A location-specific spreadsheet for estimating Zika risk and timing for Zika vector surveillance, using U.S. military facilities as an example

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ABSTRACT

Local Zika virus transmission in the United States involving one or both of the known vector species, *Aedes aegypti* and *Ae. albopictus*, is of major concern. To assist efforts to anticipate the risks of transmission, we developed an Excel spreadsheet tool that uses vector and virus temperature thresholds, remotely sensed maximum temperature, and habitat suitability from models to answer the questions: “is Zika transmission likely here?” and “when should we conduct vector surveillance?”. An example spreadsheet, updated regularly and freely available, uses near real-time and forecast temperature data to generate guidance, based on a novel four level Zika risk code, for 733 U.S. military facilities in the 50 states, the District of Columbia, and the territories of Guam and Puerto Rico.

KEY WORDS: Zika, *Aedes aegypti*, *Aedes albopictus*, Risk, Excel
INTRODUCTION

In 2016, Zika virus disease and congenital infections became nationally notifiable conditions in the United States (Council of State and Territorial Epidemiologists, 2016). A total of 2,382 confirmed and probable cases of ZIKAV disease with illness onset were reported to ArboNET, the U.S. national arboviral surveillance system managed by CDC and state health departments, during January 1 – July 31, 2016 (Walker et al. 2016). In July 2016 the first locally acquired cases of Zika virus (ZIKAV) from mosquitoes were confirmed for the U.S. state of Florida (Likos, 2016). Aedes mosquitoes transmit ZIKAV, chikungunya virus (CHIKV), dengue virus (DENV), and yellow fever virus (YFV), among others, so co-infections are possible. Although Ae. albopictus is thought to be a competent vector of ZIKAV (Grard et al. 2014), Ae. aegypti has been implicated as the primary transmitter of the virus in human populations in the ongoing outbreak in the Americas (Guerbois et al. 2016, Ferreira-de-Brito et al. 2016). This is likely the result of Ae. aegypti preferring to feed more frequently on humans (Scott et al. 1993, 2000), and being highly peridomestic compared to Ae. albopictus, which can inhabit more rural environments (Braks et al. 2003; Tsuda et al. 2006).

In this study, we concentrated on U.S. Department of Defense (DoD) facilities but the approach could be used for any area of interest. Some military facilities have long standing mosquito surveillance programs (Foley et al. 2011a), and Zika virus surveillance is being enhanced in the U.S. military as a result of the recent threat, for example, through funding from the Global Emerging Infections Surveillance and Response (GEIS), section of the Armed Forces Health Surveillance Branch in the Defense Health Agency’s Public Health Division (Pellerin, 2016). According to a March 2016 U.S. DoD memo, 190 DoD installations are located in areas where mosquitoes capable of carrying ZIKAV occur, and increased vector monitoring will be conducted in installations in 27 states, the District of Columbia, Guam and Puerto Rico (Kime, 2016). Four regional commands exist under the U.S. Army Medical Command, and all of these have Entomological Sciences Divisions that conduct mosquito surveillance. Additionally, the U.S. Air Force School of Aerospace Medicine, the U.S. Navy and Marine Corps Public Health Center and regional Navy Environmental and Preventative Medicine
Units, and the Navy Entomology Center of Excellence, assist those undertaking vector surveillance or arbovirus testing.

For a military entomologist tasked with establishing and maintaining an *Aedes* spp. / ZIKAV surveillance program in temperate areas that experience high mosquito seasonality, two important questions arise: 1) is ZIKAV transmission possible here?; and 2) when should we conduct vector surveillance?. In the following we describe an Excel-based tool that is designed to assist entomologists and other health personnel address these two questions.

Habitat suitability models displaying potential distribution have been published for both *Ae. aegypti* and *Ae. albopictus* (Attaway et al. 2016, Brady et al. 2014, Campbell et al. 2015, Khormi & Kumar 2014, Medley 2010), as well as for ZIKAV (Carlson et al. 2016, Messina et al. 2016, Perkins et al. 2016, Samy et al. 2016). While these models often display average yearly suitability they do not necessarily provide information that could be used for decisions about the timing of surveillance activities, and are global in extent rather than focused on particular areas where a surveillance program might be established. Questions about timing of mosquito monitoring and allocation of resources requires a consideration of what conditions limit adult mosquito activity and ZIKAV dissemination in the field.

Relative humidity, rainfall, drought, and wind velocity affect survival and behavior of mosquitoes, and therefore transmission (Kramer & Ebel, 2003). However, temperature is the most important ecological determinant of development rate in *Ae. aegypti* (Couret & Benedict 2014), and one of the principal determinants of *Aedes* survival (Brady et al. 2013). Temperature also directly affects the replication rate of arboviruses, thus affecting the extrinsic incubation period (Gubler et al. 2007). What then, do we know about how temperature limits *Aedes* and arboviruses like ZIKAV?

In Saudi Arabia, Khormi et al. (2011) found that the minimum temperature range of 18-25 °C is suitable for *Ae. aegypti* survival, and the survival rate increases up to 38 °C. Conner (1924) and Wayne & Graham (1968) found that *Ae. aegypti* is most active at temperatures between 15 °C and 30 °C, while other field and laboratory observations found survival rates from about 18 °C to ≤ 38 °C, based on daily or monthly minimum and maximum temperatures (Macfie, 1920; Bliss & Gill, 1933; Christopher, 1960). In a
study of *Ae. aegypti* distribution using the program CLIMEX, Khormi & Kumar (2014) set the limiting low temperature at 18 °C, the lower optimal temperature at 25 °C, the upper optimal temperature at 32 °C and the limiting high temperature at 38 °C. Brady et al. (2014) limited their predictions of temperature suitability to areas with a maximum monthly temperature exceeding 13°C for *Ae. albopictus* and 14°C for *Ae. aegypti*. These threshold temperatures were based on previous studies of the observed temperatures below which biting and movement behaviors are impaired [Christophers, 1960; Estrada-Franco & Craig, 1995; Carrington et al. 2013a,b).

Studies suggest that an increase between 14-18 °C and 35-40 °C can lead to higher transmission of dengue (Wallis, 2005). Xiao et al. (2014) found that oral infections of DENV2 did not produce antigens in the salivary glands of *Ae. albopictus* kept at 18°C for up to 25 days but did produce antigens at 21°C during this period. It is not known if *Ae. albopictus* held longer at the lower temperature would have disseminated infections, but Dohm et al. (2002) found that *Culex pipiens* required 25 days at 18°C to disseminate infections of West Nile Virus. For comparison, WNV is capable of replication from 14-45°C (Cornel et al. 1993, Kinney et al. 2006). Tilston et al. (2009) analyzed monthly average temperature of cities that experience chikungunya outbreaks and found that start and finish occurred when average monthly temperatures were 20°C or higher. At the upper temperature limit, Kostyuchenko et al. (2016) found that ZIKAV is more thermally stable than DENV, and is also structurally stable even when incubated at 40°C, mimicking the body temperature of extremely feverish patients after virus infection (but see Goo et al. 2016).

Remotely sensed temperature data is freely available from multiple sources as both near-real time recordings and forecast predictions. Combining remotely sensed temperature data with predicted distributions of the vectors and virus could provide insight into when areas of interest are suitable for transmission and should be actively monitored. Our aim was to produce a knowledge product and surveillance decision tool that makes use of publicly available information about potential distribution and thermal requirements of the vectors and virus at U.S. military facilities.
MATERIALS AND METHODS

Areas of interest

The location and boundary of U.S. military facilities was obtained from the US Census Bureau’s TIGER/Line 2015 shapefile product (http://www.census.gov/geo/maps-data/data/tiger.html). This shapefile lists facilities in the continental United States (CONUS), Alaska, Hawaii, Puerto Rico and Guam. As some facility names comprised multi-part polygons, these were reduced from 804 to 733, to match the number of unique facility names, using the Dissolve tool in ArcMap 10.4 (ESRI, Redmond, CA – used throughout). The centroid of each facility was selected to produce a shapefile of points using the Feature to Point tool (inside polygon option checked) of ArcMap. The georeference of each point was obtained by the Add XY Coordinates tool and joined to the points shapefile. Extraction of all facility centroid raster values was first obtained by the Extract values to points tool then for polygons using the Zonal statistics as Table tool, and the results merged. This approach was needed because smaller polygons would not produce results using the Zonal statistics as Table tool, which necessitated using the raster data associated with the points for these facilities.

Temperature data

To monitor temperature in near real-time, daily time averaged maps of air temperature at the surface (Daytime/Ascending) were downloaded from the Giovanni 4.19 (Released Date: 2016-04-12. Data provided by the NASA Goddard Earth Sciences (GES) Data and Information Services Center (DISC)) data portal at 1° spatial resolution. Daily gridded temperature analyses were also collected from the NOAA, U.S. National Weather Service Climate Prediction Center (CPC). Forecast temperature data was also provided by the CPC and the NOAA National Digital Forecast Database (NDFD) at 5 km spatial resolution. For predictions based on monthly averages, monthly gridded climate data with a spatial resolution of 1 km were downloaded from the WorldClim (Version 1.4) Global Climate Data center.

Habitat suitability models
We chose the models of *Ae. aegypti* and *Ae. albopictus* by Kraemer et al. (2015), as these are recent and are based on an extensively documented set of presence observations for each vector. For this study, we used the habitat suitability model for ZIKAV transmission by Messina et al. (2016). The 0.5 model suitability score was arbitrarily used as the cut-off for presence/absence.

**Thresholds**

Temperatures suitable for activity of *Ae. aegypti* and *Ae. albopictus* combined was estimated as 13 – 38°C, and for ZIKAV this was 18 – 42°C. We acted conservatively by using temperatures at the extremes of the reported suitable temperature range, and maximum rather than mean air temperatures.

**Human population data**

In order to more fully understand the potential impact of ZIKAV risk to military and non-military personnel and their families in and around each facility, we explored risk in terms of human population data, with the following considerations. The flight range of *Ae. aegypti* and *Ae. albopictus* is in the order of hundreds of meters only (Honório et al. 2003, Harrington et al. 2005) and each facility would differ in the average distance that human carriers of ZIKAV would routinely travel to and from each facility. Additionally, some facilities are remote, while others are adjacent to or enclosed within urban and suburban areas. Despite these complications, we created a buffer of 5 km around all facility polygons to capture the human population density according to LandScan 2011 (Oak Ridge National Laboratory). This was accomplished using the LandScan raster and the Buffer and sum output in the Zonal Statistics as Table tools in ArcMap. A buffer of 5 km is a conservative estimate and is meant to give a uniform measure for each facility of the potential host density effected in an outbreak or vector control situation.

**Excel-based Zika risk tool**

A goal of this project was to display disparate data sources visually and in a simple and intuitive way in order to more effectively communicate the level of risk at
each military facility. The risk estimation and alert system needed to be in a format that
was readily understandable and that can be easily accessed by military users, who
often have IT security restrictions or bandwidth caps. We chose MS-Excel® (Microsoft
Corp, Seattle, WA), as a universal platform for performing calculations and reporting
results. This software had the added advantage that the scatterplot function can be
used to map each military facility (Foley, 2011b), with icons displaying various
categories of risk, and using a geocorrected map background (Esri, DeLorme, USGS,
NPS. World Terrain Base - Sources: Esri, USGS, NOAA) for each U.S. State. Other
notable features that were used in the Excel risk estimation tool were the formula
functions, conditional formatting to represent categories of numbers as different types of
symbols, dependent dropdown lists and hyperlinks to allow users to navigate more
quickly to the results of individual facilities, and textualized results that users can read
as statements describing the situation and as guidance for vector surveillance.

**Calculations within the Excel Risk Estimation Tool**

Given the maximum temperature is available for a site (i.e. “Temp.”), the
following lists an example sequence of tasks and their calculations, with explanations
and the Excel formula (in square brackets), culminating in a risk rating:

1. Column A. “Was temperature suitable during period for the vector?”, i.e. if the
   maximum was 13 to 38°C, it is 1 otherwise 0 [ =IF((Temp.>=13)-
   (Temp.>38),1,0)],

2. Column B. “Was temperature suitable during period for virus replication in
   mosquito?”, i.e. if the maximum was 18 to 42°C, it is 1 otherwise 0 [ 
   =IF((Temp.>=18)-(Temp.>42),1,0)]

3. Column C. What is the sum of the thermal suitability values for vector (Column A)
   and virus (Column B)? (i.e. possible choices are: 0, 1 or 2)

4. Column D. If temperature for the vectors (Column A) was within the required
   range, what is the model suitability for vector?, i.e. this was the maximum
   modeled suitability (0 – 1.00) for either *Ae. aegypti* or *Ae. albopictus*
5. Column E. Score vector model suitability as 3 if \( \geq 0.5 \), otherwise 2 \([=IF(Column D<0.5,2,IF(Column D\geq0.5,3))]\). The 0.5 model suitability score was arbitrarily used as the cut-off for presence/absence.

6. Column F. If temperature for the virus (Column B) was within the required range, what is the model suitability for the virus? (0 – 1.00)

7. Column G. Score virus model suitability as 7 if \( \geq 0.5 \), otherwise 5 \([=IF(Column F<0.5,5,IF(Column F\geq0.5,7))]\). The 0.5 model suitability score was arbitrarily used as the cut-off for presence/absence.

8. Column H. What is the “Combined Score” for the interaction of temperature suitability of vector and virus, vector model suitability, and virus model suitability score (i.e. \( C\times E\times G \))? The use of 0, 1 and prime numbers for the component scores produces a unique semi-prime number for the product, i.e. 0, 10 (=1*2*5), 14 (=1*2*7), 15 (=1*3*5), 21 (=1*3*7), 20 (=2*2*5), 28 (=2*2*7), 30 (=2*3*5), or 42 (=2*3*7). A zero indicated that the temperature at the site was unsuitable for both vector and pathogen, so suitability scores were irrelevant, and combination scores were all scored zero.

9. The nine possible Combined Scores were divided into 6 categories based on whether preconditions do not exist for transmission, are unsuitable for transmission, are somewhat suitable for transmission, or are suitable for transmission (Figure 1).

10. Column I. An Overall Zika Risk Code was established based on the Combined Score (Figure 1), and rates conditions as low (Blue: Code 1) to high risk (Red: Code 4). The nine possible Combined Scores are initially divided according to whether temperature conditions are not suitable (Code 1), or suitable, for the vectors and virus (Codes 2 - 4). Codes 2 - 4 are then characterized according to increasing habitat suitability, with Code 4 being where models predict suitable habitat for vectors and virus.

11. Action statements were constructed based on the temperature and habitat model suitability scores (Figure 2). For example, if conditions are too cold for the development of the vectors, and models predict that the location is unsuitable for the vectors then the Action statement would be: “Too cold or hot for vectors -
surveillance unnecessary. When temp. suitable, model suggests vectors unlikely or low numbers.". Alternatively, if conditions are warm enough for the development of the vectors, and models predict that the location is highly suitable for the vectors then the Action statement would be: “Temp. suitable for vectors - surveillance may be needed. When temp. suitable, model suggests vectors likely - may need control, education, and policies minimizing exposure.”

**Figure 1.** An overall Zika Risk Code based on the combined score, which rates conditions from low risk (Blue: Code 1) to high risk (Red: Code 4).
**Figure 2.** Action statements constructed on the basis of the temperature and habitat model suitability scores

| Variable                     | Outcome                                      | Action Statement                                                                 |
|------------------------------|----------------------------------------------|----------------------------------------------------------------------------------|
| Temperature threshold for Zika vectors | Temperature below threshold (≤ 13°C) | Too cold for vectors - surveillance unnecessary.                                |
|                              | Temperature above threshold (≥ 13°C)         | Warm enough for vectors - surveillance may be needed.                             |
| Vector Suitability           | Low vector suitability (≤ 50%)               | When warm enough, model suggests vectors unlikely or low numbers.                |
|                              | High vector suitability (≥ 50%)              | When warm enough, model suggests vectors likely - may need control, education, and policies minimizing exposure. |
| Temperature threshold for Zika virus | Temperature below threshold (≤ 18°C) | Too cold for Zika - surveillance unnecessary.                                    |
|                              | Temperature above threshold (≥ 18°C)         | Warm enough for Zika - surveillance may be needed.                               |
| Zika Suitability             | Low Zika suitability (≤ 50%)                 | When warm enough, model suggests Zika unlikely.                                  |
|                              | High Zika suitability (≥ 50%)                | When warm enough, model suggests Zika likely - may need control, education, and policies minimizing exposure. |
|                              | No data                                      | No Model result for vector suitability.                                          |

**RESULTS**

The Excel files provided comprise 12 monthly files based on average monthly maximum temperatures (suitable for longer term planning), and near real-time and forecast file, updated weekly. These files are freely available via the VectorMap website (http://vectormap.si.edu/Project_ESWG_ExcelZika.htm). The tool provides risk maps of facilities as a continental overview (Figure 3), and on a U.S. State basis (Figure 4). Results for individual facilities are navigable via dropdown menus and hyperlinks (Figure 5). State-wide summary data of risk profile and humans potentially impacted is given in Figure 6. The temporal changes in average risk based on the 12 monthly files is given in Figure 7 in terms of the number of facilities affected (of 733) and the number of people within 5 km of these facilities. April to October was the period of greatest risk with suitable conditions for Zika transmission (i.e. code 4) potentially affecting a maximum of 114 facilities in 12 states and territories, and 4,546,505 people within the vicinity of these facilities, of a total of 32,811,618 within the vicinity of all 733 facilities. The maximum number of facilities recording code 4 in any one month (e.g. August) were: Florida (36), Hawaii (16), Louisiana (12), Texas (11), and Virginia (11). Of these, the number of people within 5 km of these facilities were: Texas (1,215,230), Florida (1,125,032), Louisiana (462,586), Virginia (409,066), and Hawaii (247,918).
These data may assist public health planning, and can be seen as an indicator of potential disease burden, or of people potentially benefiting from a well-informed vector surveillance and control program conducted within military facilities. Results are provided in a variety of symbologies and as textualized statements of how the factors examined may impact ZIKAV transmissions, and recommended actions for entomologists conducting routine vector surveillance. The action statement textualizes the data and is designed to assist a preparedness posture particularly around vector surveillance and control. Changes in the action statement over the year, for example as a result of rising temperature, can be used as a guide to affect changes in vector surveillance and control activities at particular facilities.

**Figure 3.** Average maximum temperature conditions for January for vectors and ZIKAV at military facilities within the lower 48 states of the U.S.
Figure 4. Thermal conditions for January (above) and August (below) for vectors and ZIKAV at military facilities in California. Note, unsuitable conditions in August in the south are due to temperatures being too high for the vectors.
Figure 5. An overall Zika virus risk code for near real-time and forecast periods (A) is assigned based on a combination of: temperature suitability for adult activity of the vectors (\textit{Ae. aegypti} and \textit{Ae. albopictus}) (B), modeled habitat suitability of the vectors (C), temperature suitability for Zika virus replication within the vectors (D), and modeled habitat suitability of Zika virus transmission (E). If suitable conditions exist (Zika Risk Code 4), the number of people within 5 km is shown (F) as one indication of the number of potential hosts in the vicinity, or the number of humans potentially benefiting from facility-wide vector surveillance and control programs.
Figure 6. Summary risk data for each U.S. State to assist with public health and resource allocation planning.
DISCUSSION

This Excel tool is designed to provide insights into ZIKAV transmission potential at U.S. military facilities, but could be applied to other arboviruses and situations, such as cities (Monaghan et al. 2016), tire dumps or parks. The spreadsheet is flexible in that vector and virus suitability model scores, temperature limits, and the wording of action statements can be replaced depending on the context, and as new information comes to light.

For U.S. military situations, this tool could be used in conjunction with the Electronic Surveillance System for the Early Notification of Community-based Epidemics (ESSENCE) or Medical Situational Awareness in Theater (MSAT), which
reports on febrile illnesses and rash in the military population. Coordination of result
reporting through the Armed Forces Pest Management Board (AFPMB) and VectorMap
may also be desirable. The Navy and Marine Corps Public Health Center’s guide
(NMCPHC, 2016) states that “each installation’s medical personnel should conduct
ongoing *Aedes* surveillance during the mosquito season appropriate to their region and
take preventive and responsive action to reduce disease risk to active duty, government
employees, and family member populations”. In addition, the DoD instruction
OPNAVINST 6250.4C “requires all Navy and Marine Corps installations to have an
Emergency Vector Control Plan (EVCP) for disease vector surveillance and control
during disease outbreaks”. The spreadsheet described in this study should complement
“installation pest management plans, including the EVCP, as a way to assess the risk of
vector borne diseases, and implement strategies to reduce the risk to personnel
assigned to installations” (NMCPHC, 2016).

Knowing when conditions are suitable for vectors is crucial for monitoring the
success or failure of any control program. Appendix C of NMCPHC (2016) consists of a
chart to determine the risk of infection on an installation and when to apply vector
control measures. This four level vector threat response plan relies on information about
vector abundance and reports of disease transmission. We see the Excel spreadsheet
risk tool as a valuable adjunct to the NMCPHC plan, as it would assist with defining the
length of the mosquito season, and the judicious deployment and timing of
entomological resources. Each military facility is unique, and varies in size, function,
human density, and suitable mosquito habitat, so not all of the 733 facilities addressed
in this study will be at risk of mosquito-borne disease and suitable candidates for
mosquito surveillance. However, all locations, at worst, should be useful as a point of
reference for other nearby locations where mosquito surveillance is conducted.

The Zika Risk Code developed here (Figure 1) derived some inspiration from
Figure 3 of Fischer et al. (2013), who combined models of vector habitat suitability with
temperature categories for CHIKV replication to produce a matrix of climate related risk
classes.
It is important to note that each data source used in this analysis has the potential for errors which should be considered when determining risk. For example, habitat suitability models for each vector may not be accurate for all areas, and only predict average yearly suitability. Temperature data refers to the maximum day-time air temperature near the surface (averaged over various spatial resolutions) from daily data for a recent date range, which NASA acknowledges has limitations. Vectors can also seek microclimates (e.g. indoors, subterranean habitats) that may be warmer or cooler than the outside temperature that is estimated by remote sensing data. Temperatures within the suitable range may not effect organisms uniformly. According to Westbrook et al. (2010) adult females reared from immature stages at 18°C, were six times more likely to be infected with CHIKV than females reared at 32°C. Westbrook et al. (2010) noted that climate factors, such as temperature, experienced at the larval stage, which would not be detected by adult trapping programs, can influence the competence of adult females to vector arboviruses.

We also do not account for temperature fluctuations; according to Lambrechts et al. (2011), mosquitoes lived longer and were more likely to become infected with DENV under moderate temperature fluctuations, than under large temperature fluctuations. Thangamani et al. (2016) and Ferreira-de-Brito et al. (2016) found that ZIKAV can be vertically transmitted in *Ae. aegypti* but not *Ae. albopictus*. This capability suggests mechanisms for the virus to survive in eggs that can survive for months in a dried dormant state during adverse conditions, e.g. a harsh winter that would normally kill adults.

The risk levels calculated in the spreadsheets deliberately uses simplified assumptions about temperature and does not consider precipitation, interspecific competition, anthropogenic factors such as imported cases, built-up areas, vegetation indices, and economic indices that can modify risk in complex and less understood ways. It is recommended that a level of caution be taken when interpreting the data provided by this system. It is wise to monitor activity in surrounding facilities and any reputable information from other sources before acting on any recommendations given here. It is further recommended that the near-real time and forecast analysis should be
viewed in conjunction with the monthly average Excel vector hazard files which uses average monthly maximum temperature, to gain further longer term insights into where thermal conditions will support vector activity.

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REFERENCES

Attaway DF, Waters NM, Geraghty EM, Jacobsen KH. 2016. Zika virus: Endemic and epidemic ranges of Aedes mosquito transmission. J Infect Public Health. pii: S1876-0341(16)30147-2. doi: 10.1016/j.jiph.2016.09.008. [Epub ahead of print]

Bliss AR, Gill JM, 1933. The effects of freezing on the larvae of Aedes aegypti. Am J Trop Med Hyg 13, 583-588

Brady O.J., Johansson M.A., Guerra C.A., Bhatt S., Golding N., Pigott D.M., Delatte H., Grech M.G., Leisnham P.T., Maciel-de-Freitas R., Styer L.M., Smith D.L., Scott T.W., Gething P.W., Hay S.I. 2013. Modelling adult Aedes aegypti and Aedes
albopictus survival at different temperatures in laboratory and field settings.

Parasites & Vectors, 6, 351

Brady OJ, Golding N, Pigott DM, Kraemer MU, Messina JP, Reiner RC Jr, Scott TW, Smith DL, Gething PW, Hay SI. Global temperature constraints on Aedes aegypti and Ae. albopictus persistence and competence for dengue virus transmission. Parasit Vectors. 2014 Jul 22;7:338. PubMed PMID:25052008.

Braks M.A., Honório N.A., Lourenço-De-Oliveira R., Juliano S.A., Lounibos L.P. 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 L.P., Luther C., Moo-Llanes D., Ramsey J.M., Danis-Lozano R., Peterson A.T. 2015. Climate Change Influences on Global Vector Distributions for Dengue and Chikungunya Viruses. Philosophical Transactions of the Royal Society B, 5;370(1665). pii: 20140135. doi: 10.1098/rstb.2014.0135.

Carlson CJ, Dougherty ER, Getz W. 2016. An Ecological Assessment of the Pandemic Threat of Zika Virus. PLoS Negl Trop Dis. 10(8):e0004968. doi: 10.1371/journal.pntd.0004968. eCollection 2016.

Carrington L.B., Armijos M.V., Lambrechts L., Barker C.M., Scott T.W. 2013a. Effects of Fluctuating Daily Temperatures at Critical Thermal Extremes on Aedes aegypti Life-history traits. PLoS One 8(3):e58824.

Carrington L.B., Seifert S.N., Willits N.H., Lambrechts L., Scott T.W. 2013b. Large Diurnal Temperature Fluctuations Negatively Influence Aedes aegypti (Diptera: Culicidae) Life-History traits. Journal of Medical Entomology, 50(1):43–51

Christophers SR, 1960. Aedes aegypti (L.) the yellow fever mosquito. Its life history, bionomics and structure. Cambridge: Cambridge University Press

Connor ME, 1924. Suggestions for developing a campaign to control yellow fever. Am J Trop Med 4, 277-307

Cornel AJ, Jupp PG, Blackburn NK. 1993. Environmental temperature on the vector competence of Culex Univittatus (Diptera: Culicidae) for West Nile Virus. J. Med. Entomol. 30, 449–456.
Council of State and Territorial Epidemiologists (2016). Zika virus disease and
congenital Zika virus infection interim case definition and addition to the Nationally
Notifiable Disease List. Atlanta, GA.
https://www.cste2.org/docs/Zika_Virus_Disease_and_Congenital_Zika_Virus_Infecti
on_Interim.pdf

Couret, J. & Benedict, M.Q. 2014. A Meta-Analysis of the Factors Influencing
Development Rate Variation in Aedes aegypti (Diptera: Culicidae). BMC Ecology.
14:3 DOI: 10.1186/1472-6785-14-3

Dohm DJ, O'Guinn ML, Turell MJ. 2002. Effect of environmental temperature on the
ability of Culex pipiens (Diptera: Culicidae) to transmit West Nile Virus. J. Med.
Entomol. 39, 221–225.

Estrada-Franco J.G., Craig G.B. 1995. Biology, Disease Relationships, and Control of
Aedes albopictus. Washington DC: Pan American Health Organization

Ferreira-de-Brito A, Ribeiro IP, Miranda RM, Fernandes RS, Campos SS, Silva KA,
Castro MG, Bonaldo MC, Brasil P, Lourenço-de-Oliveira R. 2016. First detection of
natural infection of Aedes aegypti with Zika virus in Brazil and throughout South
America. Mem Inst Oswaldo Cruz. doi: 10.1590/0074-02760160332. [Epub ahead of
print]

Fischer D., Thomas S.M., Suk, J.E., Sudre, B., Hess, A., Tjaden, N.B., Beierkuhnlein, C.
& Semenza, J.C. 2013. Climate Change Effects on Chikungunya Transmission in
Europe: Geospatial Analysis of Vector’s Climatic Suitability and Virus’ Temperature
Requirements. Int. J. Hlth Geog. 12:51

Foley D.H., F.A. Maloney Jr, F.J. Harrison, R.C. Wilkerson, L.M. Rueda. 2011a. Online
spatial database of USAPHCR-W mosquito surveillance records for 1947-2009. J.
AMEDD. July-Sept 2011: 29-36

Foley D.H. (2011b). A spreadsheet mapping approach for error checking and sharing
collection point data. Biodiversity Informatics.7 (3): 137-142

Goo L, Dowd KA, Smith AR, Pelc RS, DeMaso CR, Pierson TC. 2016. Zika virus is not
uniquely stable at physiological temperatures compared to other flaviviruses. MBio.
2016 Sep 6;7(5). pii: e01396-16. doi: 10.1128/mBio.01396-16.
Grard, G., Caron, M., Mombo, I. M., Nkoghe, D., Ondo, S. M., Jiolle, D., ... & Leroy, E. M. (2014). Zika virus in Gabon (Central Africa)–2007: a new threat from Aedes albopictus?. PLoS Negl Trop Dis, 8 (2), e2681

Gubler DJ, Kuno G, Markoff L. 2007. Flaviviruses, Chapter 34, pp 1153-1252. In Fields Virology Vol. 1, 5th Ed (Eds Knipe DM, Howley PM, Griffin DE, Lamb RA, Straus SE, Martin MA, Roizman B), Lippincott Williams & Wilkins, Philadelphia, PA.

Guerbois M, Fernandez-Salas I, Azar SR, Danis-Lozano R, Alpuche-Aranda CM, Leal G, Garcia-Malo IR, Diaz-Gonzalez EE, Casas-Martinez M, Rossi SL, Del Rio-Galván SL, Sanchez-Casas RM, Roundy CM, Wood TG, Widen SG, Vasilakis N, Weaver SC. 2016. Outbreak of Zika virus infection, Chiapas State, Mexico, 2015, and first confirmed transmission by Aedes aegypti mosquitoes in the Americas. J Infect Dis 2016. doi:10.1093/infdis/jiw302

Harrington LC, Scott TW, Lerdthusnee K, Coleman RC, Costero A, Clark GG, Jones JJ, Kitthawee S, Kittayapong P, Sithiprasasna R, Edman JD. 2005. Dispersal of the dengue vector Aedes aegypti within and between rural communities. Am J Trop Med Hyg. 72:209-20.

Honório, Nildimar; Alves, Silva; Wellington da Costa, Leite; Paulo José, Gonçalves; Jaylei Monteiro; Lounibos, Leon Philip & Lourenço-de-Oliveira, Ricardo. 2003. Dispersal of Aedes aegypti and Aedes albopictus (Diptera: Culicidae) in an Urban Endemic Dengue Area in the State of Rio de Janeiro, Brazil. Memórias do Instituto Oswaldo Cruz, 98(2), 191-198 https://dx.doi.org/10.1590/S0074-02762003000200005

Khormi HM, Kumar L, Elzahrany R, 2011. Describing and analyzing the association between meteorological variables and adult Aedes aegypti mosquitoes. J Food Agr Environ 9, 954-959

Khormi, H.M. & Kumar, L. (2014). Climate change and the potential global distribution of Aedes aegypti: spatial modelling using geographical information system and CLIMEX. Geospatial Health 8(2), 2014, pp. 405-415

Kime P. (2016). Zika threat hits home: Which U.S. military hubs are most at risk? Military Times. April 10, 2016.
http://www.militarytimes.com/story/military/2016/04/10/zika-threat-hits-home-which-us-military-hubs-most-risk/82664202/

Kinney RM, Huang CY, Whitean MC, Bowen RA, Langevin SA, Miller BR, Brault AC. 2006. Avian virulence and thermostable replication of the North American strain of West Nile Virus. J. Gen. Virol. 87, 3611–3622.

Kostyuchenko Victor A., Lim Elisa X. Y., Zhang Shujun, Fibriansah Guntur, Ng Thiam-Seng, Ooi Justin S. G., Shi Jian & Lok Shee-Mei. 2016. Structure of the Thermally Stable Zika Virus. Nature, 533. doi:10.1038/nature17994

Kramer LD, Ebel GD. 2003. Dynamics of flavivirus infection in mosquitoes. Adv Virus Res. 60: 187-232

Kraemer MU, Sinka ME, Duda KA, Mylne AQ, Shearer FM, Barker CM, Moore CG, Carvalho RG, Coelho GE, Van Borrel W, Hendrickx G, Schaffner F, Elyazar IR, Teng HJ, Brady OJ, Messina JP, Pigott DM, Scott TW, Smith DL, Wint GR, Golding N, Hay SI. 2015. The global distribution of the arbovirus vectors Aedes aegypti and Ae. albopictus. eLife 2015;4:e08347

Lambrechts Louis, Paaijmans Krijn P., Fansiri Thanyalak, Carrington Lauren B., Kramer Laura D., Thomas Matthew B., and Scott Thomas W. 2011. Impact of Daily Temperature Fluctuations on Dengue Virus Transmission by Aedes aegypti. Proc Natl Acad Sci USA. 108(18): 7460–7465

Macfie JWS, 1920. Heat and Stegomyia fasciata, short exposures to raised temperatures. Ann Trop Med Parasitol 14, 73- 82

Medley K.A. 2010. Niche shifts during the global invasion of the Asian tiger mosquito, Aedes albopictus Skuse (Culicidae), revealed by reciprocal distribution models. Global Ecology and Biogeography, 19, 122-133

Messina JP, Kraemer MU, Brady OJ, Pigott DM, Shearer FM, Weiss DJ, Golding N, Ruktanonchai CW, Gething PW, Cohn E, Brownstein JS, Khan K, Tatem AJ, Jaenisch T, Murray CJ, Marinho F, Scott TW, Hay SI. 2016. Mapping global environmental suitability for Zika virus. Elife. 2016 Apr 19;5. pii: e15272. doi: 10.7554/eLife.15272.

Likos A, Griffin I, Bingham AM, Stanek D, Fischer M, White S, Hamilton J, Eisenstein L, Atrubin D, Mulay P, Scott B, Jenkins P, Fernandez D, Rico E, Gillis L, Jean R, Cone
M, Blackmore C, McAllister J, Vasquez C, Rivera L, Philip C. 2016. Local Mosquito-Borne Transmission of Zika Virus — Miami-Dade and Broward Counties, Florida, June–August 2016. MMWR. 65 (38): 1032-1038.

Monaghan AJ, Morin CW, Steinhoff DF, Wilhelmi O, Hayden M, Quattrochi DA, Reiskind M, Lloyd AL, Smith K, Schmidt CA, Scaife PE, Ernst K. On the Seasonal Occurrence and Abundance of the Zika Virus Vector Mosquito Aedes Aegypti in the Contiguous United States. PLOS Currents Outbreaks. 2016 Mar 16 . Edition 1. doi: 10.1371/currents.outbreaks.50dfc7f46798675fc63e7d7da563da76

NMCPHC, 2016. NMCPHC Aedes Surveillance Control for NMC Installations. Navy and Marine Corps Public Health Center, Document ID: HVW2YZZCCH7A-3-5489. Version: 1.0 Created at 2/23/2016 by GIBBS.JOE.JR.1060655916. http://www.med.navy.mil/sites/nmcphc/Documents/program-and-policy-support/NMCPHC-Aedes-Surveillance-Contro-for-NMC-Installations.pdf

Pellerin C. 2016. DoD adds funding to enhance Zika surveillance by military labs. DoD News, Defense Media Activity. http://www.defense.gov/News/Article/Article/760169/dod-adds-funding-to-enhance-zika-surveillance-by-military-labs

Perkins TA, Siraj AS, Ruktanonchai CW, Kraemer MU, Tatem AJ. 2016. Model-based projections of Zika virus infections in childbearing women in the Americas. Nat Microbiol. 1(9):16126. doi: 10.1038/nmicrobiol.2016.126.

Samy AM, Thomas SM, Wahed AA, Cohoon KP, Peterson AT. 2016. Mapping the global geographic potential of Zika virus spread. Mem Inst Oswaldo Cruz. 111(9):559-60. doi: 10.1590/0074-02760160149.

Scott T.W., Amerasinghe P.H., Morrison A.C., Lorenz L.H., Clark G.G., Strickman D., Kittayapong P., Edman J.D. 2000. Longitudinal Studies of Aedes aegypti (Diptera: Culicidae) in Thailand and Puerto Rico: Blood Feeding Frequency. Journal of Medical Entomology. 37(1):89–101

Scott T.W., Clark G.G., Amerasinghe P.H., Lorenz L.H., Reiter P., Edman J.D. 1993. Detection of Multiple Blood Feeding Patterns in Aedes aegypti (Diptera: Culicidae) During a Single Gonotrophic Cycle Using a Histological Technique. Journal of Medical Entomology. 30:94–99
Thangamani S, Huang J, Hart CE, Guzman H, Tesh RB. 2016. Vertical transmission of Zika virus in Aedes aegypti mosquitoes. Am J Trop Med Hyg. pii: 16-0448. [Epub ahead of print]

Tilston N., Skelly C., Weinstein P. 2009. Pan-European Chikungunya Surveillance: Designing Risk Stratified Surveillance Zones. International Journal of Health Geographics. 8:61

Tsuda Y, Suwonkerd W, Chawprom S, Prajakwong S, Takagi M. 2006. Different Spatial Distribution of Aedes aegypti and Aedes albopictus Along an Urban-Rural Gradient and the Relating Environmental Factors Examined in Three Villages in Northern Thailand. Journal of the American Mosquito Control Association. 22(2):222–228

Walker WL, Lindsey NP, Lehman JA, Krow-Lucal ER, Rabe IB, Hills SL, Martin SW, Fischer M, Staples JE. 2016. Zika Virus Disease Cases — 50 States and the District of Columbia, January 1–July 31, 2016. MMWR Early Release (http://www.cdc.gov/mmwr)

Wallis RC, 2005. A GIS model for predicting potential "high risk" areas of West Nile virus by identifying ideal mosquito breeding habitats. MSc thesis, Environmental Science, Mississippi State University

Wayne AR, Graham CL, 1968. The effect of temperature and relative humidity on the flight performance of female Aedes aegypti. J Insect Physiol, 14, 1251-1257

Westbrook Catherine J., Reiskind Michael H., Pesko Kendra N., Greene Krystle E., and Lounibos Philip L. 2010. Larval Environmental Temperature and the Susceptibility of Aedes albopictus Skuse (Diptera: Culicidae) to Chikungunya Virus. Vector-Borne and Zoonotic Diseases. 10 (3): 241-247

Xiao F.Z., Zhang Y., Deng Y.Q., He S., Xie H.G. 2014. The Effect of Temperature on the Extrinsic Incubation Period and Infection Rate of Dengue Virus Serotype 2 Infection in Aedes albopictus. Arch Virol 159: 3053–3057. doi: 10.1007/s00705-014-2051-1 PMID: 24990415