Climate Change and Emerging Infectious Diseases: What the 2015 Zika Outbreak and El Niño Imply for Diseases Around the World

**Abstract:**

Human activities have emitted enough CO2 to increase global temperatures for over a century. This warming has altered diverse ecosystems across the planet and has also affected the emergence of infectious diseases (EIDs). Although the significance of climatic change on EIDs is debated, recent methods and studies emphasize the importance of monitoring climate systems as a protective preventative health measure. This paper examines over thirty years of research connecting mosquito-borne diseases, including Zika, dengue, and Ross River Virus to various weather events, including the semi-annual El Niño.

Since 1990, the Intergovernmental Panel on Climate Change (IPCC) has published reports summarizing climate change research, including analyses associated with EIDs. Initially, the effect of climate change on EIDs was largely speculative; accurate modeling technology was limited, model outputs varied widely, and attributing outcomes to different weather events was difficult; untangling direct and secondary effects of climate change on disease proved further challenging (IPCC, 1995).

The majority of research on climate-disease linkages has concerned vector-borne pathogens. In 1996, a landmark review, completed by Patz et al., charted climate change’s influence on EIDs and argued that mosquito-borne infections were the most sensitive of all diseases to rising global temperatures. Patz et al., (1996) supported their conclusion by citing climate change’s ability to increase mosquitoes’ geographic range and reproductive and feeding frequencies, and to shorten the Extrinsic Incubation Period (EIP). EIP refers to the number of days between a mosquitoes’ ingestion of an infectious blood meal and when it is capable of transmitting the infectious disease. When EIP shortens, the likelihood that a mosquito bite will transmit an infection is greater, thus improving the vector’s efficiency. Furthermore, warmer temperatures reduce the size of adult mosquitoes, requiring females to bite more frequently to supply a sufficient blood meal to their offspring. These two outcomes combine to suggest that a rise in global temperatures will expand both the range of mosquito vectors and the frequency of bites (Patz, 1996).

By the IPCC’s third report in 2001, discussions about the significance of climate change on EIDs demonstrated the highly controversial nature of the topic. Although this IPCC report from 2001 cited improvements in predictive modeling of climate-associated changes to vector borne diseases (IPCC, 2001), a review article published the same year contested the validity of such models (Reiter, 2001). To come to this conclusion, Reiter (2001) analyzed cases of historical disease outbreaks for correlations to a plethora of determining factors, including population, urbanization, and rainfall, and consequently concluded that climate has rarely been the principle determining factor in the range or occurrence of vector diseases such as malaria, dengue, and yellow fever. Instead of climate factors, Reiter (2001) identifies political and economic factors as well as changes in human behavior as principle contributors to EIDs. Still others argued in favor of a direct relationship between climate change and vector distribution. A widely cited study completed by Jones (2008), which surveyed 335 EIDs since the 1940s, connected vector-borne diseases to climate anomalies of the 1990s, supporting the connection between climate and this category of infectious disease.

Despite continued debates, there was significant improvement in climate change research between 2000 and 2010. More sophisticated mapping was achieved by correlating the daily and seasonal changes in weather to specific vector observances (IPCC, 2001). The knowledge associated with long-term trends, however, remained minimal. Factors that determine the spread of disease are complex, and it can be difficult to assess accurate results when confounding contributions are an ever-present consideration.

Acknowledging these difficulties, further improvements have been made and, for the first time, longitudinal morbidity data sets have been collected and studied alongside meteorological data with the aim of producing more successful vector modeling. Other studies have also focused on the interdependent link between climate, socioeconomic conditions and human health (IPCC 2014). Although the current IPCC reports still highlight vector alternations as a result of changing climate, the reports also recognize alternative causes, like those from Reiter (2001), as drivers of disease emergence.

The *Aedes* genus transmits most mosquito vectored diseases affected by climate change. A 2018 study, completed by Ryan et al., observed the effects of climate change on two specific disease vectors, *Ae. Aegypti* and *Ae. Albopictus*, in relation to the specific thermal interval within which pathogen transmission was possible. Their model of transmission by these two vectors was used to predict the risk of disease spread in current climates and explore predicted risks to best-case and worst-case future scenarios of climate change. Using this model, it was concluded that if climate change follows a worst-case scenario, as established by general circulation models, there would be an increase in both the range and population size of *Ae. Aegypti*. Conversely, a decrease in range and population would be expected for *Ae. Albopictus*, as it survives more optimally in intermediate climates. Both of these vectors are associated with the spread of dengue and Zika; changes in their distribution could have potent effects on the delivery of the diseases they transmit around the world. This being said, it is imperative to note that climate change will inevitably affect individual ecosystems differently. In a 2014 paper, Estrada-Penā et al., emphasized the importance of individualized frameworks to combine every driver of pathogen transmission to humans. While the specific impact of climate change on vectors has been debated, the effect of human activities on global temperatures has been maintained and possible repercussions associated with EIDs cannot be ignored.

Some of these repercussions have occurred already. In 2015, the first case of locally acquired Zika virus was confirmed in Brazil, and a public health emergency was declared in February 2016. That national emergency has since been lifted, but the Zika virus and its effects on the people of Brazil remain. Perhaps the largest consequence induced by Zika virus is microcephaly, a common complication of Congenital Zika Syndrome (CZS) in which a child is born with a head circumference about a third of the normal size.

Though mosquitoes are nothing new to Brazil, the birth defects associated with them are. Before 2015, Zika was thought to be a minor disease, persisting asymptomatically in 80% of cases and causing flu-like symptoms or occasionally a rash in others. Microcephaly was only recently associated with the virus (Calvet et. al, 2016), which can cause serious problems in diagnosis, as Zika is symptomatically similar to many other diseases, including dengue and Chikungunya, which are also transmitted from the *Ae. Aegypti* and *Ae. Albopictus* mosquitoes.

Microcephaly can cause delayed neurological progression, seizures, breathing problems, trouble seeing, and restricted body movement (CZS, 2019). Zika’s effects on newborns have been recorded, but possible adult complications remain unknown. Perhaps more disturbing, about 20% of children born with CZS will be born with a normal head circumference, but these children will still experience delays in development and will sustain brain damage. In this case, their normal head size may be a burden rather than a benefit, as caregivers may find it difficult to isolate the issue of CZS when their child lacks clear physical presentations of the syndrome.

While there are facilities in Brazil which offer specialized care for children born with microcephaly, some infants are beyond a physician’s care (Belluck and Franco, 2017). Developmental delays in these cases are classified as too severe to justify a center’s continued support. Children in this state require constant intervention, which can include the maintained delivery of expensive seizure prevention medication, regular attention to the child’s development, continuous tracking of the child’s eye movement and observation of the progression of their sense of touch.

Even if parents are unable to support a child with CZS, there is often no choice in the matter. Brazil has very strict laws concerning abortion; only women whose lives are at risk from pregnancy or whose child is the result of rape may terminate their pregnancy. If these women choose not to abort, they are left to deliver a child they know will require extreme and constant care to survive. It is because CZS increases the risk of pregnancy and that women have avoided or delayed pregnancy that a lower than average birth rate in Brazil followed the epidemic (Castro et. al, 2018). Though in the past there was a lack of evidence to support a link between CZS and stillbirth, a recent study, completed by Dudley et al., (2018) observed greater miscarriages in ZIKV infected nonhuman primates compared to controls, which could mean that stillbirth in humans as a result of CZS may be more frequent than originally anticipated. This could have consequences for the political and economic climates of Brazil in the near future, all resulting, indirectly, from climate change.

After the increase in incidence of microcephaly and CZS, researchers have attempted to develop accurate animal models to predict disease sequelae of CZS in adulthood. One study, completed by Cui et al., (2017), raised congenitally ZIKV-infected mice into puberty and evaluated their motor and visual capabilities in comparison with a control group to assess the possible public health burden of CZS into adulthood. From this experiment, most of the infected mice survived into adulthood, but sustained deficits in the retina, which contributed to visual impairments. The adult mice tested also showed severely limited motor abilities, observed from gait analysis. These developments could be predictive of the disease sequelae for children born in Brazil with CZS and they support the idea that Zika targets congenital neural progenitor cells (Cui et al., 2017).

Though media coverage of the Zika epidemic has fallen since the public health emergency ended, the virus is still present in Brazil, and could be expanding its endemic range. In 2016, Zika was limited to the northern portions of Brazil, as the *Ae. aegypti* mosquito largely prefers warmer climates. With climate change and increasing temperatures, *Ae. aegypti* is expected to expand its range to include São Paulo, the country’s biggest city, and thus put another 18 million people at risk for Zika and its associated diseases (Jacobs, 2019).

Though the dramatic outbreak in Zika may seem to have come unexpectedly, the 2015 epidemic of Zika in Brazil is associated with another phenomenon of that year: El Niño. El Niño is an irregular semi-annual weather event characterized by unusually warm, low nutrient ocean water. The warm water affects high altitude winds which can cause unusual patterns of precipitation across the land masses around it. In Brazil specifically, the 2015 El Niño was historic in terms of the drought it triggered. Perhaps counterintuitively, drought can increase populations of some mosquitoes, including *Ae. Aegypti*, as they reproduce in containers of water stored on people’s properties and, in droughts, people are more likely to collect and store water (Pontes et al., 2000).

 Recently, researchers have begun to analyze changes in the manifestation of El Niño as a result of climate change. There has been a catalogued shift of El Niño patterns moving from warm sea surface temperatures (SSTs) in the Eastern Pacific to the Central Pacific. Analysis and future predictions of El Niño events indicate that with increasing greenhouse gases, the ratio of CP-El Niño to EP-El Niño will continue to diverge (Di Lorenzo et al., 2010). This could therefore more intensely affect weather around the world and, as Yeh et al. (2009) concluded, specifically lead to an increase in drought in India and Australia. Analysis of El Niño events further suggests that variability in the Pacific tropics contributes to low-frequency climate shifts, making future global warming scenarios unpredictable.

 These expected alterations in El Niño could have serious effects on arbovirus disease spread in many world regions. Similar to Zika, dengue is an arbovirus distributed primarily by the *Ae. aegypti* mosquito. Researchers have already made connections between the semi-annual El Niño and dengue epidemics around the world. One study completed by Tipayamongkholgul et al., in 2009, observed the effects of the El Niño-Southern Oscillation (ENSO), which includes the phenomena of El Niño, La Niña, and a neutral phase between the two, on dengue epidemics in Thailand between 1996-2005. The paper concluded that the strength of the El Niño consistently preceded dengue outbreaks and therefore considered El Niño a primary driving force for dengue spread. A similar study, completed in 2018 by Vincenti-Gonzalez et al., correlated dengue incidence across Venezuelan cities to climate factors such as rainfall, temperature and SST. There was a common correspondence of peak dengue cases to peak temperature anomalies, including those caused by ENSO, indicating that ENSO heightens the number of dengue cases by causing warmer local temperatures and lower levels of precipitation, further supporting the aforementioned drought hypothesis. If patterns of ENSO are changing, or becoming more intense due to human activities, dengue incidence for the populations of Thailand and Venezuela could increase.

 Ross River Virus (RRV) is another arbovirus which may be affected by El Niño. Unlike dengue and Zika, RRV is mainly endemic in Australia and is associated with the *Aedes vigilax* and *Aedes notoscriptus* mosquito species (Queensland Health). RRV is known to cause temporary rash and fever with lasting joint pain, which will occur three to eleven days after a bite from an infectious mosquito. Similar to Zika in Brazil and dengue in Venezuela and Thailand, there have been numerous studies connecting the spread of RRV in Australia to climate change and ENSO. The occurrence of ENSO has been proposed as an accurate model to evaluate potential outbreaks of RRV (Woodruff, 2002; Maelzer, 1999). This evidence correlating ENSO to RRV spread, along with data obtained from investigations of Zika and Dengue, combine to suggest that the effects of El Niño are associated with greater disease outbreaks around the world. While the effects are globally distributed, most of the increasing disease trouble is placed on countries already struggling with other health burdens, including those resulting from other adverse climate effects, such as food loss and increased drought, leaving them less than equipped to face this additional health disparity.

Over the past several decades, there has been more and more research investigating the effects of human activities on climate change. Though primary consequences such as ice-melting and sea level rise are important to recognize, there are many secondary outcomes which are too often ignored by world leaders and unrecognized by the general public. Investigators have associated many connections between climate variation and disease exposure, specifically in the context of the semi-annual El Niño. It is hypothesized that El Niño, known to increase local temperatures and drought occurrence, is capable of increasing mosquito population and disease spread. The case studies of Zika, dengue, and Ross River Virus combine to suggest that variable weather, almost certainly caused by human activity, is closely associated with greater disease transmission around the world. Though these cases are very similar, each case further emphasizes the need for greater focus on local conditions and culture to combat the threat of climate change. Though disease spread may not be primarily associated with climate variability, it is an essential consequence of fluctuating weather, and deserves appropriate care and policy to prevent future EIDs, which themselves have dire consequences for the human population.

References

Belluck, P., & Franco, T. (2017). For Brazil’s Zika families, a life of struggle and scares. *The New York Times*.

Calvet, G., Aguiar, R. S., Melo, A. S., Sampaio, S. A., De Filippis, I., Fabri, A., ... & Tschoeke, D. A. (2016). Detection and sequencing of Zika virus from amniotic fluid of fetuses with microcephaly in Brazil: a case study. *The Lancet infectious diseases*, *16*(6), 653-660.

Castro, M. C., Han, Q. C., Carvalho, L. R., Victora, C. G., & França, G. V. (2018). Implications of Zika virus and congenital Zika syndrome for the number of live births in Brazil. *Proceedings of the National Academy of Sciences*, *115*(24), 6177-6182.

Congenital Zika Syndrome & Other Birth Defects. (2019, May 8). Retrieved from <https://www.cdc.gov/pregnancy/zika/testing-follow-up/zika-syndrome-birth-defects.html>.

Cui, L., Zou, P., Chen, E., Yao, H., Zheng, H., Wang, Q., ... & Zhang, J. (2017). Visual and motor deficits in grown-up mice with congenital Zika virus infection. *EBioMedicine*, *20*, 193-201.

Di Lorenzo, E., Cobb, K. M., Furtado, J. C., Schneider, N., Anderson, B. T., Bracco, A., ... & Vimont, D. J. (2010). Central pacific El Nino and decadal climate change in the North Pacific Ocean. *Nature Geoscience*, *3*(11), 762.

Dudley, D. M., Van Rompay, K. K., Coffey, L. L., Ardeshir, A., Keesler, R. I., Bliss-Moreau, E., ... & Pecoraro, H. L. (2018). Miscarriage and stillbirth following maternal Zika virus infection in nonhuman primates. *Nature medicine*, *24*(8), 1104.

Estrada-Peña, A., Ostfeld, R. S., Peterson, A. T., Poulin, R., & de la Fuente, J. (2014). Effects of environmental change on zoonotic disease risk: an ecological primer. *Trends in parasitology*, *30*(4), 205-214.

Field, C. B. (Ed.). (2014). *Climate change 2014–Impacts, adaptation and vulnerability: Regional aspects*. Cambridge University Press.

Jacobs, A. (2019). The Zika Virus is Still a Threat. Here’s What the Experts Know. *The New York Times*.

Jones, K. E., Patel, N. G., Levy, M. A., Storeygard, A., Balk, D., Gittleman, J. L., & Daszak, P. (2008). Global trends in emerging infectious diseases. *Nature*, *451*(7181), 990.

Maelzer, D., Hales, S., Weinstein, P., Zalucki, M., & Woodward, A. (1999). El Niño and arboviral disease prediction. *Environmental Health Perspectives*, *107*(10), 817-818.

McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., & White, K. S. (Eds.). (2001). *Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change* (Vol. 2). Cambridge University Press.

Patz, J. A., Epstein, P. R., Burke, T. A., & Balbus, J. M. (1996). Global climate change and emerging infectious diseases. *Jama*, *275*(3), 217-223.

Pontes, R. J., Freeman, J. Oliveria-Lima, J.W., Hodgson, J. C., & Spielman, A. (2000) Vector densities that potentiate dengue outbreaks in a Brazilian city. The American journal of tropical medicine and hygiene, 62(3), 378-383.

Queensland Health (n.d.). Ross River Virus. Retrieved from <http://conditions.health.qld.gov.au/HealthCondition/condition/14/217/120/ross-river-virus>.

Reiter, P. (2001). Climate change and mosquito-borne disease. *Environmental health perspectives*, *109*(suppl 1), 141-161.

Ryan, S. J., Carlson, C. J., Mordecai, E. A., & Johnson, L. R. (2019). Global expansion and redistribution of Aedes-borne virus transmission risk with climate change. *PLoS neglected tropical diseases*, *13*(3), e0007213.

Tipayamongkholgul, M., Fang, C. T., Klinchan, S., Liu, C. M., & King, C. C. (2009). Effects of the El Niño-Southern Oscillation on dengue epidemics in Thailand, 1996-2005. *BMC public health*, *9*(1), 422.

Vincenti-Gonzalez, M. F., Tami, A., Lizarazo, E. F., & Grillet, M. E. (2018). ENSO-driven climate variability promotes periodic major outbreaks of dengue in Venezuela. *Scientific reports*, *8*(1), 5727.

Woodruff, R. E., Guest, C. S., Garner, M. G., Becker, N., Lindesay, J., Carvan, T., & Ebi, K. (2002). Predicting Ross River virus epidemics from regional weather data. *Epidemiology*, 384-393.

 Yeh, S. W., Kug, J. S., Dewitte, B., Kwon, M. H., Kirtman, B. P., & Jin, F. F. (2009). El Niño in a changing climate. *Nature*, *461*(7263), 511.