The Thermal Potential for the Spread of Mosquito Borne Diseases Due to Climate Change in Oklahoma

[1]Jenelle A. Edwards
Valencia College, Orlando, Florida
National Weather Center Research Experiences for Undergraduates Program
Norman, Oklahoma

[2]Justin K. Davis
Department of Geography and Environmental Sustainability
Norman, Oklahoma

[2]Michael C. Wimberly
Department of Geography and Environmental Sustainability
Norman, Oklahoma

ABSTRACT

One possible outcome of climate change is the spread of vector borne diseases. According to the World Health Organization, vector borne diseases account for more than 17% of all infectious diseases, killing more than 700,000 people annually. Warming temperatures can cause vectors to spread into more favorable environments, increasing the rate that mosquitoes and viruses reproduce, mature, and spread. A particularly important mosquito vector is *Aedes aegypti*, known as the “Yellow Fever” mosquito. We explored the temperatures at which *Aedes aegypti* can transmit Zika and dengue, predicted where in Oklahoma temperatures are suitable for *Aedes aegypti* to carry out this process, and determined the potential effects of temperature fluctuations due to climate change on transmission potential (days out of the year where $R_0 > 0$). Using daily temperature data collected by the Oklahoma Mesonet since 1999, we determined where there were suitable conditions for Zika and dengue transmission by *Aedes aegypti* by comparison with upper and lower temperature limits for each virus. Using downscaled climate projections developed by the Climatology Lab at the University of Idaho, we evaluated the average temperature shift throughout the state, determining a delta value, and added that to the current temperatures to analyze where the transmission potential for ZIKV and DENV could be in the years 2070 to 2099. For Zika transmission, it increased from 112 days to 136 days with RCP 4.5 and to 153 days with RCP 8.5. The number of days out of the year for dengue transmission increased from 171 to 191 days with RCP 4.5 and to 206 days with RCP 8.5.

1. INTRODUCTION

Climate change poses a major threat to global ecosystems and societies. If no action is taken immediately to stop the change, we risk compromising all human lives. In recent years, there have been consistent conclusions in the scientific community that the global temperatures are increasing at an alarming rate due to the increase in the concentration of greenhouse gasses in the atmosphere. The rapid increase in temperatures is said to be responsible for numerous global issues including a rise in sea levels, increased intensity of tropical cyclones, and displacement of biodiversity. With the global temperature likely to increase to 1.5 °C since preindustrial times, these issues will only worsen without immediate evaluation to determine what actions need to be taken (IPCC 2018).

In this research, we focused on the thermal potential of mosquito borne disease transmission due to climate change in the state of Oklahoma. Thermal potential refers to the potential for a variable to change due to variances in heat energy. In this case, we are looking at the transmission potential (R_0) of the Zika (ZIKV) and dengue (DENV) viruses by the vector *Aedes*

[1] *Corresponding author address:* Jenelle Edwards, Valencia College, (Center for Analysis and Prediction of Storms, The University of Oklahoma National Weather Center 120 David L. Boren Blvd, Suite 2500 Norman, OK 73072-7309, USA)
Email: jedwards87@mail.valenciacollege.edu

aegypti under varying temperatures in Oklahoma. According to the World Health Organization (2017), vector borne diseases account for more than 17% of all infectious diseases, killing over 700,000 people annually. With thermal energy acting as a catalyst for the spread of diseases, we can only expect these statistics to become more threatening.

4.1 ***Aedes aegypti***

According to the University of Florida's Institute of Food and Agricultural Sciences (2008) the vector *Aedes aegypti*, an invasive species, originated in Africa and was introduced to the Americas during the time of European colonization. They are now found in tropical and subtropical regions globally. These vectors tend to be attracted to human blood, allowing them to thrive in densely populated areas. This quality makes them an exceptional vector to start an epidemic. Often, *Aedes aegypti* can be found breeding in artificial areas such as standing water, old flower pots, or bird baths (Ferede et. al. 2018). This is one of the reasons why they can thrive in human- dominated areas. Because they are an r-selected species, their population can grow exponentially in a short amount of time, allowing them to quickly adapt to new regions and spread fatal viruses such as dengue, Zika, chikungunya, and yellow fever.

These qualities of this mosquito are concerning because if they were to become infected in a densely populated area, the results could be devastating for people living in nearby areas. According to the Centers for Disease Control and Prevention (2017), Oklahoma sits on a species range boundary for populations of *Aedes aegypti.* The boundary creates a zone of uncertainty where it is not definitively known if these potentially fatal diseases could pose an issue or not. A study done in 2016 shows that there are indeed *Aedes aegypti* found in Oklahoma, mostly concentrated in areas in the south near Lawton and Altus during the summer months (Bradt et. al. 2017). In research done in 1930, *Aedes aegypti* were found as far north as Stillwater and Edmond (Rozboom 1930). With populations of this vector already found in parts of Oklahoma, there is already an increased chance for disease transmission in this state. In the event that temperatures increased, there is a possibility of the transmission potential for arboviruses increasing at higher latitudes. If climate models suggest a shift in temperatures, how will the transmission potential of ZIKV and DENV change throughout the state?

4.2 ***Climate in Relation to Spread of Diseases:***

Climate change greatly affects the potential for disease transmission. As the temperatures continue to increase, there will be warming at higher latitudes, allowing for arboviruses, which are viruses spread by arthropods, to move to areas where they were not initially (Tesla et al. 2018). Warmer temperatures also increase the rate at which mosquitoes develop into a full-grown adult, mosquito biting rate and fecundity, and mosquito reproductive success. These factors contribute to the increase in the rate at which a mosquito is able to contract a virus and transmit it. However, there is an optimum temperature range for transmission of different viruses, thus, above and below a certain temperature threshold (dependent on the species of mosquito and the virus), the potential for transmission will decrease until there is no potential. However, if the temperatures remain in this optimum range, the transmission potential would increase.

The population of *Aedes aegypti,* in an area with optimal temperatures, also plays a role in the potential of diseases spreading. The more hosts that are infected, the greater the likelihood of the disease becoming a widespread issue. The spreading of these types of viruses in the 21st century is easier due to globalization, allowing the pathogen, with the help of human made infrastructure, to easily travel over oceans, spreading from continent to continent. Because *Aedes aegypti* is present in the southern part of Oklahoma but has not been found in the north since the 1930's, there is a boundary created as to where they could potentially spread diseases. We investigated three main topics in this research. We researched the range of temperatures that *Aedes aegypti* can transmit Zika and dengue. We analyzed if current temperature trends in Oklahoma are suitable for *Aedes aegypti* to contract and transmit these diseases. We also investigated the effect of climate change on temperatures in Oklahoma and how this might affect the transmission potential of Zika and dengue.

2. Methods

2.1 *Current Transmission Potential*

To determine the transmission potential of ZIKV and DENV for different parts of Oklahoma, a calculation of the R_0 value, using temperature, can be done. R_0 is the basic reproduction rate that measures the transmission potential of a virus based on several possible factors. This means if R_0 is less than 1, the virus will infect less than one person and eventually die out and if R_0 is more than 1, the virus will infect more than 1 person per case, spreading exponentially (Delamater et. al. 2019). In this case, we are focusing on temperatures, however, other meteorological factors could include humidity and precipitation. In a paper written by Mordecai et.al (2017), she examined how temperature affects the rate of disease transmission between the vectors *Aedes aegypti* and *Aedes albopictus*, another vector that can transmit diseases at a lower temperature than *Aedes aegypti*. Through the use of mechanistic models, she determined that transmission can occur between 17.8°C (64.0 °F) and 34.6°C (94.3°F) and peaks at 29.1°C (84.4°F) for DENV and between 22.8°C (73.0°F) and 34.5°C (94.1°F) and peaks at 28.9°C (84.0°F) for ZIKV in *Aedes aegypti* (Mordecai 2019). If the temperature goes below or above the indicated limit, the R_0 value will be less than 0. Transmission cannot occur at temperatures that do not support the mosquito and virus existence and fecundity, therefore it is within those upper and lower limits that transmission can happen.

By comparing data from the 120 Oklahoma Mesonet stations (from 1999 to 2018) and the temperature ranges for R_0, determined by Mordecai et al. (2019), we were able to analyze the current thermal potential for ZIKV and DENV transmission in Oklahoma. First, we needed to find R_0. To do this, we used data from the Oklahoma Mesonet and bounded it between the temperatures at which *Aedes aegypti* can transmit Zika and dengue. Once we had this, we were able to calculate the transmission potential of each of the diseases (Figure 1). To complete this, we calculated the number of days in each year that R_0 is greater than 0. To analyze this, we used Inverse Distance Weighting interpolation in R programming, or IDW, to show where the transmission potential of ZIKV and DENV could have possibly been in the years 1999 to 2018.

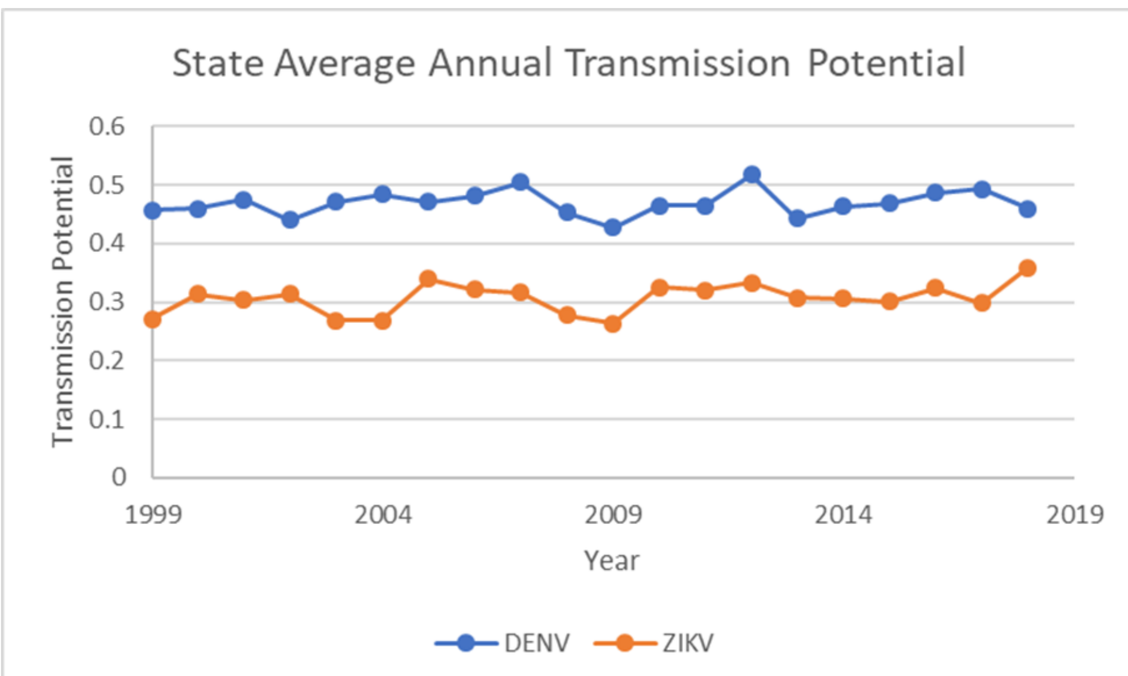

Figure 1: Oklahoma average transmission potential of Zika (orange) and dengue (blue).

2.2 *Future Transmission Potential*

By using Representative Concentration Pathway (RCP) values 4.5 and 8.5, a prediction of the number of days in the future transmission season can be determined. Using data created by the Multivariate Adaptive Constructed Analogs (MACA), from the Climatology Lab at the University of Idaho, we used RCP 4.5 and RCP 8.5 projected temperatures in eight different locations in the state of Oklahoma (Abatzoglou and Brown 2012). To account for the spaces between each Mesonet station, we used Inverse Distance Weighting interpolation in R programming, or IDW, to make a prediction as to where the transmission potential of ZIKV and DENV could possibly be in the years 2070 to 2099. This data can be found at http://www.climatologylab.org/maca.html. Information about the locations of the eight averaged values can be found in Table 1 below.

By taking the average temperatures from the Oklahoma Mesonet data, gauging the amount of temperature fluctuation in the future was more concrete. To get our average base temperature of approximately 60.5°F, we took the average daily temperatures of each Mesonet Station. We then took daily averages across all stations and summarized that information into a 20-year climatological average. We then calculated the average daily predicted temperatures from 2070 to 2099 for RCP 4.5 and RCP 8.5 from the eight different locations. By subtracting our base temperature from the average RCP 4.5 and RCP 8.5 temperatures, we were able to get a delta value, or the amount of change in temperature, that we could add to our transmission potential calculations to get a prediction of transmission potential of ZIKV and DENV for each climate model. The delta value for RCP 4.5 was 3.9°F and for RCP 8.5 was 8.6°F. By adding those values to the daily average temperatures, we modeled the possible future thermal potential of Zika and dengue transmission in Oklahoma.

Region	Location	RCP 4.5 Mean Temperature (°F) (2070 – 2099)	RCP 8.5 Mean Temperature (°F) (2070 – 2099)
South West	34.6046, -99.1059	64.92	70.63
South East	34.3546, -95.4393	65.89	70.83
Central	35.1463, -96.8976	65.79	70.37
West Central	35.6046, -99.3142	64.25	67.56
East Central	35.2712, -95.1893	65.86	70.52
North West	36.7296, -101.3975	59.83	65.17
North East	36.3546, -95.1476	63.63	69.28
North Central	36.4379, -97.6059	64.40	68.04
State Average	-	64.32	69.05
Temperature Δ	-	3.87	8.60

Table 1: This table shows the locations that each RCP projected temperature originates from. By selecting locations across the state, we were able to calculate an average change in temperature.

3. Results

3.1 *Current Transmission Potential*

After analyzing the mean daily temperatures in relation to the transmission thresholds, we noticed that each year from 1999 to 2018 had temperatures that could potentially support transmission of these diseases by *Aedes aegypti*. The percentage of days out of the year that we could see a potential for Zika transmission ranged from about 20% to 40%. For dengue this range increased slightly to 40% to 60% of the days being ideal to carry out the process of disease transmission from 1999 to 2018. The highest transmission potential for both ZIKV and DENV is found along the southern edge of Oklahoma, but some years extend slightly further north than others. We noticed this trend in years that appeared warmer than others.

For example, Figure 2 shows the annual average transmission potentials on a year that was, based on the temperature analysis, warmer than average (2012), about average (2015), and a year that was cooler than average (2009). In 2012, the transmission potential ranged from about 30% to 35% for Zika and about 50% to 55% for dengue. In 2015, the transmission potential ranged from about 25% to 30% for Zika and about 45% to 50% for dengue. And in 2009, the transmission potential ranged from about 20% to 25% for Zika and about 40% to 45% for dengue.

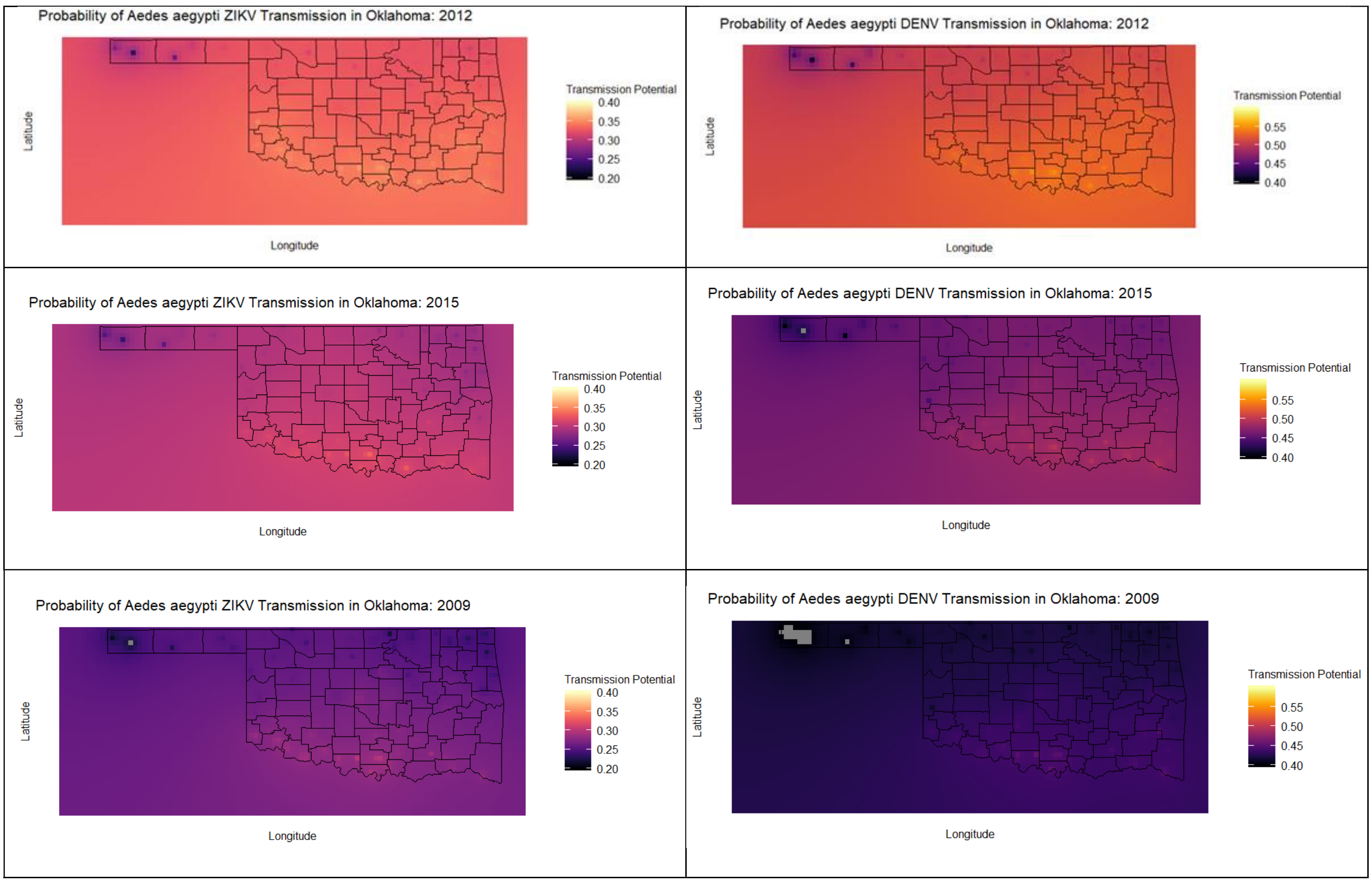

Figure 2: Transmission potential of *Aedes aegypti* Zika (left) and dengue (right) in 2012 (high transmission), 2004 (medium transmission), and 2009 (low transmission)

3.2 *Future Transmission Potential*

For Zika, as the temperatures increase over the climate models' predictions from 2070 to 2099, the potential for disease transmission also increased. The transmission potential starts at around 25% to 30% of days being ideal in the years 1999 to 2018, but it increases to between 35% and 40% in RCP 4.5. In RCP 8.5, Zika transmission potential increases to 40% to 45% of days (Figure 3). This means that the current transmission season for Zika lasts for about 3.5 months and would increase to approximately 4.5 months in RCP 4.5 and to approximately 5.0 months in RCP 8.5 by 2070 to 2099 (Figure 5).

With dengue, we see a similar trend. As temperature increases, the transmission potential also increases. The starting average transmission potential during the years 1999 to 2018 began at 45% to 50% of the days out of the year being suitable for dengue transmission. At RCP 4.5, there is a slight increase in transmission potential. It increases from the range 45% to 50%, to about 50% to about 55%. At RCP 8.5, there is a more substantial increase. The average transmission potential ranging from 55% to 60% of days out of the year being suitable for dengue transmission based on temperature averages (Figure 4). This means that the current transmission season for dengue lasts for about 5.5 months and would increase to approximately 6.0 months in RCP 4.5 and to approximately 7.0 months in RCP 8.5 (Figure 5).

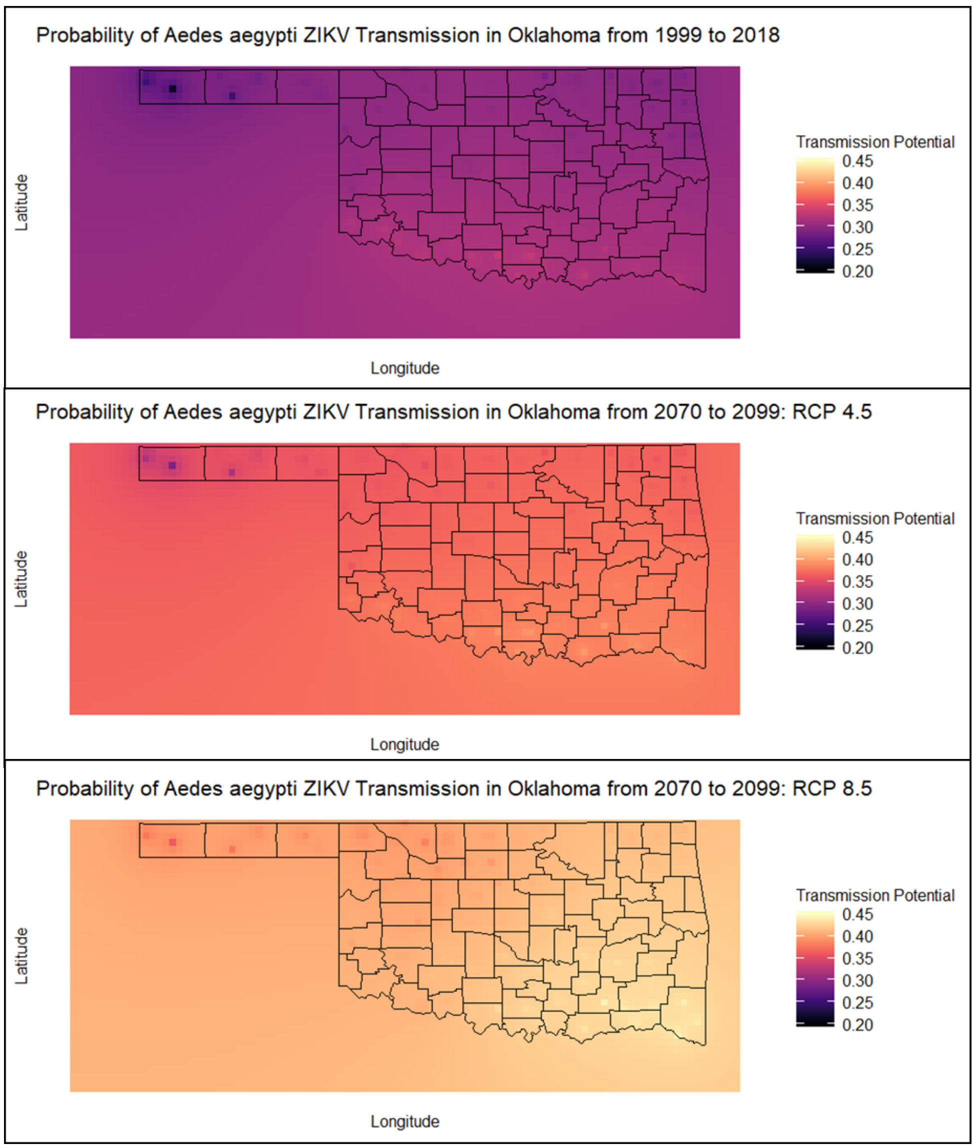

Figure 3: Transmission potential of Zika in the state of Oklahoma under the current, RCP 4.5 and RCP 8.5 climate predictions.

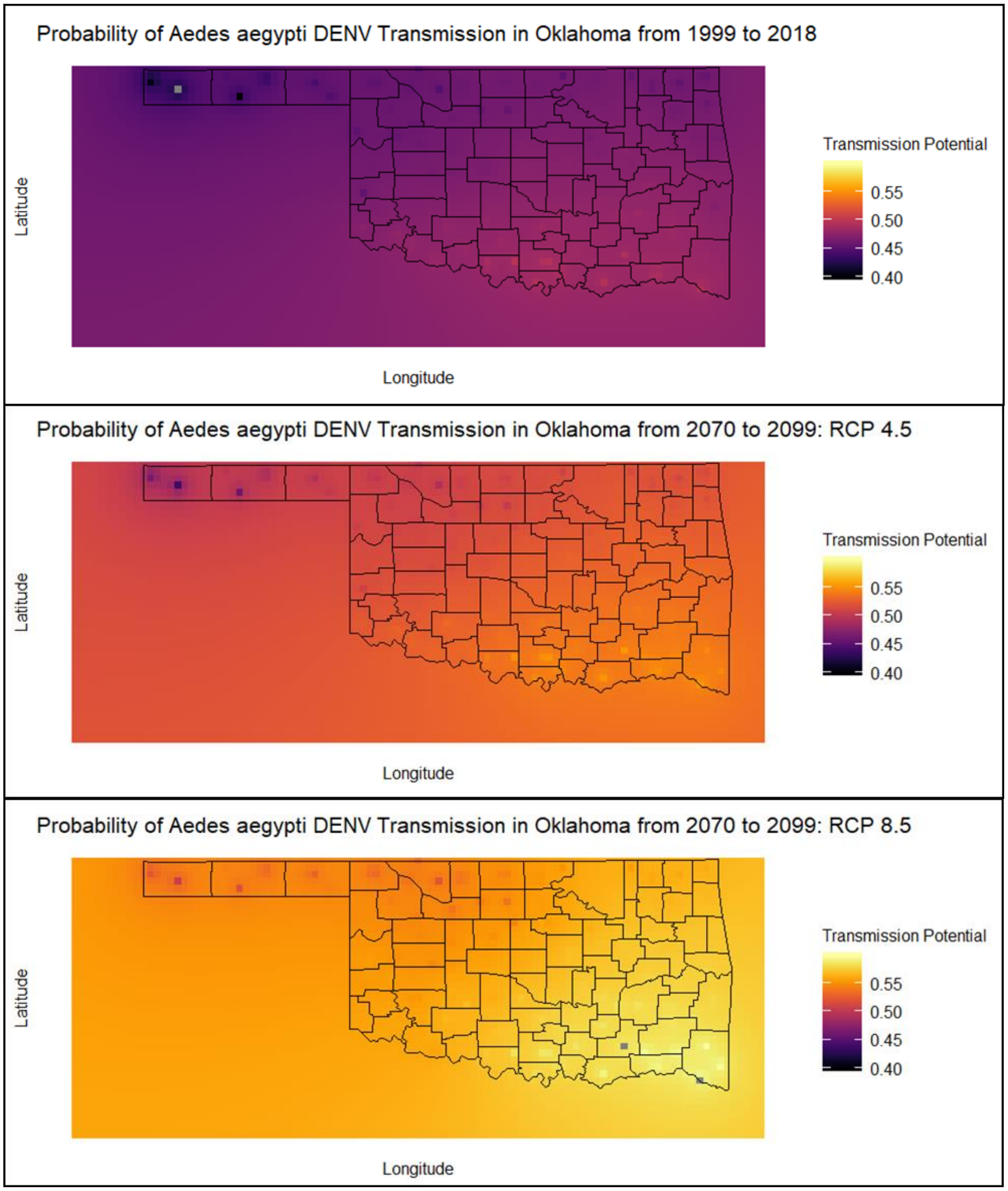

Figure 4: Transmission potential of dengue in the state of Oklahoma under the current, RCP 4.5 and RCP 8.5 climate predictions.

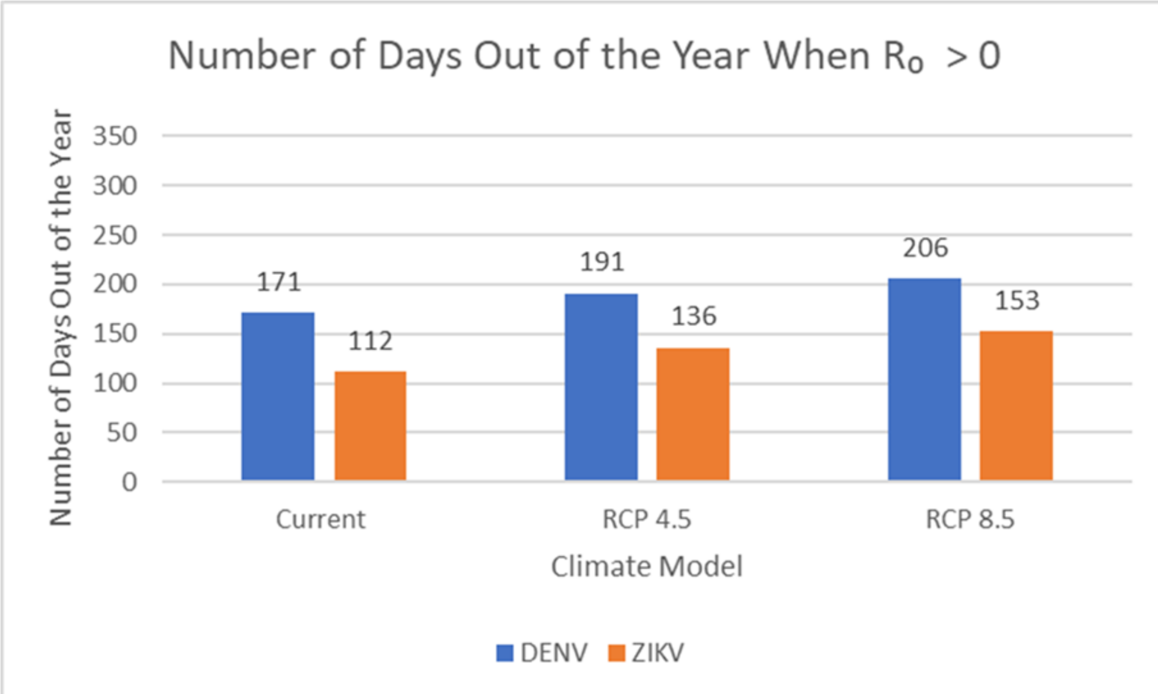

Figure 5: Number of days per year that there is a potential for disease transmission in the state of Oklahoma for each climate model scenario.

4. Discussion & Conclusion

If the global temperatures continue to increase due to climate change, there will be a higher potential for disease transmission in Oklahoma, possibly even spreading to the northern Great Plains. The temperature, if kept within the ranges defined above, will speed up the growth, reproduction, and metabolism of the vector as well as the virus. If temperatures slip beyond the defined temperature values for the two diseases investigated, there will not be potential for transmission of these diseases. This is because the R_0 value would be below 0, disallowing the growth and spread of viruses.

In Oklahoma, the transmission potential of ZIKV is lower than that of DENV. This is because the temperature range for DENV extends to a lower limit than that of ZIKV. Because Oklahoma is fairly temperate for the majority of the year, this lower temperature limit allows for the transmission potential of DENV to be higher than that of ZIKV. Although transmission potentials will not always increase with temperature, like we see in our results, we notice it in Oklahoma because it is more temperate. If we were to look in another region of the United States that is more tropical, such as South Florida, based on these results, we would expect to see a higher transmission potential for ZIKV than in Oklahoma because of the year-round warm temperatures, to a certain extent due to the range of temperatures.

This research is just a small fraction of the countless possibilities that could be examined in vector borne disease transmission. Although our results show the transmission potentials of Zika and dengue via *Aedes aegypti,* there are many other species of mosquitoes, such as *Aedes albopictus*, that may be able to transmit diseases at overall lower temperatures and are more common in the continental United States than *Aedes aegypti*. There is much research done on a global scale but not as much done on a local scale. Becoming more familiar with other state level predictions could create a more accurate depiction of what the transmission potential of diseases might be in more localized areas. Considering other factors such as precipitation, humidity, heat index, urbanization, and different species of mosquitos, could give more accurate predictions of transmission potentials.

6. ACKNOWLEDGMENTS

I would like to thank Daphne LaDue, the National Weather Center Research Experience for Undergraduates (REU) program, and the Department of Geography and Environmental Sustainability (DGES) for this opportunity to conduct research. I would also like to thank Dawn Nekorchuk for assistance with coding. This material is based upon work supported by the National Science Foundation under Grant No. AGS-1560419.

7. REFERENCES

Abatzoglou J.T. and Brown T.J. A comparison of statistical downscaling methods suited for wildfire applications, International Journal of Climatology (2012), 32, 772-780, accessed 08 July 2019, https://climate.northwestknowledge.net/MACA/data_csv.php

Bradt, D. L., Bradley, K. K., Hoback, W. W., and Noden, B. H., 2017: New Records of *Aedes aegypti* In Southern Oklahoma, 2016, Journal of the American Mosquito Control Association, 33(1), 56-59, (1 March 2017), https://doi.org/10.2987/16-6627.1

Brock, F. V., K. C. Crawford, R. L. Elliott, G. W. Cuperus, S. J. Stadler, H. L. Johnson, and M. D. Eilts, 1995: The Oklahoma Mesonet: A technical overview. J. Atmos. Oceanic Technol., 12, 5-19., DOI: 10.15763/dbs.mesonet

Centers for Disease Control and Prevention, 2017: Estimated potential range of *Aedes aegypti* in the United States, Accessed 12 July 2019, https://www.cdc.gov/zika/vector/range/html.

Delamater, P. L., Street, E. J., Leslie, T. F., Yang, Y., and Jacobsen, K. H., 2019: Complexity of the Basic Reproduction Number (R0). *Emerging Infectious Diseases*, *25*(1), 1-4. https://dx.doi.org/10.3201/eid2501.171901

Ferede, G., Tiruneh, M., Abate, E., Kassa, W. J., Wondimeneh, Y., Damtie, D., and Tessema, B., 2018: Distribution and larval breeding habitats of *Aedes* mosquito species in residential areas of northwest Ethiopia. Epidemiology and health, 40, e2018015. doi:10.4178/epih.e2018015

Intergovernmental Panel on Climate Change, 2018: Special Report: Global Warming of 1.5 C, Accessed 10 June 2019, https://www.ipcc. ch/sr15/

McPherson, R. A., C. Fiebrich, K. C. Crawford, R. L. Elliott, J. R. Kilby, D. L. Grimsley, J. E. Martinez, J. B. Basara, B. G. Illston, D. A. Morris, K. A. Kloesel, S. J. Stadler, A. D. Melvin, A.J. Sutherland, and H. Shrivastava, 2007: Statewide monitoring of the mesoscale environment: A technical update on the Oklahoma Mesonet. J. Atmos. Oceanic Technol., 24, 301–321., DOI: 10.15763/dbs.mesonet

Mordecai E. A., and Coauthors, 2017: Detecting the impact of temperature on transmission of Zika, dengue, and chikungunya using mechanistic models. PLOS Neglected Tropical Diseases 11(4):e0005568. https://doi.org/10.1371/journal.pntd.0005568.

Mordecai, E. A., and Coauthors, 2019: Thermal biology of mosquito-borne disease. Ecology Letters, Accessed 26 May 2019, https://onlinelibrary.wiley.com/doi/full/10.1111/ele.13335

Rozboom, L. E., 1930: The Overwintering of *Aedes aegypti* L in Stillwater Oklahoma. Accessed 25 May 2019, https://ojs.library.okstate.edu/osu/index.php/OAS/article/viewFile/3108/2824

Tesla, B., Demakovsky, L. R., Mordecai, E. A., Ryan, S. J., Bonds, M. H., Ngonghala, C. N., Brindley, M. A., and Murdock, C. C., 2018: Temperature drives Zika virus transmission: evidence from empirical and mathematical models285Proc. R. Soc. B. http://doi.org/10.1098/rspb.2018.0795

World Health Organization 2017: Vector- Bourne Diseases, Accessed 28 June 2019, https://www.who.int/news-room/fact-sheets/detail/vector-borne-diseases

Zettel, C and Kaufman, P, 2008: University of Florida IFAS: Featured Creatures. Accessed 19 July 2019, http://entnemdept.ufl.edu/creatures/aquatic/aedes_aegypti.html