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Modeling the Impact of Climate Change on Zika Virus Transmission Suitability Risk for the Continental United States

1 Abstract

The spread of the Zika Virus (ZIKV) through Brazil following the 2014 FIFA World Cup received alarming global attention in anticipation of the 2016 Summer Olympics. By the time the Olympic torch had made it to Rio de Janeiro for the start of the games, local transmission had already been confirmed by the CDC in Miami, Florida (CDC, Florida investigation links four recent Zika cases to local mosquito-borne virus transmission, 2016). A relatively unknown arbovirus until the recent outbreak in the Americas, the epidemiological community rallied quickly to understand ZIKV, its vectors, and the environmental conditions that constrain its transmission. In July of 2016 a pivotal study was published by Mordecai, and others, establishing temperature as the primary environmental factor in transmission potential of ZIKV. Furthermore, they defined the bounding, substantial, and peak transmission potential at different temperature ranges for the two vectors that carry ZIKV in the Americas, the *Aedes aegypti* and *Aedes albopictus* mosquitos (Mordecai, 2016). As global temperatures continue to rise in response to anthropogenic and natural climate change, the geographic ranges of ZIKV's vectors continue to expand and suitable conditions for elevated transmission potential improve. Here suitability for ZIKV transmission is evaluated for the Continental United States (CONUS) for three Inter-Governmental Panel on Climate Change scenarios for through 2050. Using the methodology of Craig, et al., fuzzy logic was used to model transmission-suitability using environmental and biological constraints on vector development and the transmission cycle between vector and humans (Craig, 1999). The resultant maps show the geographic expansion in the CONUS, through 2040, of areas that are suitable for transmission of ZIKV by its vectors, with a slight drop in 2050. The Lower Mid-West and Gulf States are affected the most with most states having a transmission suitability score of .50 or better by 2025.

2 Background

The ZIKV was first discovered, accidentally, in 1947 by scientists who were researching yellow fever in the Zika forest in Uganda. Zika Virus was originally thought to occur in monkeys until 1952 when it was detected in humans in both Uganda and the United Republic of Tanzania (G.W.A. Dick, 1952). The virus spread intermittently across Africa and parts of Asia, with very few cases reported annually on each continent (Hennessey M, 2016) until the 2007 outbreak of the virus in the Yap Islands of Micronesia when the first recognized major outbreak of the virus affected 73% of the population aged 3 or older (Duffy, 2009). In 2014 another large outbreak affected French Polynesia, infecting as many as 32,000 people (Cauchemez, 2016). That same year the first recorded case of the virus in the Western Hemisphere was in Chile's Easter Islands, later spreading to Brazil by 2015 where it became prevalent (Gatherer, 2016).

As of October 6th, 2016, there were 196,976 suspected and 101,851 confirmed cases of ZIKV in Brazil since the outbreak began (PAHO/WHO, 2016). The impact of ZIKV has been particularly noteworthy because of the suspected link to the congenital defect, microcephaly; PAHO reports that there have been 2,076 cases of microcephaly in the Americas in its 2015-2016 case reporting numbers (PAHO/WHO, 2016). The speed with which ZIKV has spread throughout the Americas has alarmed health officials, with the first cases of local ZIKV transmission in the United States reported in southern Florida on July 29th, 2016 (Goldschmidt, 2016).

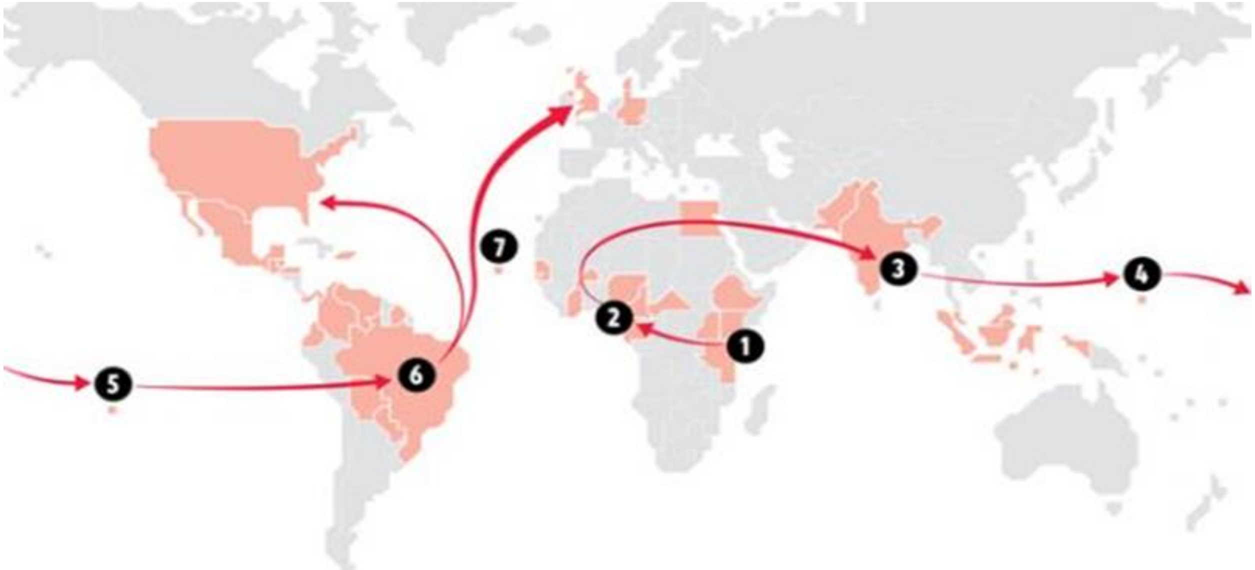


Figure 1. Global distribution of Zika in chronological order of the virus spread (Withnall, 2016).

Globally, ZIKV has its strongest presence in South America but has been rapidly spreading to Latin America and the Caribbean through local and imported cases (CDC, All Countries & Territories with Active Zika Virus Transmission, 2016).The virus was first detected in Brazil in May of 2015 and has since spread to many of the South and Central American countries; some theories have ZIKV arriving in Brazil during the 2014 World Cup (Eisenstein, 2016). In March of 2016 the Centers for Disease Control and Prevention had positive detections of the ZIKV in 37 countries and U.S. territories, issuing Level 2 travel advisories for all of them. Imported cases of ZIKV have been found in all but 5 states in the USA as of July, 2016, but has spread locally through its Caribbean and South Pacific territories (CDC, Zika virus disease in the United States, 2015-2016, 2016).

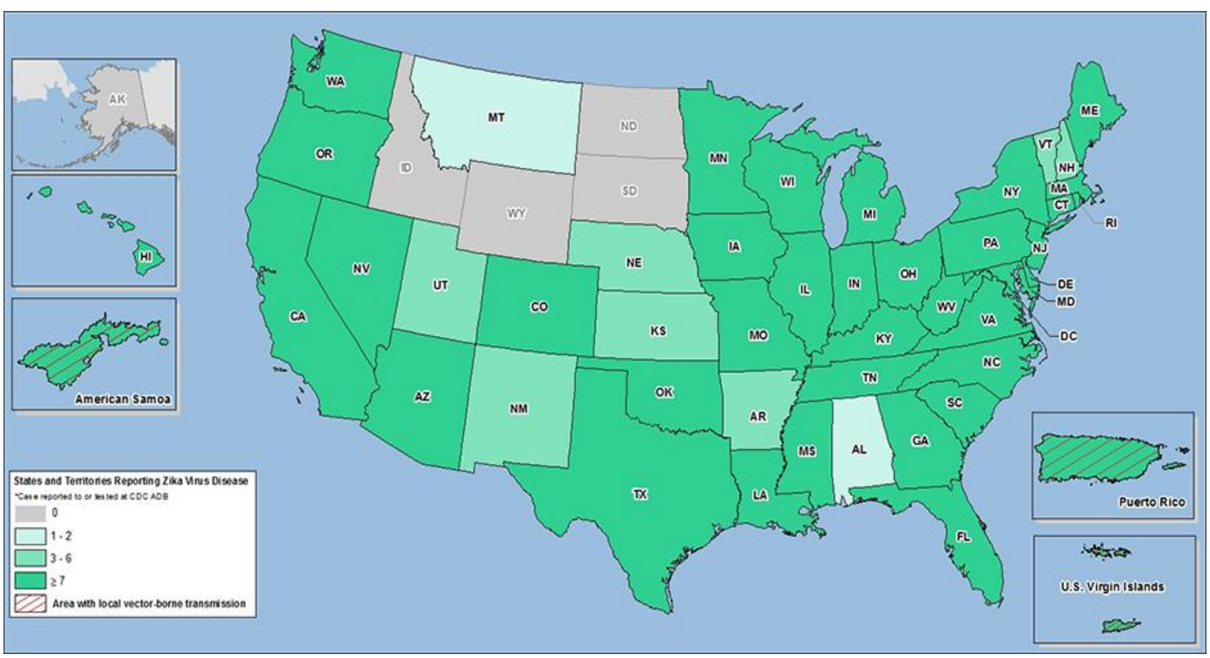


Figure 2. Local and imported cases of the Zika virus in the United States as of July 13, 2016 (CDC, Zika virus disease in the United States, 2015-2016, 2016).

Zika Virus is a member of the Flavivirus genus that causes relatively mild symptoms in humans, with many adults not even realizing they have contracted the disease; as few as ¼ become symptomatic (Dasgupta, 2016). Common symptoms are fever, rash, joint pain, muscle pain, headache, or conjunctivitis (red-eyes) (CDC, Zika Virus, 2016).

Infected persons usually exhibit symptoms caused by the virus from several days to a week, with the virus being present in the blood of the host for up to a week after they subside but can be found for longer in some persons (CDC, Zika Virus, 2016). A growing body of research attributes ZIKV to Guillain-Barré Syndrome, a condition where a person's immune system attacks its own nervous system. While the long-term effects of ZIKV are still relatively unknown in adults, the effects have become troublingly apparent in infants and children (CDC, Zika and Guillain-Barre Syndrome, 2016). The CDC is in the early stages of concluding that ZIKV can cause Microcephaly and other fetal brain defects in the fetus of women who contact or are infected with ZIKV during pregnancy or during the perinatal period right before birth. Microcephaly is a condition where babies are born with smaller than expected heads due to abnormal brain development (CDC, CDC Concludes Zika Causes Microcephaly and Other Birth Defects, 2016). The effects of ZIKV on developing, post-natal, children are not understood, but there are intense efforts being undertaken by the global scientific community to determine if there are long term developmental defects that could be attributed to it.

There are three primary methods through which ZIKV has been found to be transmitted to humans. The first, and most common, mode of transmission is through the bite of an infected mosquito of the Aedes genus, specifically the A. aegypti and A. albopictus (Hahn, 2016). A second mode of transmission that has shown to be quite common is through sexual activity (WHO, Zika Virus, 2016). The CDC recommends abstaining from sexual activities for 8 weeks when a person returns from a ZIKV infected area without showing any symptoms and up to 6 months if a person has tested positive for the virus (WHO, Zika Virus, 2016). The third mode of transmission is congenitally, between a mother and her fetus. There are currently studies being conducted to determine if Zika can be transmitted through incidental contact with bodily fluids or through blood transfusions (WHO, Zika Virus, 2016). The WHO estimates that three to four million people will be infected by the, 'explosive,' spread of the ZIKV in the Americas throughout the end of 2016 (Cha, 2016). Once contracted the incubation period of the virus is 3-12 days (Petersen, 2016). Due to the lack of mature research on the virus it is unknown if the incubation period is different between the known modes of transmission of the virus, which would be useful in determining what mode of transmission the virus was acquired – directly from a mosquito (vector-host) or through secondary transmission (host-host) (e.g. sex and congenitally).

The primary vector of virus transmission to humans in the United States is *A. aegypti*, whose population has grown with the growth and urbanization of human populations (Hahn, 2016). The secondary vector of virus transmission in the Americas is *A. albopictus*, whose population is present in rural, suburban, and vegetated urban areas (Leisnham, 2014). Both species of mosquitoes are competent vectors of Zika Virus, however research has shown that *A. albopictus* is a less competent vector than *A. aegypti* (WHO, Zika Virus Technical Report, 2016). In the United States, *A. albopictus* has a much larger geographic presence than *Aedes aegypti*, with dense populations on the eastern seaboard, the Midwest, and some counties that are near to the U.S./Mexican border (Hahn, 2016).

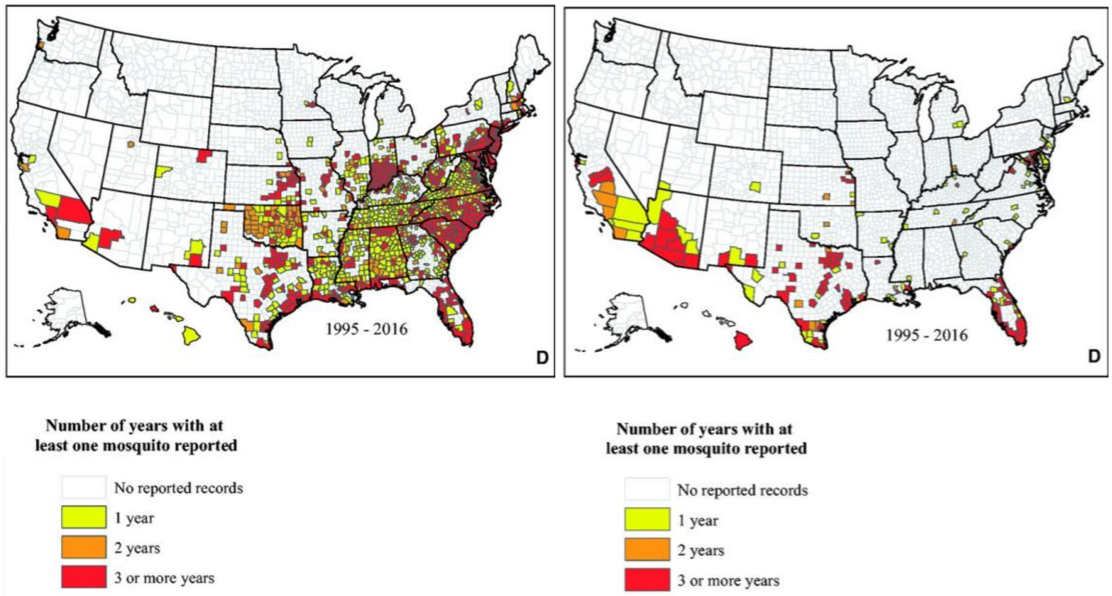


Figure 3. Historical occurrences of A. albopictus (left) and A. aegypti in the United States between January 1995 and March 2016 (Hahn, 2016)

Both the primary vector, *A. aegypti,* and secondary vector, *A. albopictus*, of ZIKV are increasingly found in the continental United States on a, mostly, seasonal basis (Monaghan, 2016). In their research Monaghan, et al., evaluated the seasonal presence of *A. aegypti* in fifty cities in the continental U.S., including those not found in the approximate maximum extents for both *A. aegypti* and *A. albopictus* (Monaghan, 2016)*,* seen in **Figure 8***.* The researchers found the potential range of *A. aegypti* to be much greater than the observed maximum range for the species, with many of the cities in the Southeast, Mid-Atlantic, and Mid-West states having moderate to high potential abundance under current climactic conditions, with the highest potential abundance in the coastal regions of states in the Southeast; because of arid conditions, many cities in the Western U.S. had low to moderate potential abundance (Monaghan, 2016).

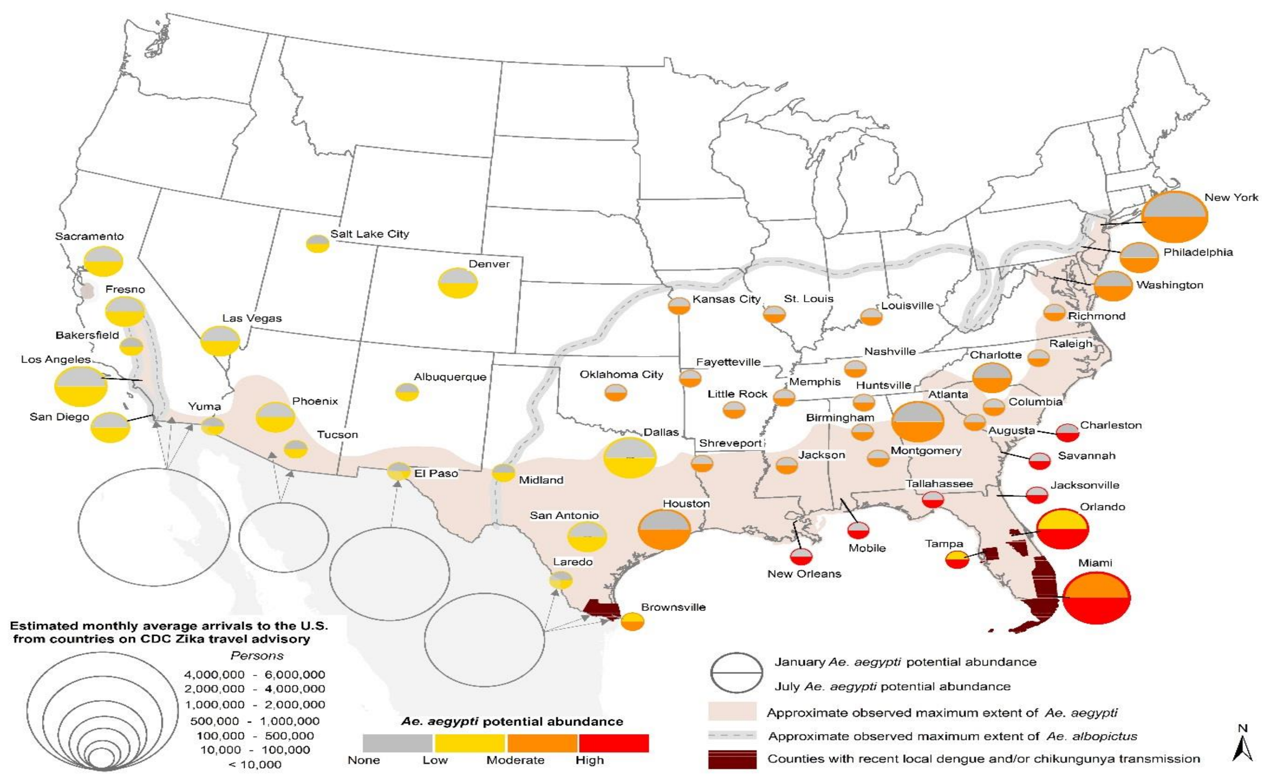


Figure 4. Map of Ae. aegypti abundance in fifty U.S. cities (Monaghan, 2016).

The research team analyzed the potential abundance, by month, for the fifty cities, whose maps are shown in **Figure 4**, showing that by mid-July all fifty cities are meteorologically suitable for *A. aegypti* (Monaghan, 2016). Most notably, of the twelve maps in **Figure 9**, five consecutive maps show a moderate to high potential abundance of ZIKV's primary vector in Southeast and Mid-Atlantic states, from June until October (Monaghan, 2016). This is particularly concerning since that annual five-month window may allow for stable transmission of ZIKV in those areas.

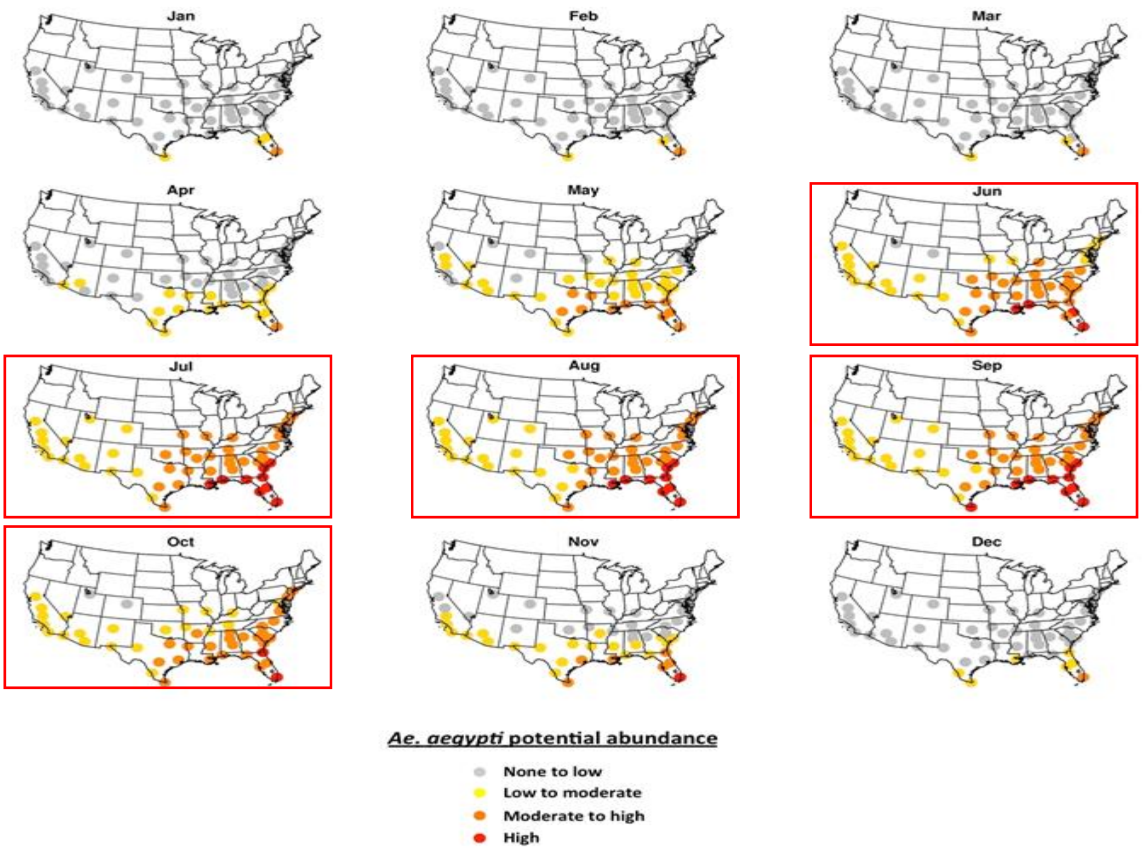


Figure 5. Maps of monthly A. aegypti potential abundance over 50 U.S. cities. Monthly maps outlined in red represent a widespread moderate to high potential abundance in the Southeast and Mid-Atlantic states (Monaghan, 2016).

With near universal scientific consensus, the Intergovernmental Panel on Climate Change has warned that by 2100 global temperatures will rise by 1.4-5.8^{o}C, having pronounced effects on human health (McMichael, 2006). The effects of climate on the risk of vector-borne diseases to human health are easily defined and studied, with mosquito-borne infections increasing with warming and changes in rainfall patterns (McMichael, 2006). Both the ZIKV and the mosquitoes who carry it survive in specific temperature ranges within which they can survive and spread (Mordecai, 2016). With temperatures projected to rise, the range for vector-borne diseases will expand geographically, with some areas becoming suitable for the vectors and others becoming unsuitable because of excessive heat, extreme fluctuations in temperatures, or drought (McMichael, 2006). Additionally, climate change will extend the periods throughout the year when transmission potential is increased or peaks, through longer summers and shorter winters (McMichael, 2006).

3 Transmission Dynamics of ZIKV

Increasingly research on ZIKV has begun to focus on understanding the transmission dynamics of how it spreads to identify potential strategies to combat it. First, it is necessary to understand how the virus develops in both the vector and the host. Second, environmental constraints can be established for transmission suitability. Finally, both biological and environmental factors can be used to define the transmission cycle.

Once ZIKV is transmitted to a person via a mosquito bite, sexual activity, or congenitally, the intrinsic incubation period of the virus is 3-12 days (Loos, 2014) however, during the incubation period a mosquito can contract the virus during blood meal (Institut Pasteur, 2016). After feeding on an infected host the extrinsic incubation period of a virus in *A.*

aegypti female mosquitoes has been shown to be as few as 5 days in Singapore (Wong, 2013) and as high as 15 days (Musso, 2016). In *A. albopictus* the extrinsic incubation period was shown to be between 7-10 days (Wong, 2013).

One study showed *A. aegypti* to be the more competent vector than *A. albopictus*, in a laboratory setting, by having a shorter extrinsic incubation period. Mosquitoes of both species, collected from Florida, had higher populations that became infectious at the 4- and 7-day post infection marks, than those mosquitoes collected from Brazil (Chouin-Carneiro, 201 6).

In their research, Mordecai, et al., identified temperature as having the greatest impact on ZIKV transmission, as well as the DF and Chikungunya viruses (Mordecai, 2016). The transmission potential of ZIKV to humans was shown to be substantial between 23-32^{o}C, peaking between 27-29^{o}C (Mordecai, 2016), however it cannot survive in temperatures above 60^{o}C (Musso, 2016). For *A. aegypti* the transmission potential peaks at 29.1^{o}C, is zero below 17.8^{o}C and above 34.6^{o}C while for *A. albopictus* transmission potential peaks at 26.4^{o}C, is zero below 16.2^{o}C and above 31.6^{o}C (Mordecai, 2016). These temperature ranges establish the primary constraint for transmission suitability and can be evaluated against predicted climate scenarios.

Relative humidity (RH) and rainfall, to a lesser extent, have been found to have an impact on the presence of *A. aegypti/A. albopictus* and their biting behavior with other viruses such as Dengue (Campbell, 2015), which also should be considered as a part of the transmission dynamics of ZIKV. A study of temperature and humidity on Dengue transmission potential in Peru revealed high potential when mean temperature was > 25^{o}C and 75% mean humidity, highest when mean temperature was 25-29^{o}C with mean humidity >80%, moderate potential with mean temperature 25-30^{o}C and mean humidity below 75%, and low potential when mean humidity fell below 65% (Campbell, 2015).

For *A. albopictus* several rainfall and RH conditions were identified for survival; key conditions among them that are relative to this study are that annual precipitation is at least 200 mm, summer maximum temperature does not exceed 40^{o}C, January minimum temperature does not fall below -2^{o}C, summer RH is ≥30%, and winter RH is ≥50% (Proestos, 2015).

A study of RH on both *A. aegypti* and *A. albopictus* mosquitoes in Florida found that eggs of both species experienced high mortality at 25%, with *A. albopictus* the most sensitive to desiccation at lower temperatures (≤22^{o}C) over one month, and *A. aegypti* showing high sensitivity to desiccation after 3 months when RH is 25% (mortality increasing with temperature) and higher temperatures (≥26^{o}C, mortality increasing with decreasing RH), as seen in **Figure 10** (Juliano, 2002).

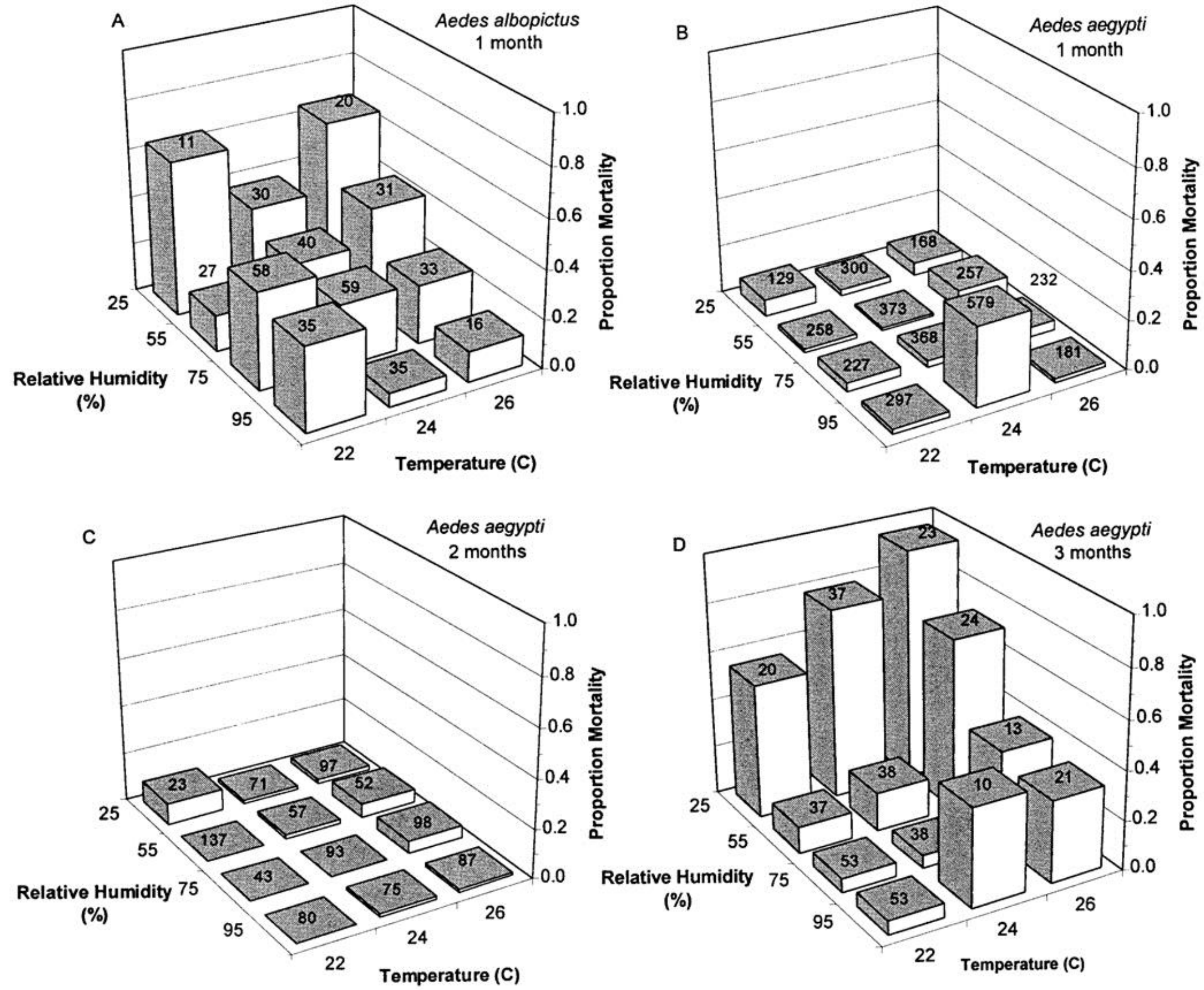


Figure 6. "Mortality of eggs at different relative humidities and temperatures. Numbers of eggs tested are above each bar. a Aedes albopictus at 1 month. b A. aegypti at 1 month. c A. aegypti at 2 months. d A. aegypti at 3 months." (Juliano, 2002)

In a similar study, eggs of both *A. aegypti* and *A. albopictus* were found to succumb to desiccation at RH at or below 42%, at periods of 62.1 days and 27.6 days, respectively (Sota, 1992). For *A. aegypti* eggs were shown to survive for up to 128.3 days at 88% RH and 101.9 days at 86% RH while *A. albopictus* eggs were shown to survive for up to 78.1 days at 88% RH and 54.7 days at 68% RH (Sota, 1992).

Another factor that has been found to influence the presence of the vector has been altitude; both of ZIKV's vectors are rarely found above elevations of 2,000 meters or more (CDC, Questions and Answers: Zika risk at high elevations, 2016).

Understanding the vector lifecycle, temperature, rainfall, and RH constraints on the vector allow the transmission cycle to be established. The arbovirus transmission cycle is the time it takes for a mosquito to reach adulthood and become infectious (Weaver, 2004). For the purposes of this research a transmission cycle can be defined as sum of the following:

- The time that a virus takes to achieve viremia in a host (3-12 Days) (Petersen, 2016) (Loos, 2014)
- The period of viremia in an infected host (1-7 Days) (CDC, Zika Virus, 2016)
- The time it takes for a female mosquito to develop to an adult
  - *A. aegypti*: 8-14 days (Oxitec, 2013)
  - *A. albopictus*: 9-12 days (Hawley, 1988)
- The lifespan of a vector minus the extrinsic incubation period of the virus in the vector
  - *A. aegypti*: (14-28 days) – (5-15 days) (Zettel, 2008)
  - *A. albopictus*: (30-40 days) – (7-10 days) (Hartman, 2011) (Wong, 2013)

Using these numbers for *A. aegypti* the transmission cycle can range from 21-46 days while for *A. albopictus* the transmission cycle can range from 34-61 days. Some research suggests that female *A. aegypti* can pass ZIKV to their eggs (University of Texas Medical Branch at Galveston, 2016), which would shorten the transmission cycle 4-19 days to 17-27 days. The sustained transmission of ZIKV in the continental United States relies on the seasonal presence of *A. aegypti* and *A. albopictus*, which has been found, in a study of 50 cities across the continental United States, to take three months to establish a moderate abundance in an area (Monaghan, 2016).

When taken together, the time transmission cycle time and the time to establish a moderate mosquito population define a transmission season. For *A. aegypti* the transmission season would be 3.66-4.5 months. For *A. albopictus* the transmission season would be 4-5 months. For the purposes of this study the longer time of the two transmission season ranges will be used to analyze the transmission suitability.

With this understanding of the biological, environmental, and temporal factors that constrain the suitability for ZIKV transmission, the spatial range of the virus can be modeled.

4 METHODOLOGY

The model that Craig, et al., used was validated against historical maps and case data of malaria in southern Africa, Kenya, and Tanzania, agreeing with those data (Craig, 1999). The methodology used for that study would make an ideal candidate for evaluating ZIKV transmission potential/risk in the continental United States because of the minimal data necessary. Climate prediction data does exist that contains mean temperature and rainfall data and the recent research of Mordecai, et al., establishes temperature constraints for ZIKV transmission, which they identify as the most important contributing factor for transmission. By establishing rainfall constraints from other research the opportunity to replicate the fuzzy logic model may be possible. The species with the highest sensitivity to desiccation is *A. albopictus*, meaning that the annual rainfall requirement of 200 mm would make a logical limitation for the species presence (Proestos, 2015). In addition, the environmental parameters Craig, et al., used, elevation constrains the presence of both vectors to 2,000 meters or less, which will be used as a limiting factor in identifying transmission suitability (CDC, Questions and Answers: Zika risk at high elevations, 2016).

Data Sources

NCAR

The National Center for Atmospheric Research maintains high-resolution climate data for the 5th Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) as point GIS shapefiles at 4.5km spacing for both Average Monthly Temperature and Precipitation through 2099, for the four Representative Cost Pathway (RCP) models: 2.6, 4.5, and 6.0. RCP 2.6 is the most conservative of the models, indicating a 0.4-1.6^{o}C warming of the atmosphere (NCAR, 2017). RCP 4.5 is the most aggressive model for the study period, predicting a 0.9-2.0^{o}C warming of the atmosphere. RCP 6.0 is the is less aggressive than RCP 4.5, but considerably more aggressive than RCP 2.6, predicting 0.8-1.8^{o}C warming however, beyond the study period this model becomes the more aggressive model on warming.

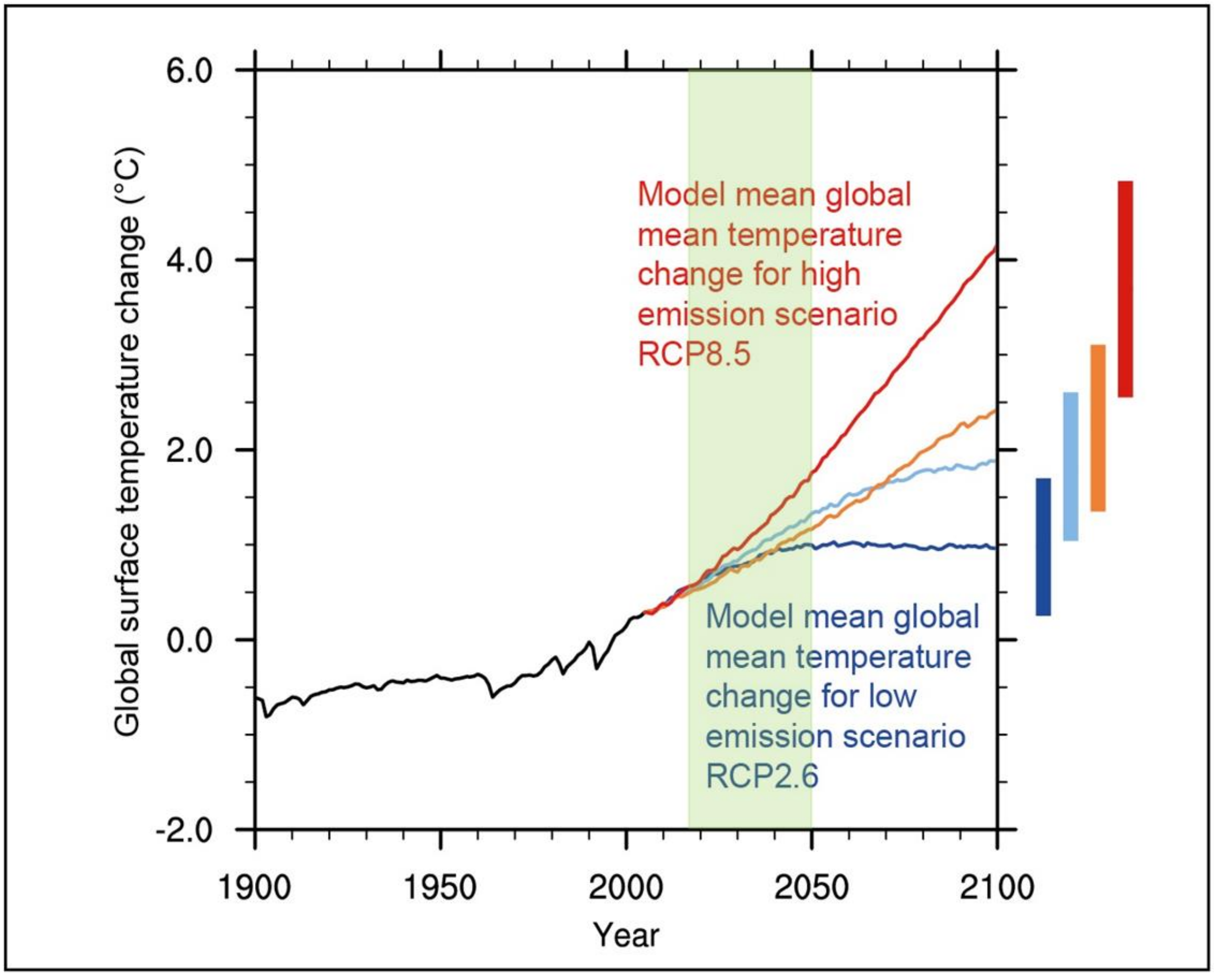


Figure 7. Graph of global surface temperature (⁰C) change for the IPCC's AR5 (CMIP5) RPC 2.6 (Dark Blue), RCP 4.5 (Light Blue), RCP 6.0 (Orange), and RCP 8.5 (Red). The bars on the right show the bounds for temperature increases for the corresponding model. The area in green is the period this study is concerned with (IPCC, 2013).

Monthly average temperature and precipitation data was downloaded for 2017, 2020, 2025, 2030, 2040, and 2050 for each of the three RCP models, clipped to the CONUS, converted from Fahrenheit to Celsius for temperature data, and then converted to raster format using Esri's ArcPy Python library.

ASTER

The Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM), version two, is an elevation dataset available for the CONUS, with root-mean-squared-error accuracies from 10-25 meters. One degree by one degree rasters were downloaded from NASA's Earth Observing System Data and Information System then loaded into an ArcGIS File Geodatabase as Mosaic Data Set.

Data Processing

The methodologies of Craig, et al., and Messina, et al., have been found to be effective at spatially modeling arbovirus transmission risk (Craig, 1999) (Messina, 2016). The analytical methodology of this research follows the process Craig, et al., utilized to model Malaria (*Plasmodium falciparum*) in Anopheles mosquitoes in Sub-Saharan Africa (Craig, 1999) which was broken into the following steps:

1. **Rescale Climate Data:** The pertinent climate data outlined by Messina, et al., was rescaled to between 0 (unsuitable transmission conditions) and 1 (suitable transmission conditions) using a simple sigmoidal fuzzy membership curve:

$$y = cos^2\left[\frac{x-U}{S-U} * \frac{\pi}{2}\right]$$

for:

a. Temperature Suitability Surfaces:

  i. Temperature Suitability for Transmission from *A. aegypti* where *U*=18°, *S*=27°C for the increasing curve and *S* =29°C, *U*=34°C for the decreasing curve:

    1. Unsuitable: <17.8°C, >34.6°C
    2. Increased Risk: 17.8-29.1°C, 29.1-34.6°C
    3. High Risk: 29.1°C

  ii. Temperature Suitability for Transmission from *A. albopictus* where *U*=18°, *S*=25.5°C for the increasing curve and *S*=26.5°, *U*=28°C for the decreasing curve:

    1. Unsuitable: <16.2°C, > 31.6°C
    2. Increased Risk: 16.2-26.4°C, 26.4-31.6°C
    3. High Risk: 26.4°C

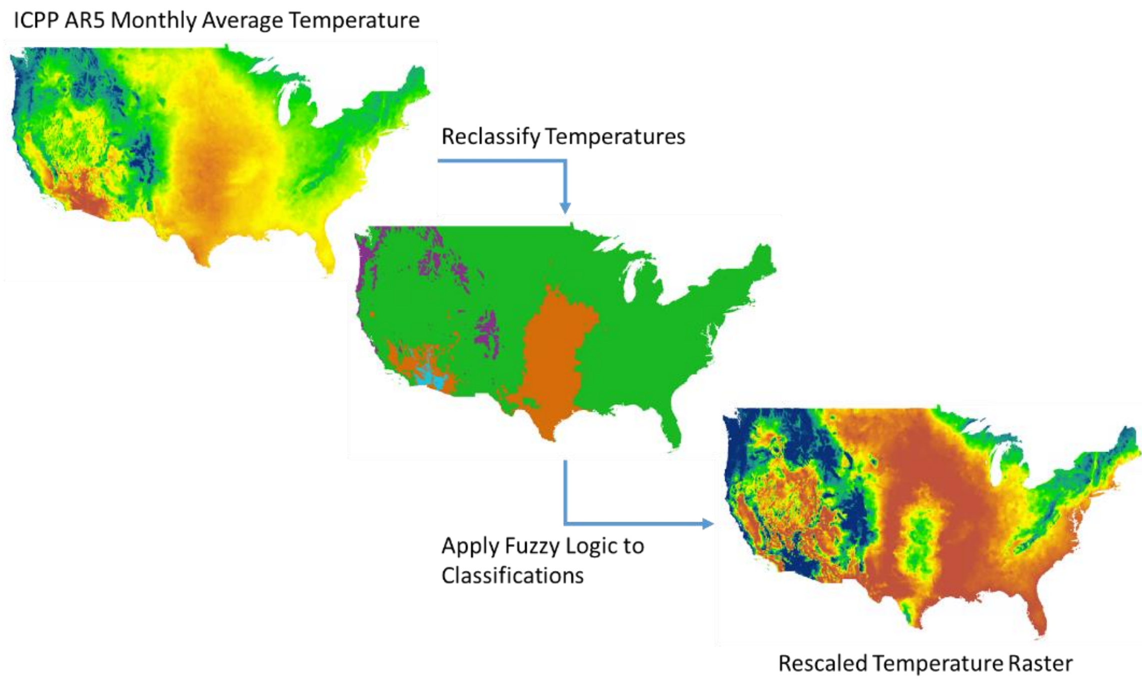


Figure 8. The process of rescaling monthly average temperature rasters for analysis.

b. Rainfall Suitability for Transmission where:

  i. Unsuitable: < 200mm annual precipitation
  ii. Suitable: ≥ 200mm annual precipitation

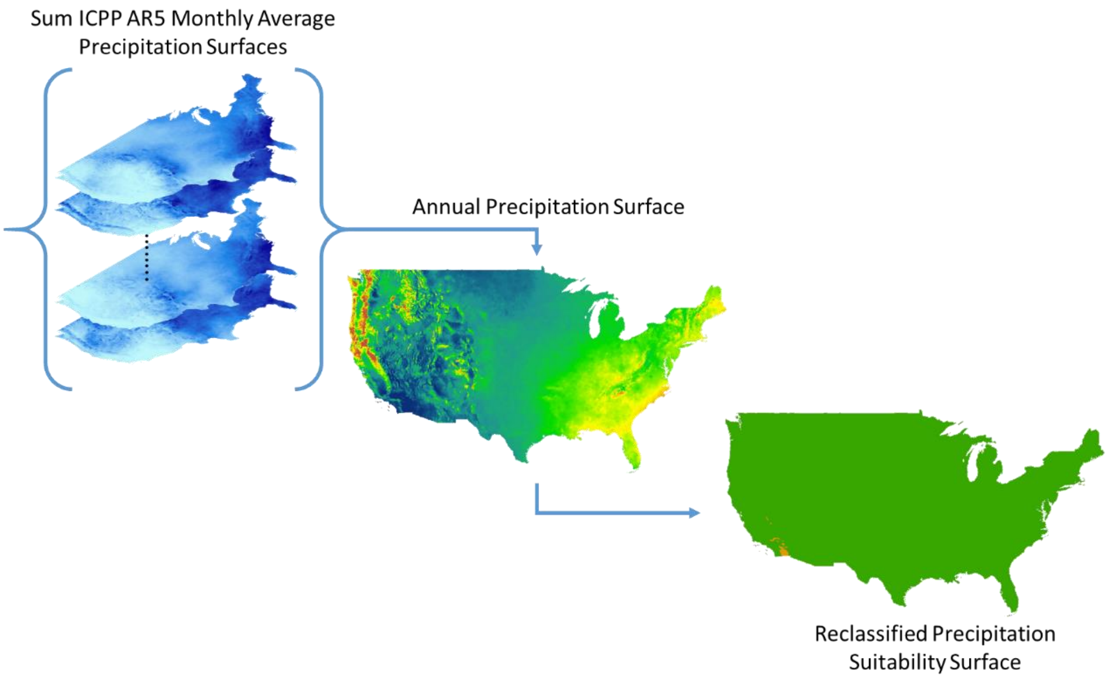


Figure 9. The process of developing and reclassifying the annual precipitation surface

c. Altitude Suitability for Vectors where:

i. Unsuitable: Elevation > 2,000 meters

ii. Suitable: Elevation < 2,000 meters

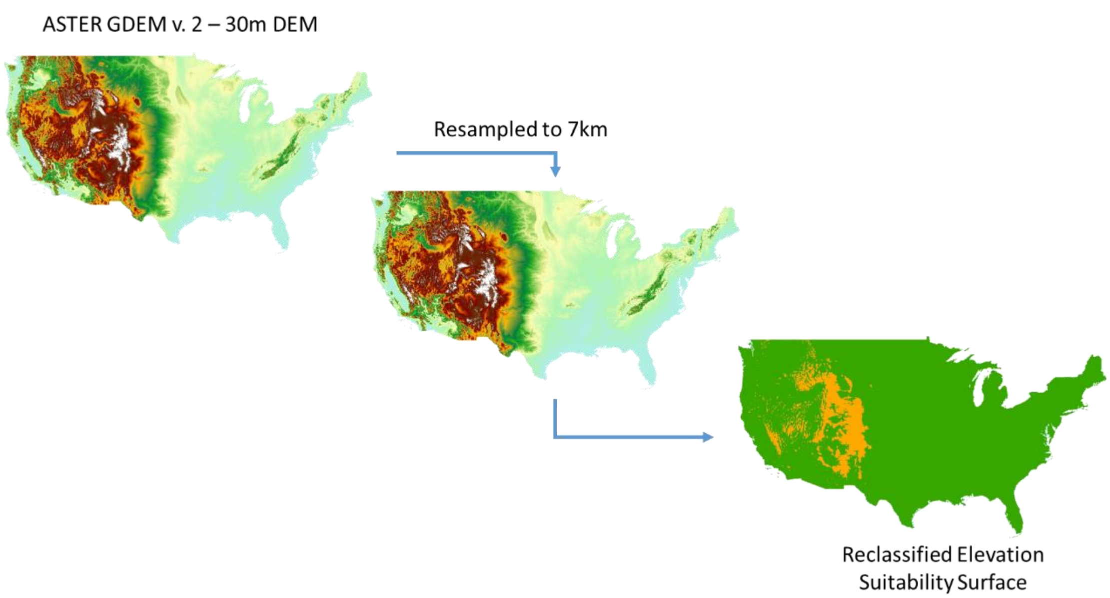


Figure 10. The process of reclassifying the elevation suitability surface.

2. **Evaluate ZIKV Transmission Suitability of Climatic Variables at All Locations**: For each month calculate the transmission suitability of the dynamic climatic variables for each location by comparing the maximum value of

vector temperature suitability values, the rainfall suitability value, and the altitude suitability value, taking the minimum value to establish the suitability for ZIKV transmission.

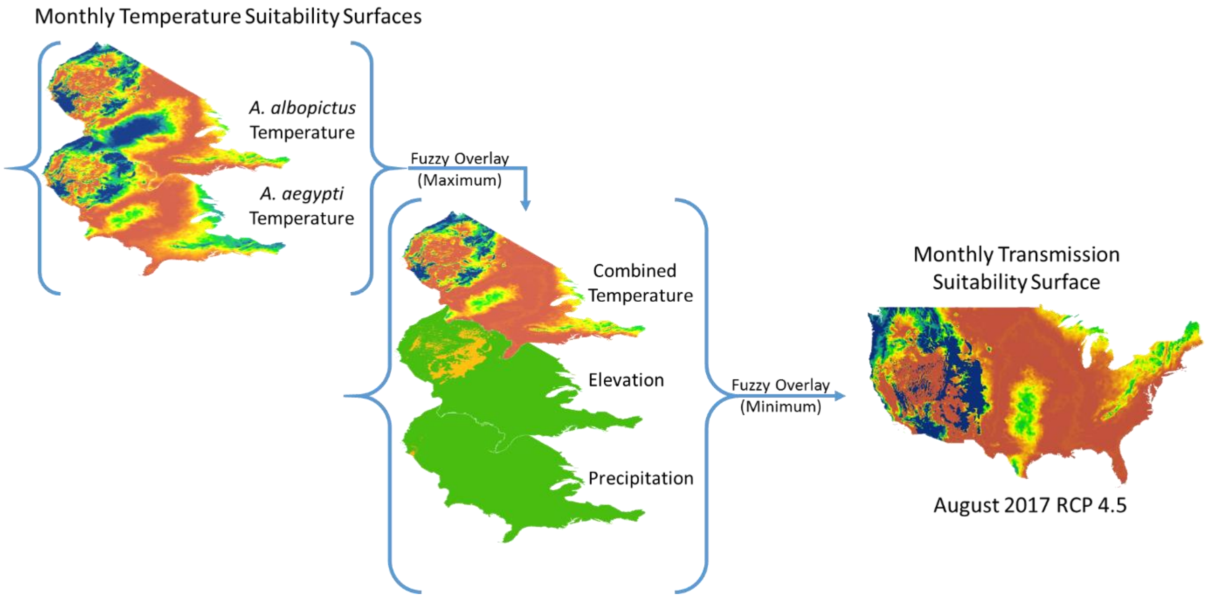


Figure 11. Process for computing Monthly Tranmission Suitability Surface applied to August 2017 for the RCP 4.5 model.

3. **Evaluate ZIKV Transmission Suitability for Transmission Season:** Craig, et al., defined a, 'Transmission Season,' as the time window that was, 'long enough for vector populations to increase and for the transmission cycle to be completed' (Craig, 1999). Monaghan, et al., established that it takes three months for *A. aegypti* and *A. albopictus* to reach a moderate abundance in the continental United States (Monaghan, 2016). The transmission cycle for *A. aegypti* is 21-46 days while the transmission cycle for *A. albopictus* is 34-61 days; because of the variability in transmission cycle ranges for the purposes of this study the transmission cycle will be two months. The minimum period for a transmission season will be five months, which will be determined for each month by taking the highest suitability value spanning the chronological five-month period.

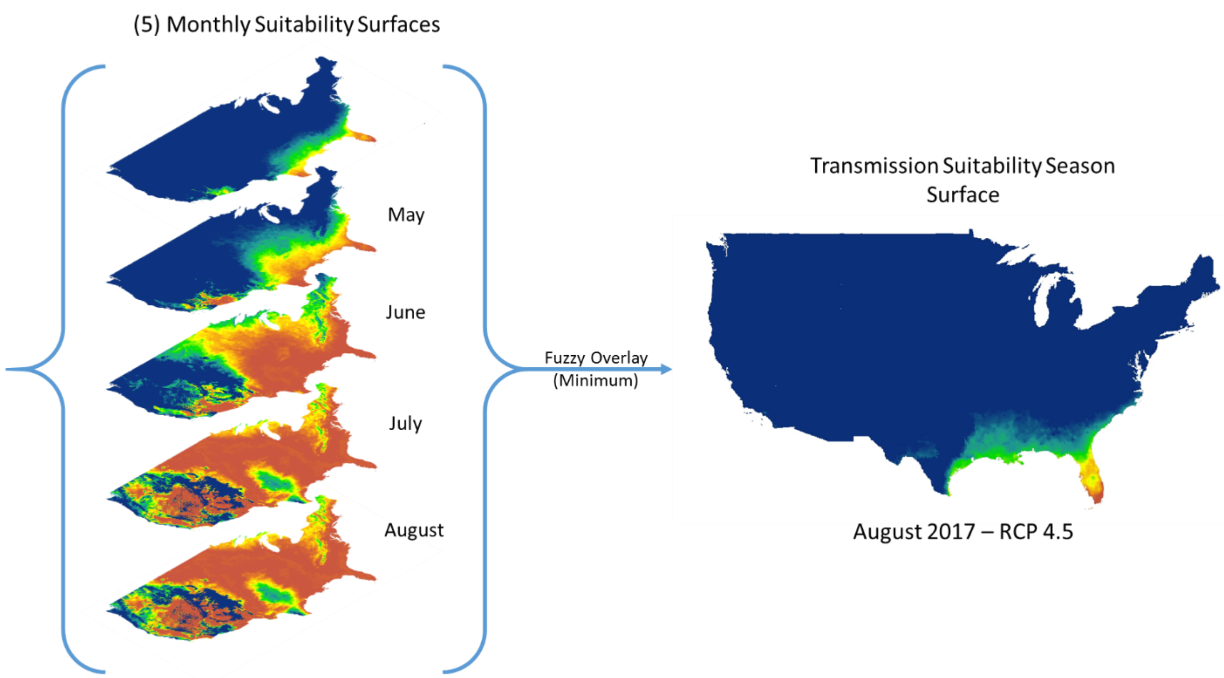


Figure 12. Process for creating a Transmission Suitability Season Raster, applied to August 2017 for the RCP 4.5 model.

4. **Combine Transmission Season Surfaces to Create ZIKV Risk Map:** To create the ZIKV transmission suitability risk map the twelve transmission season surfaces were combined, taking the maximum value for each location from any of the surfaces for that year.

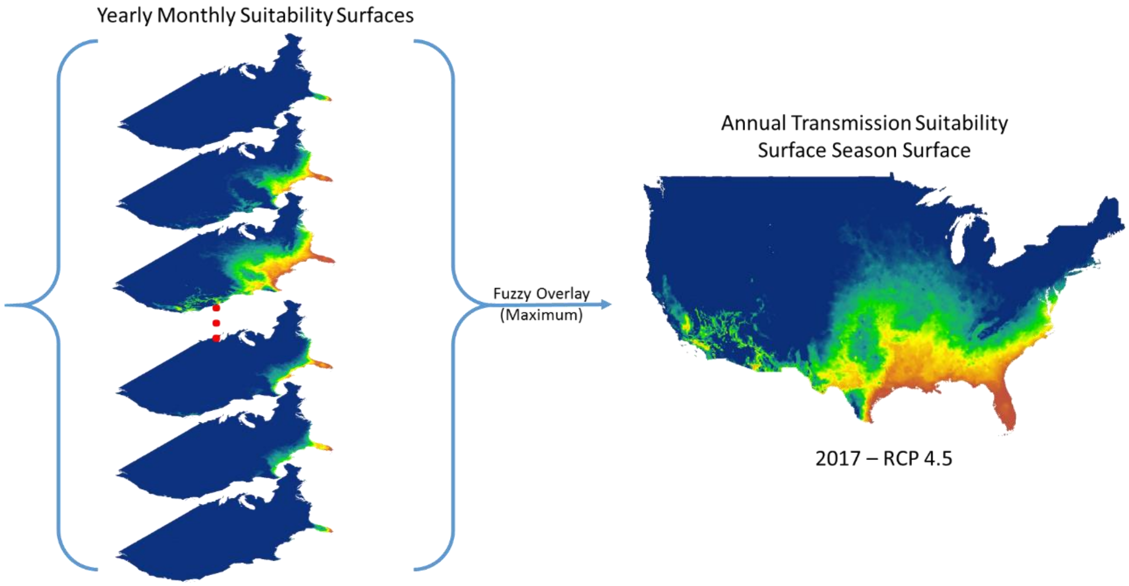


Figure 13. Process for computing the Annual Transmission Suitability Surface, applied to the 2017 RCP 4.5 model.

All data average-precipitation and -temperature data points were downloaded from the NCAR website, converted to raster, and processed per the stated methodology. Elevation data was downloaded from NASA's EOSDIS website, mosaiced, resampled to the 7km resolution of the other two datasets, and then reclassified. All processing was done using Esri's ArcPy Python library in the PyCharm IDE.

5 Results & Analysis

After processing, the data revealed unexpected results that may have been counter-intuitive when initially reviewed. The geographic range of suitability for ZIKV transmission potential that was greater than zero shows a general trend towards contraction over the study period, with a small expansion for the RCP 4.5 and 6.0 models in 2030, and a similar small expansion for the RCP 2.6 model in 2040.

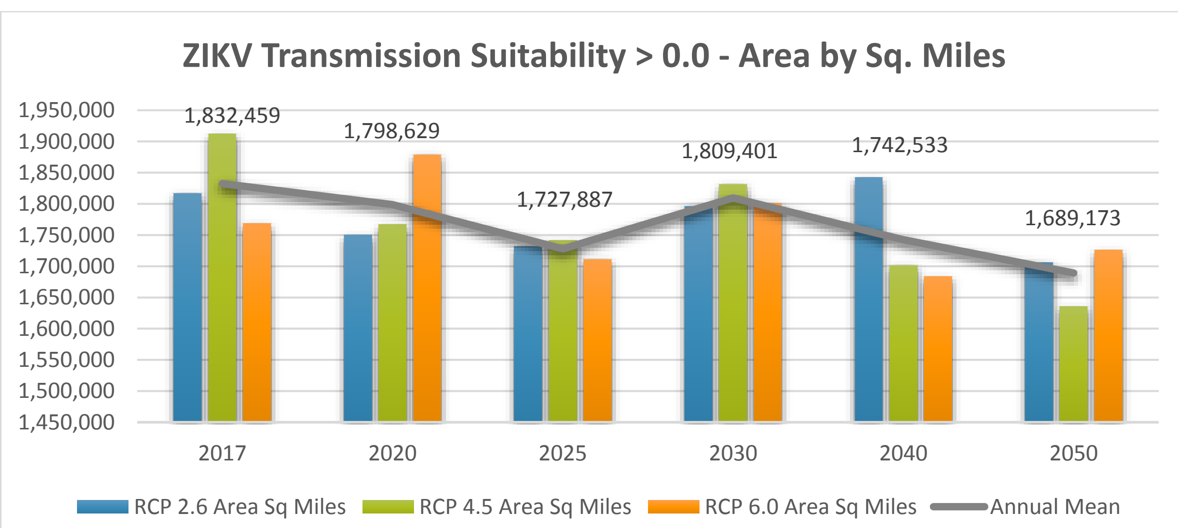


Figure 14. Geographic area, by square miles, of ZIKV Transmission Suitability greater than zero. Labels are for annual mean of the RCP-2.6, -4.5, and -6.0 models.

Despite the overall national areal contraction of ZIKV transmission suitability the trend is counter when examined regionally. In the Southeast, the Gulf States, West-Central Texas, in isolated parts of the Southwest, and Southern California a regional expansion or intensification of transmission suitability occurs. Another anomalous finding is the hole that dilates during the study period over North Texas, Oklahoma, Western Arkansas, and Kansas. In reviewing the intermediate processing data, it was found that a transmission season with suitability for any more than moderate transmission potential had trouble coming together beyond 2017 because of the temperature extremes over the consecutive 5-month period; the notable exception to this is the near closing of the hole in 2030 in the RCP 6.0 model.

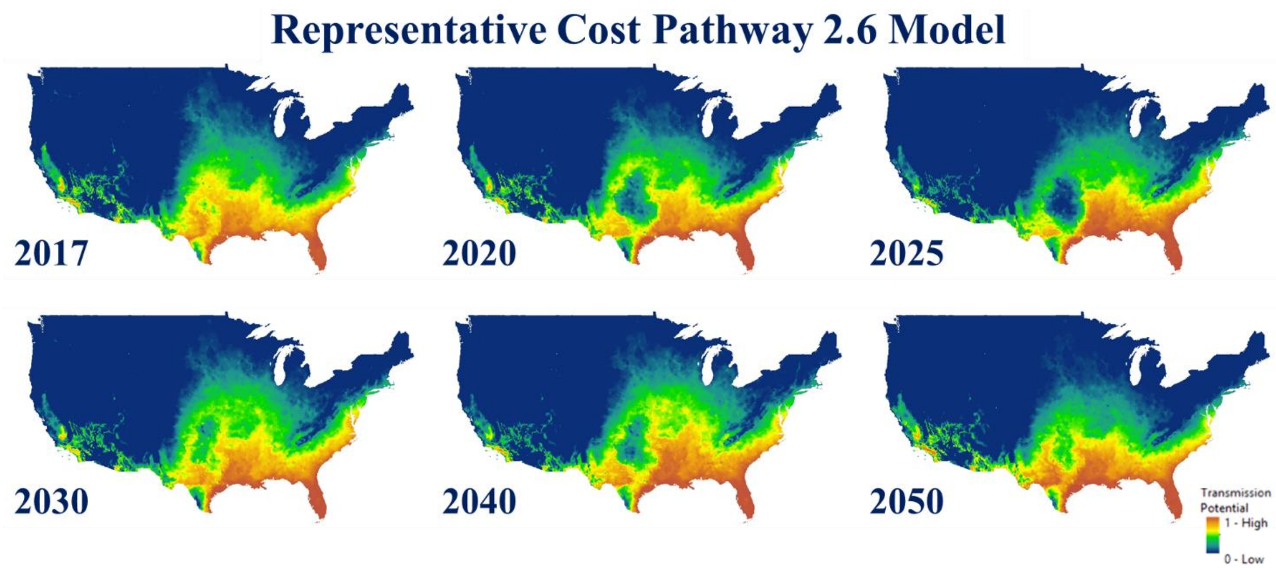


Figure 15. Time series of annual transmission suitability for the IPCC AR5 RCP 2.6 model over the study period.

In the conservative RCP 2.6 model, over the study period, there is a contraction of the geographic range for transmission suitability through 2025, most markedly with the hole that opens in the center of the country. During that same period, there is an intensification of transmission suitability in the southeast that continues through 2040, but then contracts in 2050. From 2025 through 2050, the hole in the center of the country closes while in Western-Texas and the border areas along the rest of the Southwest undergoes an intensification of transmission suitability. In this model the Gulf States are most vulnerable, with areas near their coastline likely to experience the highest impact from ZIKV. Notably Sothern- and Central-California see a decrease in transmission suitability through 2025, but then see an increase through the rest of the study period.

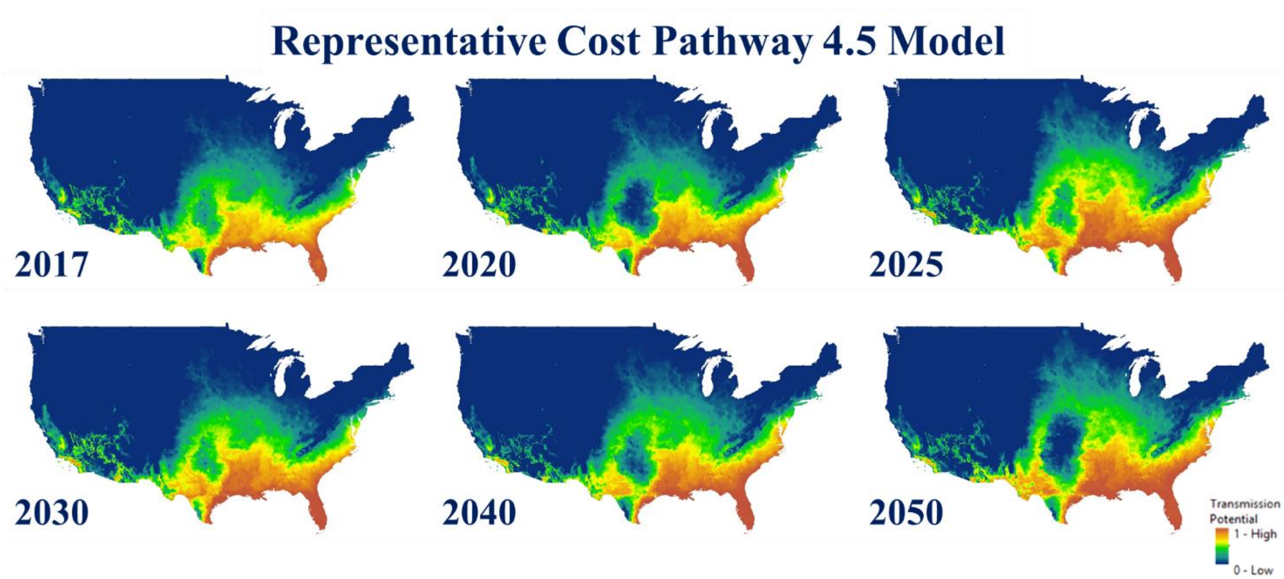


Figure 16. Time series of annual transmission suitability for the IPCC AR5 RCP 4.5 model over the study period.

In the aggressive RPC 4.5 model, the same contraction of geographic range for transmission suitability continues through 2025, expanding again through 2040 to its greatest areal extent, and then contracting to its lowest areal extent over the study period in 2050 for all models, as seen in **Figure 14**. The hole in the center of the country occurs in this model as well, although it opens in 2020, contracts through 2030, then continues to get larger through 2050, where it becomes the largest of any of the models. This model, however, shows a continual intensification and expansion of transmission suitability in the Gulf States throughout the study period. The Central- and Western-Texas region sees an expansion through 2030, a contraction by 2040, and re-expansion through 2050. Southern- and Central-California see an increase in transmission suitability values, peaking in 2030, and then dropping slightly through 2050.

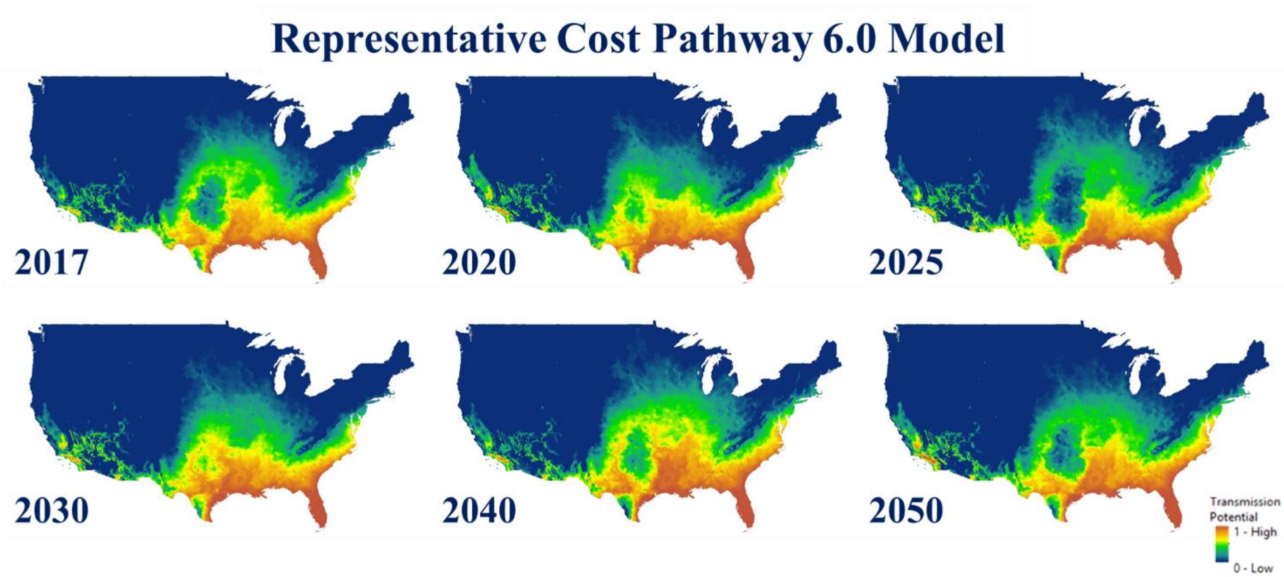


Figure 17. Time series of annual transmission suitability for the IPCC AR5 RCP 4.5 model over the study period.

The moderately aggressive RCP 6.0 model shows similarities to the previous models, with a pronounced hole of low to zero transmission suitability present in the center of the country for most the survey period. Unlike the other models though, its greatest areal extent occurs in 2020 and then fluctuates up and down for the rest of the study period. In this model the coastal areas of the Gulf States are impacted the most by ZIKV, with a notable exception for Central- and Western-Texas as well as Louisiana and Arkansas which are impacted heavily through study period; a pattern which is congruent amongst all the RCP models. This model shows the least intensity amongst the Southwest border for Arizona and New Mexico but, however, shows the most intensity of any of the RCP models for Southern California.

Through all the models there are some key differences. One key similarity is the presence of intensification and geographic expansion for transmission suitability for Eastern-Texas, Louisiana, Arkansas, and Mississippi, from 2025 on for all RCP models. This area, and Florida, are likely to be the most impacted by ZIKV and other tropical arboviruses. **Appendix A** contains time series of the Southeast. Another area that saw key similarities throughout the study period for all models was the hole of low to zero transmission suitability over Northeast Texas, Oklahoma, and Southern Kansas. The hole oscillates in shape and intensity throughout all the models, but is very similar for all models in 2020, 2025, and 2040. Southern California and the Tucson, Arizona areas all have a persistent presence of high transmission suitability across all models throughout the study period. Time series maps of the hole and the Southwest are located in **Appendix B**.

Using 2012 U.S. Census Bureau Block Group GIS data, it was possible to extract the number of people who could be impacted by ZIKV transmission suitability over the study period. The graph in **Figure 18** shows a trend like the graph in **Figure 14**; the annual mean line looks nearly identical. A key point to note, is that among all the models over the entire study period, no less than 242 million people live in areas where there is some ZIKV transmission suitability.

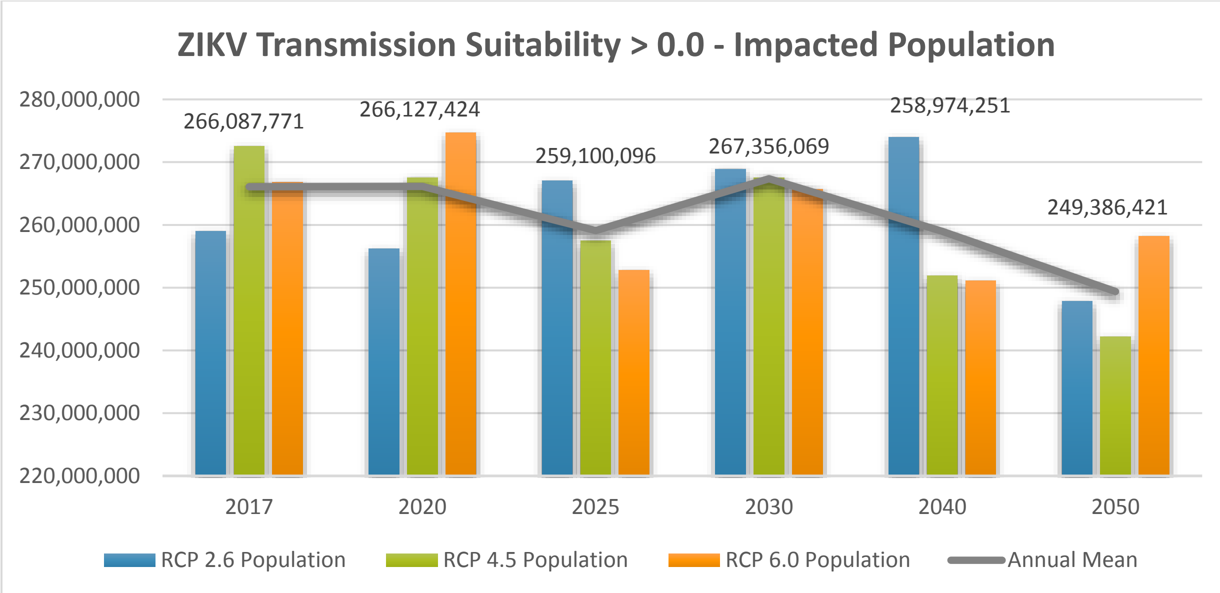


Figure 18. Graph of population that inhabit areas where ZIKV transmission suitability is greater than zero. 2012 U.S. Census Block Group population data was used for this analysis.

In the models, there is an overall decrease in the geographic extent and number of people inhabiting area with ZIKV transmission suitability above zero over the period of the study; this does not, however, tell the whole story. If the models are filtered so they only show transmission suitability values greater than or equal to 0.50, a much different pattern emerges.

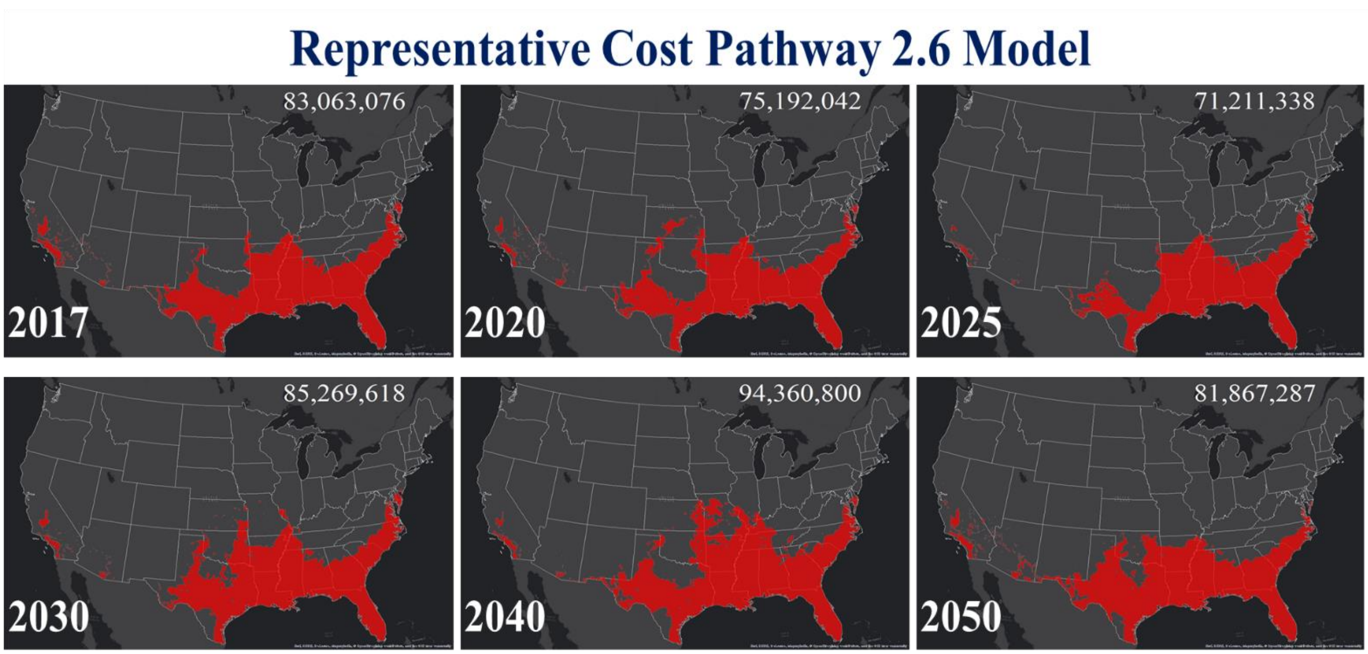


Figure 19. Time series of RCP 2.6 for transmission suitability greater than or equal to 0.50. Impacted population is shown the upper right hand of each image.

The RCP 2.6 model shows that the geographic extent of the transmission suitability ≥ 0.50 contracts until 2025, then experiences a growth through 2040, before a slight contraction in 2050. **Figure 19** shows this happen in maps, with the impacted population labeled. What is important to note is that, counter to the trend shown when transmission suitability is greater than zero, that the geographic extent of the area of high transmission suitability, for the RCP 2.6 model, tends to grow throughout the period of the study, as seen in **Figure 25**.

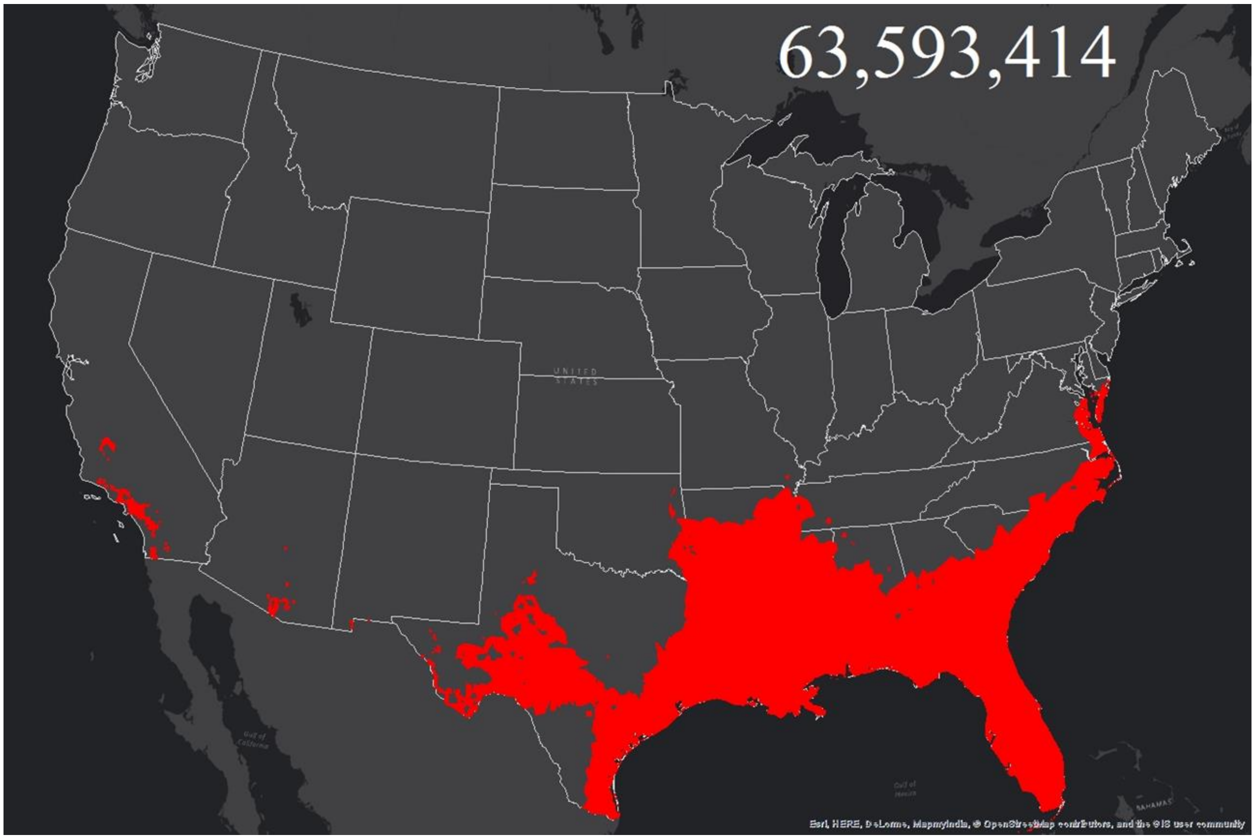


Figure 20. The common geographic extent during the whole study period for the RCP 2.6 model that has transmission suitability ≥ 0.50

By running an intersect function on the six models in **Figure 19**, the geographic extent for transmission suitability ≥ 0.50 during the entire period of the study was computed. Per this model, the environmental conditions are more likely than not be conducive for transmission of ZIKV from the present through 2050 for the coastal areas of the Gulf States and the Southeast. The model shown in **Figure 20** represents the most conservative estimate of a persistent ZIKV threat to the CONUS through the mid-21st century, potentially impacting 63.5 million people (2012 U.S. Census Block Group Population).

Figure 21. Time series of RCP 4.5 for transmission suitability greater than or equal to 0.50. Impacted population is shown the upper right hand of each image.

The RCP 4.5 model of high transmission suitability, shown in **Figure 21**, continues a similar trend to the RCP 2.6 model, generally increasing in areal extent and impacted population over the study period. Where it differs, slightly, is that there is not an initial contraction in through 2025, instead happing from 2025 until 2040. The RCP 4.5 model also covers less areal extent than RCP 2.6, only besting it in 2025 and 2050, when it shows the greatest extent of all the RCP models.

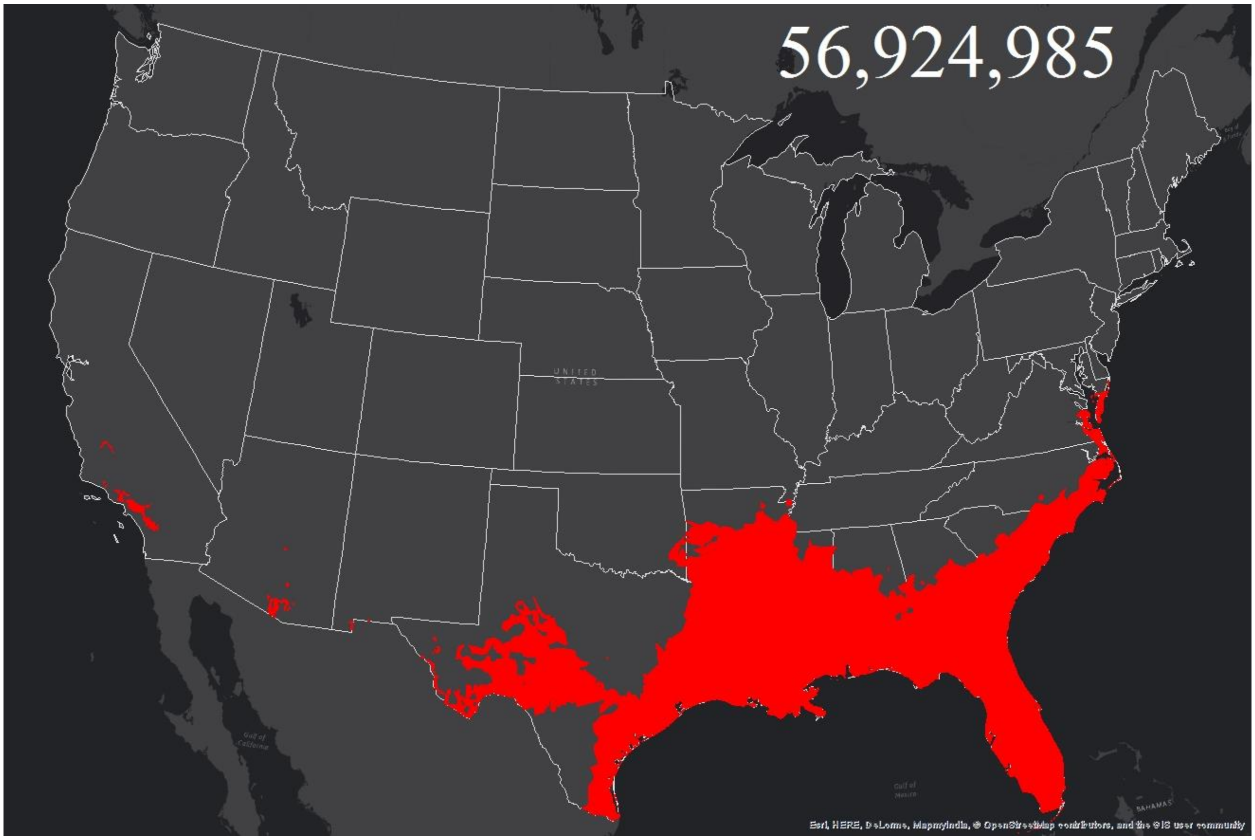


Figure 22. The common geographic extent during the whole study period for the RCP 4.5 model that has transmission suitability ≥ 0.50.

The resultant model of the common geographic extent of ZIKV transmission suitability ≥ 0.50 across the study period for the RCP 4.5 model, shown in **Figure 22**, shows a slight contraction over the model in **Figure 20**. Notably, the RCP 4.5 model impacts approximately 6.6 million less people, despite being the more aggressive model. The RCP 2.6 model extends further north into Tennessee and west into Oklahoma, as well as having a more northerly presence, albeit marginally, into Alabama and Georgia, impacting the populated suburbs of Birmingham and Atlanta. The common geographic extent of the RCP 4.5 model also extends inland the least of the other two

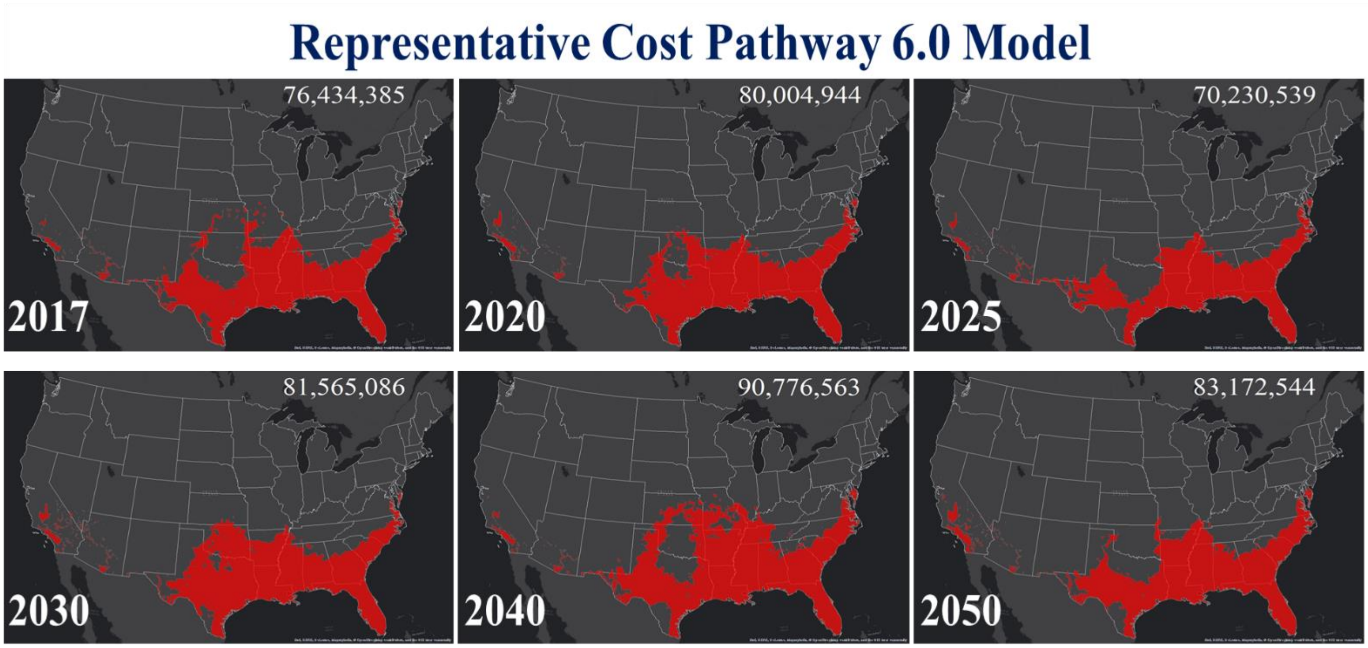


Figure 23. Time series of RCP 6.0 for transmission suitability greater than or equal to 0.50. Impacted population is shown the upper right hand of each image.

The high transmission suitability time series for the RCP 6.0 model, shown in **Figure 23**, continues the same contraction, expansion, and contraction pattern seen in the RCP 2.6 time series in **Figure 19** and better understood in **Figures 25 & 26**. While this model is considered the more moderate of the two aggressive models, it ends up having a greater areal extent than the RCP 4.5 model, likely due to less extreme temperature swings. This model penetrates further into Oklahoma and Kansas more than the other two models, while having a more northerly presence in Alabama and Georgia than the other two.

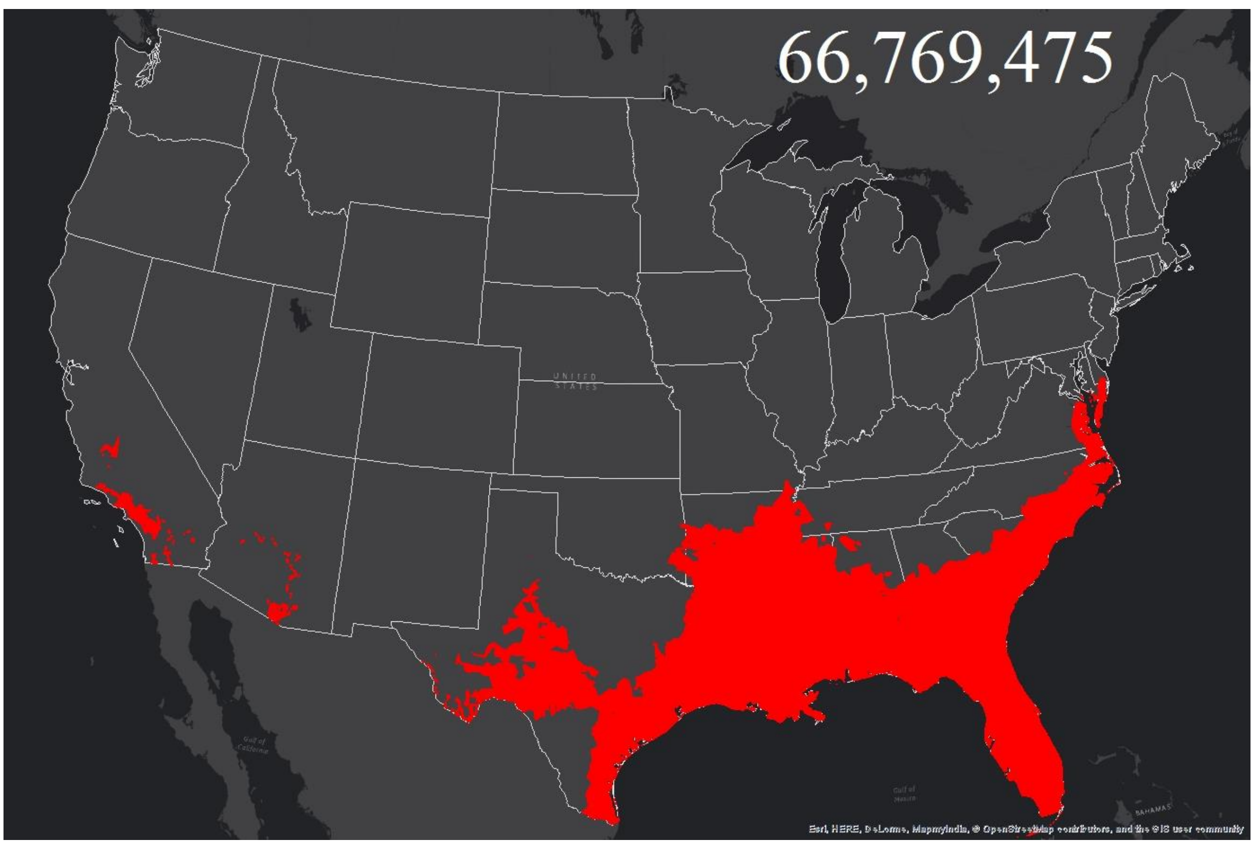


Figure 24. The common geographic extent during the whole study period for the RCP 4.5 model that has transmission suitability ≥ 0.50.

The common geographic extent of ZIKV transmission suitability ≥ 0.50 is the largest of all similar models, extending 416,209 square miles. This model, shown in **Figure 24**, extends further inland along the Gulf States and the Southeast than the other models; more importantly, the model shows the largest areal extent in California of the other two models. Overall, this model impacts 3.2 million more people than the RCP 2.6 model, and 9.8 million more people than the RCP 4.5 model.

The graphs in **Figures 25 & 26** show how the areal extent and impacted population generally trend towards growth over the study period, despite the contraction in 2050 that is also seen in **Figures 14 & 18**.

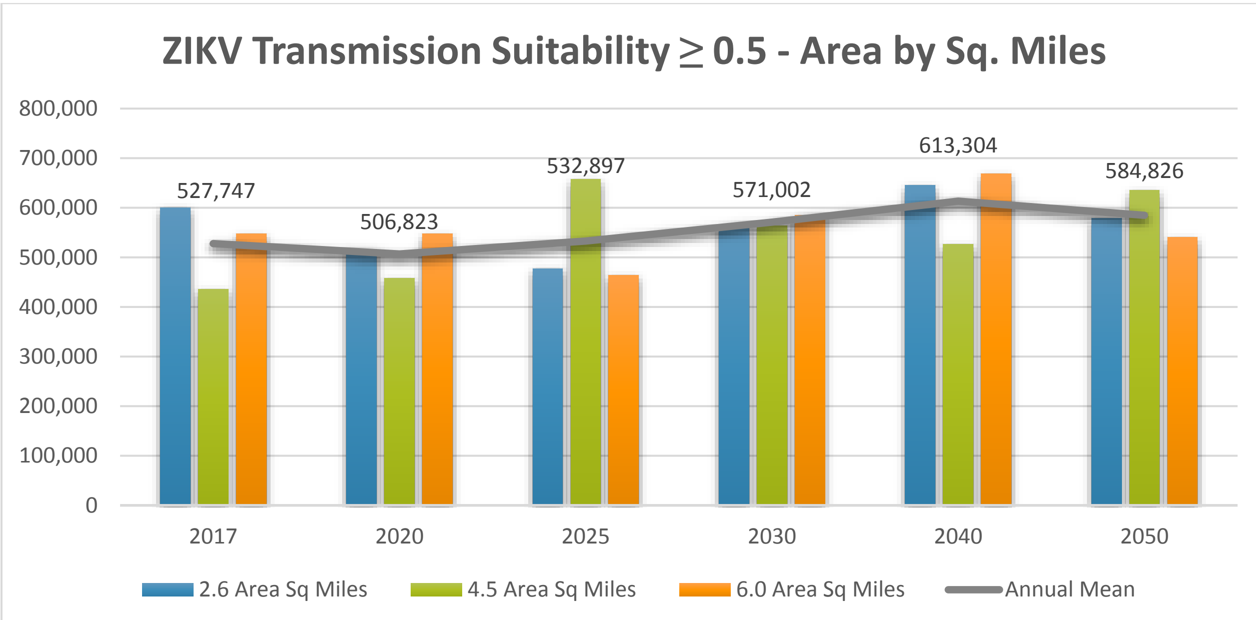


Figure 25. Geographic area, by square miles, of ZIKV Transmission Suitability ≥ 0.50. Labels are for annual mean of the RCP-2.6, -4.5, and -6.0 models.

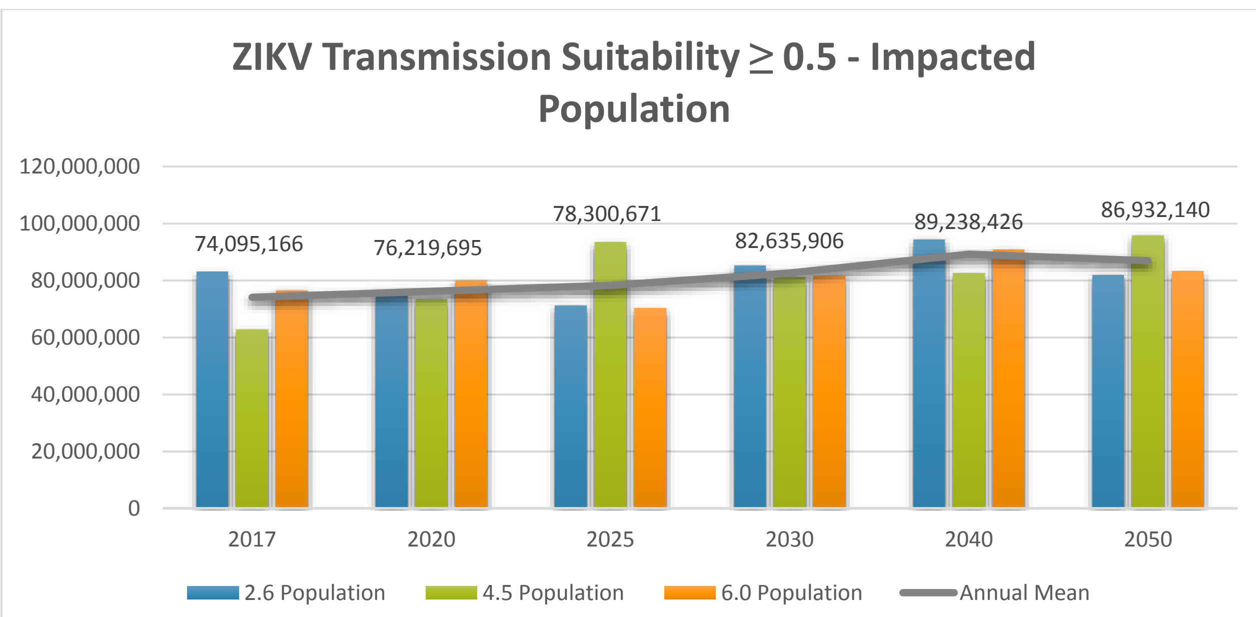


Figure 26. Graph of population that inhabit areas where ZIKV transmission suitability ≥ 0.50. 2012 U.S. Census Block Group population data was used for this analysis.

6 CONCLUSIONS

ZIKV and other tropical arboviruses will continue to pose a perennial health threat to the continental United States as climate change progresses. Determining the transmission suitability for the spread of ZIKV by the vectors *A. aegypti* and *A. albopictus* will be an important first step in identifying at risk populations. This research endeavors to draw awareness to the emerging threat of ZIKV and, by proxy, other tropical arboviruses to the continental United States by analyzing the future range of their vectors and transmission potential. The resultant maps can be used to assist public health officials in creating a strategy to combat the continuing threat of ZIKV.

7 REFERENCES

Ahrens, C. (2007). *Meteorology Today: An Introduction to Weather, Climate, and the Environment.* Belmont, CA: Thomson Learning, Inc. .

Borenstein, S. (2016, 2 3). *Higher temperatures make Zika mosquito spread disease more*. Retrieved from AP - Big Story: http://bigstory.ap.org/article/ae4d08ccee7746f0b4f916a901fe236c/higher-temperatures-makes-zika-mosquito-spread-disease-more

Brady, O. J.-d.-F. (2013). Modelling adult Aedes aegypti and Aedes albopictus survival at different temperatures in labratory and field settings. *Parasties & Vectors*. doi:DOI: 10.1186/1756-3305-6-351

Braks, M. H.-D.-O. (2003). Convergent Habitat Segregation of Aedes aegypti and Aedes albopictus (Diptera: Culicidae) in Southeastern Brazil and Florida. *Journal of Medical Entomology, 40*(6), 785-794.

Campbell, K. H.-T. (2015). Weather Regulates Location, Timing, and Intensity of Dengue Virus Transmission between Humans and Mosquitoes. *PLOS | Neglected Tropical Diseases*, 1-26. doi:http://dx.doi.org/10.1371/journal.pntd.0003957

Cauchemez, S. B.-A.-G. (2016). Association between Zika Virus and microcphaly in French Polynesia, 2013-15: a retrospective study. *The Lancet, 387*(10033), 2125-2132.

CDC. (2012, September 27). *Mosquito Life-Cycle.* Retrieved from Centers for Disease Control and Prevention: http://www.cdc.gov/dengue/entomologyecology/m_lifecycle.html

CDC. (2016, July 14). *All Countries & Territories with Active Zika Virus Transmission*. Retrieved from Centers for Disease Control and Prevention: http://www.cdc.gov/zika/geo/active-countries.html

CDC. (2016, July 15). *CDC Concludes Zika Causes Microcephaly and Other Birth Defects*. Retrieved from Centers for Disease Control and Prevention: http://www.cdc.gov/media/releases/2016/s0413-zika-microcephaly.html

CDC. (2016). *Dengue and the Aedes albopictus mosquito*. Retrieved from Centers for Disease Control and Prevention: http://www.cdc.gov/dengue/resources/30jan2012/albopictusfactsheet.pdf

CDC. (2016, April 2). *Surveillance and Control of Aedes aegypti and Aedes albopictus in the United States*. Retrieved from Centers for Disease Control and Prevention: http://www.cdc.gov/chikungunya/resources/vector-control.html

CDC. (2016, July 15). *Zika and Guillain-Barre Syndrome*. Retrieved from Centeres for Disease Control and Prevention: http://www.cdc.gov/zika/about/gbs-qa.html

CDC. (2016, July 15). *Zika Virus*. Retrieved from Centers for Disease Control and Prevention: https://www.cdc.gov/zika/symptoms/symptoms.html

CDC. (2016, July 13). *Zika virus disease in the United States, 2015-2016*. Retrieved from Centers for Disease Control and Prevention: http://www.cdc.gov/zika/geo/united-states.html

CDC. (n.d.). *Lesson 1 Understanding the Epidemiologic Triangle through Infectious Disease.* Retrieved from Centers for Disease Control and Prevention: https://www.cdc.gov/bam/teachers/documents/epi_1_triangle.pdf

Cetron, M. (2016, March 11). *Revision to CDC's Zika Travel Notices: Minimal Likelihood for Mosquito-Borne Zika Virus Transmission at Elevations Above 2,000 Meters*. Retrieved from Centers for Disease Control and Prevention: http://www.cdc.gov/mmwr/volumes/65/wr/mm6510e1.htm

Cha, E. S. (2016, February 1). *Zika virus: WHO declares global public health emergency, says causal link to brain defects 'strongly suspected'*. Retrieved from The Washington Post: https://www.washingtonpost.com/news/to-your-health/wp/2016/02/01/zika-virus-who-declares-global-public-health-emergency-given-rapid-spread-in-americas/

Chouin-Carneiro, T. V.-R. (2016). Differential Susceptibilities of Aedes aegypti and Aedes albopictus from the Americas to Zika Virus. *PLOS | Neglected Tropical Diseases*.

Clements, A. (2012). *The Biology of Mosquitoes Volume 3.* Cambridge, UK: Cambridge University Press.

Craig, M. S. (1999). A Climate-based Distribution Model of Malaria Transmission in Sub-Saharan Afric. *Parasitology Today, 15*(3), 105-111.

Darsie, R. W. (1981). *Identification and Geographical Distribution of the Mosquitoes of North America, North of Mexico.* Washington, D.C.: WALTER REED ARMY INST OF RESEARCH.

Dasgupta, S. R.-S.-D. (2016, April 22). *Patterns in Zika Virus Testing and Infection, by Report of Symptoms and Pregnancy Status — United States, January 3–March 5, 2016*. Retrieved from Centers for Disease Control and Prevention : http://www.cdc.gov/mmwr/volumes/65/wr/mm6515e1.htm

DengueVirusNet. (2016). *Aedes aegypti*. Retrieved from Dengue Virus Net: http://www.denguevirusnet.com/aedes-aegypti.html

DengueVirusNet. (2016). *History of Dengue*. Retrieved from Dengue Virus Net: http://www.denguevirusnet.com/history-of-dengue.html

DengueVirusNet. (2016). *Life Cycle of Aedes Aegypti*. Retrieved from Dengue Virus Net: http://www.denguevirusnet.com/life-cycle-of-aedes-aegypti.html

Dialo, D. S. (2014). Zika Virus Emergence in Mosquitoes in Southeastern Senegal. *PLOS | One*. doi:10.1371/journal.pone.0109442

Duffy, M. C. (2009). Zika Virus Outbreak on Yap Islancd, Federated States of Micronesia. *The New England Journal of Medicine*, 2536-2543.

Eisen, L. E. (2011). Using Geographic Information Systems and Decision Support Systems for the Prediction, Prevention, and Control of Vector-Borne Disease. *Annual Review of Entemology, 56*, 41-61.

Eisenstein, M. (2016, March 16). Disease: Poverty and pathogens. *Nature: Interational Weekly Journal of Science, 531*, 61-63.

Fischer, D. T. (2013). Climate change effects on Chikungunya transmission in Europe: geospatial analysis of vector's climatic suitability and virus' temperature requirements. *International Journal of Health Geographics, 12*(51).

G.W.A. Dick, S. K. (1952, September). Zika Virus (I). Isolations and Serological Specificity. *Transactions of The Royal Society of Tropical Medicine and Hygiene, 46*(5), pp. 509-520.

Gatherer, D. K. (2016, February). Zika virus: a previously slow pandemic spreads rapidly through the Americas. *Journal of General Virology*, 269-173.

Goldschmidt, D. (2016, July 29). *Florida health officials confirm local Zika transmission*. Retrieved from CNN.com: http://www.cnn.com/2016/07/29/health/florida-health-officials-confirm-local-zika-transmission/

Haddow, A. S. (2012). Genetic Characterization of Zika Virus Strains: Geographic Expansion of the Asian Lineage. *PLOS | Neglected Tropical Diseases*. doi:10.1371/journal.pntd.0001477

Hahn, M. E. (2016, June). Reported Distribution of Aedes (Stegomyia) aegypti and Aedes (Stegomyia) albopictus in the United States, 1995-2016 (Diptera:Culicidae). *Journal of Medical Entomology*.

Hamel, R. L. (2016). Zika virus: epidemiology, clinical features and host-virus interactions. *Microbes and Infection, 18*(7-8), 441-449. doi:10.1016/j.micinf.2016.03.009

Harrington, L. E. (2001). Why Do Female Aedes aegypti (Diptera: Culicidae) Feed Preferentially and Frequently on Human Blood? *Journal of Medical Entomology*, 411-422.

Hartman, K. (2011). *Aedes albopictus*. Retrieved from Animal Diversity Web: http://animaldiversity.org/accounts/Aedes_albopictus/

Hawley, W. (1988). The biology of Aedes albopictus. *Journal of the American Mosquito Control Association*, 1-40.

Hennessey M, F. M. (2016, January 22). Zika Virus Spreads to New Areas — Region of the Americas. *MMWR Morb Mortal Wkly Rep*, pp. 55-58. Retrieved 7 15, 2016, from http://www.cdc.gov/mmwr/volumes/65/wr/mm6503e1.htm#suggestedcitation

Hii, Y. Z. (2012). Forecast of Dengue Incidence Using Temperature and Rainfall. *PLOS | Neglected Tropical Diseases, 6*(11), e1908. doi:https://dx.doi.org/10.1371%2Fjournal.pntd.0001908

Johansson, M. D. (2009). Local and Global Effects of Climate on Dengue Transmission in Puerto Rico. *PLOS | Neglected Tropical Disease, 3*(2), e382. doi:doi:10.1371/journal.pntd.0000382

Juliano, S. O. (2002). Desiccation and thermal tolerance of eggs and the coexistence of competing mosquitoes. *National Institute of Health, Oecologia*, 458-469. doi: doi:10.1007/s004420100811

Kraemer, M. S. (2015, June 30). *The global distribution of the arbovirus vectors Aedes aegypti and Ae. albopictus*. Retrieved from eLIFE: https://elifesciences.org/content/4/e08347

Kriticos, D. W. (2012). *CliMond: global high resolution historical and future scenario climate surfaces for bioclimatic modelling.* Retrieved from www.climond.org: https://www.climond.org/Core/Authenticated/RawClimate.aspx

Lambrechts, L. S. (2015, May 25). *Consequences of the Expanding Global Distribution of Aedes albopictus for Dengue Virus Transmission*. Retrieved from PLOS: http://journals.plos.org/plosntds/article?id=10.1371/journal.pntd.0000646

Leisnham, P. L. (2014). Spatial and Temporal Habitat Segregation of Mosquitoes in Urban Florida. *PLOS | One*. doi:http://dx.doi.org/10.1371/journal.pone.0091655

Loos, S. M.-P. (2014). Current Zika virus epidemiology and recent epidemics. *Medecine et Maladies Infectieuses, 44*(7), 302-307.

Majeed, S. H. (2014). Impact of elevated CO2 background levels on the host-seeking behaviour of Aedes aegypti. *Journal of Experimental Biology*, 598-604.

McMichael, A. W. (2006). Climate change and human health: present and future risks. *Lancet*, 860-869. doi:10.1016/S0140-6736(06)

Messina, J. K. (2016, April 19). Mapping global environmental suitability for Zika virus. *eLIFE*. doi:http://dx.doi.org/10.7554/eLife.15272

Monaghan, A. M. (2016). On the Seasonal Occurrence and Abundance of the Zika Virus Vector Mosquito Aedes Aegypti in the Contiguous United States. *PLOS | Current Outbreaks*. Retrieved from http://currents.plos.org/outbreaks/article/on-the-seasonal-occurrence-and-abundance-of-the-zika-virus-vector-mosquito-aedes-aegypti-in-the-contiguous-united-states/

Mordecai, E. C. (2016, July 15). *Temperature determines Zika, dengue and chikungunya transmission in the Americas.* Retrieved from bioRxiv: http://biorxiv.org/content/biorxiv/early/2016/07/15/063735.full.pdf

Morin, W. C. (2013). Climate and Dengue Transmission: Evidence and Implications. *Environmental Heatlh Perspectives, 121*(11-12), 1264-1272. doi:DOI:10.1289/ehp.1306556

Musso, D. G. (2016). *Zika Virus*. Retrieved from American Society for Microbiology | Clinical Microbiology Reviews.

N.A. (2016). *Zika*. Retrieved from Institut Pasteur: http://www.pasteur.fr/en/institut-pasteur/press/fact-sheets/zika

Okumu, F. K. (2010). Development and Field Evaluation of a Synthetic Mosquito Lure That Is More Attractive than Humans. *PLOS*. Retrieved from http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0008951

Oxitec. (2013, December 13). *Life cycle of Aedes aegypti.* Retrieved from www.prezi.com: https://prezi.com/5a5gamxqg-tb/life-cycle-of-aedes-aegypti/

PAHO. (2014, June 30). *Factsheet Chikungunya*. Retrieved from Pan American Health Organization: http://www.paho.org/hq/index.php?option=com_content&view=article&id=8303&Itemid=40023&lang=en

PAHO/WHO. (2016). *Zika cases and congenital syndrome associated with Zika virus reported by countries and territories in the Americas, 2015-2016 Cumulative cases.* Washington, D.C.: PAHO. Retrieved from http://www.paho.org/hq/index.php?option=com_docman&task=doc_view&Itemid=270&gid=36428&lang=en

Palaniyandi, M. A. (2014). Spatial Cognition: a geospatial analysis of vector borne disease transmission and the environment, using reomte sensing and GIS. *International Journal of Mosquito Research*, 39-54.

Petersen, E. W. (2016, March). Rapid Spread of Zika Virus in The Americas - Implications for Public Health Preparedness for Mass Gatherings at the 2016 Brazil Olympic Games. *Internation Journal of Infectious Diseases, 44*, 11-15.

Proestos, Y. ,. (2015, February 16). Present and future projections of habitat suitability of the Asian tiger mosquito, a vector of viral pathogens, from global climate simulation. *Philosophical Transactions of the Royal Society | Biological Sciences*, 1-17. doi:DOI: 10.1098/rstb.2013.0554

Rios, ,. L. (2004, April). *Asian Tiger Mosquito*. Retrieved from Featured Creatures: http://entnemdept.ufl.edu/creatures/aquatic/asian_tiger.htm

Saad, L. J. (2016, March 16). *U.S. Concern About Global Warming at Eight-Year High*. Retrieved from www.gallup.com: http://www.gallup.com/poll/190010/concern-global-warming-eight-year-high.aspx

Sota, T. M. (1992). Interspecific Variation in Desiccation Survival Time of Aedes (Stegomyia) Mosquito Eggs Is Correlated with Habitat and Egg Size. *Oegologia, 90*(3), 353-358.

Stocker, T. D.-K. (2013). *Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment.* ambridge, United Kingdom and New York, NY, USA: Cambridge University Press. doi:doi:10.1017/CBO9781107415324.004

United Nations, Department of Economic and Social Affairs, Population Division. (2014). *World Urbanization Prospects: The 2014 Revision, Highlights.* New York City, NY : The United Nations.

University of Texas Medical Branch at Galveston. (2016, August 30). *Female mosquitoes can transmit Zika virus to their eggs, offspring: Killing only adult mosquitoes may not end Zika outbreaks*. Retrieved from Science Daily: https://www.sciencedaily.com/releases/2016/08/160830091524.htm

Vorou, R. (2016, July). Zika virus, vectors, reservoirs, amplifying hosts, and their potential to spread worldwide: what we know and what we should investigate urgently. *International Journal of Infectious Diseases, 48*, 85-90. doi:http://dx.doi.org/10.1016/j.ijid.2016.05.014

Weaver, S. B. (2004). Transmission Cycles, Host Range, Evolution and Emergence of Arboviral Disease. *Nature Reviews Microbiology, 2*(10), 789-801. doi:http://dx.doi.org.ezaccess.libraries.psu.edu/10.1038/nrmicro1006

WHO. (2016). *Dengue Control - The Mosquito*. Retrieved from World Health Organization: http://www.who.int/denguecontrol/mosquito/en/

WHO. (2016, April). *Media centre - Chikungunya*. Retrieved from World Health Organization: http://www.who.int/mediacentre/factsheets/fs327/en/

WHO. (2016, April). *Media centre - Dengue and severe dengue*. Retrieved from World Health Organization: http://www.who.int/mediacentre/factsheets/fs117/en/

WHO. (2016, May 20). *WHO confirms Zika virus strain imported from the Americas to Cabo Verde*. Retrieved from World Health Organization: http://www.who.int/mediacentre/news/releases/2016/zika-cabo-verde/en/

WHO. (2016, July 15). *Zika Virus*. Retrieved from World Health Organization: http://www.who.int/mediacentre/factsheets/zika/en/

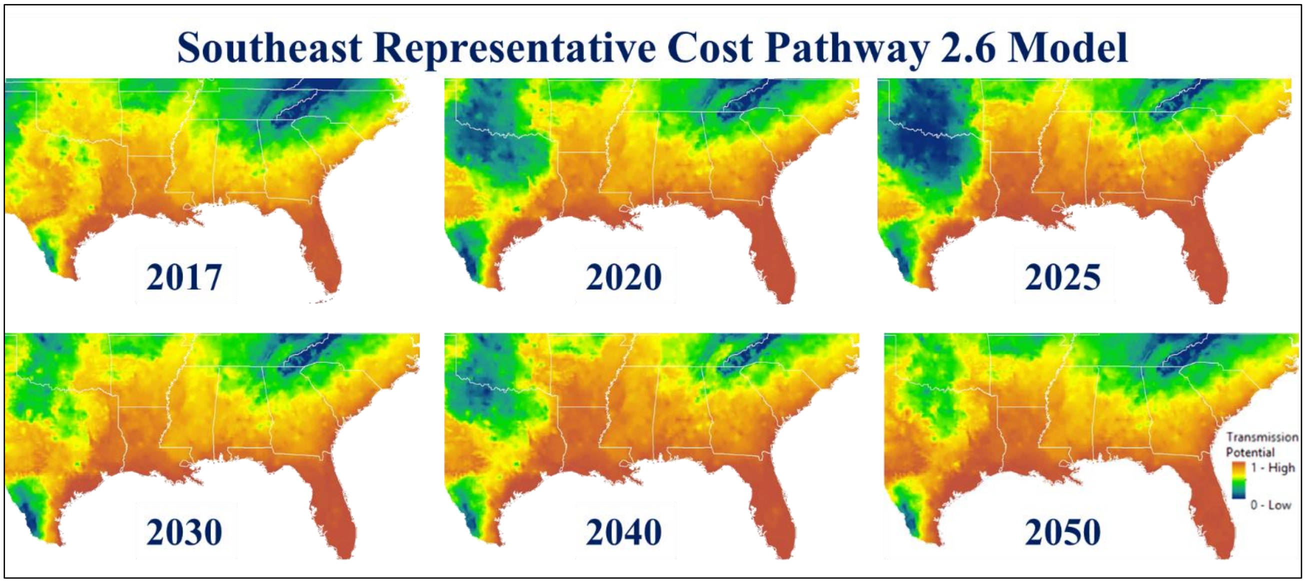
WHO. (2016, May). *Zika Virus Technical Report.* Retrieved from World Health Organization | Europe: http://www.euro.who.int/__data/assets/pdf_file/0003/309981/Zika-Virus-Technical-report.pdf

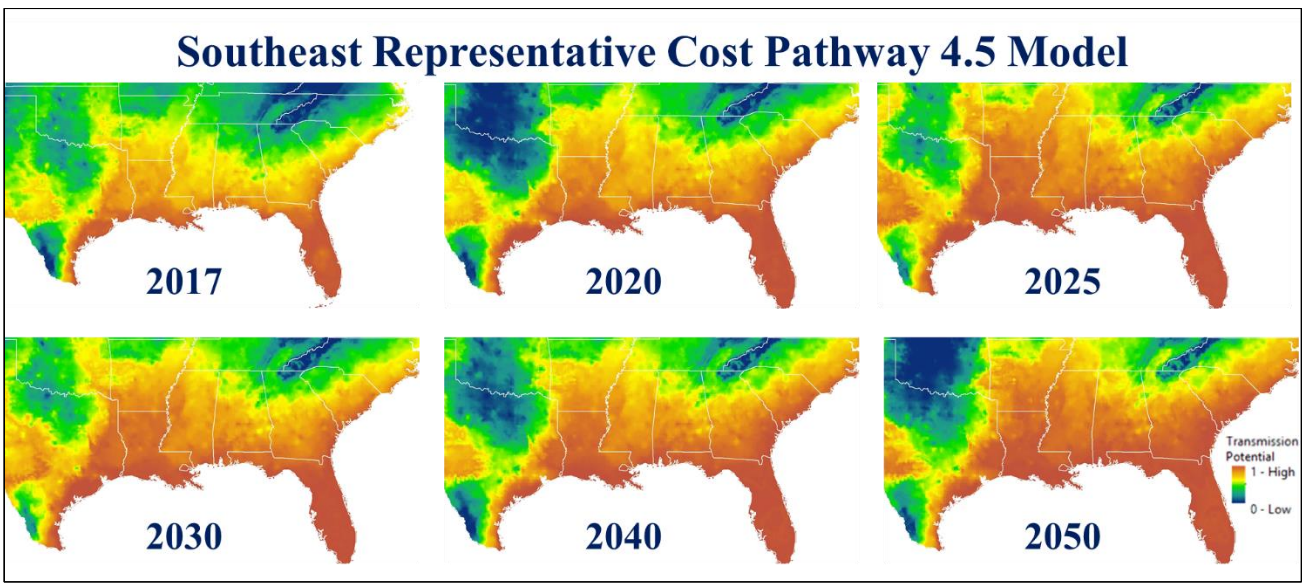
Wong, P.-S. L.-Z.-S.-C.-H. (2013). Aede(Stegomyia) albopictus (Skuse): A Potential Vector of Zika Virus in Singapore. *PLOS | Neglected Tropical Diseases*.

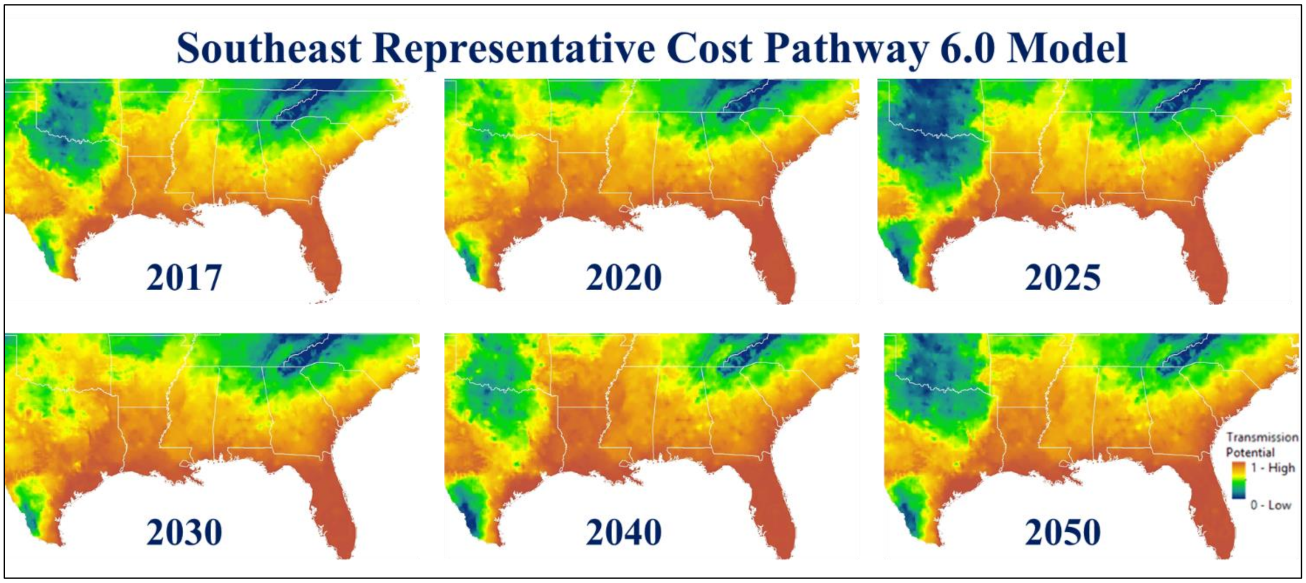
Yee, D. K. (2004). Interspecific Differences in Feeding Behavior and Survival Under Food-Limited Conditions for Larval Aedes albopictus and Aedes aegypti (Diptera: Culicidae. *Annals of the Entomological Society of America, 97*(4), 720-728.

Zettel, C. K. (2008, May). *Aedes Aegypti*. Retrieved from Featured Creatures: http://entnemdept.ufl.edu/creatures/aquatic/aedes_aegypti.htm

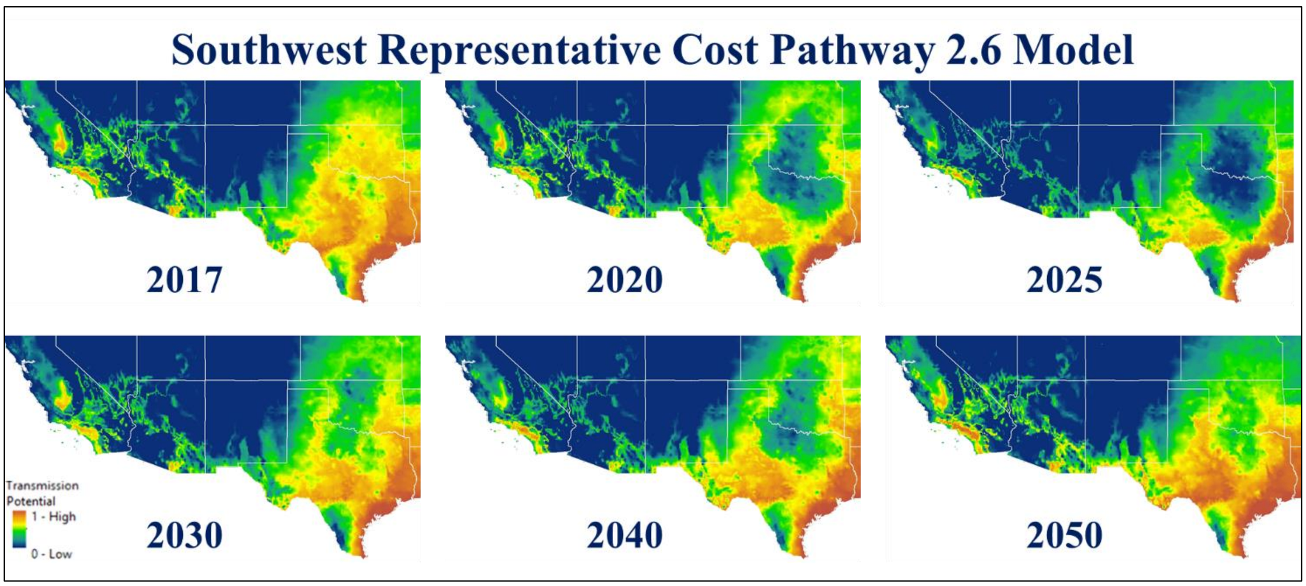
8 Appendix A – Southeast Maps

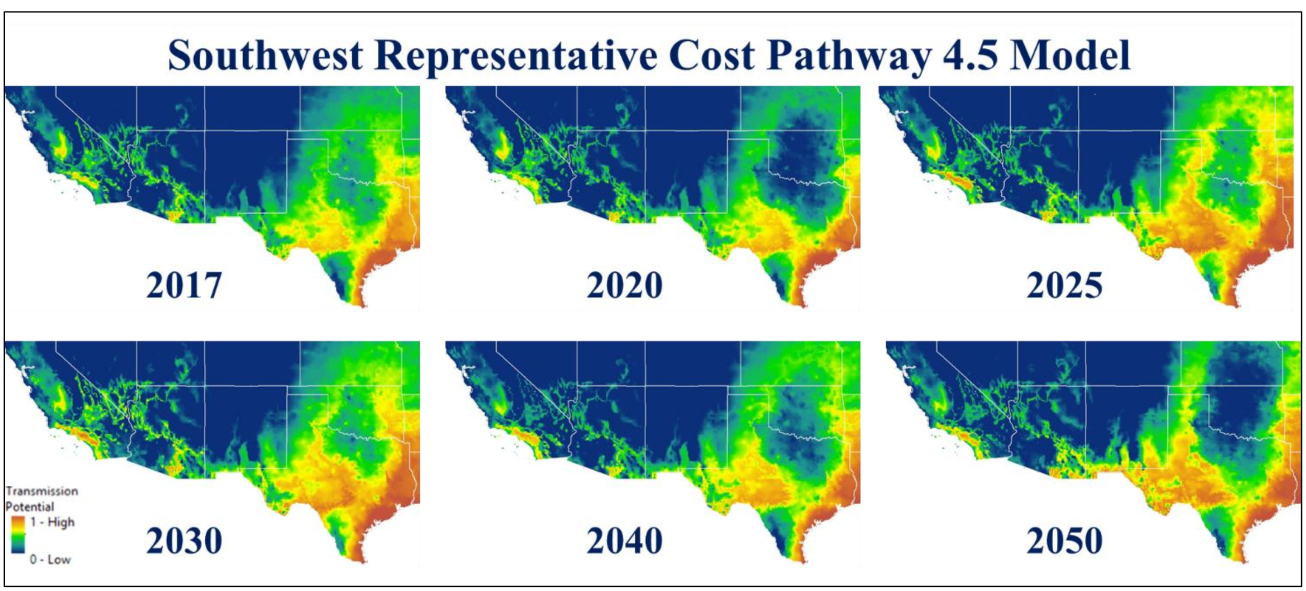


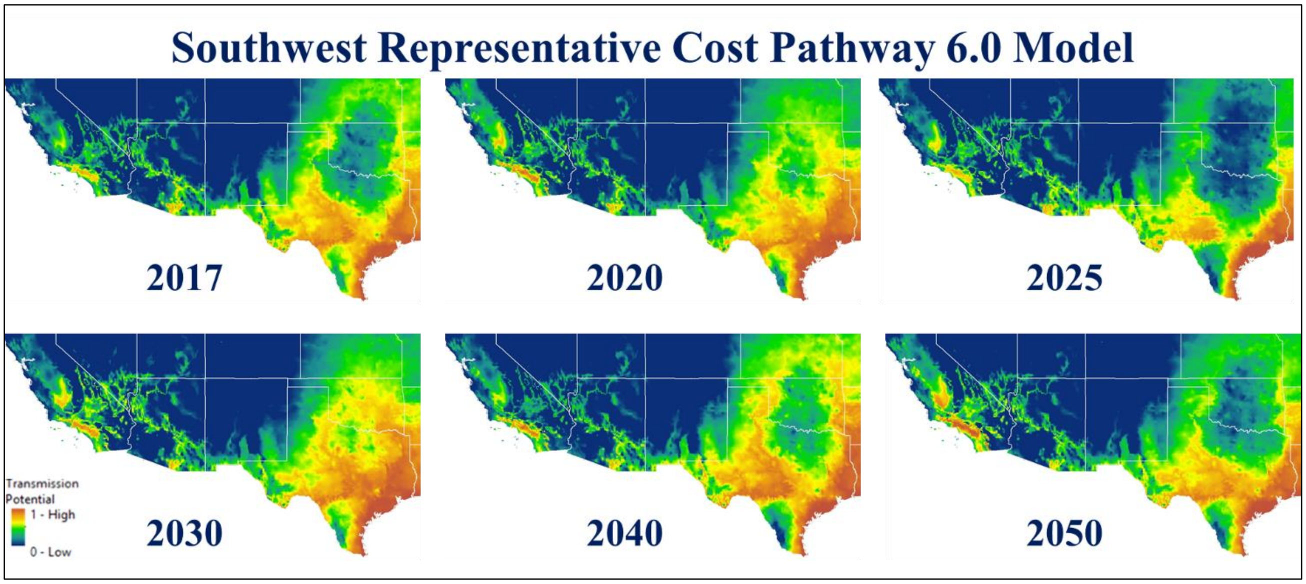




9 APPENDIX B – SOUTHWEST MAPS






Southwest Representative Cost Pathway 6.0 Model
2017
2020
2025
2030
2040
2050
Transmission Potential
1 - High
0 - Low