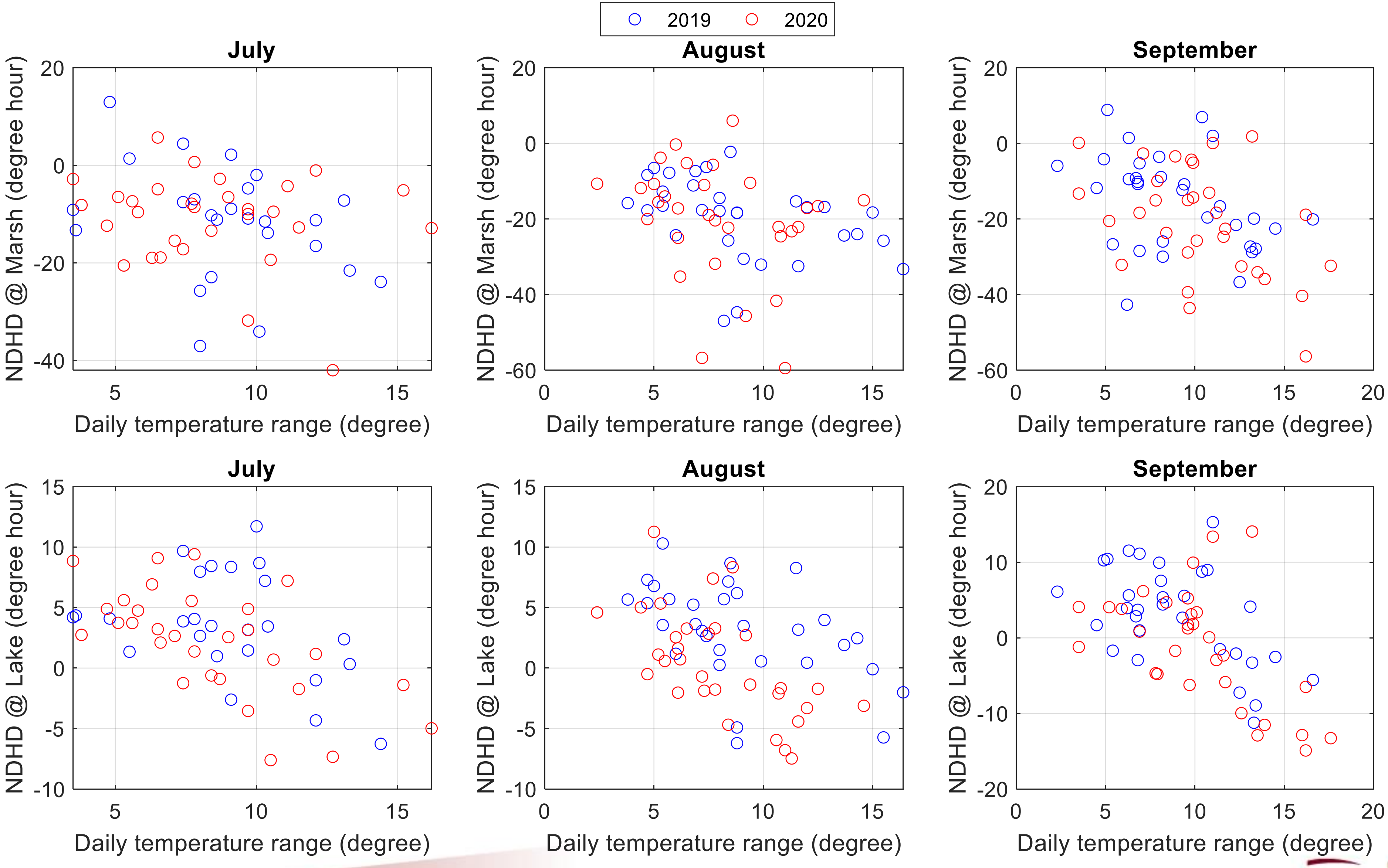
Investigating the distributions - Marsh



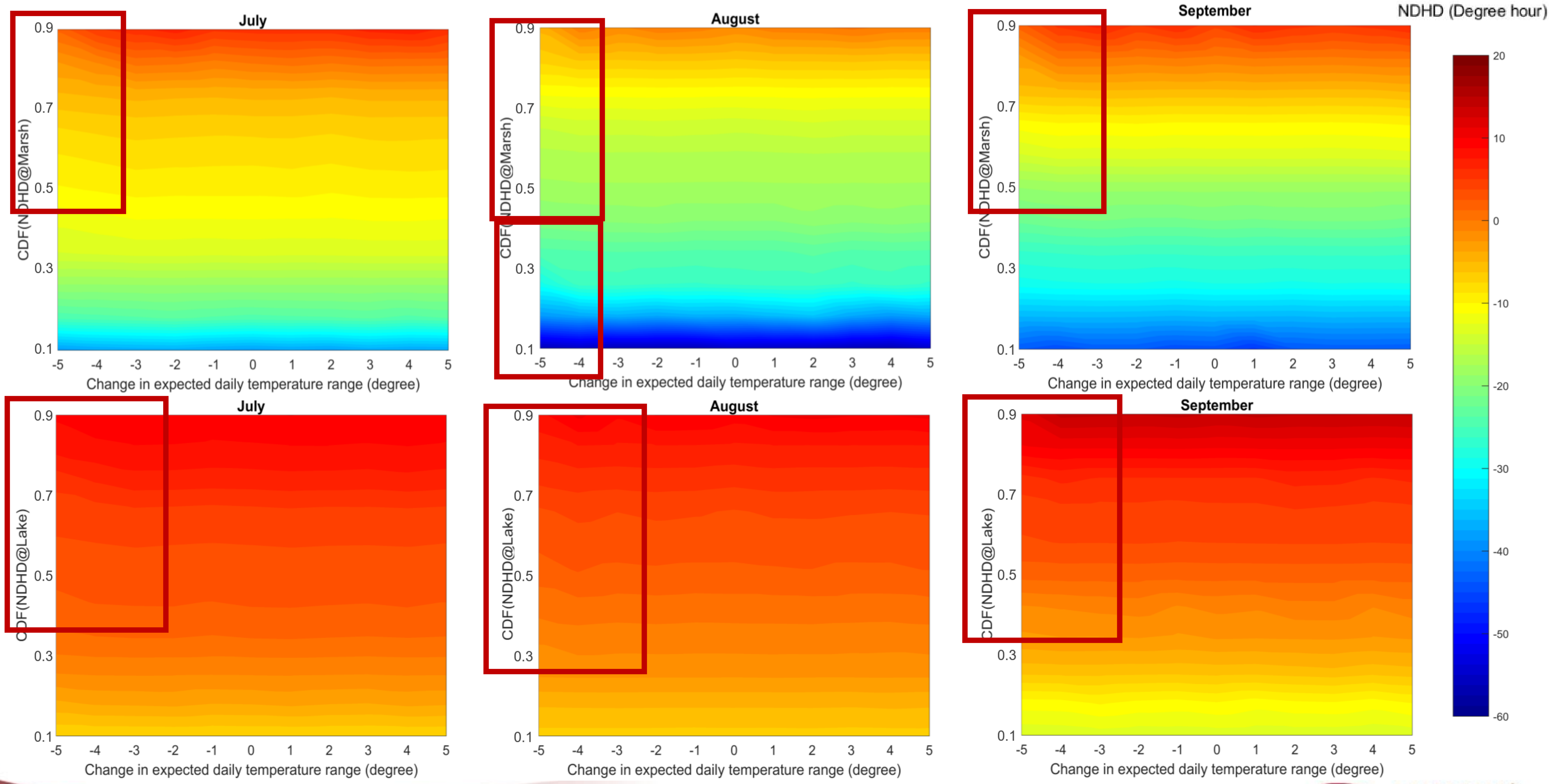
Investigating the distributions - Lake



Temperature range and NDHD are significantly dependent in July, August and September

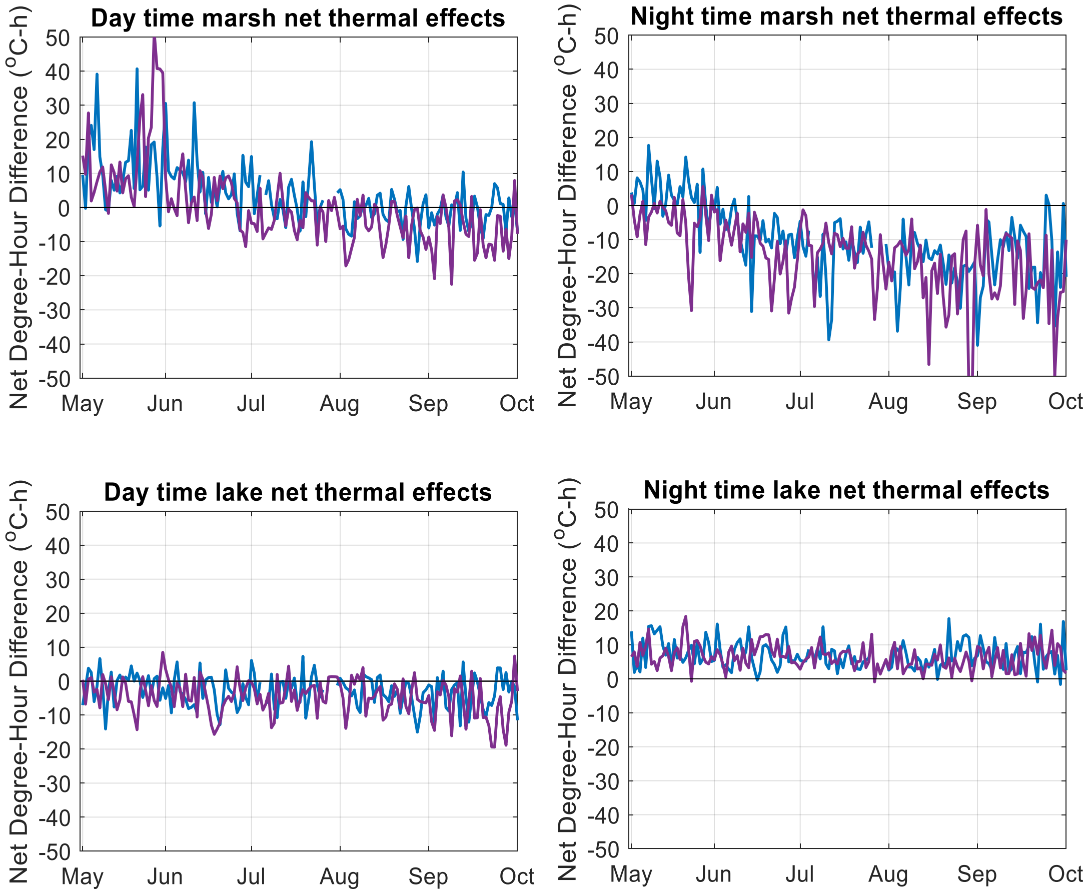


Sensitivity analysis of NDHD as a function of temperature range (Frank Copulas)



Concluding remarks

- Heat storage plays a critical role in temperature regulation
- Vegetation's effect is strong enough to shift the marsh from heating to cooling
- Lake acts as a temperature stabilizer
- As daily temperature ranges decrease, the marsh and lake will provide more cooling



Henrique Vieira and Ali Nazemi, PhD.

henrique.vieira@concordia.ca

https://www.linkedin.com/in/vieirah/

References

Braganza, K., Karoly, D. J., & Arblaster, J. M. (2004). Diurnal temperature range as an index of global climate change during the twentieth century. *Geophysical Research Letters*, *31*(13). https://doi.org/10.1029/2004GL019998

Coutts, A. M., Tapper, N. J., Beringer, J., & ... (2013). Watering our cities: The capacity for Water Sensitive Urban Design to support urban cooling and improve human thermal comfort in the Australian context. *Progress in Physical Geography*. https://journals.sagepub.com/doi/abs/10.1177/0309133312461032

Department of Environmental Protection, Montgomery County, MD. (n.d.). *Stormwater Infrastructure—Rain Garden*. Retrieved October 26, 2020, from https://www.montgomerycountymd.gov/water/restoration/green-streets.html

Genest, C., & Favre, A.-C. (2007). Everything you always wanted to know about copula modeling but were afraid to ask. *Journal of Hydrologic Engineering*, *12*(4), 347–368.

Howard, L. (1833). *The climate of London: Deduced from meteorological observations made in the metropolis and at various places around it* (Vol. 3). Harvey and Darton, J. and A. Arch, Longman, Hatchard, S. Highley [and] R. Hunter.

Karl, T. R., Kukla, G., Razuvayev, V. N., Changery, M. J., Quayle, R. G., Heim Jr., R. R., Easterling, D. R., & Fu, C. B. (1991). Global warming: Evidence for asymmetric diurnal temperature change. *Geophysical Research Letters*, *18*(12), 2253–2256. https://doi.org/10.1029/91GL02900

Kendall, M. G. (1970). *Rank correlation methods.*

Klotz, J., & Klotz, R. (n.d.). *Crooked Run Valley Rural Historic District*. Retrieved November 20, 2020, from https://en.wikipedia.org/w/index.php?title=Crooked_Run_Valley_Rural_Historic_District&oldid=929986328

Macoun marsh. (n.d.). Retrieved November 20, 2020, from https://en.wikipedia.org/w/index.php?title=Macoun_marsh&oldid=917795277

Nature-Based Solutions | UN Global Compact. (n.d.). Retrieved October 22, 2020, from https://www.unglobalcompact.org/take-action/events/climate-action-summit-2019/nature-based-solutions

Oke, T. R., Johnson, G. T., Steyn, D. G., & Watson, I. D. (1991). Simulation of surface urban heat islands under 'ideal'conditions at night part 2: Diagnosis of causation. *Boundary-Layer Meteorology*. https://link.springer.com/article/10.1007/BF00119211

UW SSEC, & WisconsinView. (n.d.). *Madison Lakes*. Retrieved November 20, 2020, from http://wisconsinview.ssec.wisc.edu/education/gallery/msn_19991015_thm.jpg

Wider Embraces. (n.d.). *Planet Earth*. Retrieved November 16, 2020, from https://widerembraces.org/