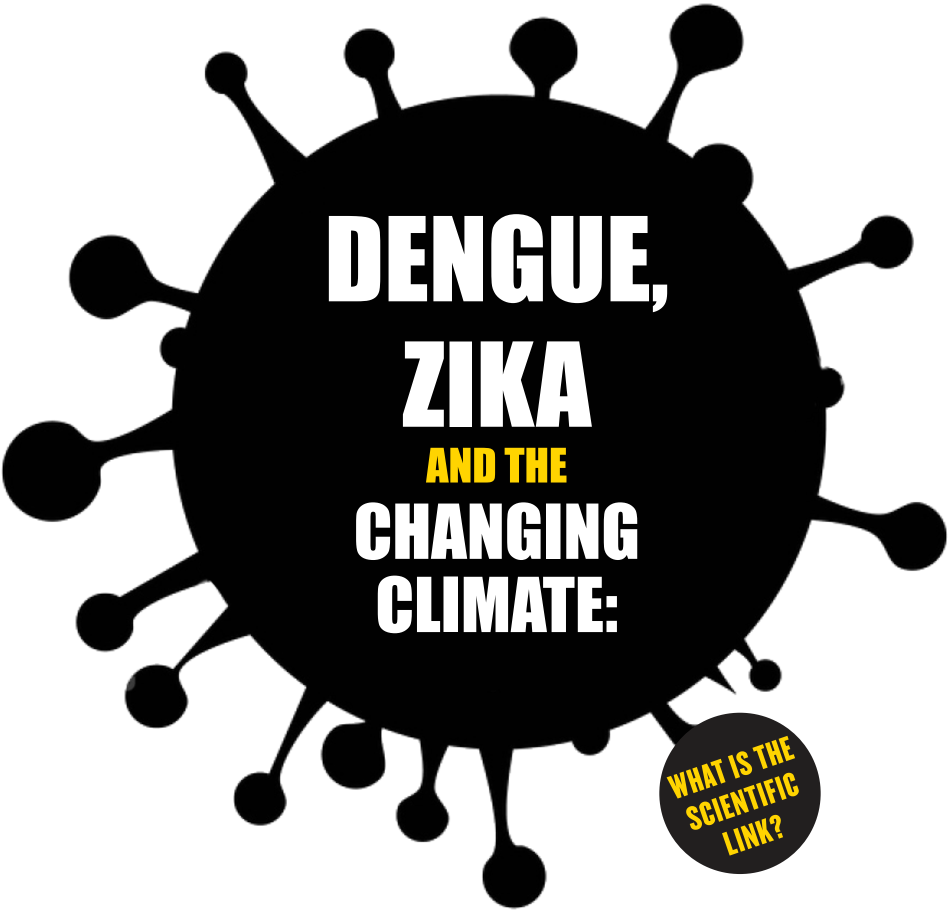
JOACIM ROCKLÖV
MIKKEL B. QUAM



DENGUE, ZIKA AND THE CHANGING CLIMATE:

WHAT IS THE SCIENTIFIC LINK?

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Content

About The Authors

Joacim Rocklöv is Ass. Prof. within Epidemiology and Global Health with a PhD in Environmental Medicine. He is the scientific leader for a research area within the Umeå Centre for Global Health Research, Umeå University. Dr. Rocklöv's group are experts in environmental epidemiology specifically focusing on using modeling to generate early warnings for climate-sensitive diseases and assess impacts of climate change on global health to inform adaptation and mitigation policy.

Mikkel B. Quam is a Ph.D. in Epidemiology and Public Health at Umeå University working in climate and health research. He has professional experiences in mathematics/statistics, local and global public health, as well as international non-governmental organizations before coming to the Umeå Centre for Global Health Research. As an epidemiologist, Quam is interested in modeling time dependent infectious disease dynamics governed by global change and environmental drivers including weather, and climate to inform evidence-based prevention policy.

FOREWORD:
Mattias Goldmann is the CEO of Fores, and has been awarded the title as Sweden's most powerful voice in sustainability in 2016. Mattias has extensive experience from environmental consultancy, transport policy and emissions reduction management. For two years he was stationed in Kenya, developing projects that are beneficial for both climate and health.

EDITORS:
Markus Larsson is the program manager for Climate and Environmental studies as Fores. He holds a PhD in Environmental strategic analysis from the Royal Institute of Technology (KTH), and has experience from international trade, agriculture and sustainability in the financial sector.
Emilia Ingemarsdotter works within the Climate and Environmental program at Fores. She holds a BSc in engineering physics and a MSc in industrial ecology, both from Chalmers University of Technology.

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Foreword

Prepare for a changing climate, prepare for new diseases – but fight climate change to avoid them!

If you think you are too small to make a difference, go to bed with a malaria mosquito.

This old saying is truer than ever. The mosquitoes are carrying not only malaria, but also dengue, Zika, chikungunya and other infectious diseases, causing millions of premature deaths, billions of dollars in health related costs, and immeasurable suffering.

In the indirect sense, the mosquito saying is just as true, and inspiring. An average mosquito only weighs around four milligrams, yet in only a few seconds it can cause large changes in our lives. We all know how one person can make a huge impact in the lives of many, for good and for bad, in much the same way. The transition to a more sustainable, low-carbon lifestyle is led by these individuals who manage to influence others, sometimes in mere seconds. These change-provoking individuals are needed now more than ever, as we see the urgent need to fight climate change more efficiently than we have thus far. But we also need to realize that we are well beyond the point where we can focus only on reducing emissions; we need to adapt to a changing climate. Enter the mosquito.

Incidence of mosquito-carried Zika and dengue are currently increasing at alarming rates in many parts of the world. According to the WHO the Zika epidemic was in February 2016 declared a Public Health Emergency of International Concern (PHEIC) and dengue is considered the globe's most important viral disease carried by mosquito.

The *Aedes aegypti* and *Aedes albopictus* mosquitos are the most important vectors for dengue and Zika. Until now, these diseases have been generally limited to areas of the tropics, where climatic conditions are most conducive for the insects to thrive and reproduce. With climate change, this is now likely to change. The diseases' area of transmission is likely to expand, the season of transmission to be longer, and the intensity of transmission could increase in many regions.

Subtropical and temperate areas, including Southern Europe, that do not have much experience with these diseases should prepare for this rapidly changing reality. They may experience smaller outbreaks, as well as, in some areas, wide spread epidemics. Even areas that will not directly be affected even with a changing climate, will more often have to deal with citizens returning from infected areas carrying the disease – both because the areas are getting bigger, transmission is likely to intensify (especially in cities), and because we will continue to travel more.

While it is important to prepare for potential outbreaks of the diseases, the spreading of Zika and dengue is also an urgent call for climate action. Previously, the discussion on victims of climate change centred around polar bears, future generations, and, perhaps, people living on small islands soon to be under water. We now realize that climate vulnerability is right here, right now, which will help us to act faster and more decisively. Just as the ongoing pandemic has spawned rapid international response efforts, the future increased risk of Zika and dengue transmission may be a decisive factor to prioritize collective action against climate change.

That is how powerful that little mosquito is.

Mattias Goldmann
CEO, Swedish Green and liberal think tank Fores

Förord

Förbered dig för ett förändrat klimat, förbered dig för nya sjukdomar - men bekämpa klimatförändringarna för att undvika dem!

Om du tror att du är för liten för att göra skillnad, gå till sängs med en malariamygga.

Detta gamla talesätt är mer sant än någonsin. Myggor bär inte bara malaria, men också denguefeber, Zika, chikungunya och andra sjukdomar, vilket leder till miljontals förtida dödsfall, miljarder i hälsorelaterade kostnader och ett omätbart lidande.

Också indirekt är talesättet sant – och inspirerande. En genomsnittlig mygga väger bara cirka fyra milligram, men kan på några sekunder orsaka stora förändringar i våra liv. Vi vet alla hur en person kan göra stora påverkan, på gott och ont, ungefär på samma sätt. Övergången till en mer hållbar, koldioxidsnål livsstil leds av dessa individer som lyckas påverka andra, ibland på bara några sekunder.

Nu behövs dessa förändringsdrivande individer mer än någonsin, för att bekämpa klimatförändringarna mer effektivt än vi har gjort hittills. Men vi måste också inse att vi är långt bortom den punkt där vi bara kan fokusera på att minska utsläppen; vi måste anpassa oss till ett förändrat klimat. Och här kommer myggan in.

WHO slår larm om att förekomsten av myggburen Zika och denguefeber ökar oroväckande snabbt i många delar av världen. *Aedes* myggan är den viktigaste vektorn för denguefeber och Zika. Hittills har den i huvudsak varit i begränsad till områden i tropikerna, där klimatförhållandena är mest gynnsamma för myggan att trivas och föröka sig. Med klimatförändringarna kommer detta sannolikt att förändras. Området där smittan sprids förväntas utvidgas, säsongen för överföring bli längre och intensiteten för överföring öka.

Subtropiska och tempererade områden som inte har mycket erfarenhet av dessa sjukdomar bör förbereda sig för denna snabbt föränderliga verklighet, med individuella infektioner samt, i vissa områden, utbredda epidemier. Det gäller bland annat Sydeuropa. Också områden som inte direkt påverkas även med ett förändrat klimat, kommer oftare att behöva hjälpa medborgare som blivit smittade när de varit i infekterade områden - både på grund av att området blir större, att smittspridning ökar (framförallt i städer) och eftersom vi reser mer. Det gäller bland annat Sverige.

Även om det är viktigt att förbereda sig för eventuella utbrott av sjukdomarna, så är spridningen av Zika och denguefeber också en uppmaning till snabbare och mer kraftfulla satsningar för att hejda klimatförändringarna. Tidigare har sinnebilden för de som drabbas varit isbjörnar och kommande generationer, samt människor som lever på små öar som riskerar att snart vara under vatten. Vi inser nu att sårbarheten för ett ändrat klimat är här och nu, och det kommer att hjälpa oss att agera snabbare och mer beslutsamt.

Kanske kan spridningen av Zika och denguefeber bli en avgörande faktor för att ge kampen mot klimatförändringarna högsta prioritet

Det visar hur kraftfull denna lilla mygga är.

Mattias Goldmann
VD, gröna och liberala tankesmedja Fores

Summary

The World Health Organization has claimed dengue, a widespread disease that can result in hemorrhagic fever, the most important viral disease carried by mosquitos; in February 2016, they also declared the ongoing Zika epidemic a Public Health Emergency of International Concern, due to the fetal brain damage associated to infection among pregnant women. The incidence of both Zika and dengue is currently increasing at alarming rates in many parts of the tropical and sub-tropical world. Over the last half century, the frequency and severity of outbreaks as well as the expanding distribution of the diseases has been markedly fueled by modern dwelling, urbanization and globalization. The expansion and increasing trends of infections of dengue and Zika is highly related to the proliferation of its vectors. The diseases are most efficiently transmitted by *Aedes aegypti* (but also by *Aedes albopictus)* mosquitos. The risk for both dengue and Zika has been generally limited to areas of the tropics, where climatic conditions are most conducive for the insects to thrive and reproduce. However, scientific evidence from a variety of perspectives suggest that changing climates, in combination with other factors, can shift the geographical extent and intensity of transmission of Zika and dengue vectors. This report discusses and describes the scientific linkage between the changing climate and changing patterns in dengue and Zika infections. We present a synopsis of the scientific evidence relating climatological factors to the past, present, and potential future distribution of the diseases. In particular, we focus anticipated future transmission dynamics of dengue and Zika in different areas and related policy implications.

We find that the extent, to which climate influences environments and environments facilitate disease transmission, depends on the presence of suitable vector mosquitos, viruses in circulation, and the persistent contact with susceptible human hosts. While mosquitos are present in much of the parts of the world with suitable climate conditions for dengue and Zika transmission, they do not successfully exploit this climate niche in all regions, and by so the expansion can sometimes be more a questions of time rather than climate change. Similarly, despite reoccurring and

growing introductions of viruses throughout the world through infected travels, dengue and Zika virus circulation is further geographically and temporally limited. For Europe, the changing climate change poses a risk of dengue or Zika emergence, when compared with other parts of the world, however. However, for most part of Europe the diseases are unlikely to become endemic throughout the 21th century.

Until an effective vaccine can be developed and fully approved for both dengue and Zika, focus on disease control, surveillance, and prevention should remain a high priority in endemic areas and areas with high potential for future outbreaks. Decision support systems integrating weather observations and forecasting to infectious disease prediction models, and also utilizing data on global mobility, need to be further developed to better guide timeliness and location of preparedness and control measures preventing further outbreaks across the globe, including Europe. Further on, scientific evidence shows that mitigating climate change would be positive for human health in reducing transmission risk of dengue and Zika and the introduction of vectors in naïve areas.

Introduction

The World Health Organization (WHO) has identified dengue as the globe's most important viral disease carried by mosquitos and declared the ongoing pandemic of Zika as a Public Health Emergency of International Concern (PHEIC) in February 2016[1, 2]. Although the viruses have been known to scientists for quite some time, incidence of both Zika and dengue are currently increasing at alarming rates in many parts of the world[3]. Over the last half century, the frequency and severity of outbreaks as well as their expanding distribution in time and space are all contributing to the observed thirty-fold upsurge in dengue infections, which can be fatal[1]. In a much shorter timeline, a recent Zika pandemic associated with microcephaly, has spread throughout much of the Americas and poses an emerging threat to human health throughout the globe[4, 5].

Transmitted most efficiently by *Aedes aegypti* (but also by *Aedes albopictus*) mosquitos, risk for both dengue and now Zika has been generally limited to areas of the tropics, where climatic conditions are most conducive for the insects to thrive and reproduce[6]. However, scientific evidence from a variety of perspectives suggest that changing climates, in combination with other factors, could shift the geographical extent and intensity of some infectious diseases[1]. Scientists and public health authorities are currently examining how changing climates impact transmission dynamics of the most burdensome arboviral diseases: dengue and Zika.

In this study report, we aim to briefly describe the scientific linkage between changing climates and changing patterns in dengue and Zika infections. In the proceeding chapters, we present a synopsis of the scientific evidence relating climatological factors to the past, present, and potential future distribution of the diseases. In particular, we focus on anticipated future transmission dynamics of dengue and Zika in different areas and related policy implications.

BACKGROUND

The 21st century is projected to experience unprecedented changes in climate due to the emissions of carbon dioxide and other greenhouse gases[1, 6-9]. Although manifest heterogeneously across the globe, these changing climates are slated to include increases in temperatures in many settings. Among scientists, there is a high level of agreement, that the amount of anticipated change is expected to be greater in some temperate areas closer to the poles. However, populations living closer to the equator may be more vulnerable and less able to adapt even to relatively small changes in climate[1, 10-14].

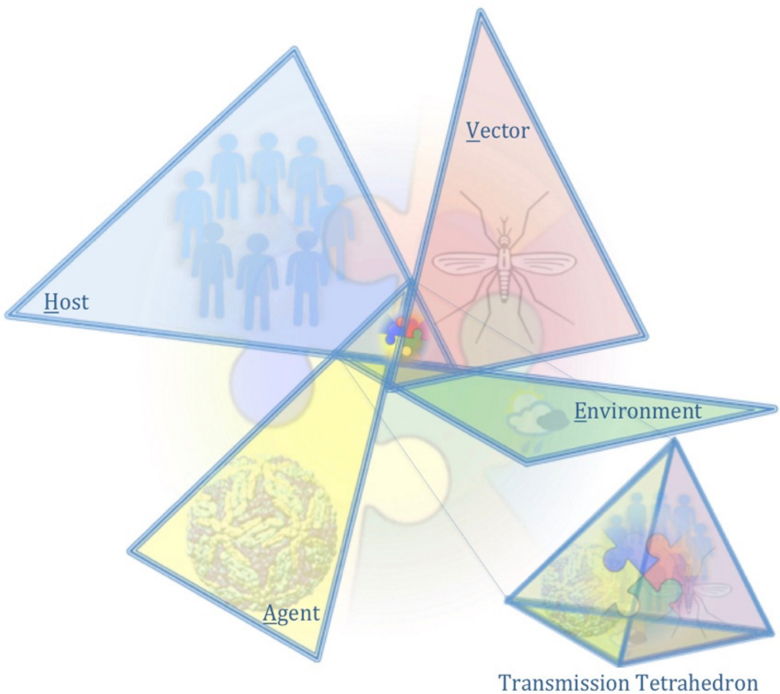
The changing climate can act along with other concurrent global dynamics to contribute to changes in the spreading of dengue and Zika. Changes may include expansion of the diseases' areas of transmission, extension of the transmission season, and increased intensity of transmission in some areas. However, other areas may experience some reprieve as some environments' future climate may be less conducive for transmission than the current conditions[10].

In order to assess the impact of the changing climate on human health, scientists try to identify a link between patterns in climate and patterns in the distribution of health, illness, and disease infections. If more is known about how, where, and when the disease infects humans, associations may become apparent. After long-term analysis of some infectious diseases, patterns tend to emerge, which may indicate endemic transmission (or a lack thereof). This could be characterized by a recurrent distribution of infections in specific areas, and/or certain times of year, and/or in similar patient populations at approximately the same amount year to year. Epidemic transmission is when outbreaks occur. In other words, it is when patterns of disease exceed expectations based on past observations. Epidemics may happen frequently within larger areas of endemic transmission. Scientists can ascertain some diseases' environmental sensitivity by studying the patterns of both endemic and epidemic infectious diseases alongside weather, climate, and other environmental factors. There is strong consensus that some vector-borne diseases, including dengue and Zika, are environmentally sensitive infectious diseases[1, 10, 11, 15-19].

THEORETICAL FRAMEWORK

Figure 1 shows the Host-Agent-Vector-Environment Transmission Tetrahedron (opposite page). This is a theoretical framework illustrating the multi-dimensional elements necessary to "H.A.V.E." dengue or Zika transmission[20]. In this model, Host(s) are susceptible humans; Agent(s) are virus(es), dengue or Zika; Vector(s) are mosquitos capable of carrying the specific disease; and Environment(s) are the conducive conditions, which facilitate transmission[20].

Figure 1: Host-Agent-Vector-Environment:
H.A.V.E. Transmission Tetrahedron[20]



The green base of the tetrahedron represents an environment, which is suitable for dengue or Zika transmission. In terms of defining the scientific link between the changing climate and dengue and Zika, understanding the current environmental suitability for these diseases is a fundamental first step.

This is because observed and expected shifts in climate are anticipated to generate local environmental changes, both natural and human caused[1, 14, 20-22]. The environmental sensitivity of infections that are carried by mosquitos can be in a multitude of forms, but usually relate to how mosquito vector populations grow[23, 24]. Another avenue of environmental sensitivity is related to how effectively the mosquitos take up and spread disease-causing agents such as dengue and/or Zika viruses[10, 11, 13, 23]. With Zika and dengue, it has been well established that certain mosquitos are vectors, responsible for most transmission, especially in areas with ongoing local spread of infections. While environmental conditions can influence breeding opportunities for mosquitos and their ability to attenuate and spread virus, they also determine patterns in human settlement and individuals' behavior, which may encourage or discourage exposure to vector mosquitos carrying viruses[1, 10, 20].

ENVIRONMENTAL SENSITIVITY

The environment can be determined or at least mediated by climate and weather. In this manner, changes in climate and subsequently weather can relate to the geographical extent and timing of interactions that are environmentally dependent. Acting as a dynamic container for potential transmission, spatial and temporal changes in the environment facilitate and obstruct the interactions between hosts, agents, and vectors, which are most directly involved in disease transmission. Climate and or weather can therefore govern the environmental dynamics influencing the suitability for and the stability of dengue and Zika transmission.

Climate drivers can determine some of the necessary environmental conditions for dengue and Zika to be persistently transmitted. However, climate is not the only environmental determinant of climate-sensitive disease. Therefore, a conducive climate alone is not necessarily sufficient for endemic transmission.

CHANGING CLIMATES

The impact of a changing climate on any given mosquito-borne disease will also depend on how many other factors interact within local environments and influence transmission cycles in the future. The individual role of climate (and changing climate) even for the same disease in the same region may have greater or lesser impact on disease transmission depending on how strongly climate determines individuals' exposure to infection. In some areas, climate may be the only limiting factor for the specific vector mosquitos to reproduce, develop, and efficiently transmit disease. However, in other areas, climate itself may be highly conducive to promote disease transmission, but settlement patterns and behaviors combined with infrastructure in the built environment may also be well adjusted to limit exposure to mosquito populations carrying disease[7, 25, 26]. With respect to biology, Zika and dengue are both expected to be impacted by fluctuations in mosquito populations. It should be noted, however, that dengue has a long documented history of transmission in many areas, while much still remains unknown about Zika[2, 3, 20, 27-29].

As the climates changes, societal, economic, political, and human health implications for dengue and Zika will have global repercussions. However, the current and projected disease distribution will be uneven and to a degree uncertain. Correspondingly, the adaptation to changing climate conditions in terms of management and control strategies for dengue and Zika should be coordinated at all levels, involving both international stakeholders and local communities in the solutions. Locally, strengthening disease and vector surveillance will likely increase the resilience of communities in the future, by better identifying and controlling outbreaks in their early stages. Additionally, anticipating increasingly globalized disease transmission and great uncertainty in the impacts of changing climates, societies should strengthen public health preparedness and pandemic response systems in partnership with one another. This would likely result in better management and mitigation of the human health consequences of unexpected epidemics of emerging infections which are likely to become a recurring part of the global landscape in the 21st century.

Relevance for Latin America, Asia & Africa:

The relevance of the changing climatic patterns on dengue and Zika depends on the extent to which climate is the determining factor in ongoing or future transmission[1, 13, 20, 30]. Latin America, Asia, and Africa are expansive areas and account for much of the global tropical and subtropical land areas. Although macro-climatological changes impact these areas' environments with regard to dengue and Zika, weather and weather events are more likely to guide the understanding of short term local disease dynamics and be most relevant in these areas[10]. While not homogenously spread throughout, neither over time nor in space, many countries in Latin America, Asia, and Africa have or have had transmission of dengue and Zika[15, 18, 28, 31-33].

Vector populations capable of spreading dengue and Zika are persistent and widespread in even more areas of Latin America, Asia, and Africa than the diseases are currently or historically reported[28, 29, 34]. The extent to which changes in dengue and Zika in the tropics can be attributed to the changing climate independent from other concurrent factors of global change in the future remains somewhat uncertain[12, 13, 23]. For such areas, the relevant question for populations and policy makers with regard to dengue, Zika, and changing climates is not whether or not the vectors and eventually the diseases will emerge or re-emerge. Rather, the focus should be on examining when, where, and at what level of severity dengue (and potentially Zika) will occur. This information is pertinent for designing interventions to protect vulnerable groups[1-3, 32, 35].

VULNERABILITY

If changing climates can increase the size of the potential transmission container in terms of populations at risk and time periods of potential infections, then in combination with increasingly frequent local, interregional, and international travel, viruses also spread to more areas, further and faster [4, 20, 36-41]. Lower resource settings of Latin America, Asia, or Africa are expected to experience some of the highest increased burdens of dengue, Zika, or both. In these rapidly developing areas, which may be less able to invest in successful vector control interventions and public health infrastructure to mitigate the burdens of dengue and Zika, even small shifts in disease patterns may be more relevant due to relative higher vulnerability [1, 20].

The vulnerability results from an inability to address shifting disease patterns due to changing climate. This will be most prominent in areas with low ability to absorb shocks in the healthcare and public health systems incurred by novel or severe or increasingly frequent outbreaks of dengue or Zika. For dengue and Zika, the burden of disease, although not the main focus of this report is crucial in understanding the relevance of the changing climate. With resource-intensive care, early diagnostics and proper disease management in a health care facility dengue mortality is avoidable. Zika is known to be associated with microcephaly, among various other neurological disorders, not all of which are well understood[3, 4, 20, 30]. Since widespread implementation of vaccines has not yet come in place, and approved medicine is not available for either dengue or Zika, the burden of these diseases on already stressed health systems can be catastrophic[1, 35].

RESPONSE CAPABILITIES

Many countries with well-adapted surveillance systems and extensive community-level vector control may be more adept to prevent patterns of disease to change even when changing climate provides increased suitability[42-46]. In these countries development may also have started to equip the health systems with forecasts of disease outbreaks, extending the surveillance into predictions of the near-time future. These forecasts are anticipated to lead to the development of early warning and response systems, allowing a timelier and more location sensitive implementation of disease control measures. This development in technical and response capacity, aligns well to more effectively adapt to the changing climate situation.

Some countries may experience dengue (or Zika) burdens so high that health professionals are overwhelmed and resources for prevention are unavailable or exhausted already[1]. Still other countries are suspected to have high undocumented or under-reported transmission of disease (particularly dengue in parts of Africa), which may increase in the future[34].

The heterogeneity in response capabilities is likely to echo the heterogeneity in shifting disease patterns in some areas, but not in all. Currently, the weather patterns that form climatic seasonal expectations of precipitation and temperature dynamics, among other factors, create conditions which facilitate disease. In those places, where resources have been mobilized and where the existing burden stimulated investment in good surveillance systems and eradication of vector breeding areas, anticipated changes in climatic conditions may not be sufficient to necessitate further response. Elsewhere, current patterns of disease may be more climate sensitive or near a tipping point, which could be reached with small changes in climate. Presently, in some areas, human (settlement) behavior or physical geography (including altitude) combine with climate to protect populations from exposure to infectious mosquitos, but this may change with minor warming[6, 10, 12, 13, 20, 24, 39, 47].

CLIMATE-MEDIATED TRANSMISSION

Currently, for parts of Latin America, Asia, and Africa within the tropics, the climate is favorable in some areas during certain times of the year, for the proliferation of specific mosquitos proficient in spreading dengue and Zika. Regions at highest risk for transmission are therefore limited to areas having capable dengue or Zika vector populations and necessary climatic conditions. Furthermore, the mosquitos might be able to transmit disease year-round or only seasonally or not at all depending on the size of the mosquito population and its ability to incubate and convey virus to humans. A vector population's distribution and capacity to transmit diseases is sensitive to climate and weather conditions[10, 20, 21, 23, 48-51]. For example, rainfall patterns can influence annual cycles of mosquito breeding.

Additionally, humidity and temperature minimums may impact the rates of development throughout the vectors' lifecycle. Furthermore, temperature may impact factors such as the rate of biting or the time needed to replicate the virus, which initiate the transmission cycle. For this reason, areas already having conducive environments and vector populations, where weather is a major determinant of disease patterns, may be highly vulnerable to even very small changes in climate. Even small changes on a global scale may impact the size of local vector populations, the duration of transmission seasons, and/or the frequency or severity of outbreaks. As this happens in many places simultaneously which are also becoming more connected economically, and have more people who travel between them, the potential for sharing pathogens through infected persons also increases[2-4, 20, 24, 28, 30, 31, 52].

CHANGING CLIMATES

Much of Latin America, Asia and Africa already have regular transmission or outbreaks of various vector-borne diseases including dengue and to a lesser extent until recently, Zika[28, 29, 34]. Many regions in these areas have tropical and sub-tropical climates, which on a macro level are highly suitable to support the *Aedes* mosquito vector species most efficient at carrying both Zika and dengue. Scientists generally anticipate the changing climate to change the severity and duration of the transmission season [10, 13, 44, 46, 53-56]. However, since these changes may lead to some time periods for some places exceeding optimal conditions, while others have greater time at optimal conditions, the overall net increase or decrease in disease incidence remains uncertain [10, 13, 44, 46, 53-56.] Additionally, in areas of the subtropics or places at higher altitudes, some evidence suggests that there may also be slight expansion of the areas of dengue and/or potential Zika transmission under warming scenarios. This is considered more likely as *Aedes* vectors have shown themselves able to expand their spatial distribution and established dominance within new niches and seems to be expanding within and outside the tropics in the recent past, as climate has also been changing [3, 13]. Especially, the *Aedes albopictus* mosquito has been shown to be able to persist at higher altitudes, further outside urban areas, and at cooler temperatures than *Aedes aegypti* [57-61].

Within Latin America, the changing climate has been linked to changes in dengue transmission patterns and even the current

Zika pandemic by some scientists [31, 62]. The evidence for this is related to analysis of anomalies in climate conditions during years associated with increased incidence of dengue and even the onset of the Zika pandemic [31, 62].

GLOBAL CHANGE

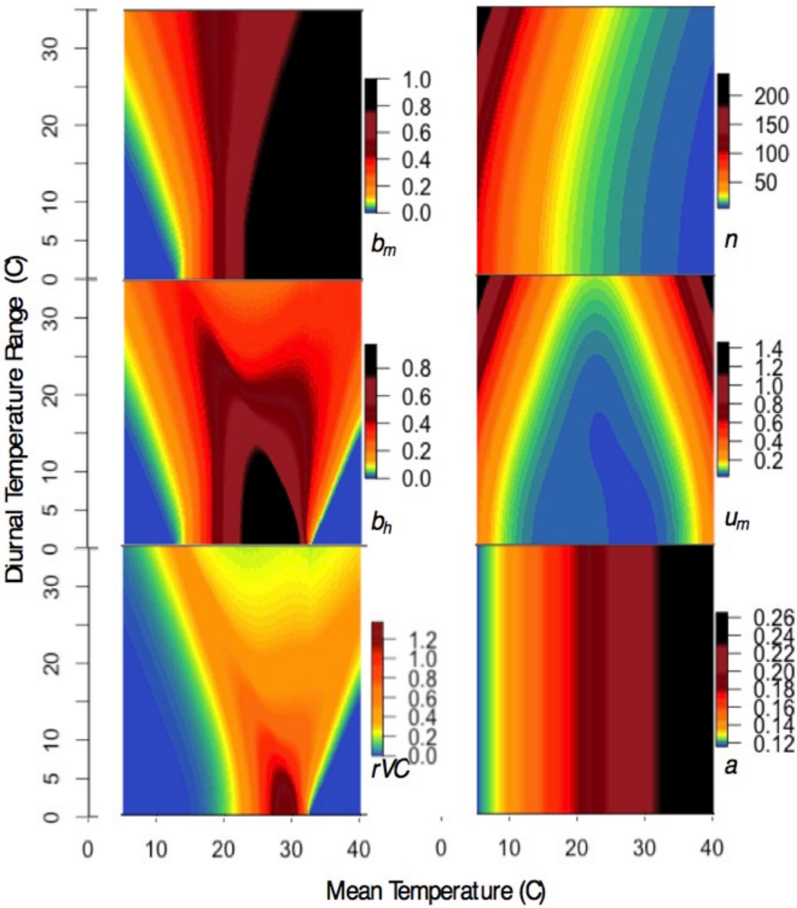
Climate is but one part of a larger global change narrative, which is the more comprehensive driver of many vector-borne diseases in Latin America and elsewhere around the world [3, 4, 20, 31]. In the rapidly urbanizing metropolitan areas of tropical and subtropical Latin American and the Caribbean Islands, *Aedes* mosquito populations are common [10, 20, 28, 63, 64]. In this part of world epidemic transmission of arboviruses like dengue, chikungunya, and yellow fever have plagued local populations for hundreds of years [1, 20]. Other than climate and weather, many factors define the rise and fall of disease(s) observed: human population dynamics, waste management, construction practices, water system infrastructure, personal protective behaviors, human mobility and the circulation of new virus types, just to name a few[1, 20]. The recent increase in dengue incidence reflects a number of modern changes including those instigated or exacerbated by changing climates[1, 3, 13, 20].

TEMPERATURE AND EPIDEMIC POTENTIAL

Climate can determine some of the baseline conditions for an environment conducive for disease transmission; which once fulfilled and/or optimized, disease incidence can increase[3, 13, 20, 32]. In Latin America, slight warming has occurred and is anticipated to continue to occur in the 21st century. Depending on the degree to which warming occurs, conditions in larger geographic areas of Latin America, Africa, and Asia may reach or exceed optimal temperature, for a greater portion of each year[13, 23].

Figure 2 shows the temperature dependencies of 5 parameters, which influence the potential for epidemic dengue transmission (which in this respect is similar to Zika), based on models by Liu-Helmersson and colleagues, as published in 2014[23]. Based on published laboratory experiments, Liu-Helmersson's adaptation of the Relative Vectorial Capacity (rVC, lower left) indicates that the optimal temperature for dengue epidemic potential is

Figure 2: Dengue Temperature Dependency [20]



~29 ˚C. Any yellow to red colored area represents values of relatively high vectorial capacity with ecological potential for epidemic transmission of disease, given physiological observations of the mosquitos' temperature dependent competency to spread dengue virus.

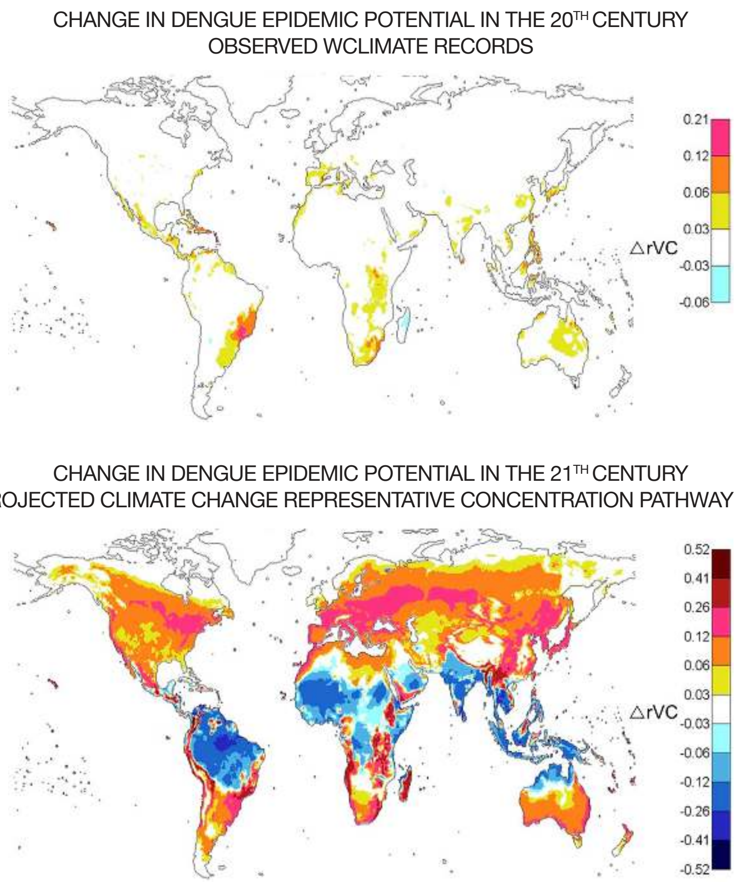
To an extent rVC can be used to describe the widest expected environments suitable for dengue and/or Zika establishment in naïve areas, once the vectors are present and the virus is introduced[3, 13, 23]. In the figure, a represents the average daily mosquito-human biting rate; b_h indicates the probability of disease transmission from infected mosquitos to human per bite; b_m denotes the probability of infected humans to transmit the virus to mosquitos per bite; expresses the duration of the virus attenuation in the mosquito once infected before it can infect human; and μ_m is the mortality rate of the mosquito vectors[13, 20, 23, 32]. The laboratory studies informing these temperature dependencies were conducted using *Aedes aegypti* and later *Aedes albopictus* mosquitos from various sites[13, 20, 23, 32, 57, 58, 65]. Temperature, however, may only be a portion of the climate change links to dengue and Zika in the future[6, 19, 22, 33, 34, 50, 62, 66, 67]. There are also anticipated changes in precipitation patterns, which could impact the frequency of heavy rain and draughts and also impact the spatial and temporal proliferation of vector populations [31, 55, 62, 68, 69].

FUTURE PROJECTIONS

Furthermore, the extent of warming and emissions may determine whether much of the tropics remain at near optimal conditions for dengue and Zika, or whether some areas become so warm that vector populations die off rapidly during warmer times of the year[3, 12, 13, 23, 57, 58, 65, 70, 71]. In the former scenarios, with relatively low warming, many areas will approach optimal temperature conditions suitable for highest incidence of dengue and Zika. The latter scenario may instead result in a bimodal (two-peaks) seasonality of expected disease transmission, which may actually have decreased incidence of disease compared to current conditions[13, 23].

Scientists Liu-Helmersson and colleagues have applied historical data and projected future scenarios of continued current emissions to use models to assess the potential change in dengue due to changes in climate[23]. The figure below, adapted from their findings, shows that minor changes observed over the last century are already increasing potential suitability of dengue in portions of Latin, America, Africa and Asia, while future extreme temperatures may kill off adult mosquitos sufficiently to reduce dengue likelihood[23]. This output was based on the temperature dependent model for dengue epidemic potential known as relative vectorial capacity (rVC, described above). The top map shows that the recent increase in temperature observed in the 20th century corresponds to increases in the vector mosquitos' (*Aedes aegypti*) capacity to spawn epidemics and spread disease. Parts of Africa, Asia, and in particular Latin America show the greatest increase in potential for dengue transmission over the first 100 years of modeling analysis.

Figure 3: 200-year Analysis of Warming and Dengue [23]



In the bottom map, the authors assumed that the future climate would be warmer in many locations with an average global temperature increase of about 4 degrees, according to the representative concentration pathway 8.5, which assumes current emissions of greenhouse gases would continue over the remainder of this century. This scenario is commonly adopted as one of the worst-case emissions scenarios, whereby 'business as usual' practices are maintained and little or no carbon emissions mitigation practices are implemented. As one clearly sees in the bottom map of Figure 3, some areas of the tropics are expected to have decreased epidemic potential for dengue at the end of this century due to excessive warming. This may correspond to overall decreases in incidence among those areas having greatest current cases, however nearby areas which are have increasingly optimal conditions (outside the tropics) are expected to support increased incidence. One should note that this analysis only takes into account the role of temperature changes due to climate change in determining the likelihood of dengue outbreak, while many scientists agree non-climate factors may be more important changes impacting transmission in the remainder of the 21st century.

CLIMATE VARIABILITY

Weather anomalies are often measurements used to indicate climate variability. Both increased and decreased rainfall, compared to historical averages, can be positively associated with breeding areas for vectors in Latin America, Africa, and Asia, due to the adaptation response of human populations [10, 16, 26, 42, 48, 62, 69, 72]. Increased rainfall may result in more natural environments for breeding, while lack of rain may result in water conservation and collection practices using artificial containers. In Latin America, evidence shows the 2014-2016 pandemic of Zika corresponded with warmer and dryer years than normal. In many communities of this region, individuals reportedly responded to the drought conditions (climate variability) by collecting rainwater in containers, which inadvertently became breeding sites for mosquitos in close proximity to human dwellings. With warming conditions (climate change) and plenty of mosquitos, the newly introduced Zika virus was able to spread rampantly through highly susceptible populations[31, 62].

In this manner, the changing climate, climate variability, and weather anomalies may all have contributed to the conditions, which facilitated the inception of the ongoing Zika pandemic[31, 62].

Weather and climate anomalies are also consistently associated with changes in patterns of dengue (although much less documented Zika)[15, 26, 48, 75, 78, 79]. Dengue is similarly related to changes in climate, which push temperatures toward more optimal conditions for disease transmission or rainfall patterns enabling larger vector populations[9, 18, 80-82]. Scientific evidence from comprehensive datasets about dengue in South East Asia identify large-scale drivers of rainfall anomalies, such as El-Nino Southern Oscillation (ENSO) as drivers for disease. In studies conducted in many sites, the timing of epidemic years was related to ENSO[21, 31, 55, 62, 75, 83]. This environmental sensitivity to macro-level climate variability indicates that dengue may continue to increase under changes in climate, since stronger and/or more frequent ENSO events are projected to coincide with changing rainfall and temperature regimes in the 21st century.

CLIMATE AND TRAVEL

The extent to which Zika will fulfill its environmental niche and the long-term duration of Zika transmission in Latin America is yet to be seen but will be governed at least in part by changes in climate. Due to the interconnectivity between the emerging economies of Latin America and parts of Asia and Africa, the scale of Zika transmission in one place determines the potential for Zika emergence in other places with suitable conditions. Such places are likely become be more numerous and widespread under scenarios of continued climate change[1, 3-5, 7, 10, 20, 29-32, 35-38, 40, 41, 43, 73-76]. Not unexpectedly, Zika has now been reported among travelers worldwide[2-4, 74, 77]. Locally acquired cases have been reported in nearly every county of the Americas and a few countries outside of the Americas, and more countries are likely to be affected in the future[2-4, 30].

DENGUE VERSUS ZIKA

Although the pathways for linking climate with both dengue and Zika are generally similar, the long-term expectations of each disease under scenarios of climate change may be slightly different for Latin America, Africa, and Asia. Dengue is currently more widespread than Zika, and for the most part also still occurring more frequently in places where both exist. Before the pandemic, Zika circulated rarely, in small outbreaks usually not reoccurring in the same site. Zika is therefore, outside Latin America, a potential emerging threat right now, which is also climate-sensitive, whereas dengue is more of a known quantity.

Furthermore, persons who have been infected with one of the four serotypes of dengue, remain susceptible to infection from other types of dengue. In areas, where all four types of dengue are circulating, the turnover in the susceptible groups is high, leading to persistent transmission of virus, even if many people have already been infected by one type of dengue[1]. Zika, on the other hand, may more quickly exhaust susceptible population in any given area, and thus has decreasing incidence and decrease spread, even as environmental conditions become more optimal with changing climate. The role which immunity, partial immunity, and subclinical infections play in the transmission cycles of both diseases represent important sources of uncertainty in the scientists' future projections under climate change.

IN SUMMARY

In many densely populated areas of the tropics, the climate is already conducive and expected to remain so throughout much of the 21st century[1]. Perhaps even more important in these areas will be the extreme weather events, which the changing climate brings more frequently and with greater severity. Such events have historically preceded major outbreak events of both diseases[12, 23]. In the short term, even the relatively small changes in climate as observed with the year-after-year temperature records may have modest initial impact of increased incidence of dengue and Zika in Latin America, Asia and Africa compared to other factors[1, 20]. However uncertain, longer-term impacts are highly relevant, even if disease incidence reduces but spatial and temporal patterns change, becoming more uncertain[10, 12, 39, 43, 45-47]. This is especially problematic for some of the most vulnerable localities in these regions, considering how resource-demanding vector control and facility-based care for dengue and Zika infections can be[1].

Many regions in in Latin America, Africa, and Asia should refine their surveillance systems to optimize swift, effective, and targeted management of outbreaks of vector-borne disease. In endemic areas, investment in climate services for early warnings for dengue and Zika may aid preparedness of the health service providers to respond to disease transmission events. This could increase the resilience to the deleterious impact of climate change for many communities in the tropics. Leveraging community resources and local populations to help with vector breeding site irradiation, adult vector control and swifter health seeking behavior may be useful to decrease the vulnerability of populations living in Latin America, Africa, and Asia to dengue and Zika.

Relevance for Europe

The relevance of the changing climatic patterns for dengue and Zika depends on the extent to which climate is the determining factor in ongoing transmission in a given area. The relevance is compounded by the extent to which the public health and/or health care systems could manage the disease(s) or is prepared to prevent the human population from becoming infected. Since Europe is generally better equipped in many aspects than some areas of Latin America, Africa, and Asia, local transmission of dengue and Zika have occurred only very rarely in Europe during the last century. Accordingly, vector surveillance, disease control, and epidemic preparedness have not been as highly prioritized in Europe for the control of these emerging arboviral threats in the recent past.

SEASONALITY

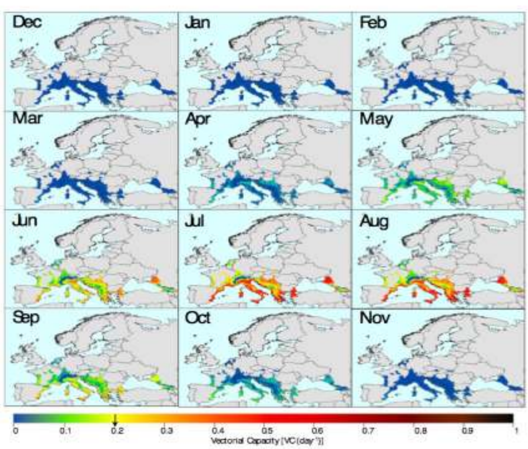
The historical and future potential for dengue and Zika to be locally acquired in Europe is highly seasonal[3, 9, 13, 20, 24]. When compared to more tropical areas of Latin America, Asia, and Africa, where in some areas, the climate can sustain year-round transmission, Europe therefore has much lower potential for emergence of endemic dengue and Zika. However, the seasonality does not exclude the possibly of epidemic transmission of disease in all areas. Populations in Europe tend to be more susceptible than those in endemic areas, due to a lower percentage of the population having prior exposure to either dengue or Zika. Therefore, if and when outbreaks do occur, if uncontrolled, the incidence could still be high in a population that is almost entirely unexposed, even with only briefly conducive, sub-optimal climate conditions for transmission[3, 20, 32, 36, 37].

The current and historical climate of Europe has been known to support epidemic transmission of various vector-borne diseases, some of which were recurring with regular seasonality[1, 20]. Dengue epidemics in Europe are historically rare, however, one major epidemic occurred around Athens, Greece in late 1920s having reportedly over 1 million cases[13, 20]. In contemporary Europe, so far in the 21st century, several local transmission events have occurred in mainland areas surrounding the Mediterranean, however, in general these have included only very few locally acquired cases[13, 37]. Of more consequential note, in 2012 in the Portuguese Island of Madeira, an outbreak of dengue occurred with thousands of infections, many of which were discovered upon returning home to other European countries[1, 20, 37].

CLIMATE VARIABILITY

While the individual role of the changing climates in these novel outbreaks of dengue remains unclear, these outbreaks were co-occurring with weather anomalies, as is the case with some epidemics outside of temperate areas. In this manner, it appears that relatively minor shifts in weather and climate even within a single year could contribute to the occurrences or reoccurrences of dengue in areas, where vectors have been introduced and where conducive environments are limited seasonally. If for instance a particularly warm spring occurs, mosquito populations may be in much higher numbers when a virus is introduced randomly, and thus spawn an outbreak, which could otherwise have been avoided or would have been less likely to occur[3, 9, 13, 20, 24, 61, 84].

Figure 4: Current Dengue Epidemic Potential where Aedes Mosquitos are present[20]



The figure above utilized a methodology adapted from the research of Liu-Helmersson et al. to determine the current weather-based seasonal window for epidemic transmission of dengue in Europe. This model has been validated on two outbreaks of dengue in temperate areas [13, 20, 32]. Based on the temperature dependency parameters assumptions in Figure 2, but adapted for the Aedes albopictus vector mosquitos found in the colorized parts of Europe, this deterministic model indicates the current largest spatial and temporal container that is suitable for outbreaks of dengue to begin. It should be noted, especially in Europe, that outbreaks of dengue are rare and have not historically occurred in all the areas with suitable climates for transmission. That being said, one can still note that the seasonality of potential outbreaks of dengue in Europe is limited to months of June-September during the period 2006-2015. The color-scale from blue to yellow indicates low risk of transmission and limited growth in a potential epidemic, even if an infected human were to be exposed to local mosquitos. Yellow-red indicates a period/location where an outbreak could persist in favorable climate conditions. The current incidence of locally-acquired dengue and Zika in Europe is limited by the range of *Aedes* mosquitos, which is also climate sensitive [3, 9, 13, 20, 24].

DENGUE VERSUS ZIKA

So far, the likelihood of local Zika transmission in Europe is generally believed to be very similar to dengue, though the likelihood for an introduction of Zika is likely to be much lower than for dengue[1-3, 30, 40, 41]. In general, historically and in the current pandemic, local transmission of Zika has not occurred in temperate areas, while dengue has. Currently, outside of the tropics, only very limited local transmission of Zika is occurring in Florida and in one province in Argentina. Compared to dengue, Zika is still less widespread globally, and generally has lower incidence, thus is less likely to be imported by infected travelers to Europe[20, 30, 41]. Because the focus of current surveillance efforts is to quell the spread of Zika (as compared to dengue), in no small part due to Zika being associated with neurological and birth abnormalities, travel-associated Zika infection are likely reported more even though they are likely occurring less frequently than dengue. To-date in 2016 according to Pan American Health Organization, Brazil which is at the epicenter of the Zika pandemic, dengue is still reported with incidence ~7 times greater than Zika (www.paho.org).

CHANGING CLIMATES

Under projected scenarios of climate change, Europe like many areas in northern latitudes is expected to experience longer warmer summers. The warming anticipated is also likely to be greater in terms of average degrees of warming than in many of tropical areas, although some parts of Africa anticipates extensive warming as well. For local transmission of dengue and Zika, the warming associated with the changing climates could potentially facilitate increased geographic range of *Aedes* vectors and extend the transmission season.

Figure 5: Dengue Epidemic Potential in Europe[13]

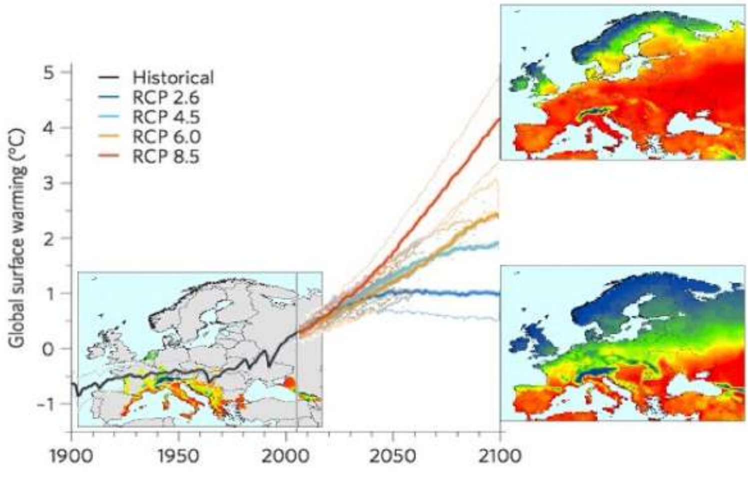


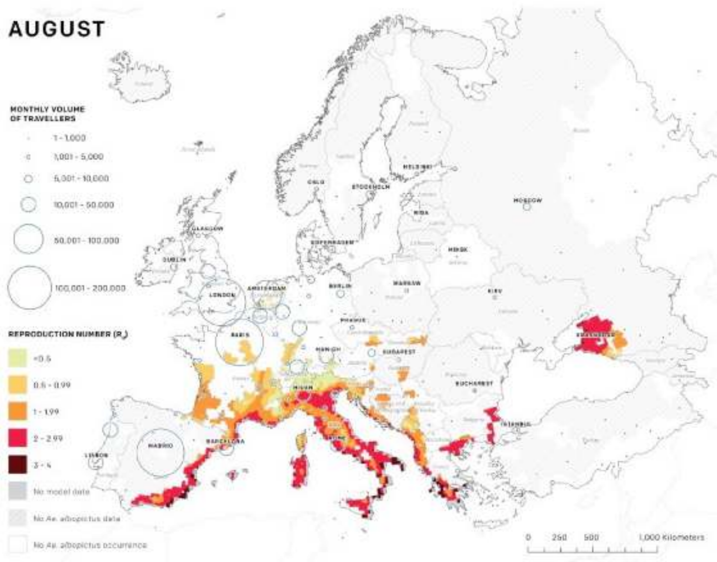
Figure 5 shows the expected pattern of changing suitability for dengue epidemics in Europe over the 21st Century under two different climate change scenarios compared to the present[13]. Unlike the current time period figure on the left which benefits from information on the current distribution of vectors, the figures on the right assume that mosquitos capable of dengue and Zika transmission continue their northward expansion of territory. With a global increase of~4°C warming, Representative Concentration Pathway 8.5 (right top) depicts a bleak future without policies to reduce climate change through the emissions reductions, compared to extensive mitigation practices (2.6, right bottom)[13]. Based on the same dengue transmission model, the potential for dengue epidemics to occur (yellow-red colors) in areas already having relevant dengue mosquitos does exist currently during the summer in Mediterranean coastal areas and nearly all of Italy. At the end of the 21st century (top right), this could expand to most of continental Europe; however, this could be partly contained with reduced emissions (bottom right)[13]. It should be noted that the true expansion of the vectors and their ability to drive epidemic throughout Europe is assumed based on temperature dependent parameters in the absence of vector control and other disease prevention interventions.

CLIMATE AND TRAVEL

While the changing climate may be only one factor in the potential emerging threat dengue and Zika pose to Europe, it remains an important one for public health preparedness. Given that dengue and Zika are climate-sensitive and that the impact of the changing climate will be most notable at the limits of current time-space patterns of disease, shifts in climate regimes have high relevance for Europe. For most of the recent past, neither the vector ecology, nor instances of virus introduction events were sufficiently coinciding to produce epidemic transmission of major vector borne diseases in Europe or other temperate areas. Currently as the world's high income temperate areas become more and more connected with emerging economies facing endemic transmission of tropical diseases, introduction of viruses become more frequent[1, 3, 4, 13, 20, 30-32, 37, 85].

Figure 6 depicts the basic reproductive number (R0) for Zika based on weather observations in areas with mosquitos that can transmit the virus, estimated for August 2016[3]. The basic reproductive number indicates the number of new individual infections that result from one person being infected, before that person recovers. Therefore, areas having at least R0 > 1, theoretically have climate conditions and mosquito vectors competent enough to

Figure 6: Potential Zika Spread into Europe[3]



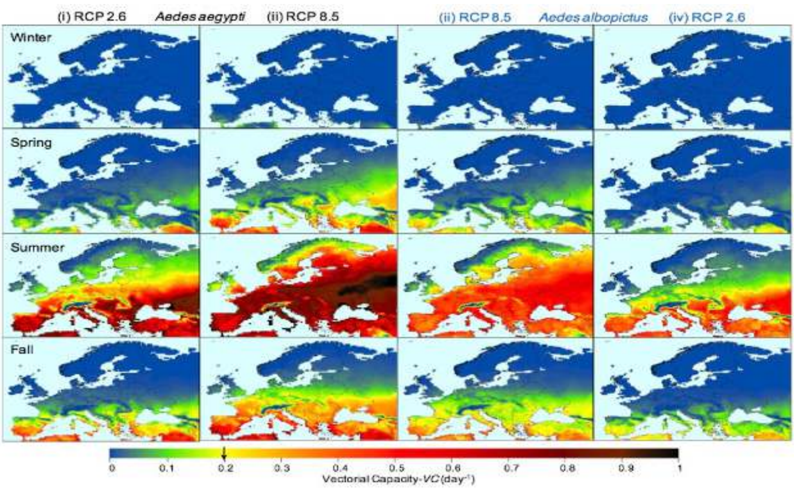
sustain an epidemic of Zika or a situation where additional cases are growing exponentially. Additionally, to better understand where the risk for this potential to be realized is greatest, Rocklöv and colleagues, who conducted the study, overlaid the number of travelers arriving to Europe from places having ongoing Zika transmission[3]. As with dengue, the climatic conditions for Zika in Europe are already present in some localities, particularly during summer and early fall in Southern Europe and this is expected to increase[3, 9, 13, 20].

Although travel between endemic areas and Europe is occurring throughout the year, it tends to peak at times when vector populations are also nearly at their seasonal peaks and climate conditions are most conducive in Europe[1, 3, 37, 40]. Changing climates are anticipated to enable a greater portion of the year for larger areas of Europe to transition into more optimal environmental conditions for mosquitos to carry arboviruses. Particularly in the warmer parts of southern Europe, most scientific evidence supports the finding that potential for local dengue and Zika transmission in Europe will increase, and thus outbreaks will potentially become more frequent in the future[3, 9, 13, 20, 24, 61].

FUTURE PROJECTIONS

Although increases in temperature under scenarios of changing climates is anticipated to be greater in Europe than in most parts of in Latin America, Africa, and Asia, Europe's climate is currently relatively temperate and largely seasonal. Therefore, because of its more extensive seasonal changes in weather and overall cooler current temperatures, the changing climate results in more optimal conditions for potential dengue and Zika transmission in Europe, in contrast to areas of the tropics, where conditions can seasonally become too warm for mosquitos to thrive. Even with the most efficient dengue and Zika mosquitos, which have not yet successfully expanded in most of Europe (left two columns), under the scenario with most warming (second from left column), transmission is seasonally limited by Europe's cool winters and springs, as depicted in Figure 7 adapted from Liu-Helmersson and colleagues[13].

Figure 7: End of Century Dengue Epidemic Potential assuming Aedes Mosquitos invade all of Europe[13]



This projection of increasing local transmission of dengue and/or Zika is anticipated to be greatest under scenarios of most extreme climate change compared to those involving the most mitigation of greenhouse gas emissions. Therefore, there is a potential to reduce the potential for the emergence of dengue and/or Zika epidemics in Europe if policies to reduce emissions are prioritized globally[9, 13, 20]. In any scenario, due to already emitted greenhouse gases, scientists project the current warming trend to continue throughout the 21st century[9, 13, 20]. Therefore, compared to current and past risks of dengue and Zika emergence, generally the anticipated future potential for transmission is increasing.

VECTOR DISTRIBUTION

The projections in Figure 6 are based on the assumption that the mosquito populations, both *Aedes aegypti* (currently limited to Madeira, Portugal, and the eastern coast of the Black Sea) and *Aedes albopicutus* proliferate throughout Europe in the future. The assumption that vectors will fully exploit the ecological niche throughout Europe enabled by more optimal climates and continued travel, trade, and human settlement behaviors is a limitation unlikely to be fully realized. Therefore, the climate effect is expected to be most amplified where synergistic effects of the invasive *Aedes albopictus* vector occupying much of Italy, Southern France, Eastern Spain, and much of the Balkan States, and increased travel generated infections coincide temporally and spatially[3, 9, 13, 20, 24, 40, 84].

COUNTRY-LEVEL SUMMARY

In most places, the environmental niche for the specific mosquitos most suitable for carrying Zika and dengue is currently unexploited, but this is rapidly changing. To an extent the seasonality of travel and vector proliferation, where suitable vectors are present in Southern Europe have been protective against year-round and year-to-year transmission of dengue in the past. In the future, under climate change scenarios, the shield provided by temperate seasonal climate against some vector-borne diseases is expected to start to deteriorate.

Quam conducted a systematic evaluation of every country in

Country	H	A	V	E	Elements
Albania	+	0	Ae. albopictus, established	+	3
Andorra	+	0	0	+	2
Armenia	+	0	0	0	1
Austria	+	0	Ae. albopictus, introduced	0	2.5
Azerbaijan	+	0	0	+	2
Belarus	+	0	0	0	1
Belgium	+	0	Ae. albopictus, introduced	+	2.5
Bosnia/ Herzegovina	+	0	Ae. albopictus, established	+	3
Bulgaria	+	0	Ae. albopictus, established	+	3
Croatia	+	Coast 2010	Ae. albopictus, established	+	3.5
Cyprus	+	0	0	+	2
Czech Republic	+	0	Ae. albopictus, introduced	+	2.5
Denmark	+	0	0	+	2
Estonia	+	0	0	0	1
Finland	+	0	0	0	1
France	+	Coast 2010	Ae. albopictus, established	+	3.5
Georgia	+	0	Ae. Aegypti, established	+	3
Germany	+	0	Ae. albopictus, introduced	+	2.5
Greece	+	Coast 1928	Ae. albopictus, established	+	3.5
Hungary	+	0	0	0	1
Iceland	+	0	0	0	1
Ireland	+	0	0	0	1
Italy*	+	0	Ae. albopictus, established	+	3
Latvia	+	0	0	0	1
Lithuania	+	0	0	0	1
Luxembourg	+	0	0	+	2
Malta	+	0	Ae. albopictus, established	+	3
Monaco	+	0	Ae. albopictus, established	+	3
Montenegro	+	0	Ae. albopictus, established	+	3
Netherlands	+	0	Ae. Albopictus & Ae. Aegypti, int.	+	2.5
Norway	+	0	0	0	1
Poland	+	0	0	0	1
Portugal*	+	Island 2012	Island of Madeira only, Ae. Aegypti, est.	+	4-M, 2-P
Rep. Moldova	+	0	0	+	2
Romania	+	0	0	0	1
Russian Feder-ation	+	0	Ae. Albopictus & Ae. Aegypti, est.	+	3
San Marino	+	0	Ae. albopictus, established	+	3
Serbia	+	0	Ae. albopictus, introduced	+	2.5
Slovakia	+	0	Ae. albopictus, introduced	+	2.5
Slovenia	+	0	Ae. albopictus, established	+	3
Spain	+	0	Ae. albopictus, established	+	3
Sweden	+	0	0	0	1
Switzerland	+	0	Ae. albopictus, introduced	+	2.5
FYR- Macedonia	+	0	0	0	1
Turkey	+	0	0	+	2
Ukraine	+	0	0	0	1
United Kingdom	+	0	0	+	2

Table 1: H.A.V.E. Transmission Framework Applied to Identify Potential Dengue Emergence in Europe [20]

Europe and tabulated according to the H.A.V.E. transmission theoretical framework (figure 1)[20]. Countries having some established vector populations within close proximity to large metropolitan settlements, seaports, and/or large international airports are at highest relative potential for dengue (and potentially Zika) emergence and are identified with red shading in Table 1 below. Those shaded in orange and yellow, currently lack vector populations necessary for transmission but have suitable environments with brief introduction of vectors (orange) or are expected to continue to have increasingly suitable conditions in the next century given changes in climate (yellow). Countries in blue currently do not have vector populations capable of carrying dengue and Zika identified or only have had very brief seasonally suitable climate conditions for transmission and despite extensive warming are not expected to experience future outbreaks of either disease, although imported cases may occur with increasing frequency.

*Shaded areas indicate countries with elevated potential for dengue emergence given current and future vector distribution and environmental conditions. Red signifies the most vulnerable countries, followed by orange, yellow and blue.

Policy Recommendations

At the global level, the Intergovernmental Panel on Climate Change (IPCC) has been an instrumental player in bridging policy and decision making with scientific evidence on the changing climate since its initialization nearly 30 years ago. While not actually involved in conducting scientific research itself, the IPCC does convene experts to contribute to regularly generated reports on the subject. Like previous reports, the IPCC's most recent Fifth Assessment Report published in 2014 contained a chapter examining evidence on many topics including human health impacts. In this chapter, which predated the current Zika pandemic, dengue was discussed as a climate-sensitive disease.

In autumn 2015, the United Nations announced the Sustainable Development Goals (SDGs), an ambitious 15-year agenda to transform the globe. One of the priority areas in this international focus on sustainable development is *Climate Action* ("Take urgent action to combat climate change and its impacts"). Leaders from around the world came to a new agreement to mitigate climate change, at the 21st Conference of the Parties (COP) in Paris in December 2015. There is now widespread consensus that the climate is changing and that this could pose problems for human health, well-being, and development. There is also widespread interest in limiting the destructive aspects of climate change by averting emissions and by adapting to threats.

There appears to be a great international political will to assess the impacts of the changing climate, adapt to it, protect the most vulnerable, and even to mitigate emissions to limit it. This is evidenced by the inception of the United Nations Framework Convention on Climate Change (UNFCCC), the evidence assembled through the IPCC, the priorities set in the SDGs and the new agreements made at COP21 in Paris. The scientific evidence supports the notion that the damaging impacts to human health related to dengue and Zika virus transmission can be exacerbated in some areas due to climate change, but also that coordinated mitigation efforts could reduce these effects.

The expected short-term increases in areas and time periods, where and when mosquito-borne virus transmission could persist, represent an urgent threat to vulnerable populations in emerging economies, although not uniformly distributed. When climate and therefore disease transmission become less predictable, individual and population health is likely to suffer. This is especially problematic for those in lower and middle-income areas of Latin America, Africa, and Asia. In Europe and other temperate areas, similar short-term implications of the changing climate on climate sensitive diseases including dengue and Zika may already have influenced changing patterns in disease and vector ecologies. This can stimulate small scale emergence of disease and fertilize the ground for pending pandemics.

The extent to which climate influences environments and environments facilitate disease transmission, depends on the presence of suitable vector mosquitos, viruses in circulation, and the persistent contact with susceptible human hosts. While mosquitos are present in many parts of the world with suitable climate conditions for dengue and Zika transmission, they do not successfully exploit this climate niche in all regions nor time periods. Similarly, despite reoccurring and growing introductions of viruses throughout the world through infected travels, dengue and Zika virus circulation is further geographically and temporally limited.

Ultimately, even in some places, where vectors are relatively abundant and virus introductions are regular, human host behavior and settlement patterns can either permit or hinder exposure through biting. This tends to differ, usually along a socio-economic gradient within endemic areas and can be a reason for less than expected transmission of Zika and dengue in some temperate areas, like parts of the Southeastern United States in recent decades. For these reasons, as scenarios of climate change may well predict that greater portions of the globe will experience longer periods of disease suitable climatic conditions, in light of the other changes in the 21st century with rapid development expected in much of the tropics, the actual incidence of dengue and Zika is difficult to assess and could decrease in some areas.

For areas of the tropics in Latin America, Africa, and Asia, where slightly warmer temperatures combined with disruptions in rainfall patterns promote more frequent and severe epidemics of dengue and Zika in the near future, policy makers should focus on protecting vulnerable groups of individuals from getting potentially infectious mosquito bites. Although there are many preventive strategies, identifying hot spots through comprehensive surveillance systems is key to informing meaningful vector control and early warning strategies. Additionally, public health campaigns to mobilize community breeding site termination should be adopted in a targeted manner to counteract the more favorable climate conditions on vector propagation. This could be especially useful where human behavioral factors potentiate natural dynamics in cultivate mosquito breeding sites in close proximity to susceptible hosts. Lastly, the most vulnerable populations, like children and pregnant women, should be prioritized in prevention, surveillance, and clinical health systems to ensure that prompt diagnostics and proper management is available to meet the potentially increasing burden of dengue and Zika.

In terms of research for Latin America, Africa, and Asia, there is still a dearth of knowledge about the occurrence of both diseases in some of the lowest-resource areas. Additionally, much is still unknown about how the counteracting effects of climate change and development will impact dengue and Zika in the long term and deserves further research in the future.

For Europe, the changing climate poses a less certain risk of dengue or Zika emergence, when compared to other parts of the world, however, climate itself seems to play a larger role in preventing current transmission there. Along the perimeter of the current transmission zone, which includes some areas of Europe, subtler indications of the changing climate become apparent. In these areas, changing climates may facilitate further expansion of vector populations or broaden the potential season of transmission. In some areas of Europe, there are already extensive populations of the highly relevant secondary vector for dengue and Zika, *Aedes albopictus*. Introduced relatively recently and rapidly expanding its niche by out-competing other species, this invasive mosquito vector is more capable of adapting to more temperate climates.

In temperate settings, where this is also coinciding with the changing climate and introductions of various viruses, policy makers should prioritize vector surveillance and control activities to limit the future threat from change climate. Table 1 in the final section of the previous chapter outlines in red shading, which countries are at highest risk for the emergence of localized seasonal dengue transmission in the near future. These countries should adopt strengthened human and vector surveillance systems and consider making dengue and Zika diseases mandatory to report to public health authorities. Countries in orange should also remain vigilant and closely monitor the expansion and (re-) introduction of Aedes vector mosquitos to prevent the increasingly suitable climate conditions to potentiate vector-borne disease transmission. Countries in yellow are at lower overall risk, however should still monitor human infections, which up until now are imported cases and pay particularly close attention to areas with highest conduciveness for vectors, and most exposure to sea transport from areas endemic for dengue and Zika, as this can be a route of vector introduction. Countries in blue are at lowest risk for current and future localized transmission of dengue and Zika, however, anticipated changes in climates will extend the currently limited temporal window for potential outbreaks, especially if vectors expand into these areas.

Until an effective vaccine can be developed and fully approved for both dengue and Zika, focus on disease control, surveillance, and prevention should remain a high priority in endemic areas and areas with high potential for future outbreaks. Decision support systems integrating weather observations and forecasts from infectious disease prediction models, and also utilizing data on global mobility, need to be further developed to better guide timeliness and location of preparedness and control measures preventing further outbreaks in Europe. At a higher policy level, scientific evidence shows that mitigating climate change would be positive for human health, helping to reduce long-term and widespread circulation of diseases in sub-tropical and temperate areas.

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DENGUE, ZIKA AND THE CHANGING CLIMATE:

WHAT IS THE SCIENTIFIC LINK?

CONTRIBUTORS

Joacim Rocklöv | Umeå University
Mikkel B. Quam | Umeå University
Mattias Goldmann | Fores
Markus Larsson | Fores
Emilia Ingemarsdotter | Fores

DESIGN
Ivan Panov | panstudio@gmail.com

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The World Health Organization (WHO) has identified dengue as the globe's most important viral disease carried by mosquitos and declared in February 2016 the ongoing pandemic of Zika as a Public Health Emergency of International Concern (PHEIC). Although the viruses have been known to scientists for quite some time, incidence of both Zika and dengue are currently increasing at alarming rates and poses an emerging threat to human health throughout the globe. Risk for both dengue and Zika has been generally limited to areas of the tropics, where climatic conditions are most conducive for the insects to thrive and reproduce. However, scientific evidence suggests that changing climate could shift the diseases' geographical extent and intensity.

The aim of this study has been to briefly describe the scientific linkage between climate change and shifting patterns in dengue and Zika infections. Focus is put on anticipated future transmission dynamics of dengue and Zika, and related policy implications. This report was written by scientists in the field of environmental epidemiology, who actively study the impact of climate change on human health around the world. The authors' academic research has in recent years been devoted to understanding the role of weather, climate, and climate change in the occurrence of dengue, Zika, and other vector-borne diseases in both temperate and tropical areas throughout the globe.

CONTRIBUTORS

Joacim Rocklöv | Umeå University
Mikkel B. Quam | Umeå University
Mattias Goldmann | Fores
Markus Larsson | Fores
Emilia Ingemarsdotter | Fores

DESIGN

Ivan Panov | panstudio@gmail.com

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