A spatio-temporal modeling framework for *Aedes aegypti* transmitted diseases in the Caribbean

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BRCCC PROGRAMME

Programme for Building Regional Climate Capacity in the Caribbean

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GFCS GLOBAL FRAMEWORK FOR CLIMATE SERVICES

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1. Background

Epidemiological Situation of *Aedes aegypti* transmitted arboviruses in the America

Latin America and the Caribbean (LAC) are facing an unprecedented crisis of co-occurring epidemics of febrile illness due to dengue (DENV), chikungunya (CHIKV) and Zika (ZIKV) viruses [1]. These diseases are transmitted principally by the female *Aedes aegypti,* with *Aedes albopictus* as a secondary vector. *Ae. aegypti* is a highly capable disease vector because it is uniquely adapted to the urban human environment [2]. The adult mosquito rests inside the home during the day, and females feed frequently and preferentially on human hosts, behaviors that increase the probability of disease transmission [3]. No vaccines are yet available for CHIKV and ZIKV, and there is limited access to the DENV vaccine, Dengvaxia® [4–6]. The primary public health interventions are effective clinical management of the disease and vector control through insecticide application, elimination of breeding sites, public education and community mobilization [2]. Despite significant investments by the public health sector, the burden of disease continues to increase. Additionally, it is likely that when vaccines become available, they will be used in combination with vector control interventions. Novel surveillance tools and clinical management strategies are urgently needed to increase the capacity of the public health sector to prevent and respond to the concurrent disease outbreaks.

Dengue re-emerged in LAC in the late 1980s, and over the last three decades the distribution, severity, and incidence has continued to increase, from 16.4 cases per 100,000 in the 1980's to 71.5 cases per 100,000 from 2000 to 2007 [7–10]. Current estimates of apparent dengue fever infection in LAC range from 1.5 million [11] to 13.3 million [12] cases each year. Symptoms range from mild infections (fever, rash, and joint pain), to severe illness resulting in hemorrhage, shock and death [2].

Over a 5-year period, from 2012 to 2016, a total of 11,374 suspected and confirmed DENV cases were reported from Barbados, resulting in an average incidence of 80.0 cases per 10,000 people per year [13]. Over the same time period, a total of 843 suspected and confirmed DENV cases were reported from Dominica, resulting in an average incidence of 23.5 cases per 10,000 people per year.

The first cases of chikungunya (CHIKV: family *Togaviridae*, genus *alphavirus*) were reported in the Americas in 2013, resulting in over 1.8 million cases to date [14]. Clinical chikungunya infections are characterized by intense and sometimes chronic joint pain [15]. The first cases of chikungunya were reported in Dominica in December 2013 [16], with major clusters of disease in urban areas [17]. A total of 3,590 suspected cases and 173 laboratory confirmed cases have been reported by PAHO [14]. A total of 1,833 suspected cases and 114 confirmed cases of chikungunya have been reported from Barbados [14].

Zika fever (ZIKV: family *Flaviviridae*, genus *flavivirus*) emerged in the Americas in 2015 in Brazil [18]. Latin America and the Caribbean continue to experience a major epidemic, with 785,626 cases reported by 48 countries and territories to date [19]. On February 1, 2016, the World Health Organization (WHO) declared a Public Health Emergency of International Concern in response to the potential neurological and auto immune complications associated with Zika infections (e.g., Guillain-Barré syndrome and congenital syndrome in newborns) [20,21][1]. As the epidemic unfolded, the WHO issued an alert that the 2015-2016 El Niño event, which was the strongest event in recent decades, may increase the risk of Zika outbreaks in the region [22]. Studies have since shown that exceptionally warm temperatures associated with the El Niño event increased the probability of the Zika epidemic [23,24]. Zika emerged in Barbados and Dominica in early 2016. To date, 705 suspected cases and 150 confirmed cases of Zika have been reported from Barbados [19]. A total of 1,263 suspected cases and 79 confirmed cases of Zika have been reported from Dominica (Ryan et al, *in review*). The outbreak in Dominica is described in detail in this report.

Other viral diseases transmitted by the *Aedes aegypti* mosquito are also of public health concern. In December 2016, an outbreak of yellow fever (YFV: family *Flaviviridae*, genus *flavivirus*) was reported in Brazil (3,240 cases, 35% case fatality rate), and in 2017 sporadic cases have been reported from Colombia, Ecuador, Bolivia, Peru and Suriname [25].

[1] The WHO designation of the Zika epidemic as a 'public health emergency' was lifted on November 18, 2016.

A Zika prevention sign from the port in Bridgetown, Barbados.

Linking Climate and *Aedes aegypti* transmitted diseases

Prior studies have demonstrated that climate variability influences DENV transmission and *Ae. aegypti* population dynamics in Latin America and the Caribbean, indicating the potential to develop climate services for the health sector [26–32]. Warmer air and water temperatures can increase rates of larval development [33–35], adult biting rates, gonotrophic development [36,37], and can reduce the extrinsic incubation period of the virus in the mosquito [38]. Other studies have shown that *Ae. aegypti* are more likely to be found in areas with high relative humidity and high vegetation [39]. The effect of rainfall on *Ae. aegypti* is more complex due to water storage. Rainfall can increase mosquito densities by increasing the availability of mosquito breeding sites (e.g., rubbish in the patio filled with rainwater). However, drought can also increase mosquito abundance by increasing the need to store water around the home [40].

The effects of climate on *Ae. aegypti* may vary from locality to locality within a country due to spatial variability in social conditions, insecticide resistance [41], vector control efforts, and other social-ecological factors. For example, studies from regions of Puerto Rico with different microclimates found that *Ae. aegpyti* densities were positively correlated with rainfall only [28], correlated with temperature only [27], and not correlated with either temperature or rainfall [42]. Differences between sites may be due differences in access to piped water, water storage practices, people's knowledge and risk perception, and housing conditions [39,43–47].

There have been several retrospective analyses of dengue fever, *Aedes aegypti*, and climate in Barbados. An early study documented the seasonal linkages between climate and dengue from 1980 to 2000, and showed that epidemics occurred in the latter part of the year [31]. The authors also noted that there was a trend in increasing temperatures and declining rainfall in recent decades. An analysis of dengue fever and climate from 1995 to 2000 found that dengue fever was significantly associated with lagged climate variables including rainfall at a 7 week lag and minimum temperature at a 12 week lag [48]. Most recently, investigators analyzed a time series analysis of dengue and climate (rainfall and temperature) from 2004 to 2013. Although the model was able to accurately simulate retrospective dengue transmission, the model not able to effectively forecast dengue risk [49]. It should be noted that all of these analyses were conducted with total national dengue cases, and did not include spatial analyses. To our knowledge, there have been no formal studies to model dengue fever, *Aedes aegypti,* and climate in Dominica; however, the climate and health vulnerability assessment conducted in 2016 did include a descriptive temporal analysis [50].

Climate services for arboviruses

Given the linkages between arboviruses, vectors, and climate, the WHO has recommended developing climate services for health, such as early warning systems (EWS) and forecast models for dengue fever and other climate sensitive diseases. An EWS that predicts high-risk seasons and regions would allow the public health sector to conduct targeted vector control, resulting in more effective utilization of limited resources. To date there has been limited success in developing an operational EWS for dengue, although several studies have demonstrated the potential to develop such a system [51–58], including spatiotemporal models to predict *Aedes aegypti* proliferation in Cuba [59]. One of the most promising examples of an operational climate-driven dengue fever forecast model was recently described by Lowe et al. for southern coastal Ecuador [56]. In this study, the authors produced a forecast of monthly dengue fever incidence 11 months ahead of time, and later evaluated the forecast using case reports from the Ministry of Health (MoH). This model was unique is that it incorporated seasonal climate forecasts, ENSO forecasts, and data from an active surveillance study to correct for over reporting of DENV during the CHIKV outbreak. This study demonstrated the feasibility of developing climate services for dengue fever and other arboviruses, and the importance of strong long-term partnerships across the climate and health sectors.

An EWS incorporates environmental data (e.g., climate, sea surface temperature), epidemiological and entomological surveillance data, and other social-ecological data (e.g., land use, population density) in a common database. These data feed into a spatiotemporal prediction model that generates disease risk forecasts. Maps and other model outputs, such as seasonal risk maps, are linked to an epidemic alert and response system. This system serves as a decision support tool for the public health sector. These alerts can potentially trigger a chain of interventions, such as vector control or public health messaging, when a predetermined alert threshold is surpassed.

The Global Framework for Climate Services (GFCS) is the guiding mechanism to support the development of climate services for key sectors, including health. Climate services are tailored products (e.g., risk maps or drought forecasts) for a specific sector that help decision makers and practitioners to prepare and plan their actions in the context of these weather or climate events. The GFCS has been adapted to the health sector, as described in Box 1.

Box 1. The Global Framework for Climate Services (GFCS) Health Exemplar Goals, Objectives, and Outcomes [60]

1. Strengthening communication and partnerships among climate and health actors at all levels for the promotion of effective utilization of climate information within health policy, research, and practice.
2. Improved health and climate research and evidence of the linkage of climate and health.
3. Increase capacity of the health sector to effectively access, understand and use climate and weather information for health decisions.
4. Climate and weather data effectively mainstreamed to health operations.

Past projects on climate and health in Barbados and Dominica

Barbados and Dominica were selected as pilot study countries for this consultancy due to their prior experience with projects on climate and health (Box 2), and because *Aedes aegypti* transmitted diseases were identified by the health sector as a high public health priority.

Barbados was selected as the country in the western hemisphere for the WHO project on climate change adaptations strategies for human health, funded by the Global Environment Facility (GEF) Special Climate Change Fund (SCCF) [61]. The project ran from 2011 to 2015. As a result, the MoH and national meteorological service began collaborating, there was increased awareness of the effects of climate on health, and the MoH identified a person as their climate and health point of contact. One of the recommendations that emerged from this project was the development of an EWS for dengue.

In Dominica, the climate and health program began in 2013. Dominica was selected as the health exemplar for the GFCS, resulting in a national consultation on climate and health vulnerability, that ran from 2015 to 2016 [50]. This project evaluated vector borne diseases (VBDs), food safety and water, and assessed the impact of Tropical Storm Erika. As in Barbados, this project served to bring together the climate and health sectors for the first time, and they recommended the development of an EWS for dengue fever.

Ms. Ferdinia Carbone, director of the Environmental Health Department of Dominica and Dr. Anna Stewart Ibarra discuss issues related to climate services for vector borne diseases.

Box 2: Key projects on climate and health

- Assessment of climate change and health vulnerability and adaptation in Dominica (2015-2016) [50].
- Climate change adaptation to protect human health in Barbados (2011-2015) [61].
- Investigators from the Climate Studies Group, Mona, of the University of West Indies published a book entitled, "Climate Change Impact on Dengue: The Caribbean Experience [62]. One of the key recommendations was the development of a climate driven EWS for dengue.
- The MoH in Dominica is conducting a project on climate-smart healthcare facilities with the Department for International Development (DFID) of the UK and the Pan American Health Organization (PAHO) [50]
- The MoH in Dominica is developing a methodology for climate change adaptation planning for health in small island states in partnership with PAHO, the World Meteorological Organization (WMO)/WHO, and Health Canada.

Study Aims

The aim of this project was to work collaboratively with regional and national climate and health stakeholders in the Caribbean to develop a modeling framework that will ultimately provide spatio-temporal probabilistic forecasts of the risk of transmission of DENV, CHIKV, and ZIKV. The specific aims were:

1. Stakeholder engagement: Conduct stakeholder mapping and a needs assessment of climate and health stakeholders.
2. Spatiotemporal modeling: Develop probabilistic (risk) maps of *Aedes aegypti* and evaluate statistical associations and lag periods among climate, *Aedes aegypti* and DENV transmission.
3. Capacity strengthening: Webinar series on climate services for the public health sector, with a focus on *Aedes sp.* transmitted febrile illness (DENV, ZIKV, CHIKV) and spatiotemporal models.

2. Analysis of climate and health stakeholders

Rationale. Understanding stakeholder networks is key to facilitate the flow of information between the climate and public health sectors [63]. Prior studies indicate that the end-users of climate information, the public health sector in this case, are a diverse group of actors with different needs and interests [64]. The decision-making process in the public health sector may be limited by resources, information, prior experiences, and other actors or institutions [65]. In this context, the GFCS aims for stakeholder engagement between climate and health actors at all levels to promote the effective utilization of climate information within health policy, research and practice.

We conducted an assessment of stakeholder perceptions and needs in Barbados and Dominica to ensure that end-users, the health sector in this case, and climate service providers are involved in the co-development of the final product, so that it is credible and usable [66]. The assessment was designed to address the four pillars identified by the GFCS: communications and partnerships, research and evidence linking climate and health, capacity development, and mainstreaming climate services for health operations (Box 2). We identified the roles and responsibilities of key climate and health stakeholders, and analyzed their perceptions, interests, and needs [67,68]. The results of this study provide recommendations to enhance an interdisciplinary dialogue and partnership within an active community of practitioners and experts in the area of climate and health [60,66]. This study compliments prior studies conducted in the Caribbean on community perceptions on climate change and public health [69].

Box 3. Key themes on climate and health for the stakeholder analysis

Pillar 1: Communications and partnerships

- Stakeholder mapping
- Priorities/mandates/competencies
- Strategies to strengthen the collaboration between climate and health sectors

Pillar 2: Research and Evidence linking climate and health

- Past projects on climate and health
- Risk factors for *Aedes aegypti* transmitted diseases
- Effects of climate on health (other than *Aedes aegypti* transmitted diseases)

Pillar 3: Capacity development

- Current strengths and weakness of the climate and health sectors
- Needs of the climate and health sectors

Pillar: 4 Mainstreaming climate services for health operations

- Current use of climate/weather information in VBD planning and interventions
- Ideas for climate services
- Issues to address in developing a climate service
- Application of climate service for public health decision making and planning

Methods. We conducted interviews and surveys of key informants from the climate and health sector, as done in prior studies [70–73]. The survey and interview instruments were developed for this project (Appendices 3,4, and 5), and were field tested prior to implementation. Components of the survey on perceptions on climate variability and health were adapted from a national-level study of climate change perceptions in the health sector in the United States [74,75]. Surveys were conducted by MoH practitioners who attended national consultations on the development of climate services for arboviruses in Barbados and Dominica. Interviews were conducted face-to-face with key informants from the climate and health sectors (n=36) in April and May 2017. Key informants were identified by local partners, and through snowball methodology. Interviews were audio recorded following permission from the interviewee; recordings were transcribed and coded using standard qualitative methods to identify key themes [76,77] (Box 3). We surveyed health practitioners (n=32) who attended national consultations on the development of climate services for arboviruses in Barbados and Dominica in April 2017. Survey responses were later entered into an online digital database using Qualtrix.

Background on study participants. We surveyed 32 health sector practitioners from the following jurisdictions: ten from Dominica, twenty from Barbados, and two with a regional jurisdictional. Most of the respondents (n=28) were from Ministries of Health; one respondent was a vector control services provider, and two respondents were from the regional PAHO office. Most of the participants were women (71.9%) and most had a Master's degree as their highest level of training (59.4%). The majority of respondents (62.5%) had been working in the health sector for 15 years or more. We interviewed 36 key informants, with 70% from the health sector and 30% from the climate sector. Most informants worked at the national or sub-national level (75%), and one quarter worked at the regional level (25%). On average the interviewees had 19 years of experience in their sectors. Informants represented diverse fields, including meteorology, geography, climatology, water engineering, public health, environmental health, epidemiology, agrometeorology, microbiology, wastewater management, hydrogeology, among others.

An overview of the competencies and mandates of the climate and health sectors with respect to the development of climate services for VBDs is presented in Appendix 1. Detailed results of the theme analysis of the interviews are shown by country and region in Appendix 2, and survey results are shown in Appendix 8.

Pillar 1: Communications and partnerships: creating an enabling environment and identifying effective strategies

Perceptions on climate variability and health. The majority of the public health practitioners felt that their jurisdiction is currently experiencing one or more serious public health problems as a result of climate variability (68.8% agreed or strongly agreed) (Table 1). Additionally*,* most respondents agreed that their jurisdiction is experiencing an increased the risk of diseases transmitted by *Aedes aegypti* due to climate variability (78.1% agreed/strongly agreed), and that the risk will increase in the future (81.3% agreed/strongly agreed). The respondents concluded that they are worried about the effects of climate variability on health (93.8%), and that this is an urgent problem in their jurisdiction (81.3%). To a lesser extent, they also indicated that the public was concerned about the health impacts of climate variability (56.3% agreed/strongly agreed)

The respondents considered that they are knowledgeable about the potential public health impact of climate variability (78.2% agreed/strongly agreed). To a lesser extent, they indicated that the senior management are knowledgeable (53.2% agreed/strongly agreed) and that dealing with the effects of climate variability on health is a priority for their health department (59.4% agreed/strongly agreed). Although most felt that there are options or solutions to reduce the effects of climate variability on health (65.6% agreed/strongly agreed), they recognized limitations in their capacity to respond. Respondents indicated that their health department did not have sufficient resources or expertise to create and implement an effective plan to protect local residents from the impacts of climate variability (37.5% agreed/strongly agreed that they had sufficient expertise to assess the impacts; 31.2% agreed/strongly agreed that they had sufficient expertise to create a plan; 9.4% agreed/strongly agreed that they had sufficient resources). Due to these limitations, respondents were unclear as to whether their health department would be able to effectively communicate the health impacts of climate variability to local communities (31.2% disagree/strongly disagree versus 40.6% agree/strongly agree).

Current partnerships. Interviewees from the MoH of Barbados and Dominica identified PAHO, CARPHA, and CIMH as the key regional institutions (Figure 1). The Red Cross was the most frequently mentioned non-governmental organization (NGO). To date, the MoHs work with their respective national meteorological institutes on specific projects or as needed, but there is no formal collaboration. Key international partners or funders included Health Canada, the Global Environmental Facility (GEF), and Department for International Development of the United Kingdom (DFID), and the U.S. Centers for Disease Control (CDC). At a national level, the MoHs partner with the Ministry of Education, the Government Information Service (in Barbados only) and private sector media for public education and messaging for VBD prevention. For vector control, they partner with the institutions responsible for solid waste management, tourism, utility companies, local government (e.g., village councils in Dominica), the water authority, town planning, and land surveyors departments. Faith-based organizations and other community-based organizations (e.g., Scouts, Rotary Club) have played an important role in community mobilization for vector control. In Barbados, the MoH also partners with the Department of Emergency Management (DEM) for pandemic preparedness, and they lead the health services standing committee of the DEM. Agencies working on disaster risk management are relevant during climatic extreme events as they can critical information on health impacts, coordinate a response, and provide humanitarian aid.

Table 1. Perceptions on climate variability and health. Results shown as % (n).

Questions	No response	Don't know	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
My jurisdiction is currently experiencing one or more serious public health problems as a result of climate variability.	6.3 (2)	3.1 (1)	0 (0)	12.5 (4)	9.4 (3)	56.3 (18)	12.5 (4)
My jurisdiction is currently experiencing an increased risk of diseases transmitted by *Aedes aegypti* due to climate variability.	3.1 (1)	6.3 (2)	0 (0)	3.1 (1)	9.4 (3)	50 (16)	28.1 (9)
In the next 20 years, my jurisdiction will experience increasing risk of diseases transmitted by *Aedes aegypti* due to climate variability.	3.1 (1)	12.5 (4)	0 (0)	3.1 (1)	0 (0)	46.9 (15)	34.4 (11)
I am worried about the impact of climate variability on the health and well-being of people in my jurisdiction	3.1 (1)	0 (0)	0 (0)	0 (0)	3.1 (1)	46.9 (15)	46.9 (15)
The effects of climate variability on the health of people in my jurisdiction is an urgent problem	3.1 (1)	3.1 (1)	0 (0)	0 (0)	12.5 (4)	59.4 (19)	21.9 (7)
There are options/solutions to reduce the effects of climate variability and to improve the health of people in my jurisdiction	3.1 (1)	3.1 (1)	0 (0)	15.6 (5)	12.5 (4)	40.6 (13)	25 (8)
The people in my jurisdiction are worried about the effects of climate variability on their health and well-being.	6.3 (2)	3.1 (1)	0 (0)	21.9 (7)	12.5 (4)	50 (16)	6.3 (2)
My health department currently has ample expertise to assess the potential public health impacts associated with climate variability that could occur in my jurisdiction	3.1 (1)	0 (0)	0 (0)	40.6 (13)	18.8 (6)	34.4 (11)	3.1 (1)
Dealing with the public health effects of climate variability is an important priority for my health department	6.3 (2)	0 (0)	0 (0)	12.5 (4)	21.9 (7)	31.3 (10)	28.1 (9)
I am knowledgeable about the potential public health impacts of climate variability.	3.1 (1)	0 (0)	0 (0)	15.6 (5)	3.1 (1)	71.9 (23)	6.3 (2)
The other relevant senior managers in my health department are knowledgeable about the potential public health impacts of climate variability.	12.5 (4)	3.1 (1)	0 (0)	18.8 (6)	12.5 (4)	43.8 (14)	9.4 (3)
My health department currently has ample expertise to create an effective plan to protect local residents from the health impacts of climate variability	6.3 (2)	6.3 (2)	0 (0)	34.4 (11)	21.9 (7)	28.1 (9)	3.1 (1)
My health department currently has sufficient resources to effectively protect local residents from the health impacts of climate variability	9.4 (3)	6.3 (2)	9.4 (0)	46.9 (15)	18.8 (6)	9.4 (3)	0 (0)
My health department is able to effectively communicate the health impacts of climate variability to local communities	9.4 (3)	0 (0)	3.1 (1)	28.1 (9)	18.8 (6)	37.5 (12)	3.1 (1)

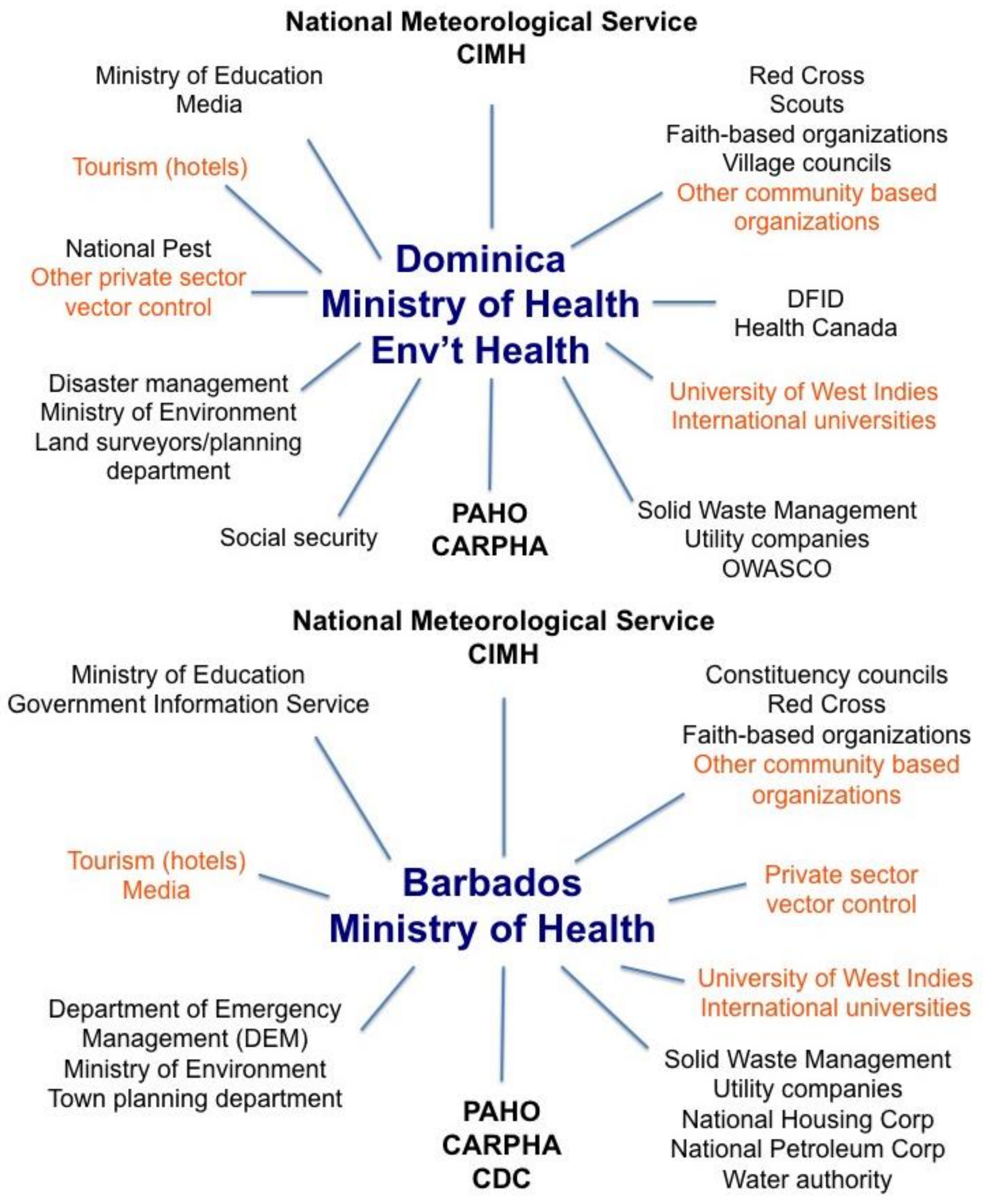


Figure 1. **Stakeholder analysis.** Organizations that work with the Ministries of Health in Barbados and Dominica on issues related to vector control and climate services for health. Organizations in orange are those that key stakeholders identified as needing to develop a stronger relationship, e.g., the tourism, media, private sector vector control, community-based organizations, and universities.

Future partnerships. The private sector, especially tourism, media and vector control companies, was one of the key sectors that the MoH identified as an area to strengthen their partnerships. Tourism is an economic driver throughout the Caribbean, and disease epidemics have a major impact on tourism. Informants suggested that vector control activities could become part of the corporate social responsibilities of companies in the tourism sector (e.g., hotels) in order to reduce the burden on the MoH. Private media companies could also assist with public health messaging, as has been done in both countries. Informants identified the need to strengthen partnerships with private sector vector control companies, which are contracted by individuals and companies to spray insecticides to control adult mosquitoes. These companies are largely unregulated, and their activities could potentially increase insecticide resistance. The need to license and regulate private vector control companies was identified as a priority area. Academic institutions, such as the University of West Indies and international universities, were identified as another key sectoral collaboration to strengthen. These partnerships could increase research on climate and health and provide training opportunities. The last sector to strengthen was civil society organizations. Informants highlighted the importance of engaging NGOs and faith-based organizations in order to mobilize communities to take actions to reduce the burden of VBDs.

Strategies for collaboration between the climate and health sectors

> "Sometimes it's about forgetting yourself and putting yourself in the other person's shoes to really figure out what the need is about. That's true engagement."

Interviewees were asked to identify effective strategies to strengthen the partnership between the climate and health sectors. Informants from the health sector emphasized the importance of engaging senior leaders from the MoH to raise the profile of climate and health on the health agenda, and to ensure that actions are driven from the top-down. They highlighted the importance of signing a formal agreement for collaboration between the climate, health, and other sectors, such as the multi-lateral agreement that was recently signed between CIMH, CARPHA, and other agencies in the region to advance climate services through a process of co-development and co-delivery of sector-specific information. These types of agreements signal that there is a strong commitment from the heads of the institutions and an understanding of mutual benefit. Following the signing of the agreement, it was suggested that an ad hoc or standing committee on climate and health be established in order to specify the work that would be done jointly, the roles of each partner, a timeline for an operational plan, standard operating procedures (SOPs) including a framework for communication, data sharing, and clear reporting guidelines.

Interviewees indicated that it would be important to create joint spaces for dialogue between the climate and health sectors, such as regional and national climate and health forums. One informant from the climate sector stated,

> "Just sitting with people in the sectors makes such a big difference… Understand them, what drives them, what their needs are… because we might think they need something they don't"

This would help to build relationships and increase the trust people working in both sectors, so that each group would learn about the needs and perspectives of the other, what information can be shared, and what resources are available to help each other. One interviewee stated the following,

> "Once we build the trust, then we build the network, then we can see what the willingness to collect, to centralize, to digitize, and to share the data really is."

For example, the MoH could partner with the national meteorological services to ensure that new weather stations are placed in areas that are strategic for the surveillance of VBDs. It was suggested that the planning unit of the MoH should be included in these meetings, as they influence policy and resource allocation. It was also suggested that representatives from the national meteorological service participate in epidemiological surveillance meetings.

The partnership between the health and climate sector are critical to ensure the commitment and ownership by different stakeholders and end-users as the climate services are developed. In particular, the health sector should be represented at the highest level, and based on some memorandum of understanding and letter of intent for different programs, projects and activities with the climate-weather community and other stakeholders. From the assessment the following suggestions,

- A Memorandum of Understanding (MoU) or Letter of Intent (LOI) between the Meteorological Services (national & regional) with the public health sector is a powerful strategy to develop climate services for health, allowing all parties to identify common areas of interest.
- If authorities and decision makers are willing to support the development of climate services for health, this would involve financial and human resources. Access to funding opportunities will be enhanced by strong inter-institutional partnerships.
- National Adaptation Plans for Climate Change may be an opportunity to include a policy or mandate for climate in the health sector.

Overall, climate/weather information is considered in the health organizations (seasonality and extreme events) for general planning, but it plays a minor role in decision-making, which is mainly driven by policies, regulations, and specific competencies of the organizations. The current use of climate information is described in more detail below.

Box 4. Assessing climate services for health based on stakeholder's institutional competences and mandates (See Appendix 1 for a full description).

- Understanding and mitigating the effects of climate on health are relatively high priorities in the MoH, but climate and health is not yet a mandate.
- VBDs are a high priority because of the high burden of disease.
- The MoH is involved in demonstration projects on climate change, climate services, environmental health, and adaptation strategies.
- Currently the national meteorological services do not have a mandate to work on climate and health.
- Climate information is not used for decision-making or budget allocation; however, the schedule of vector control interventions depends on the wet and dry seasons.

In this pilot project, the climate/weather services for health (specifically for VBDs) has been considered because high policy level organizations (PAHO/WHO, WMO, CARPHA) are encouraging the application of the GFCS. However, to make this initiative sustainable, it needs the political decision to establish climate services for health as a mandate in the public health sector working in an interdisciplinary/interinstitutional team with the regional and national meteorological services in each country. The benefits of this decision could extend other sectors, at the government agencies and private sector, such as the Ministry of Environment, which works on adaptation to climate change, disaster risk management, environmental health. It would also offer the opportunity to engage regional universities, research centers, and sustainable development agencies.

In this context, informants highlighted the importance of framing climate services for health as an economic development priority due to the high social and economic burden of VBDs and other health issues. One informant from the climate sector stated,

> "I think people will embrace climate and health… [it is] a real sustainable development goal… Health has always been a critical sector"

Framing climate services for health as a development priority would increase buy-in from decision makers and funding from international development agencies.

In conclusion, an analysis of key stakeholders and partnerships is an important step in developing climate services for health. It can be done by through comprehensive mapping of other potential users of climate services, some of them mentioned in this report, to address their needs, their purposes, and scope of work.

National-level opportunities

- *Potential stakeholders to engage in the development of climate services for health include:* a) Water agencies related to water supply, and water quality (drinking and wastewater) because of their potential links to water borne diseases, b) disaster risk management agencies that deal with hydroclimatic risks that impact vulnerable populations and key infrastructure, c) environmental health offices that would need some training to assess the impacts of weather and climate in some of the issues they are monitoring (urban heat island, air pollution and climate interaction, dust storm and respiratory diseases, heat and metabolic syndrome, etc.), d) tourism, to protect the visitors health, as well considering human mobility a critical factor for disease transmission, d) private sector vector control companies and community bases organizations.
- In the decision-making arena, there is a need for economic assessments to analyze different interventions, benefits and losses, under different scenarios of climate impact, from seasonal, to extreme events (El Nino, extreme storms, etc.). The area of expertise on climate impacts (damage and losses) on health and other sectors, is relatively new, bringing the opportunity to include these kind of assessments in the development of climate services for health.
- Lastly, informants highlighted the need to train, nurture, and retain a cohort of individuals trained in climate and health in order to provide long-term sustainability for a program on climate and health

Regional-level opportunities:
For the Caribbean Region, regional perspectives and considerations are relevant for all the countries. Successful projects and tools developed in the demonstration projects can be replicated in similar setting in other countries. Some of the opportunities identified are:

- A demonstration of the benefits of climate services for VBDs interventions in one country can be used as a model for other productive sectors (tourism, water supply, disaster risk management), and other countries in the region.
- Regional institutions can work in cooperation to build technical capacities and resilient communities across the region. This is already happening, and is increasing expertise and awareness of users and providers.
- CIMH would strength their regional platform for engaging stakeholders to share lessons, promote awareness and learning on climate services based on user-needs.

Perceptions of climate and health

- Health practitioners demonstrated concern, self-awareness and a good level understanding of the public health impacts on the climate variability, including the transmission of VBDs by *Aedes aegypti.*
- Health practitioner's perceived that senior managers and authorities are less knowledgeable and concerned about the public health risks of climate variability.
- Surveys responses suggest that climate variability impacts on VBDs is a relevant public health issue, but they are not prepared to develop plans for climate and health adaptation measures. They are aware that they lack resources and expertise, areas to be addressed in Pillar 3: Capacity Strengthening.

Pillar 2: Research and evidence linking climate and health

> "What are the health impacts with future climate and how will these emerging societies in the Caribbean fare as we move forward in the 21st century under changing climate?"
>
> "We want more evidence-based decision-making. We want data… That's priority #1… to get the evidence."

Climate and non-climate risk factors for diseases transmitted by *Aedes aegypti*. Survey respondents and interviewees were asked to identify and assess climate and non-climatic risk factors for epidemics of diseases transmitted by *Ae. aegypti* (Table 2). The most important risk factor was the introduction of new viruses to susceptible populations, identified by 100% of survey respondents as important or very important. The frequent (re)-introduction of viruses and vectors is associated with human movement between the islands due to trade and tourism, which was identified as an important or very important risk factor by 90.7% of respondents. On Dominica, respondents also identified movement between rural and urban areas as a risk factor.

Water storage behavior was the second most important risk factor (96.9% important/very important). In Barbados, household water storage was associated with drought conditions and the resulting water scarcity. Another key risk factor associated with water storage in Barbados was legislation by Town and Country Planning, which requires that all building over a certain size have large water storage receptacles. This legislation was enacted to increase drought resilience; however, it lacks standards regarding how the water storage receptacles are constructed, and as a result, these have become mosquito-breeding sites. In Dominica, water storage increased after Tropical Storm Erika in 2015. The storm damaged the piped water systems and rivers were contaminated, resulting in a scarcity of potable water. As a result, homes began storing water in drums, and this practice continues today even though most homes (>90%) have access to reliable piped water. One informant described the effects of Erika,

> "After the tropical storm Erika, everything just got a little more vulnerable than it used to be… it was just one downpour of rain that caused all of the destruction."

The most important climatic risk factor was heavy rainfall (90.7% important/very important). Informants from both Barbados and Dominica identified the onset of the hot, rainy season as a risk factor, although they indicated that the linkages between rainfall and dengue fever risk has become less clear due to water storage practices. This contradiction was highlighted by two respondents,

> "If the rain falls very heavily within 2 weeks expect to have an increase in number of cases. It's always associated with rainfall."
>
> "With these droughts, there doesn't seem to be in the last few years a real dengue season."

In Barbados, an important risk factor associated with rainfall was the improper management of public utilities and infrastructure (e.g., telephone junction boxes, manhole covers, public wells, drains), which can become cryptic mosquito breeding sites that are difficult to find and treat. Other climate factors (e.g., drought conditions, warm air temperatures, El Niño/La Niña events) were identified as less important risk factors in surveys. Although some interview informants indicated that warmer temperatures would increase disease risk by speeding up the life cycle of the mosquito vector, they indicated that there was no local evidence to support this hypothesis. This lack of clarity regarding the effects of temperature on dengue risk is consistent with findings from prior studies of community perceptions in the Caribbean [69]. Interviewees from Dominica also identified a changing climate and many microclimates as risk factors. They noted that *Aedes aegypti* had spread into higher elevation areas where the mosquito had not been present in the past.

The next major risk factor was related to limited community engagement and mobilization (90.7% important/very important). The majority of survey respondents identified lack of community knowledge and awareness (81.3%) and low risk perception (81.3%) as important or very important risk factors. This was confirmed by interviewees who indicated that major risk factors were the lack of awareness, attitudes that the government was responsible for vector control, and low risk perceptions of community members.

The final risk factor identified as significant by both interviewees and survey respondents was the high degree of insecticide resistance, which reduces the efficacy of vector control interventions (87.6% important/very important). CARPHA has partnered with the MoHs to conduct insecticide resistance testing.

Table 2. Factors that trigger epidemics of diseases transmitted by *Aedes aegypti.* Results shown as % (n), listed in order of most to least important.

Categories	No response	Slightly important	Moderately important	Important	Very Important
Introduction of a new virus to a susceptible population	0 (0)	0 (0)	0 (0)	9.4 (3)	90.6 (29)
Water storage behavior	3.1 (1)	0 (0)	0 (0)	15.6 (5)	81.3 (26)
Mosquitoes that are resistant to insecticides	0 (0)	6.3 (2)	6.3 (2)	18.8 (6)	68.8 (22)
Heavy rainfall	0 (0)	3.1 (1)	6.3 (2)	46.9 (15)	43.8 (14)
Human movement	0 (0)	3.1 (1)	6.3 (2)	46.9 (15)	43.8 (14)
Insufficient staff/resources for vector control	0 (0)	0 (0)	12.5 (4)	43.8 (14)	43.8 (14)
Lack of community knowledge and awareness	0 (0)	3.1 (1)	15.6 (5)	37.5 (12)	43.8 (14)
Limited community engagement/mobilization	0 (0)	3.1 (1)	6.3 (2)	56.3 (18)	34.4 (11)
Drought conditions	3.1 (1)	31.3 (10)	9.4 (3)	25 (8)	31.3 (10)
High-risk housing conditions	9.4 (3)	12.5 (4)	21.9 (7)	25 (8)	31.3 (10)
Low risk perception by communities	3.1 (1)	3.1 (1)	12.5 (4)	50 (16)	31.3 (10)
Economic barriers to mosquito control by households (e.g., cost of screens or insecticide)	0 (0)	9.4 (3)	31.3 (10)	34.4 (11)	25 (8)
El Niño or La Niña events	3.1 (1)	6.3 (2)	18.8 (6)	50 (16)	21.9 (7)
Warmer air temperatures	6.3 (2)	25 (8)	18.8 (6)	31.3 (10)	18.8 (6)

Other effects of climate variability on health. Interview respondents were asked to identify other ways in which climate affected either directly or indirectly the health of people in their jurisdiction. Informants from both Barbados and Dominica identified a wide range of interrelated health effects associated with climate including increased risk of diabetes and heat stress associated with hotter days and nights, leptospirosis associated with flooding, communicable diseases associated with the relocation and crowding of people in shelters following extreme climate events, malnutrition associated with droughts that reduce crop yields and warming temperatures results in fish kills, and respiratory problems (e.g., asthma) associated with dry weather, dust and air pollution. One informant described the complex web of causality associated with the effects of climate on health in the following,

> "[During droughts] people are not able to go to their farms, they don't have food and their nutrition suffers. They don't have income... they cannot get their medications… So its just the rippling effect."

Respondents also recognized that most of these linkages were anecdotal or were hypotheses, since there have been few studies on climate and health, as summarized by one respondent,

> "So we have not been able to make a direct link between those diseases and climate variability and change; however, we know that there has been an increase as a result of climate variability… the data to make that linkage… is not really always available."

Factors unique to Barbados included hypertension due to sea level rise and salt water intrusion into the groundwater supply, reduced hygiene and *Pseudomonas* infections due to water scarcity and storage, skin cancer due to UV exposure, and water-borne diseases (e.g., gastroenteritis, salmonella) due to flooding resulting in contamination of the water supply with fecal matter. Factors unique to Dominica included loss of lives due to landslides and other effects of extreme climate events (e.g., Tropical Storm Erika), mental health problems, especially for vulnerable populations (e.g., the elderly), who are relocated following extreme climate events, gastroenteritis associated with dry weather conditions, and potential increased risk of gastroenteritis and cholera following extreme climate events.

Overall, informants stressed the need to strengthen the evidence base linking climate and health in their jurisdictions. They displayed a high degree of field experience and local knowledge, but indicated that they had little knowledge of empirical studies that could inform their decision-making and planning processes. One key recommendation is to continue to support different case studies in the region, such as this pilot study. Informants suggested focusing these investigations and interventions on the climate variability timescale (e.g., seasonal variation, extreme climate events), rather than the climate change time scale. Collaborative scientific articles with co-authors from the climate and health sectors would facilitate data sharing, build trust, and foment a culture of research on climate and health. Development of data sharing protocols between the climate and health sectors was identified as a priority area. This is especially important given the sensitivity of sharing health information. One informant suggested creating a shared online data portal on climate and health for the region to facilitate sharing of data and knowledge across the Caribbean.

Pillar 3: Capacity development

Health sector strengths and weaknesses for the development of climate services. Survey respondents from the health sector were asked to identify the strengths and weaknesses of their institution with respect to the implementation of an EWS for *Aedes aegypti* transmitted diseases (Figure 2, Table 8.2). The top strengths were effective public health messaging/education, effective vector and disease surveillance infrastructure, general knowledge about the effects of climate on VBDs, strong coordination with other institutions/NGOs/private sector, and mobilization and coordination with local communities.

The top weaknesses, or areas to be strengthened, were availability of financial resources, expertise in geographic information systems (GIS), statistical or modeling expertise, and computer programming expertise. Interviewees from the climate and health sectors highlighted the need for additional personnel dedicated to climate and health, given their limited human capacity.

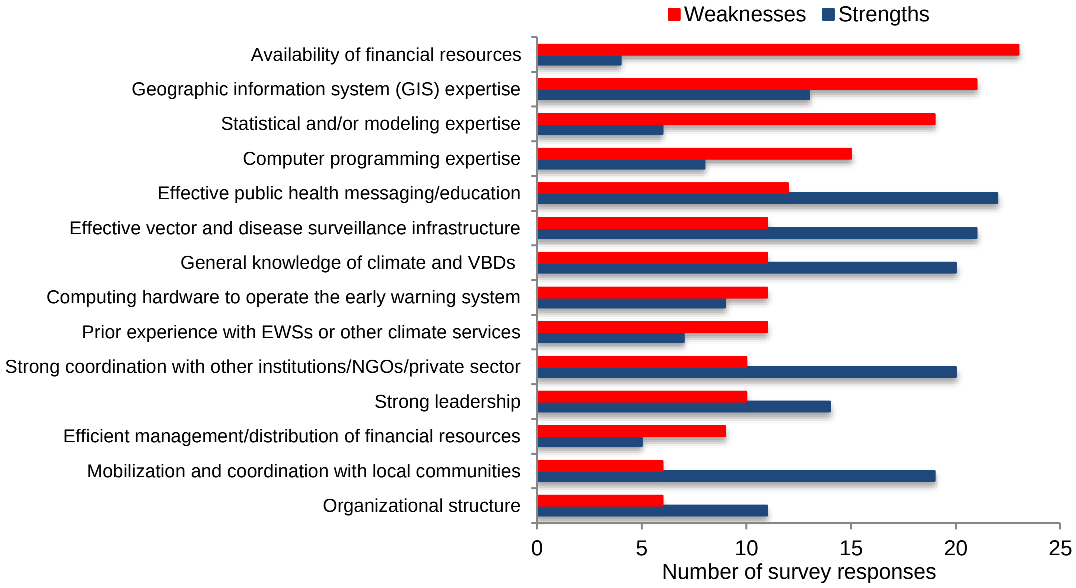


Figure 2. Strengths and weaknesses of the health sector with respect to the implementation of an early warning system for *Aedes aegypti* transmitted diseases

Software used in the health sector. Survey respondents from the health sector indicated that their departments currently use basic analysis and visualization software such as Excel (75% of respondents), Epi Info (62.5%) and Google Earth (56.3%) (Table 8.3). A smaller proportion reported using database software (Microsoft Access 50%), GIS software (ArcGIS 28.1%, QGIS 21.9%), statistical software (SPSS 21.9%, Stata 3.1%), and programming languages (Java 9.4%, visual basic 3.1%).

Technical training needs. Interviewees from the health and climate sectors identified as a high priority the need for training on climate and health linkages, greater understanding of climate services for health, and how to use climate services for health during emergencies/disasters. They suggested that training be practical and interactive, such as simulations.

The health sector also identified as a high priority the need for training on geographic information systems (GIS) to be able to identify areas at risk of vector-borne diseases (75% of respondents, Table 8.4). They identified the use of maps as a highly effective strategy to utilize the data collected from the field to make informed decisions for targeted vector control interventions, and also to communicate risk information back to the public.

> "It is so much easier, better, to use maps when you are doing presentations. Especially if you are doing something with the public where you can actually show them their community and say, 'There you have breeding sites. There is where you have the problem.' And they can actually see it. You can actually show it to them."

They also recognized the need to increase their skills in modeling and data analysis through technical workshops on how to use climate information, data, models and other tools to predict epidemics (78.1% of respondents, Table 8.4).

Other training topics identified by the MoH included how to communicate the effects of climate on health to location communities, medical entomology, writing proposals for external funding, and scientific methods. In Dominica, interviewees highlighted the need for vector control specialists in the MoH, since their environmental health officers are responsible for a broad portfolio of activities and are trained as generalists. Both countries highlighted the need for better data collection and storage practices in the health sector in order to create high-quality, long-term datasets. To address this need, there are initiatives in the region to begin collecting field entomology data using hand-held devices (e.g., cell phones, tablets). On Dominica, EHD interviewees also suggested that they be trained in how to download data from meteorological stations in order to increase the capacity of the meteorological services.

Climate sector needs. In addition to basic training on climate and health, the climate sector indicated that they wanted a better understanding of the needs of the health sector in order to support the development and implementation of climate services for health. In Dominica, the national meteorological service indicated the need for basic resources to increase their monitoring and forecasting capacities, including adequate transportation to and from meteorological stations, financial resources, and improved security at the stations.

Opportunities for capacity building

- By strengthening regional and national climate-health sector partnerships (Pillar 1), there will be more opportunities to attract the financing needed to increase local capacities to develop climate services for the health sector.
- There is a demand for basic training to increase technical knowledge on climate and health linkages. This was also identified as a key strategy to strengthen the partnership between the climate and health sectors.
- The health sector is currently using tools for basic disease mapping. GIS training was identified as a key topic for capacity building.
- It is very important to assess user–needs in order to develop tailored visualizations of VBD risk and interventions that are useful and relevant. This is an opportunity for co-production with the health and other sectors such as urban planning, disaster risk management, city utilities and services.
- Developing targeted training in GIS that is driven by user-needs will help in visualization and data analysis at local level.
- There is the opportunity to develop user-friendly tools/instruments that can be applied by the health sector without specialized expertise in their routine data and reporting activities. The co-production of tools, and products can be developed within the GFCS climate services framework.
- Overall, the appropriate involvement of stakeholders is a key element to identify users' needs, to develop users' capacities and to exploit existing capabilities.

Pillar: 4 Mainstreaming Climate Services For Health Operations

Current use of climate/weather information for planning VBD interventions. The health sector was asked about the current use of climate information in their activities. The majority of survey respondents (68.8%) indicated they had received information on the effects of climate on VBDs, and half of the respondents confirmed that climate information is used for some level of planning for disease and vector control interventions (Table 8.5). With respect to an EWS for epidemics, most respondents (78.1%) were familiar with an EWS, but when they were asked if their department has an EWS for *Aedes aegypti* transmitted diseases, they were unsure (12.5% don't know, 40.6% no, 40.6% yes). When asked if the EWS used climatic information, respondents were unsure (65.6% don't know or no response).

Interviewees from the MoHs of Barbados and Dominica indicated that they do consider the dry and wet seasons when they develop their annual plans for VBD interventions; however, they do not formally incorporate climate information, such as seasonal climate forecasts, into their planning process. The MoHs have informal collaborations with their national meteorological services, and may request climate/weather information for specific projects or as needed. The data are generally shared as excel spreadsheets. Interviewees from the MoH in Dominica indicated that they receive the CIMH drought bulletin and weather bulletins from their meteorological service; however, they indicated that this information is not used to inform decision making for VBD interventions. They suggested that these bulletins needs to be more user friendly and less technical, so that public health leaders can use the information to inform decision making. They were especially interested in the use of a climate and health bulletin, such as the bulletin that was recently launched through collaboration among CIMH, PAHO, and CARPHA. One informant summarized this idea in the following,

> "We need it [climate services] packaged in such a way that the health professional would understand. Pick it up, and look at it, and understand it"

Interviewees indicated that to date, there is no EWS that uses climate information or other climate services for VBDs in Barbados or Dominica. The alert system that currently exists for VBDs is based on epidemiological surveillance. When the number of reported cases surpasses a pre-determined threshold established by the historical average for the same week or month, an alert is issued by the MoH and PAHO. This was described by interviewees in the following,

> "Well, we're getting 10 [dengue] samples today, and we get 15 tomorrow, and we get 20 the next day… something is going on"

> "It's really more of a reactive system that we have, so we basically see how the data are coming in and we allocate or redirect our resources accordingly."

Interviewees indicated that the current system did not provide sufficient lead-time to plan and react accordingly in order to reduce the threat of an epidemic.

Ideas for climate services for VBDs. Interviewees were asked to identify climate services that would improve their day to day work related to VBDs. One interviewee from the climate sector defined an effective climate service as any information product that moves beyond the typical tercile forecast to explain what will happen with disease risk if there is above or below normal rainfall or temperature. Health stakeholders suggested that a GIS platform be developed in order to integrate and analyze real-time information on disease epidemiology, entomology, and climate. This platform could be used to produce risk maps showing the spatial distribution of mosquito vectors in relation to climate conditions. It could also be used to produce forecasts of vector abundance or disease incidence using rainfall, temperature, and other climate information. They suggested that these forecasts be converted into spatiotemporal alerts using a color-coding scheme. This approach to epidemic alerts was tested in Brazil, and prior studies have demonstrated the efficacy of communicating epidemic risk using a complex color palette [78]. Other ideas included the use of wind speed and wind direction forecasts to inform insecticide fogging operations, basic sharing of current climate/weather forecasts with those involved in VBD surveillance and control, and climate and health bulletins. Interviewees highlighted the importance of an integrated approach to the development of climate services for health which would include research, operations, a platform for data and knowledge sharing, outreach, awareness raising, education, and an in-country response and mitigation plans and policies.

The health sector were asked how they would prefer to receive information from an EWS that predicts epidemics of dengue fever, chikungunya, and Zika fever. The top responses were: a climate and health bulletin (90.6%), an interactive GIS platform (65.6%) and internal meeting within their departments (59.4%) (Table 8.6).

User-needs and Forecast scenarios. To be viable, an EWS has to be able to provide the right information early enough and reliable enough such that the MoH can save resources through targeted early interventions. A an important aspect of the user-needs analysis is to assess to utility of different types of forecasts and time frames (Appendix 6). Health sector stakeholders were asked to assess the interventions that would occur if they were provided with short (2 week), medium (3 month) and long-term (1 year) forecasts of vector abundance and disease incidence (Appendix 6). In general, they indicated that disease incidence forecasts would be more effective than entomological (vector) risk forecasts in garnering the political attention necessary to mobilize resources to implement preventative interventions. They indicated that forecasts at each time scale could provide important information to inform specific VBD interventions.

Value added of climate services for public health decision making and planning

> "If we can put mechanisms in place, long in advance, then we have more success in dealing with outbreaks. Or we can even *prevent* outbreaks."

> "When you know that there is an impending threat, you would come up with specific activities that you would conduct. It doesn't necessarily mean that those activities would be at a higher cost, but you can be more specific… It will be easier for us to respond to an impending threat, instead of running around."

Health stakeholders highlighted the ways in which climate services would improve their planning for VBD interventions. By integrating climate and/or disease forecasts into their seasonal and annual planning processes, they would be able to be more proactive. With this information, their decision making process would improve and they would be able to reduce costs, because they would able to target high risk areas during certain times of year for vector control interventions. This would result in more efficient use of limited financial and human resources, allowing the MoH to allocate their budget more effectively over the seasons. Forecasts of disease risk could also be used to inform hospitals about staffing needs, stocking of medicines, and to inform purchasing of laboratory diagnostic reagents. Early warning information could also be used to inform the development of targeted educational materials for the public, and warnings can be communicated to the public through social media and other outlets to motivate community mobilization for preventative practices. Public health practitioners also indicated that they would feel more motivated and inspired in their day-to-day work if they could see how the data that they collect is being used to inform decision-making.

Final Recommendations

One of the key conclusions of this assessment is the need to strengthen the provider-user interface, whereas currently there is only limited consideration of the products needed by the health sector users. Climate services for health will be successfully operative only with the will and support of the health sector institutions. At the same time, it is necessary to create appropriate 'communities of practices' and to emphasize the co-design of climate services products [79]. Final recommendations on the stakeholder analysis:

1. To establish a Memorandum of Understanding (MoU) or Letter of Intent (LOI) between the climate and health sectors (national & regional) with a focus on the development of climate services.
2. To consider CIMH as a regional center for promoting climate services for health, with specific demonstration projects, and building capacity around the basic and operative aspects of climate services.
3. To strengthen health sector engagement in the region through annual forums focused on climate services and capacity building tailored to the health sector. This could build on existing regional climate meetings.
4. To develop mechanisms and protocols to integrate climate data, information and knowledge with multiple health and non-health data sources and competencies that are needed to inform decisions.
5. To improve technical GIS and modeling capabilities needed to inform decisions and decision-making processes.
6. To consider the National Plans for Adaptation to Climate Change as an opportunity to strengthen climate services, applying long-term scenarios for planning in health and other sectors.
7. To use the analysis framework developed here to develop climate services for health issues beyond VBDs.

3. Spatiotemporal modeling:

3.1. Multimodel mapping and comparison with other predictive mapping studies of *Aedes* transmission in the Caribbean

In this component, we propose a 3-step approach to providing mapping products for stakeholders. Global mapping of *Aedes* transmission garners attention in the press, and among stakeholders in both health and vector management, but the scale (resolution) and different predictions can make it complicated to apply these at regional or local scales. Global geospatial models have been generated for *Ae. aegypti* [80,81], dengue fever [12,82,83], chikungunya [84], and Zika fever [85–87] (Table 3).

The primary conclusion from this analysis is that open-source data from published literature is limited to nonexistent; the scale of most published models is too broad to make clinically-meaningful predictions at the island scale; and the majority of forecasts simply indicate both Barbados and Dominica are likely to be highly suitable for Zika outbreaks with little further spatial resolution.

Vector occurrence data. Kraemer *et al.* released a compendium of occurrence data for *Ae. aegypti* and *Ae. albopictus* in conjunction with their ecological niche models for the two species [88], which have become widely popular and are almost certainly the most commonly used source of data on the occurrence of the species. The models *per se* have not been immediately available, but the occurrence data is available on Dryad (http://datadryad.org/resource/doi:10.5061/dryad.47v3c). The data presents a "comprehensive database" of known occurrences, in point and polygon form (to accommodate uncertainty), during the 1960-2014 interval. In the entire database, however, there are no recorded presences of *Ae. albopictus* on either Barbados or Dominica. A single recorded presence of *Ae. aegypti* exists for Barbados; five exist for *Ae. aegypti* on Dominica, though one appears to have been georeferenced incorrectly, and is located in the ocean (see Figure 3).

Data from the Global Biodiversity Informatics Facility (GBIF) adds little clarity. There are similarly no records of *Ae. albopictus* on either island in the GBIF database. Moreover, the Messina data was submitted to GBIF, creating a redundancy between the sources. Three additional georeferenced records are available for Dominica on GBIF; only two additional records are available for Barbados (Figure 4).

Ecological niche models. Ecological niche models are one of the most commonly-used and accessible tools in medical geography, made popular by their capacity to estimate habitat suitability based on fairly limited data. Three ecological niche models have been published explicitly for Zika virus. Because of the differences between the methods, the raw probabilities predicted by different models are not inherently comparable across models, or meaningful without the context of their respective studies. Consequently, this analysis is restricted to thresholded, binary outputs of each model. Each model is also based on climate data that is slightly misaligned with the boundaries of the island, and with source code not included in any of the published studies, the extent of the models is not easily changed. All niche models were made available for use at roughly 5 km resolution, further limiting their predictive utility for island work.

The model produced by ***Carlson et al.*** [89] uses the BIOMOD2 ensemble algorithm to predict occurrence based on Bioclim data and NDVI. The BIOMOD2 approach combines a number of different machine learning algorithms to optimize prediction and reduce bias. According to this model, the entirety of Barbados is predicted to be suitable, while a small patch of southern Dominica is marked unsuitable (Figure 5).

The model produced by ***Messina et al.*** [90] uses the most limited variable set, with a handful of climate variables, a vegetation index, land use (urban or rural), and a mechanistic temperature-based index of dengue suitability as the predictors in a boosted regression tree (BRT) model. The Messina *et al.* model is the only one to predict unsuitable area on the southern end of Barbados; and predicts a roughly similar unsuitable area on Dominica to Carlson *et al.*, though the two predictions do not match in any unsuitable pixel (Figure 6).

The model produced by ***Samy et al.*** [91] is the most severe prediction measured in total global extent. Their model utilizes maximum entropy (MaxEnt) regression but, in a rare approach, models social and environmental suitability separately. Social predictors include human population density, nightlight, "accessibility", and land cover; while ecological predictors included non-Bioclim climate variables, vegetation indices, soil characteristics, and two niche model layers (the Kraemer *et al.* niche models for *Ae. aegypti* and *Ae. albopictus*). Because Samy *et al.* suggest that socially-suitable regions might still be prone to outbreaks, the most inclusive presentation of their model is shown here, which includes areas that are at a minimum ecologically *or* socially suitable. No area in Barbados or Dominica is marked unsuitable for Zika transmission by the Samy *et al.* model (Figure 7).

While there are some small variations in predicted suitability between the three niche models, comparison between them suggests no consistent patterns. (In fact, there is no concordance between any models' predicted unsuitable area). The most useful conclusion that can be drawn from these models, at this time, is that the majority of land on both islands is likely to be suitable for sustained Zika transmission.

Mechanistic time-explicit forecasts. The final model currently available for exploration was presented by Mordecai *et al.* as a model for *Aedes*-borne diseases especially in the Americas (including dengue, chikungunya and Zika). Unlike ecological niche models, which are "top-down" and phenomenologically relate environmental predictors to known patterns of occurrence and extrapolate spatially, these mechanistic forecasts use a Bayesian model to infer suitability at a monthly scale from experimental data on mosquito life cycles and disease transmission [92].

The Mordecai *et al.* makes the most expansive predictions for suitability at a global scale, compared to ENMs; so it comes as no surprise that it also makes the strongest prediction for both Barbados (Figure 8) and Dominica (Figure 9). Six potential formulations were tested, using minimum or maximum monthly temperatures against three different Bayesian credibility interval cutoffs. In all six scenarios, the entirety of both islands was predicted to be suitable for Zika transmission a full 12 months out of every year.

Data availability & next steps. The best recommendation that can be made, based on presently available data, is that *Aedes aegypti* is present on both islands, and both appear to be majority-to-entirely suitable for year-round Zika transmission. As it stands, there is insufficient data on *Aedes* occurrence to develop island-specific ecological niche models for mosquitoes. The Mordecai *et al.* model will be re-applied using downscaled data, and the Carlson *et al.* model, the only one of the three currently available for reprojection, can similarly be applied using island-scale environmental data. More detailed entomological surveys will also help make island-scale predictions regarding the abundance of *Aedes aegypti,* and can clarify whether the apparent absence of *Ae. albopictus* is a real phenomenon or simply a lack of sampling. Further effort can similarly be devoted to obtaining more extensive predictions that have been published but are not currently available; however, these models are unlikely to add any useful information, given the existing problems with model resolution.

Table 3. Global maps of *Aedes aegypti*, dengue fever, chikungunya and Zika fever.

What	Who	Data Type (resolution)	URL or availability description
Aedes aegypti and *Aedes albopictus* distribution maps	[80]	Raw occurrence data Mapped data ($10km^2$ pixels)	http://datadryad.org/resource/doi:10.5061/dryad.47v3c VectorMap.org
Updated distribution maps for *Ae. aegypti, Ae. albopictus*	Samy A. et al. *in prep*	Mapped data (resolution uncertain)	https://figshare.com/articles/Updated_Aedes_aegypti_and_A_albopictus_map/3798120
Distribution map for chikungunya (in the Americas)	[93]	Raw occurrence data Mapped model predictions ($\sim4km^2$ pixels)	https://figshare.com/collections/Forecasting_Chikungunya_spread_in_the_Americas_via_data-driven_empirical_approaches/3624302 Unavailable
Distribution map for dengue	[12]	Raw occurrence data Mapped model predictions ($5km^2$ pixels)	https://figshare.com/articles/Dengue_type_specific_global_database_1943_2013/882870 Unavailable
Distribution maps for Zika and dengue	[85]	Raw occurrence data (Zika) Mapped model predictions (5km2)	http://journals.plos.org/plosntds/article/file?type=supplementary&id=info:doi/10.1371/journal.pntd.0004968.s001 Directly available from the authors
Distribution map for Zika	[86]	Mapped model predictions ($5km^2$)	https://figshare.com/articles/Environmental_suitability_for_Zika_virus_transmission/2574298
Distribution map for Zika	[87]	Mapped model predictions ($5km^2$)	https://figshare.com/articles/Mapping_the_global_geographic_potential_of_Zika_virus_spread/2068647

Figures

Figure 3. Kraemer *et al.* data on *Aedes* occurrence. Note that despite the presence of *Aedes albopictus* in the dataset at a global scale, there are no recorded occurrences on either island.

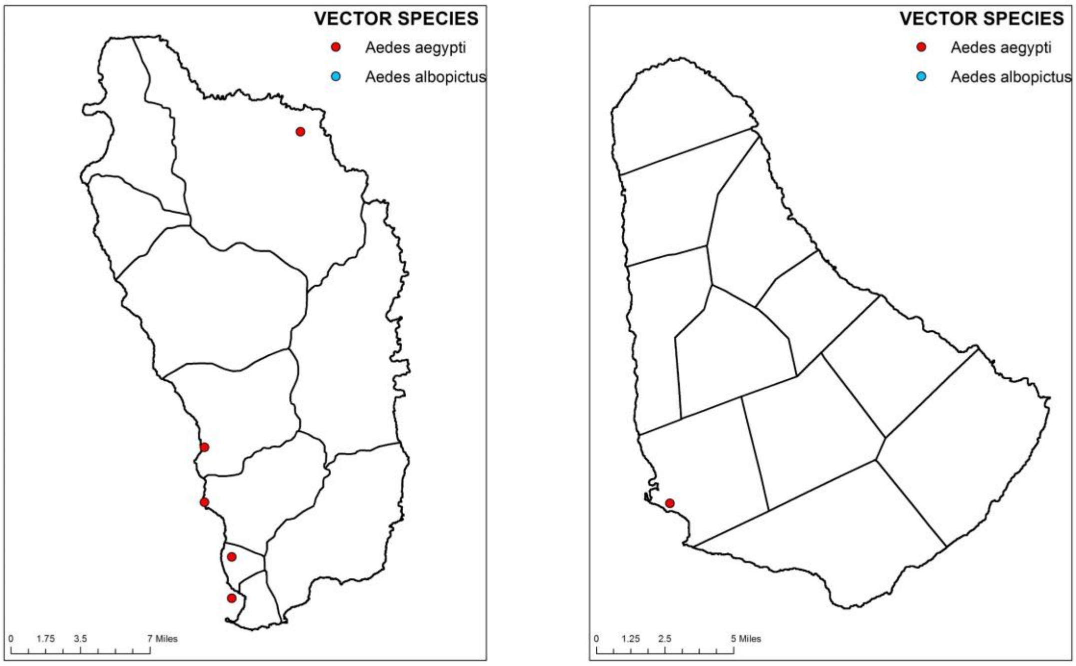


Figure 4. GBIF data on *Aedes aegypti* occurrence.

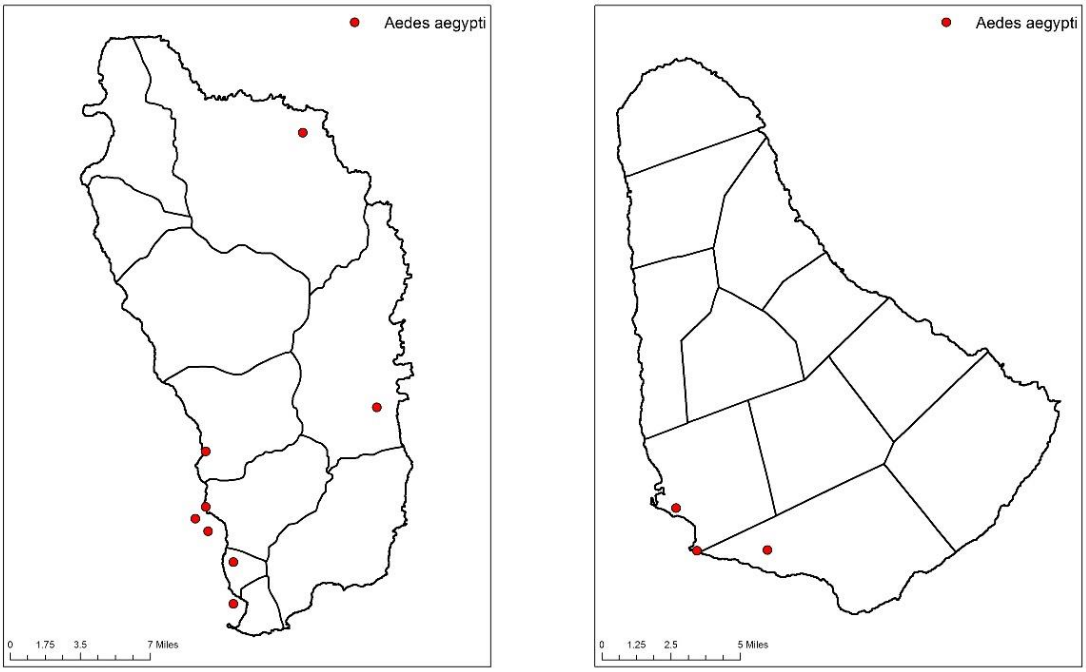


Figure 5. Carlson *et al.*'s ecological niche model for Zika virus.

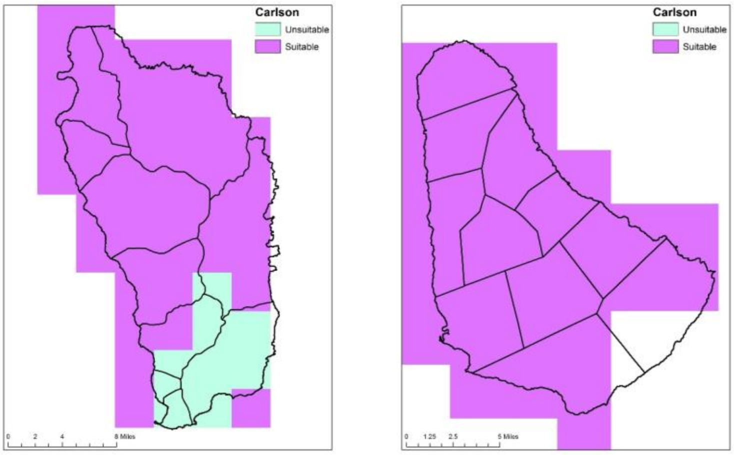


Figure 6. Messina *et al.*'s ecological niche model for Zika virus.

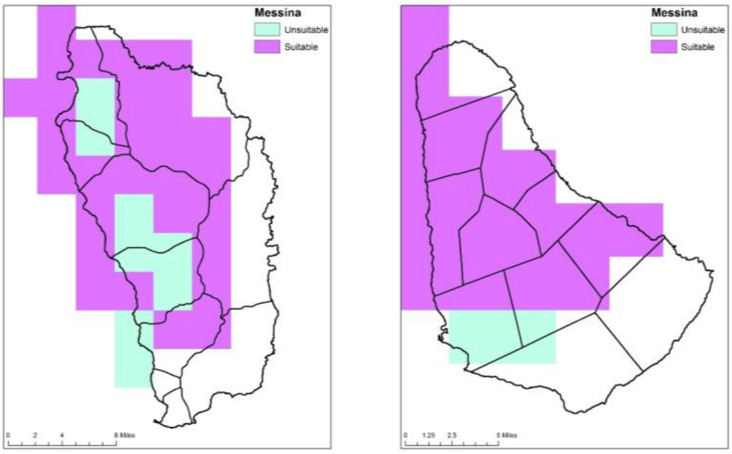


Figure 7. Samy *et al.*'s ecological niche model for Zika virus.

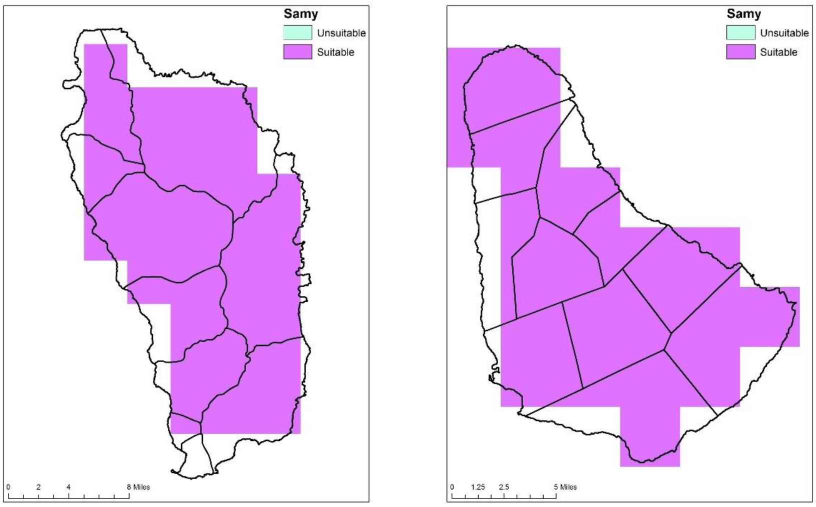


Figure 8. Barbados predictions by Mordecai *et al.* Six scenarios are presented using minimum (top) and maximum (below) temperatures to power the model and subsequently apply a 2.5%, 50% or 97.5% credibility interval (left, middle, right). All pixels are predicted suitable for 12 months of the year

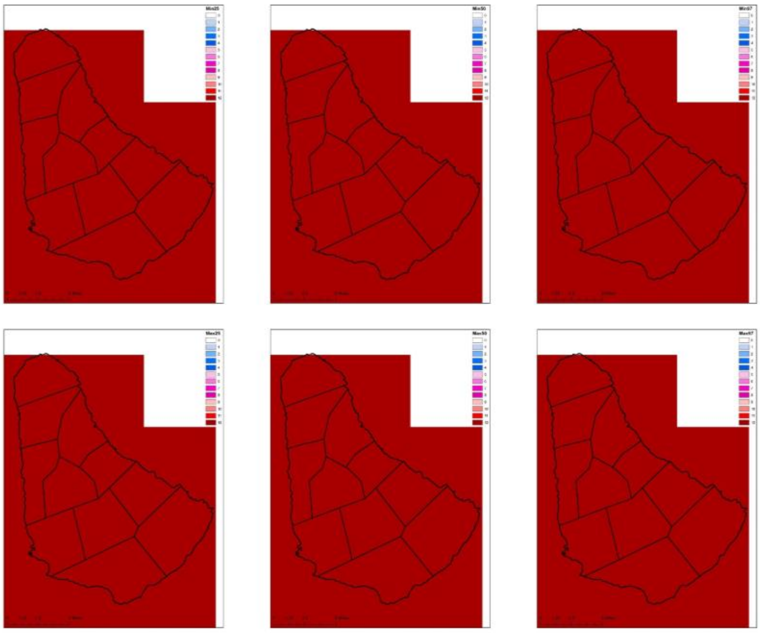
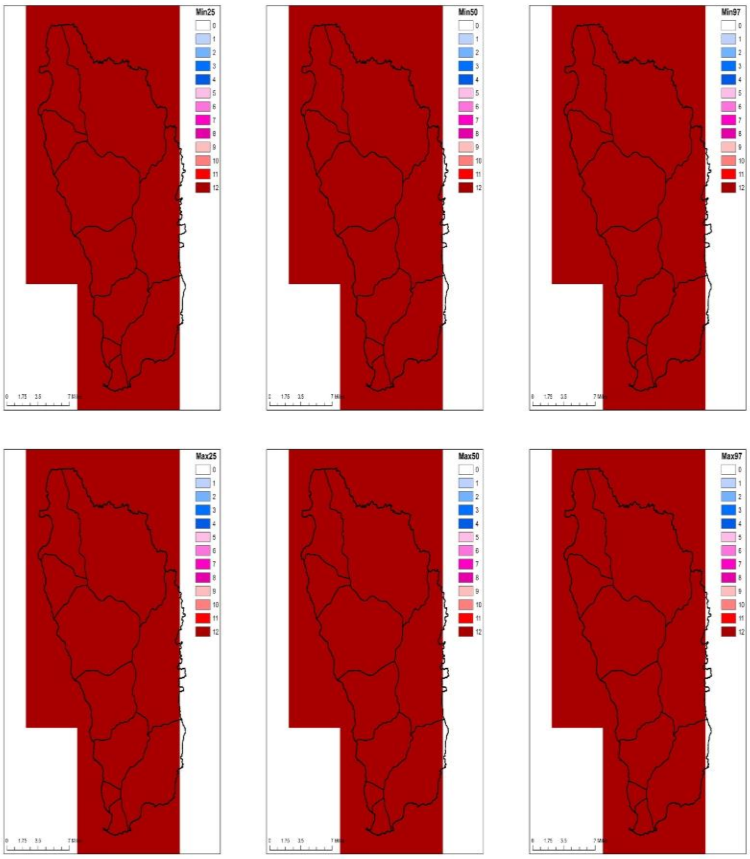


Figure 9. Dominica predictions by Mordecai *et al.* Six scenarios are presented using minimum (top) and maximum (below) temperatures to power the model and subsequently apply a 2.5%, 50% or 97.5% credibility interval (left, middle, right). All pixels are predicted suitable for 12 months of the year



3.2. Epidemiology of the Zika virus outbreak in Dominica, 2016[2]

In February 2016, the World Health Organization declared the pandemic of Zika virus a public health emergency. On March 4, 2016, Dominica reported its first autochthonous Zika virus case; subsequently, 1263 cases were reported. This report describes the outbreak to November 2016, when the last known case was reported.

Zika virus (ZIKV) is a Flavivirus transmitted primarily by *Aedes aegypti* and *Ae. albopictus* mosquitoes. The rapid spread of ZIKV from Brazil throughout the Americas, and the associated emergence of Zika congenital syndrome (ZCS) including microcephaly and other birth defects, has posed an unprecedented challenge to global health[94,95]. Zika spread through the Caribbean comparatively early in the pandemic. Autochtonous transmission in Martinique was first reported in epidemiological week (EW) 51 of 2015, the first case from Puerto Rico was reported in EW 52 of 2015[96], and many other islands began reporting cases early in 2016. However, case data from several countries has yet to be consolidated and described outside of reports by the Pan American Health Organization (PAHO).

Cases were defined by using guidelines provided by the Pan American Health Organization. Active surveillance of Zika cases started as early as January 2016, however the first laboratory confirmed autochthonous case of Zika was identified in March. Data were collected on patients' age, sex, residence, date of illness onset, clinical features, laboratory diagnostic and travel history.

The first known Zika case in Dominica, a 28-year-old woman, was reported on March 4, 2016, during EW 9 for Zika in 2016. New cases were subsequently reported through November 6, 2016 (see Figure 10). The last cases in 2016 were reported in EW 44. In total, 1263 suspected cases of Zika were reported in Dominica in 2016, of which 79 (6.25%) were confirmed with rPCR. Out of all cases, only one tested rPCR negative, but was still classified as a suspected case.

Sex was reported for 1255 of 1263 cases (99.3%). Women were disproportionately represented at roughly a two-to-one ratio, with 863 women (68.8%) and 392 men (31.2%), consistent with most other reports on Zika outbreaks[97]. Age was reported for 1245 of 1263 cases (98.6%). Mean age of cases was 28, and median age was 27. Of those, 217 cases (17.4%) were children under the age of ten, and 756 were of childbearing age (15-49). Women of childbearing age were disproportionately represented within that age range with 555 cases (73.4%); women of childbearing age also made up a sizable portion out of all 1240 cases for which age and sex were both reported (44.8%). A total of 54 reported cases of Zika in pregnant women in Dominica, of which 25 (46.3%) were confirmed. Pregnancy status was only reported for 54 of 863 women (6.3%). Of those 54, 16 were pregnant (29.6% of cases with pregnancy status recorded overall; 35.6% of the 45 cases with pregnancy status recorded for women of childbearing age).

1123 cases of 1263 received medical care (88.9%), with only 27 reported hospitalizations (2.1%). Of the 1123 cases, 844 received medical care on the same day as the case was reported. The average number of days between the onset of symptoms and medical care was 1.96 (n = 1109; [5%,95%] quantiles = [0,5]); the average number of days between days between medical care and case reporting was 0.5 (n = 1096; [5%,95%] quantiles = [0,10]). Two of the 27 hospitalizations were recorded as pregnant women, out of four with reported pregnancy status.

In response to the emerging burden of *Aedes aegypti* transmitted diseases in the Caribbean, the Caribbean Institute for Meteorology and Hydrology (CIMH) has partnered with an international team of investigators to investigate the eco-epidemiology and climate drivers of dengue fever, chikungunya, and Zika fever. This was done through the United States Agency for International Development's (USAID) Programme for Building Regional Climate Capacity in the Caribbean (BRCCC Programme), executed by the World Meteorological Organization (WMO), and implemented by CIMH. Dominica was selected as one of the pilot countries for this investigation, as it had previously been identified as the exemplar country to pilot the implementation of the Global Framework for Climate Services (GFCS) in the Americas[50]. This initiative has brought together the national and regional health and climate sectors (Dominica Ministry of Health, Dominica Meteorological Service, Caribbean Public Health Agency (CARPHA), PAHO, CIMH) to co-develop climate services for the health sector, with a focus on climate-driven spatio-temporal models to predict disease outbreaks. This study contributes to that effort by providing the first epidemiological characterization of Zika fever transmission dynamics in Dominica.

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[2] Manuscript in review at the journal *Emerging Infectious Diseases*.

Aedes mosquitoes are widespread throughout the Caribbean, with dengue and now chikungunya endemic on many islands. As part of the broader pandemic in the Americas, the Dominican outbreak highlights that the presence of *Aedes* can be permissive of explosive outbreaks of Zika, even on small islands. As was also seen with chikungunya[16], the rapid proliferation of Zika cases may be unavoidable in current climates with current vector control measures. If Zika becomes an established problem in the Caribbean like dengue, vector control efforts will need to improve to prevent further impacts on vulnerable populations like pregnant women.

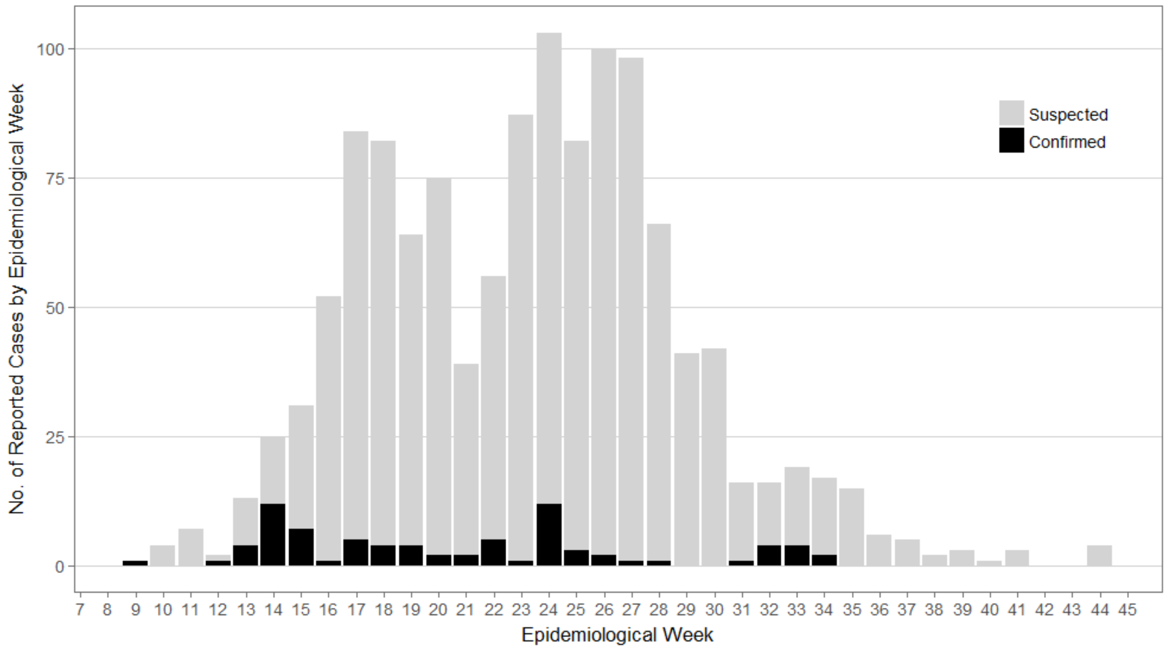

Figure 10. Zika cases (suspected in grey, confirmed in black) reported on Dominica (2016).

3.3 Temporal model of dengue cases from Barbados and Dominica

Model methods. Local climate data (precipitation, minimum temperature) and the Oceanic Niño Index were used in a Bayesian hierarchical mixed model to predict monthly dengue incidence. This modeling approach described in detail in a recent study [56,98], which forecasted monthly dengue fever using climate and ENSO in southern coastal Ecuador. A zero-inflated negative binomial model was used to model counts of dengue cases (with population offset). The developed model is driven by both climate and non-climate factors, and includes annual random effects to allow for unobserved factors and temporal auto-correlations. Climate covariates included precipitation and minimum temperature lagged by 1 month with respect to dengue, and Niño3.4 lagged by 3 months with respect to dengue (*ie,* 2 months with respect to the local climate). Lags were selected based on our experience developing dengue-climate models from other regions in the Americas. Annual random effects for were included to account for interannual changes in dengue risk attributable to unknown factors such as changes in surveillance or vector control practices, and the introduction of new serotypes and viruses (eg, introduction of chikungunya and Zika viruses).

Data sources (Figures 11 and 12):

- Monthly dengue cases from Barbados (1999-2016, lab confirmed cases) and Dominica (1993-2016, suspected and confirmed cases) were provided by the Ministries of Health.
- The national population of Barbados and Dominica was obtained from national censuses (1990, 2000, and 2010 for Barbados; 1991, 2001, and 2011 for Dominica), and the population in the intervening years was estimated assuming linear growth.
- Local weather data (rainfall, minimum temperature) were obtained from the Husbands weather station (lat: 13.15, long: -59.62) operated by CIMH and from Canefield weather station (lat: 15.33, long: -61.39) operated by the National Meteorological Service of Dominica.
- Oceanic Niño Index (ONI) was obtained from the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (CPC) of NOAA/ National Weather Service [99]. The ONI is estimated from 3 month running means of ERSST.v4 SST anomalies in the Niño 3.4 region (5°N-5°S, 120°-170°W). SST anomalies are based on centered 30-year base periods updated every 5 years.

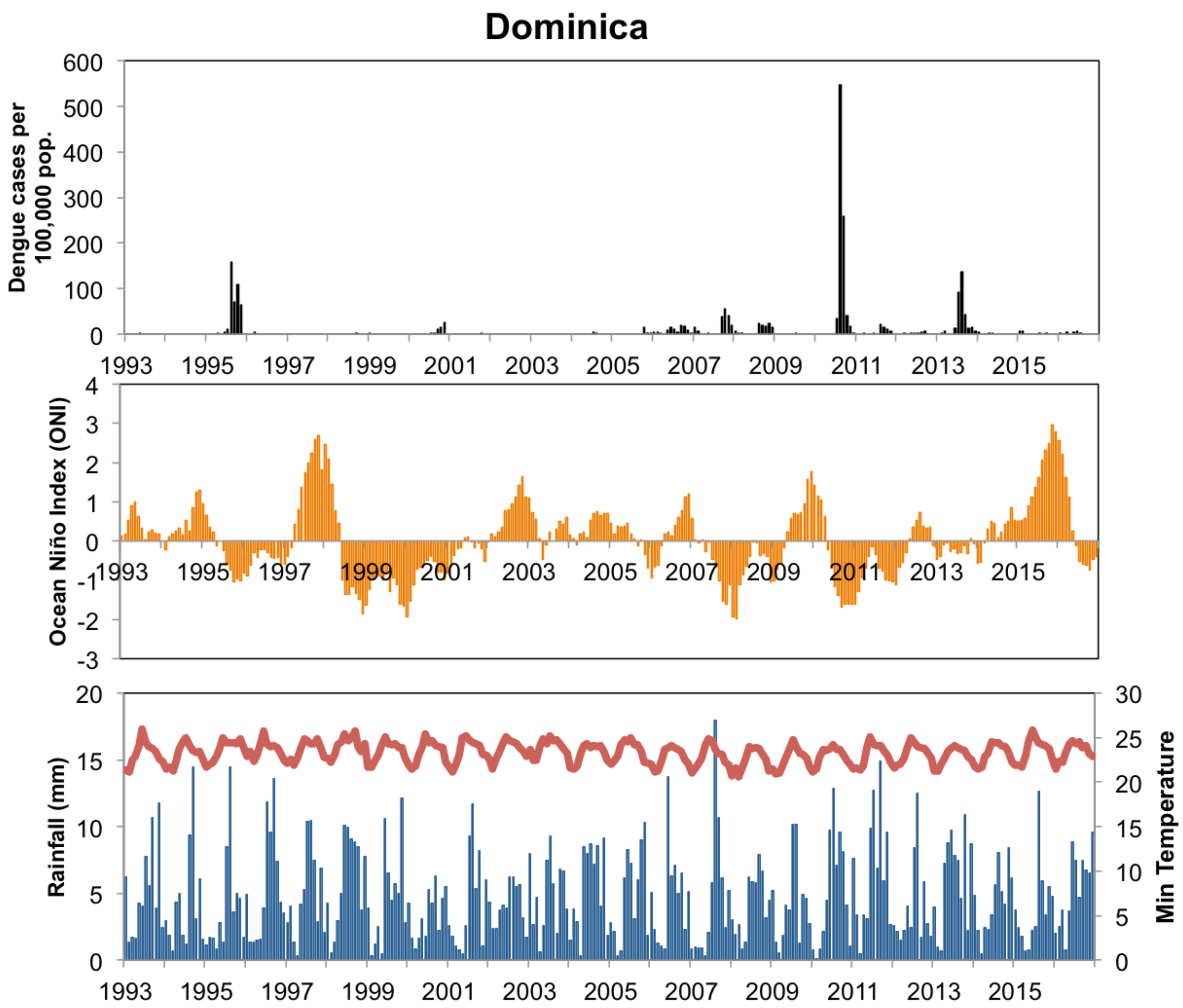

Figure 11. Monthly times series for Barbados for (A) the dengue incidence per 100,000 people, (B) Sea surface temperature anomalies in the Niño 3.4 region, also known as ONI, and (C) precipitation and minimum temperature from the Canefield weather station.

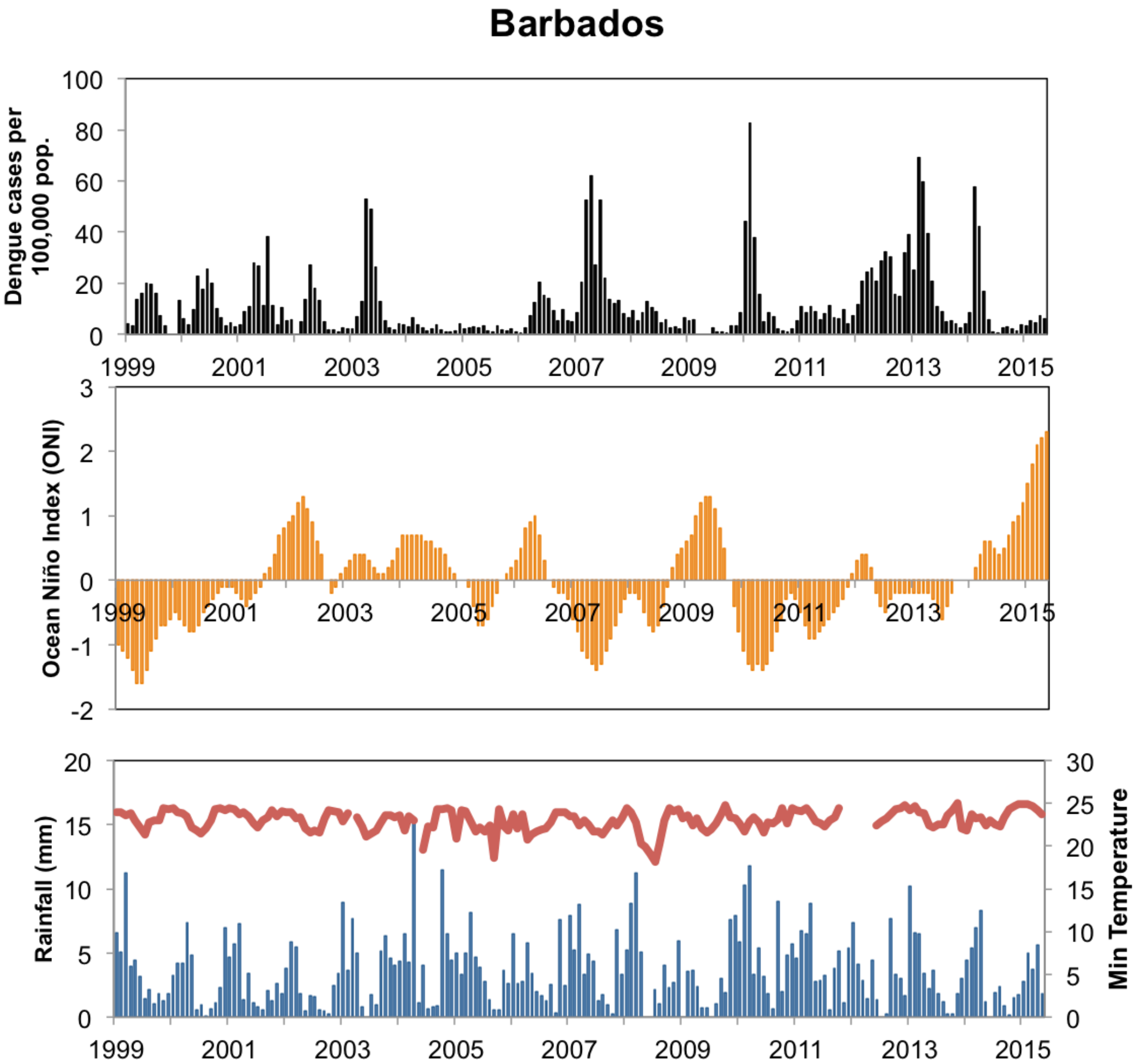

Figure 12. Monthly times series for Barbados for (A) the dengue incidence per 100,000 people, (B) Sea surface temperature anomalies in the Niño 3.4 region, also known as ONI, and (C) precipitation and minimum temperature from the Husbands (CIMH) weather station.

Results. The results of this analysis indicate the potential to use climate information to forecast dengue fever transmission in Dominica and Barbados.

Seasonality in dengue and climate. There is marked seasonality in dengue fever transmission in Dominica and Barbados (Figure 13). Cases in Dominica peak in August, two months after the peak in mean and minimum temperature, and coincident with the peak in rainfall and maximum temperature. Cases in Barbados peak in November, one month after the peak in rainfall, two months after the peak in maximum temperature, and six months after the peak in mean and minimum temperature.

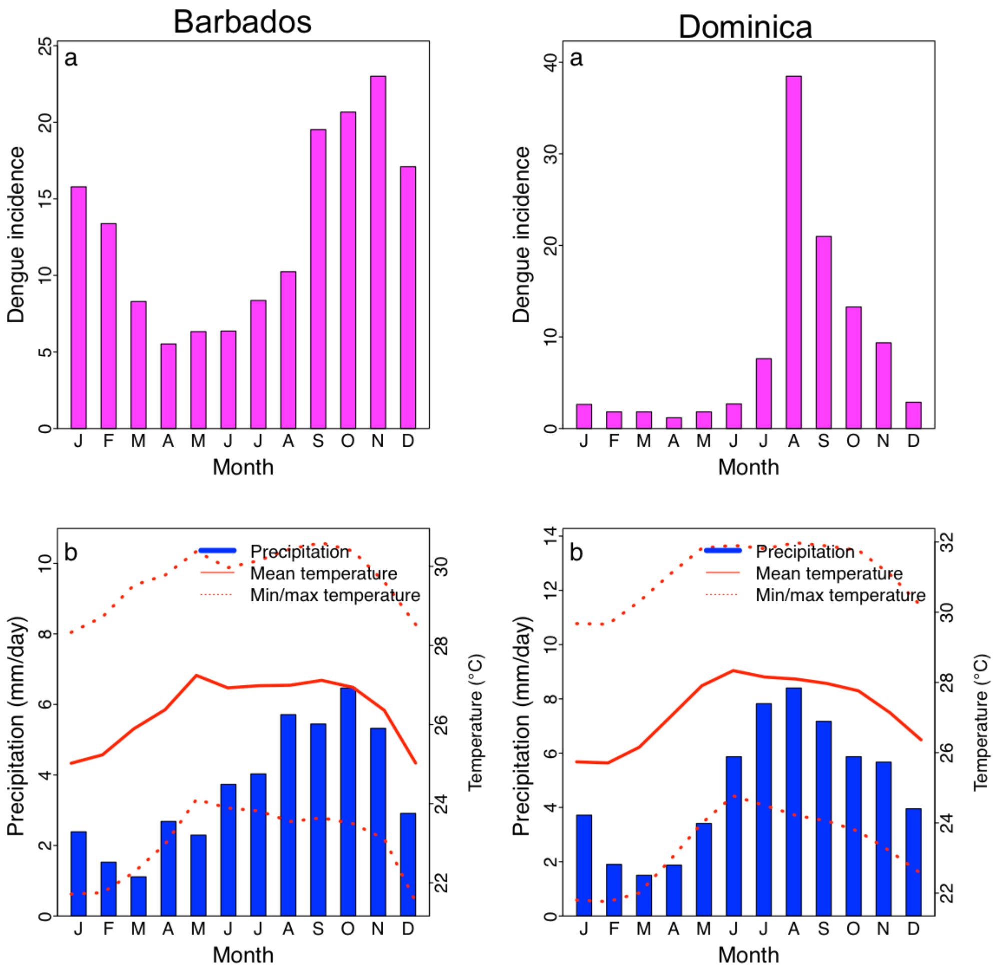

Figure 13. Mean annual cycle of (A) dengue fever incidence and (B) precipitation (bars), mean temperature (solid line), maximum and minimum temperature (dashed lines) from Barbados (1999-2015) and Dominica (1993-2016).

Annual cycle of anomalies in dengue and climate. Figures 14 and 15 show monthly anomalies in dengue incidence in Barbados and Dominica, precipitation, minimum temperature, and the Niño 3.4 index. Anomalies were calculated by subtracting the annual cycle of each variable (*ie,* the mean value for each month for the time series) from the observed monthly data for each year.

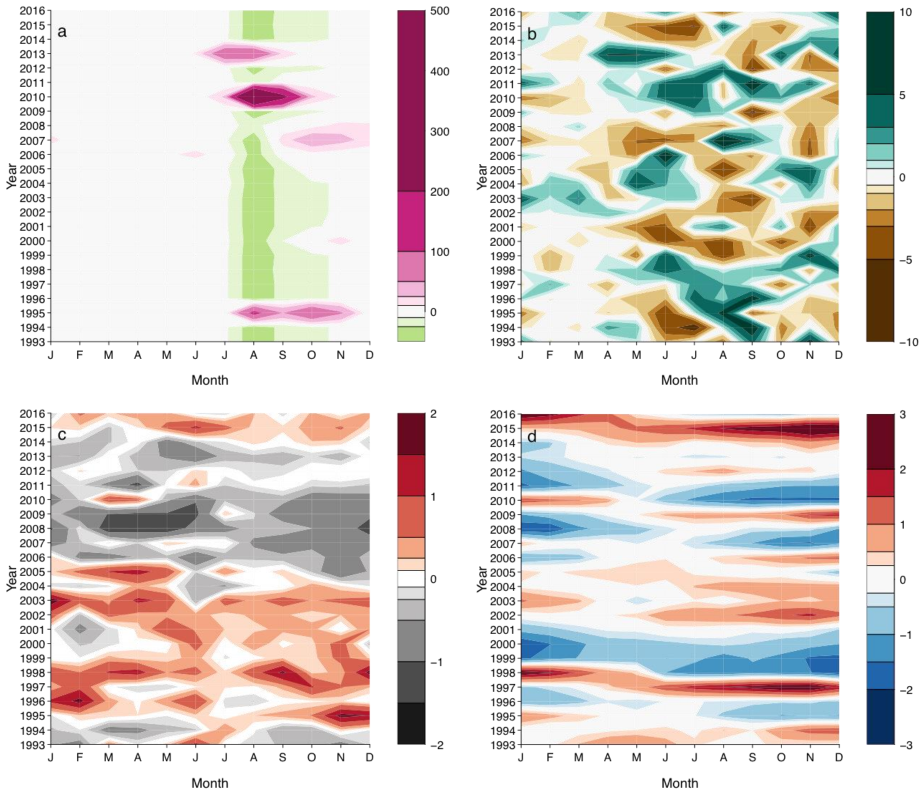

Figure 14. Annual cycle of anomalies in dengue and climate variables, from 1993 to 2016. (A) Dengue incidence anomalies for Dominica per 100,000 population; (B) precipitation anomalies (mm/day); (C) minimum temperature anomalies (°C) from the Canefield weather station; and (D) anomalies in the Niño 3.4.

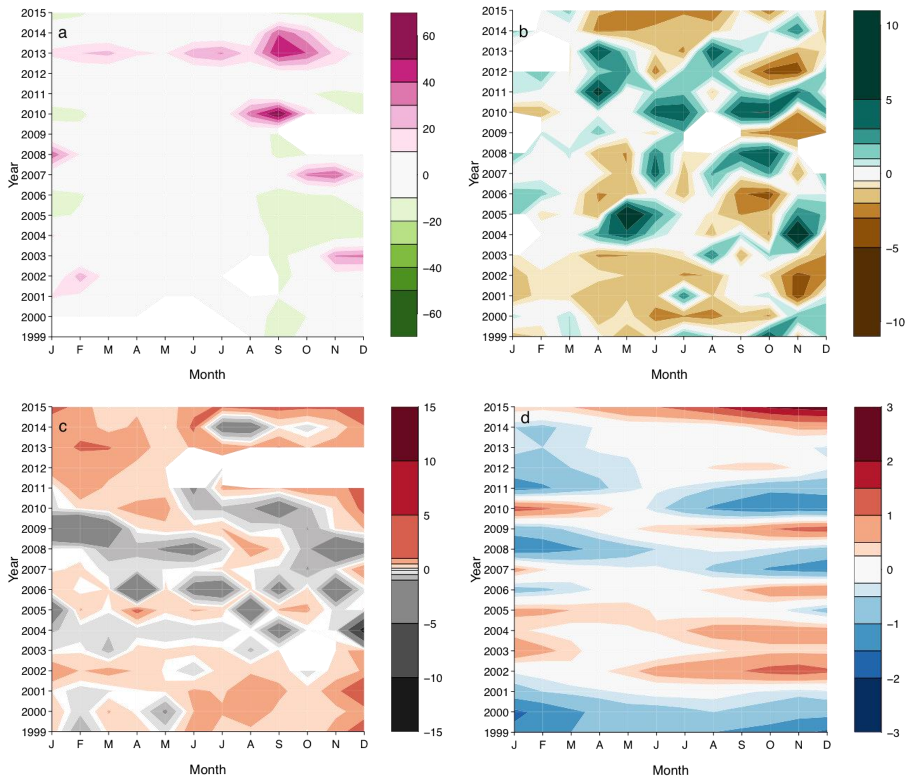

Figure 15. Annual cycle of anomalies in dengue and climate variables, from 1999 to 2015. (A) Dengue incidence anomalies for Barbados per 100,000 population; (B) precipitation anomalies (mm/day); (C) minimum temperature anomalies (°C) from the Husbands (CIMH) weather station; and the (D) Oceanic Niño Index.

Model results. A Bayesian hierarchical mixed model was developed to predict monthly dengue incidence. Preliminary results are shown in Table 4. The underlying seasonal cycle explained 18% of the variability in dengue transmission in Dominica and 24% in Barbados (Table 1). Climate information and yearly random effects explained an additional 29% of the variability in Dominica and 40% of the variability in Barbados.

The current practice of the Ministries of Health in both countries is to assume that dengue transmission will follow a similar seasonal cycle from one year to the next. Dengue cases are compared to average cases from the same week or month of the prior years. When cases exceed a pre-determined upper threshold (*i.e,* 95% confidence interval), an alert is issued. This is similar to the model that uses only the seasonal base cycle. The results from this preliminary analysis indicate the potential to create improved forecasts of dengue transmission by incorporating climate information.

Table 1. Adequacy results for models to predict dengue incidence in Barbados and Dominica. Models are ranked by a likelihood ratio R^2_{LR} statistic.

Model	**Dominica R^2_{LR}**	**Barbados R^2_{LR}**
Seasonal (current practice) (autocorrelated annual cycle)	18%	24%
Seasonal-inter-annual (climate + non-climate) (...+ autocorrelated year effect + climate: precip, Tmin and ONI)	47%	64%

Next steps: Further work is needed to investigate optimum lags and functional forms of climatic factors, and to include considerations of spatial variability. We will develop a statistical mixed modelling framework to capture spatio-temporal variations in vector-borne disease risk (dengue, chikungunya, Zika) in Barbados and Dominica. The approach will be to apply the best statistical methodologies available, exploiting state-of-the-art spatial epidemiological techniques to model spatio-temporal variations in disease risk. The developed model will be driven by both climate and non-climate factors and include random effects to allow for unobserved factors and spatio-temporal correlations. The hierarchical model will be fitted using a Bayesian estimation framework, which allowed probabilistic disease forecasts to be issued at each spatial location for a given time period. The study will build on several previous climate and health statistical studies [18–22] by moving away from simple linear regression models at the country level, involving only temporal variations in climate and disease, to spatio-temporal mixed models providing probabilistic predictions that can aid decision making and target resource allocation. Model results will be validated in time and space by performing out-of-sample predictions to test the efficacy of the modeling framework in operational prediction model. Observed climate variables will be replaced by hindcasts (retrospective forecasts) of the climate to test the predictive lead that could be gained by using seasonal climate forecasts in a vector-borne disease early warning system. The spatial resolution of model predictions will depend of the spatial scale of the underlying disease, climatic and entomological data.

3.4 Analyses of entomological data from Dominica

Methods. *Dominica* – Mosquito index data (i.e. House Index (HI), Breteau Index (BI), and Container Index (CI)) collected at the level of environmental health district (EHD) for Dominica were combined with climate data from the Canefield weather station into a monthly time series dataset spanning the years 2011-2017. The House Index is the number of homes inspected that had *Aedes aegypti* larvae or pupae present per 100 homes inspected. The Breteau Index is the number of containers inspected that had *Aedes aegypti* larvae or pupae present per 100 homes inspected. The Container Index is the proportion of containers inspected that had *Aedes aegypti* larvae or pupae present. Time series data were then mapped and plotted at various levels of spatial and temporal resolution to visually identify changes in the spatial patterns of Aedes distribution. Cross correlation analyses between HI and climate data were performed to identify temporal lags between variables.

Preliminary Results. There is both spatial and temporal variation in mosquito indices at the health district level in Dominica. Means of the three major indices for Aedes presence (HI, BI, and CI) varied spatially between health districts in 2011 – 2017. Average HI for the data collection period also displayed seasonal heterogeneity at the EHD level. Within a given year, monthly HI varied greatly between health districts, and cross correlation analysis of HI and climate data revealed differences in temporal lags between districts.

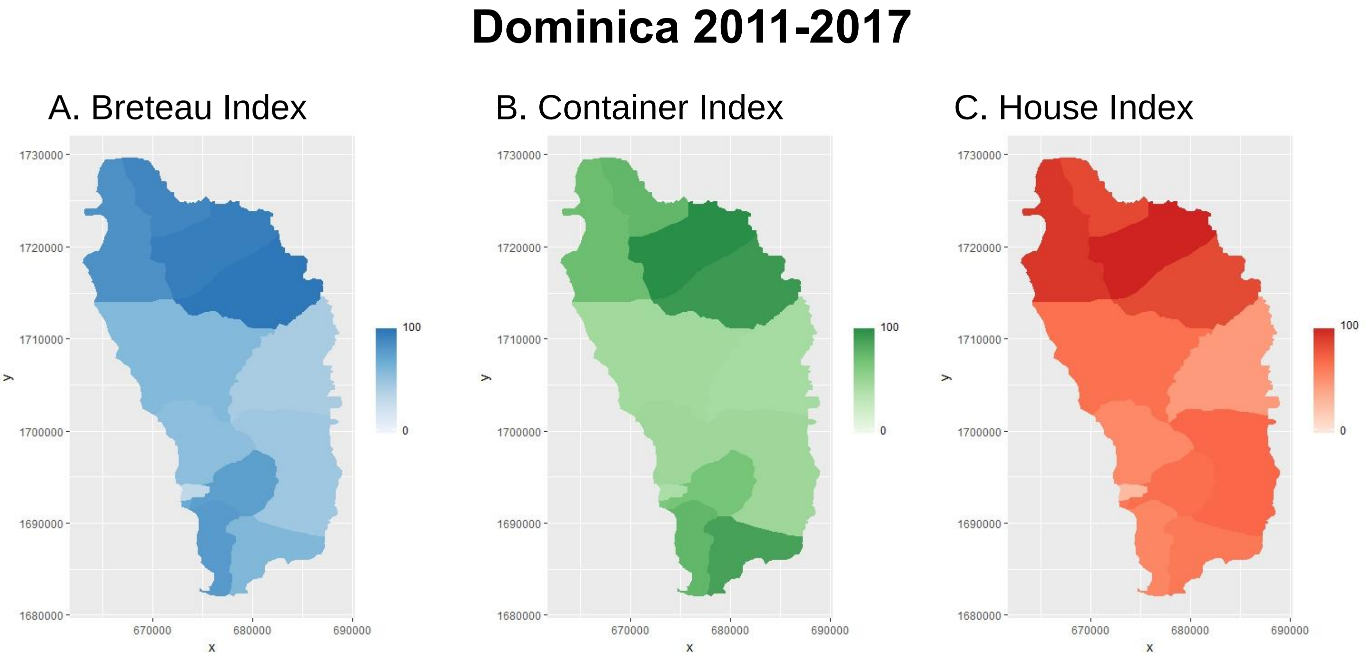

Figure 16. Average *Aedes aegypti* larval indices for Dominica over the study period (2011-2017) per environmental health district.

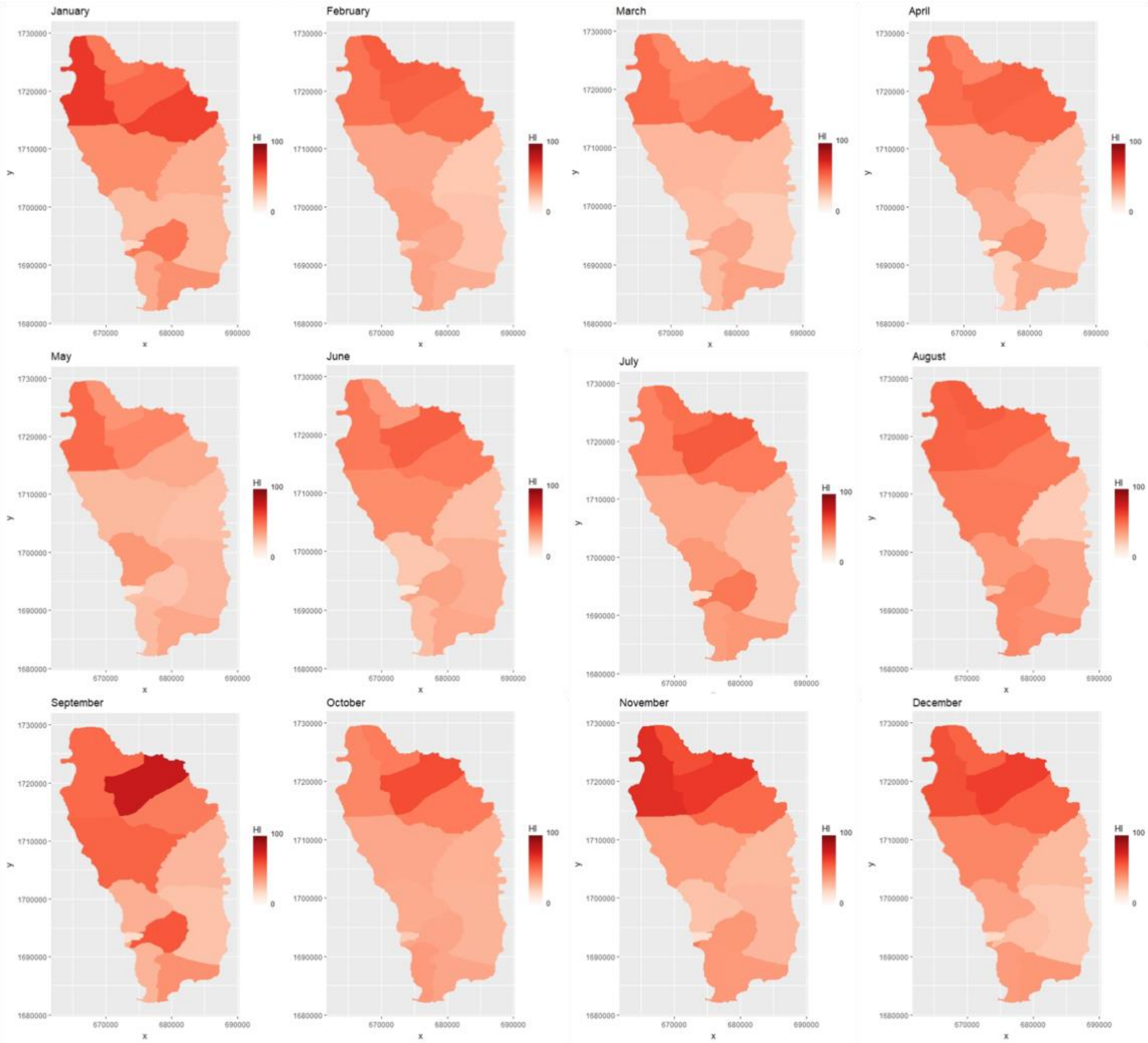

Figure 17. Average monthly House Indices per EH district in Dominica (2011-2017).

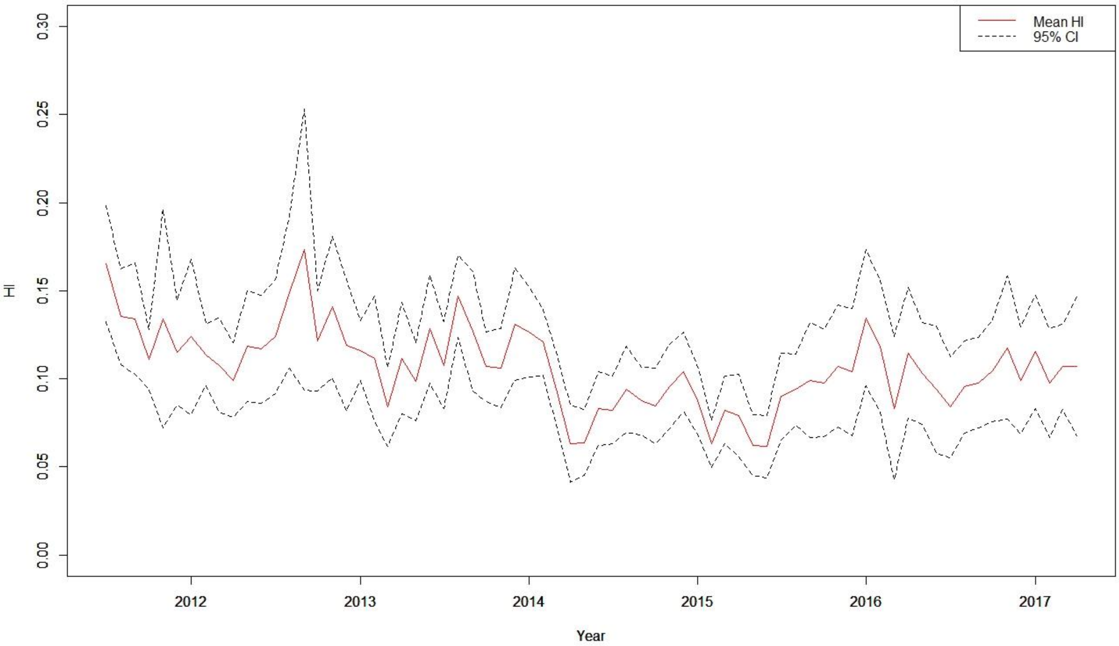

Figure 18. Average monthly House Index (95% confidence interval) for Dominica over the study period (2011-2017)

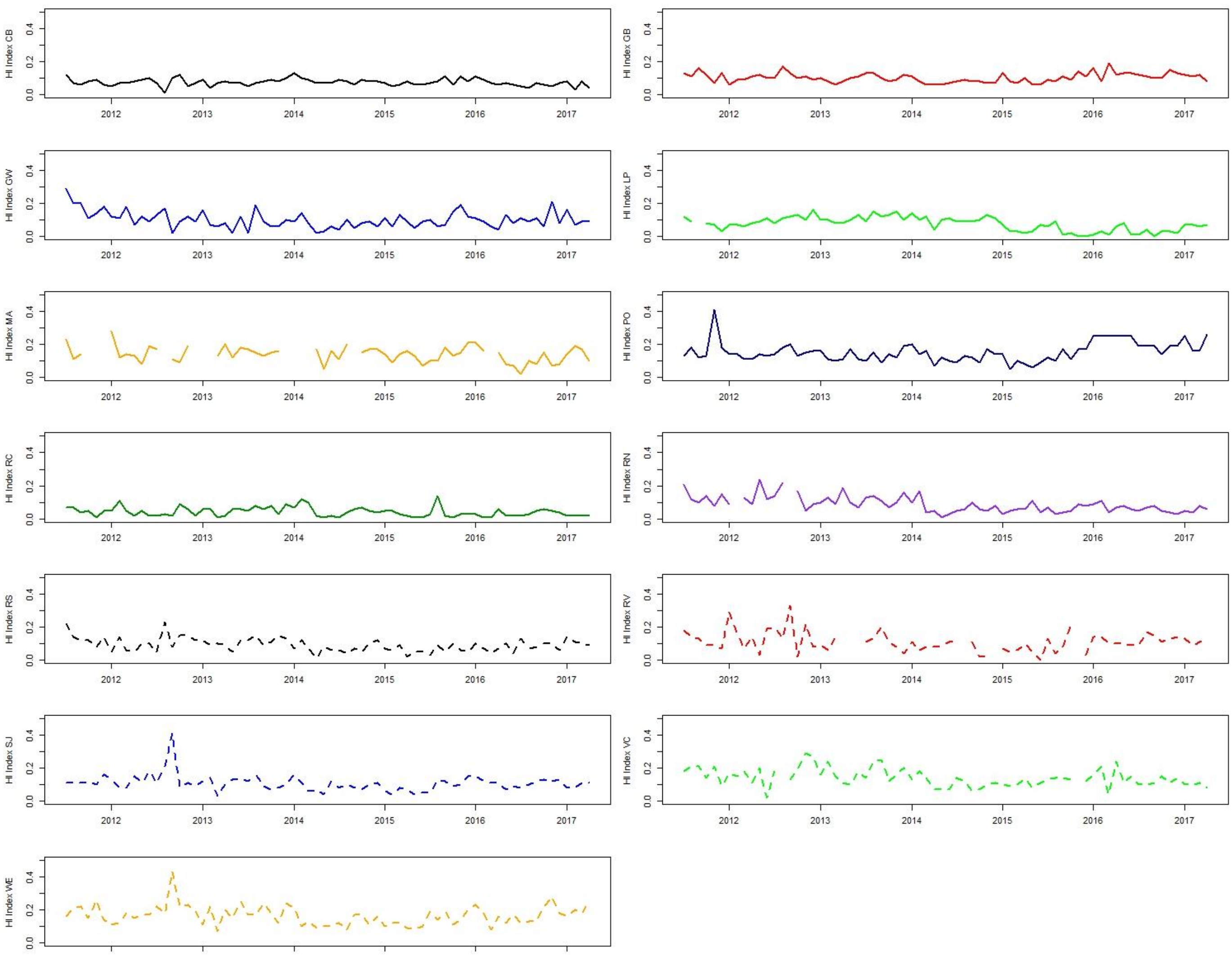

Figure 19. Monthly House Index by EH district in Dominica (2011-2017)

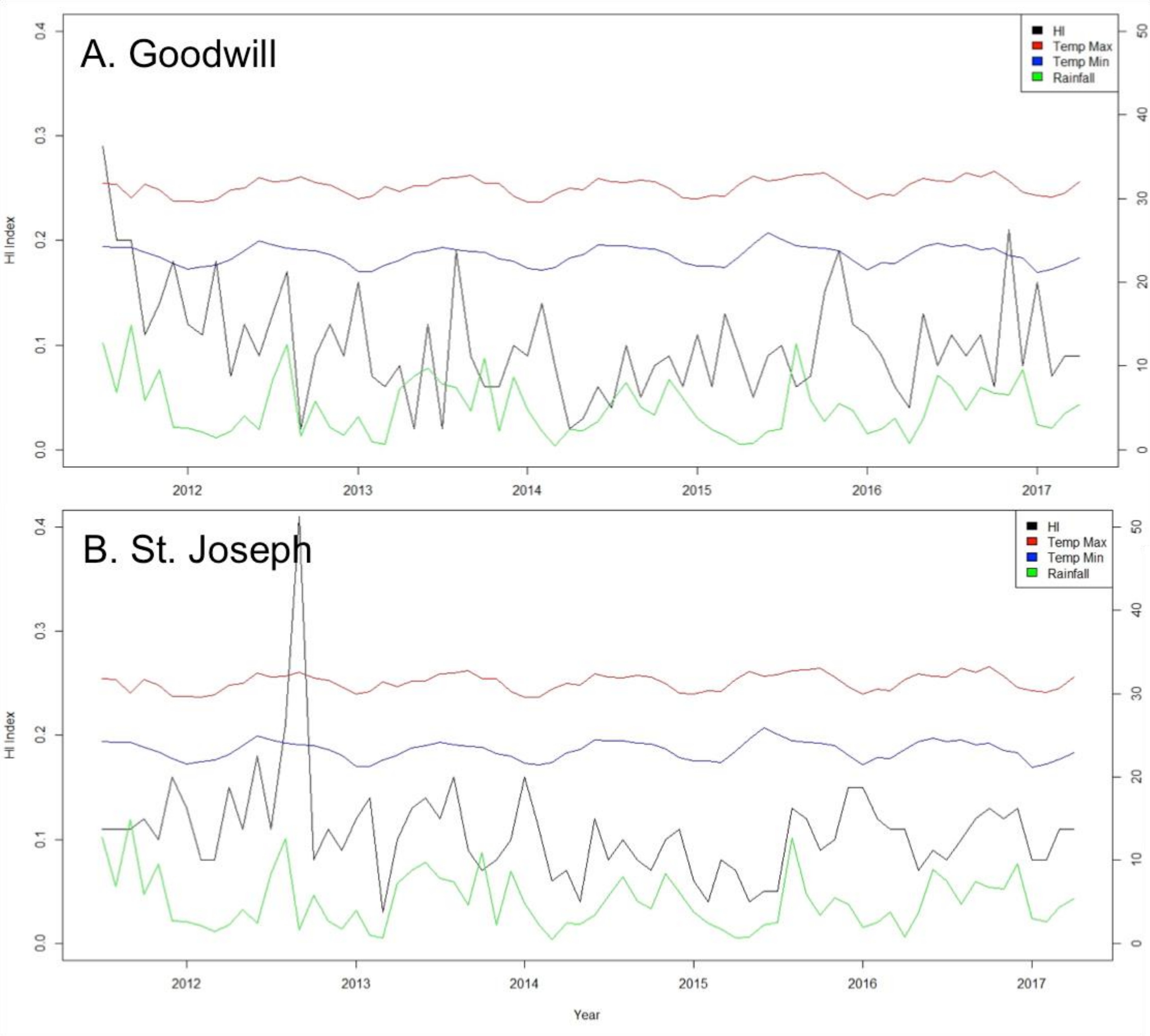

Figure 20. Time series of monthly House Indices (HI) and climate data (rainfall, min/max temp) from the Canefield station in the (A) Goodwill and (B) St. Joseph health district in Dominica.

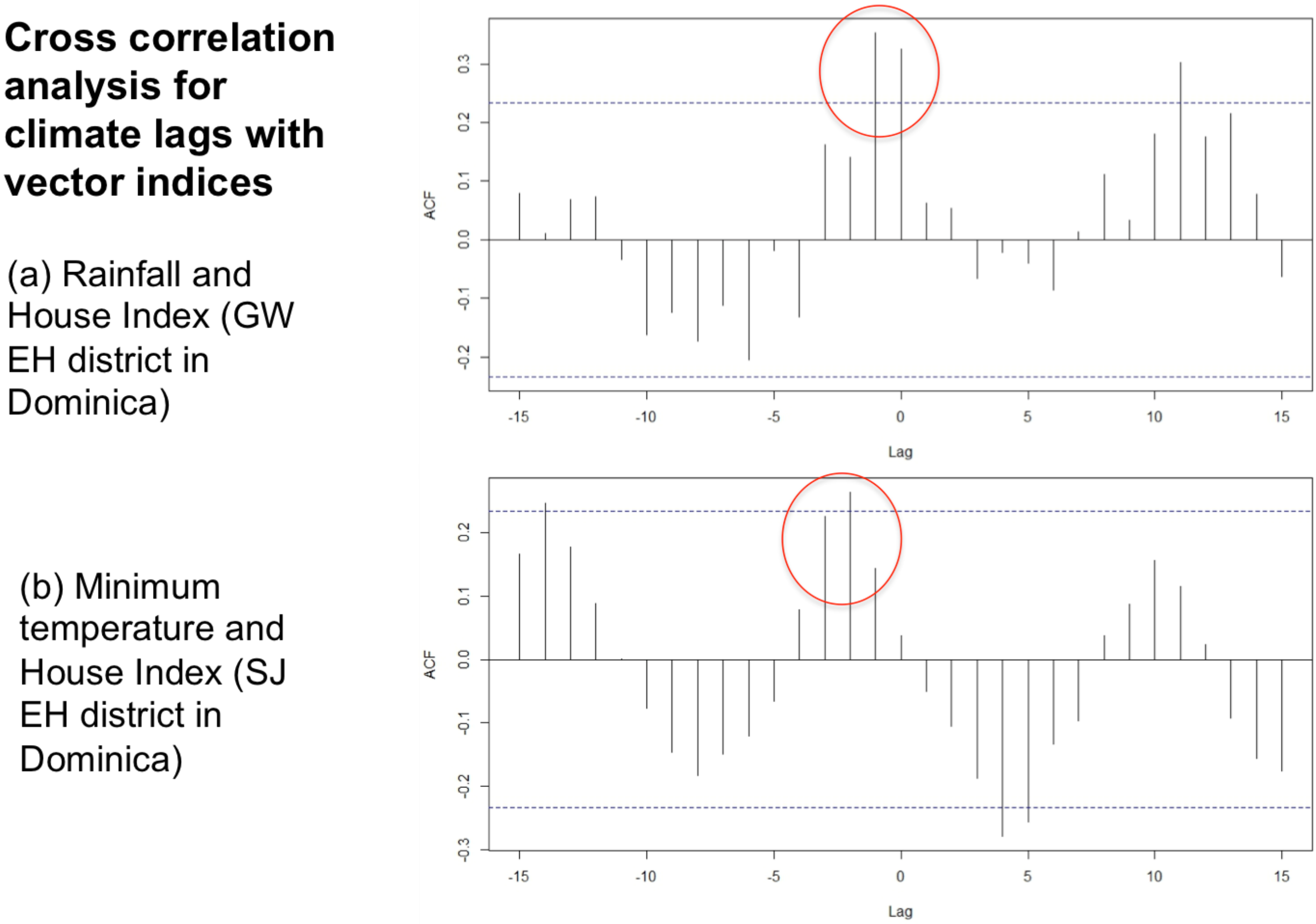

Figure 21. Cross correlations between lagged local climate variables and the House Index for (a) monthly rainfall and HI from the Goodwill district (highest correlation at a 1 month lag) and (b) minimum temperature and the HI from the St. Joseph district (highest correlation at a 2 month lag). Climate data are from Canefield station.

Next Steps. These preliminary analyses will be expanded to include all environmental health districts and mosquito indices in Dominica. Time series data and identified temporal lags will be incorporated into a multilevel statistical modeling framework that will allow for the detailed exploration of relationships between vector presence and climate drivers. Furthermore, future spatial analyses on container indices will incorporate more detailed entomological survey data (i.e. container types). Local indicators of spatial association (LISA) and spatial scan statistical analyses will be performed on EHD level entomological data to identify areas of clustering and dispersion (i.e. hotspots and coldspots).

3.5 Analyses of entomological data from Barbados

Methods. *Barbados – Aedes aegypti* index data (i.e. House Index (HI), Breteau Index (BI), and Container Index (CI)) and lab-confirmed dengue case data collected at the district level for Barbados in the year 2013 were georeferenced and put into a geographic information system (GIS) framework. Local Moran's I, a local indicator of spatial association (LISA) analysis, was performed for dengue cases, CI, and HI to identify areas of statistically significant high or low spatial clustering (i.e. hotspots and coldspots). HI and BI in the year 2013 were also mapped at the district level to visualize spatial heterogeneity in mosquito indices.

Preliminary Results LISA analysis identified local clustering and dispersion in dengue cases, HI, and CI in the year 2013, generally on the western side of the island. Mapping the average BI and HI by district in 2013 also demonstrated spatial heterogeneity in mosquito indices.

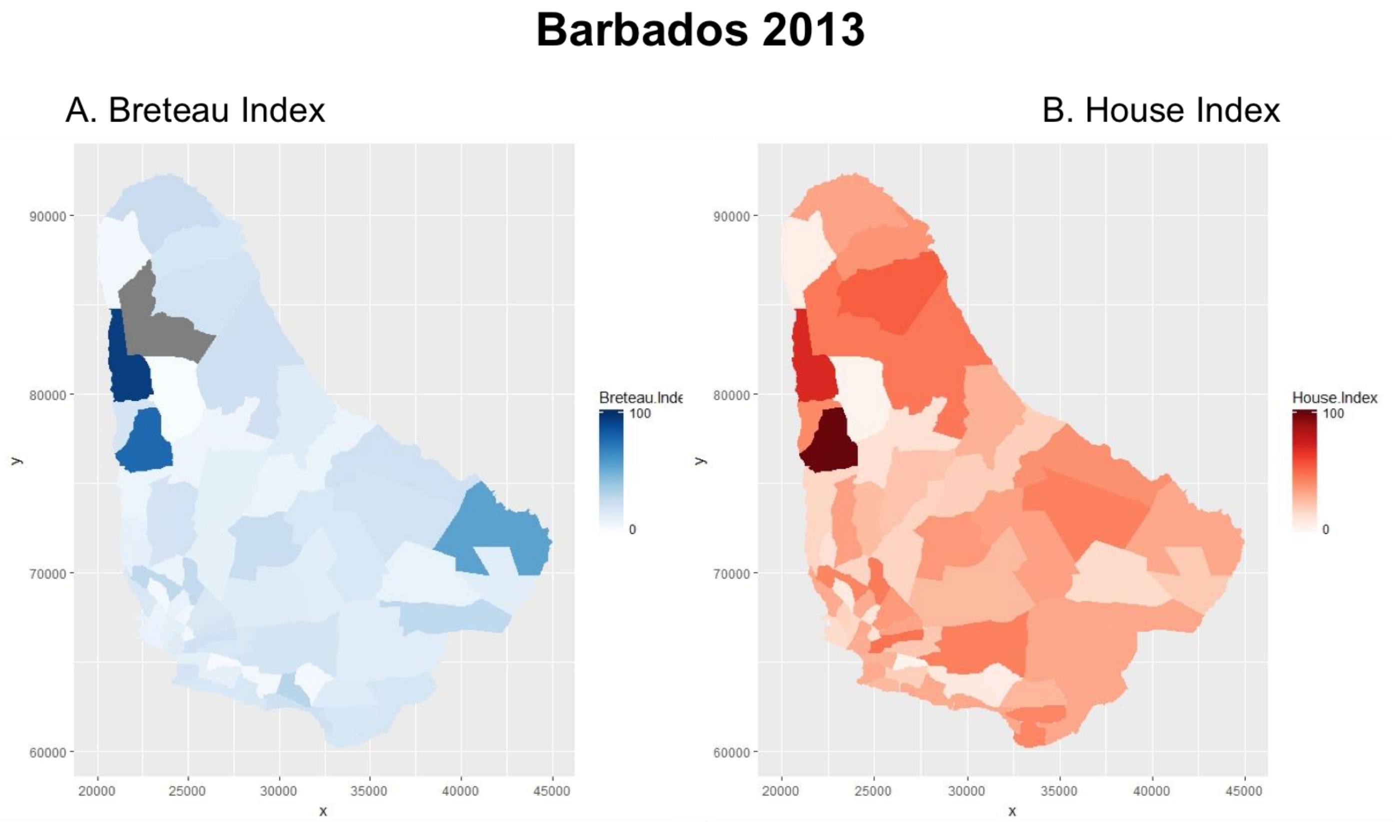

Figure 22. Average entomological indices by locality in Barbados in 2013. (A) Breteau Index and (B) House Index. Areas in grey are outliers greater than 100.

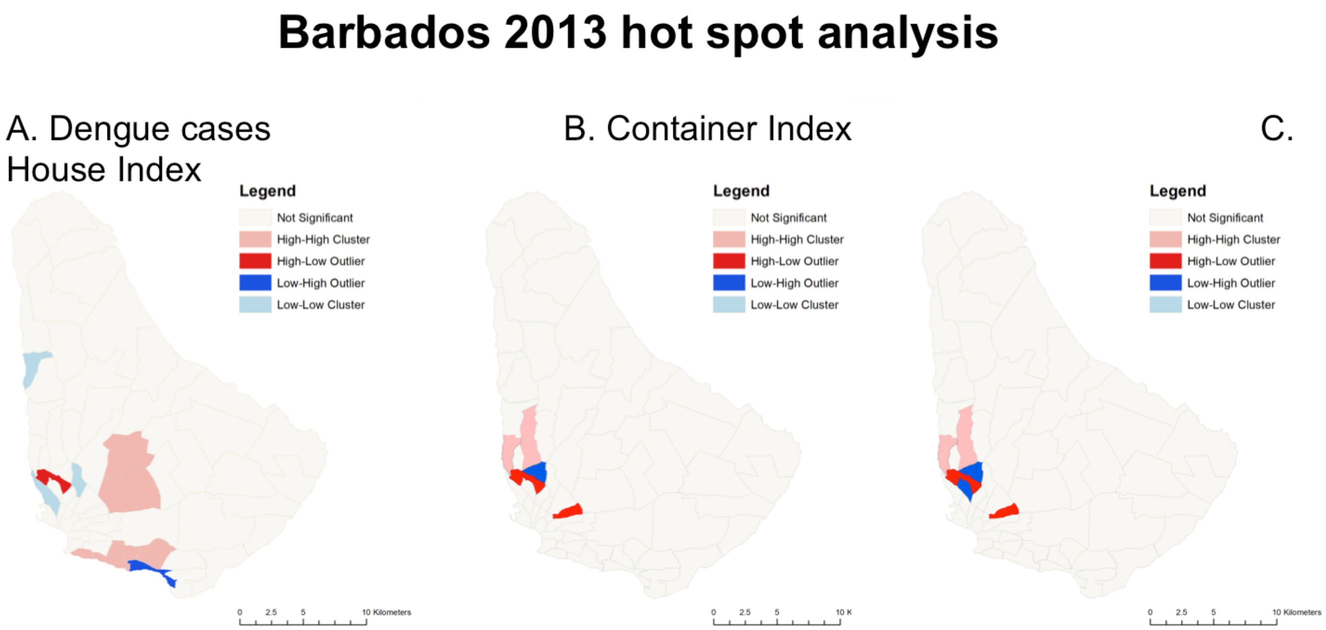

Figure 23. Analysis of hotspots for (A) dengue cases, (B) the proportion of containers positive for *Aedes aegypti* larvae or pupae (Container Index), and (C) the proportion of homes positive for Aedes aegypti larvae or pupae (House Index). Significant hot spots (high-high) and outliers (high-low and low-high) are identified through LISA analysis ($p \leq 0.05$).

Next Steps. LISA statistics will be applied to dengue case and entomological data for additional survey years, as well as for more recent chikungunya and Zika case data. Spatial scan statistical analyses, which are capable of detecting temporal as well as spatial clustering, will also be performed. Furthermore, we will combine georeferenced vector and case data with population census data and climate data for Barbados, allowing for the spatial and statistical exploration of disease risk and temporal lags.

4. Capacity strengthening

In June 2017 the consulting team conducted three webinars for the climate and health sector in the Caribbean. Webinars were hosted using Zoom, an online educational platform hosted by SUNY Upstate Medical University. Webinars were also recorded and shared for those who had registered but were unable to attend. The following topics were presented:

- June 9, 2017: Dr. Anna Stewart. Overview of Climate Services for Vector Borne Diseases and Experiences from Ecuador
- June 16, 2017: Dr. Sadie Ryan. Geospatial Tools for Vector Borne Diseases
- June 30, 2017: Dr. Rachel Lowe. Climate-Driven Early Warning Systems for Vector-Borne Diseases

A total of 69 people registered and 36 people attended the webinars, including individuals from CIMH, the Ministry of Health of Barbados, the Environmental Health Department of Dominica, PAHO, CARPHA, and the Barbados Meteorological Institute.

Webinar evaluations:
Webinars were evaluated through an online survey distributed to participants via email following the webinar. The results were as follows:

The speaker clearly presented the content.
Strongly agree 9/13; Agree 4/13
The speaker presented content that matched the subject area:
Strongly agree 8/13; Agree 5/13
Overall, the speaker was effective:
Strongly agree: 7/13; Agree 6/13

Other key consultations with the climate and health sectors:

- Initial meetings were held in Barbados with the Chief Medical Officer of the Ministry of Health, the Principal of CIMH, the director of the Barbados Meteorological Service, and other senior leaders in the climate and health sectors from April 5-13, 2017, to present the aims of the project and to conduct interviews.
- A one-hour seminar on climate, *Aedes aegypti* and early warning systems was presented at CIMH in April 7, 2017, with approximately 25 participants, including participation by individuals from CIMH, the Ministry of Health of Barbados, CARPHA, and the Barbados Meteorological Institute.
- A half-day workshop on the development of climate services for *Aedes aegypti* control was held at PAHO on April 20, 2017. The aim of this workshop was to socialize the project and to get feedback regarding the most useful forecast periods and types of forecasts.
- Participating institutions included CIMH, PAHO, the Ministry of Health of Barbados, and the Barbados Meteorological Institute. Approximately 25 people were present.
- Initial meetings were held in Dominica with the Chief Medical Officer and other leaders in the Ministry of Health, the Dominica Meteorological Service, and other actors from April 18 -20, 2017, to present the aims of the project and to conduct interviews.
- An afternoon focus group was conducted in Dominica with leaders from the Ministry of Health on April 18, 2017, to garner feedback on how to articulate data sharing and data hosting to support operational climate services for the health sector.

- The aims and advances of the project were presented to regional sectoral stakeholders at the EWISACTS meeting held in St. Vincent and the Grenadines in June 2017.
- A half-day workshop to present the results of this project and to identify next steps was held in Barbados on July 18, 2017, with 25 representatives from CIMH, CARPHA, PAHO, the Ministry of Health of Barbados, and the Barbados Meteorological Institute.
- A half-day workshop to present the results of this project and to identify next steps was held in Dominica on July 19, 2017, with approximately 30 representatives from CIMH, PAHO, CARPHA, the Ministry of Health of Dominica, and the Dominica Meteorological Institute.

A national consultation with the health sector in Dominica regarding the development of climate services for vector-borne diseases.

5. Summary

Models that describe and forecast the transmission of dengue fever and other climate sensitive diseases are important decision-support tools for the public health sector. These tools can ultimately become part of an EWS, by linking models to real-time information from seasonal climate forecasts, seasonal El Niño forecasts, disease surveillance systems, and monitoring of other risk factors. Probabilistic forecasts of disease risk generated by these models can be translated into epidemic warnings that trigger a public health preparedness plan for actions at different warning levels. These climate services for the health sector would provide decision makers with greater lead-time to proactively prevent dengue outbreaks through allocation of financial and human resources for vector-control interventions and public health outreach campaigns to eliminate breeding containers.

This project provides one of the first comprehensive assessments of the potential to develop climate services for diseases transmitted by *Aedes aegypti* mosquitoes in the Caribbean. The aim of this project was to work collaboratively with regional and national climate and health stakeholders in the Caribbean to develop a modeling framework that will ultimately provide spatio-temporal probabilistic forecasts of the risk of transmission of DENV, CHIKV, and ZIKV. This project incorporated both a stakeholder needs assessment and spatiotemporal modeling of climate and health data from two pilot countries (Dominica and Barbados).

Through the stakeholder analysis, we identified strategies to strengthen the burgeoning partnership between the climate and health sectors, we assessed health practitioners' perceptions of climate and health, we identified climate and non-climate drivers of *Aedes aegypti* transmitted diseases and we identified other ways that climate affects the health of people in the Caribbean. We then assessed the strengths and weaknesses of the health and climate sectors in order to identify key areas for capacity strengthening. Finally, we evaluated the current use of climate information in the health sector and ways that climate services can be developed and utilized in the public health decision-making process. Through a series of national consultations and an online webinar, this project helped to create a dialogue on climate services for the health sector in the Caribbean.

We analyzed existing global models that predict the risk of diseases transmitted by *Aedes aegypti* and found that these models did not provide information at a sufficiently fine spatial resolution to be useful for public health decision-making. In order to refine these models, local entomological, epidemiological, climate and census data were gathered from Barbados and Dominica. Preliminary analyses of these data are presented in this report, and provide evidence for the role of climate in seasonal and interannual variability in *Aedes aegypti* dynamics and dengue transmission in this region, laying the groundwork for developing an early warning system. The next steps will be to quantify how much predictive lead time can be gained by replacing observed climate information with seasonal (3 month) hindcasts (*i.e.,* retrospective forecasts) of both local climate conditions and the evolution of SSTs.

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7. Acronyms

BRCCC	The Programme for Building Regional Climate Capacity in the Caribbean
BTI	*Bacillus thuringiensis israelensis*
CariCOF	Caribbean climate outlook forums
CARPHA	Caribbean Public Health Agency
CDC	U. S. Centers for Disease Control
CEHI	Caribbean Environmental Health Institute
CHIKV	Chikungunya virus
CHN	Community health nurse (Dominica)
CIMH	Caribbean Institute for Meteorology and Hydrology
CMO	Caribbean Meteorological Organization
DENV	Dengue virus
DHF	Dengue hemorrhagic fever
EHD	Environmental Health Department of Dominica
ENSO	El Niño Southern Oscillation
EWISACTS	Sectoral Early Warning Information Systems Across Climate Timescales
EWS	Early Warning System
GEF	Global Environmental Facility
GFCS	Global Framework for Climate Services
GIS	Geographic information systems
HIU	Health Information Unit
MoH	Ministry of Health
NGO	Non-profit organization
NOAA/CPC	National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (CPC)
ONI	Oceanic Niño Index
PAHO/WHO	Pan American Health Organization/World Health Organization
RCC	Regional Climate Center
SST	Sea surface temperature
USAID	United States Agency for International Development
VBD	Vector-borne disease
WMO	World Meteorological Organization
ZIKV	Zika virus

8. References

1. Roth A, Mercier A, Lepers C, Hoy D, Duituturaga S, Benyon E, et al. Concurrent outbreaks of dengue, chikungunya and Zika virus infections-an unprecedented epidemic wave of mosquito-borne viruses in the Pacific 2012-2014. Euro Surveill. 2014;19:20929.

2. WHO. Dengue: guidelines for diagnosis, treatment, prevention and control. World Health Organization; 2009.

3. Scott TW, Takken W. Feeding strategies of anthropophilic mosquitoes result in increased risk of pathogen transmission. Trends in Parasitology. 2012;28:114–21.

4. Cohen J. The race for a Zika vaccine is on. Science. 2016;351:543–4.

5. Vannice KS, Durbin A, Hombach J. Status of vaccine research and development of vaccines for dengue. Vaccine. 2016;34:2934–8.

6. Smalley C, Erasmus JH, Chesson CB, Beasley DW. Status of research and development of vaccines for chikungunya. Vaccine. 2016;34:2976–2981.

7. Dick OB, Martín JLS, Montoya RH, Diego J del, Zambrano B, Dayan GH. The History of Dengue Outbreaks in the Americas. Am J Trop Med Hyg. 2012;87:584–93.

8. Nathan MB. Critical review of *Aedes aegypti* control programs in the Caribbean and selected neighboring countries. Journal of the American Mosquito Control Association. 1993;9:1–1.

9. Nathan MB, Knudsen AB. *Aedes aegypti* infestation characteristics in several Caribbean countries and implications for integrated community-based control. Journal of the American Mosquito Control Association. 1991;7:400–404.

10. San Martín JL, Brathwaite O, Zambrano B, Solórzano JO, Bouckenooghe A, Dayan GH, et al. The Epidemiology of Dengue in the Americas Over the Last Three Decades: A Worrisome Reality. The American Journal of Tropical Medicine and Hygiene. 2010;82:128–35.

11. Stanaway JD, Shepard DS, Undurraga EA, Halasa YA, Coffeng LE, Brady OJ, et al. The global burden of dengue: an analysis from the Global Burden of Disease Study 2013. Lancet Infect Dis. 2016 Jun;16(6):712-23

12. Bhatt S, Gething PW, Brady OJ, Messina JP, Farlow AW, Moyes CL, et al. The global distribution and burden of dengue. Nature. 2013 Apr 25;496(7446):504-7.

13. PAHO WHO | Dengue | Annual Cases Reported of Dengue | PAHO/WHO Data, Maps and Statistics Available from: http://www.paho.org/hq/index.php?option=com_topics&view=rdmore&cid=6290&Itemid=40734

14. PAHO. Number of Reported Cases of Chikungunya Fever in the Americas, by Country or Territory. Available from: http://www.paho.org/hq/index.php?option=com_topics&view=readall&cid=5927&Itemid=40931&lang=en

15. WHO | Chikungunya. [cited 2016 Feb 25]. Available from: http://www.who.int/mediacentre/factsheets/fs327/en/

16. Ahmed S, Francis L, Ricketts RP, Christian T, Polson-Edwards K, Olowokure B. Chikungunya virus outbreak, Dominica, 2014. Emerging infectious diseases. 2015;21:909.

17. Nsoesie EO, Ricketts RP, Brown HE, Fish D, Durham DP, Mbah MLN, et al. Spatial and temporal clustering of chikungunya virus transmission in Dominica. PLoS Neglected Tropical Diseases. 2015;9:e0003977.

18. Zanluca C, Melo VCA de, Mosimann ALP, Santos GIV dos, Santos CND dos, Luz K, et al. First report of autochthonous transmission of Zika virus in Brazil. Memórias do Instituto Oswaldo Cruz. 2015;110:569–72.

19. Mitchell C. PAHO WHO | Zika Cumulative Cases [Internet]. Pan American Health Organization / World Health Organization. Available from: http://www.paho.org/hq/index.php?option=com_content&view=article&id=12390&Itemid=42090&lang=en

20. WHO | Zika virus. WHO. [cited 2016 Feb 25]. Available from: http://www.who.int/mediacentre/factsheets/zika/en/

21. Organization WH, others. Zika situation report: neurological syndrome and congenital anomalies. 2016; Available from: http://apps.who.int/iris/bitstream/10665/204348/1/zikasitrep_5Feb2016_eng.pdf

22. WHO | El Niño may increase breeding grounds for mosquitoes spreading Zika virus, WHO says [Internet]. WHO. [cited 2016 Feb 25]. Available from: http://www.who.int/hac/crises/el-nino/22february2016/en/

23. Muñoz ÁG, Thomson MC, Stewart-Ibarra AM, Vecchi GA, Chourio X, Nájera P, et al. Could the Recent Zika Epidemic Have Been Predicted? Front. Microbiol., 12 July 2017 | https://doi.org/10.3389/fmicb.2017.01291

24. Caminade C, Turner J, Metelmann S, Hesson JC, Blagrove MS, Solomon T, et al. Global risk model for vector-borne transmission of Zika virus reveals the role of El Niño 2015. Proceedings of the National Academy of Sciences. 2017;114:119–124.

25. PAHO WHO | Yellow fever | Yellow Fever. Available from: http://www.paho.org/hq/index.php?option=com_topics&view=readall&cid=2194&Itemid=40784&lang=en

26. Amarakoon AMD, Chen AA, Rawlins SC, Taylor MA. Dengue epidemics–its association with precipitation and temperature, and its seasonality in some Caribbean countries. West Indian Med J. 2004;53:60.

27. Barrera R, Amador M, MacKay AJ. Population Dynamics of *Aedes aegypti* and Dengue as Influenced by Weather and Human Behavior in San Juan, Puerto Rico. PLoS Negl Trop Dis. 2011;5:e1378.

28. Chester G. Moore, Barnett L. Cline, Ernest Ruiz-Tiben, Dwayne Lee, Harry Romney-Joseph, Efrain Rivera-Correa. *Aedes aegypti* in Puerto Rico: Environmental determinants of larval abundance and relation to dengue virus transmission. American Journal of Tropical Medicine and Hygiene. 1978;27:1225–31.

29. Chowell G, Cazelles B, Broutin H, Munayco CV. The influence of geographic and climate factors on the timing of dengue epidemics in Perú, 1994-2008. BMC Infectious Diseases. 2011;11:164.

30. Chowell G, Sanchez F. Climate-based descriptive models of dengue fever: the 2002 epidemic in Colima, Mexico. Journal of Environmental Health. 2006;68:40.

31. Rawlins SC, Chen A, Ivey M, Amarakoon D, Polson K. The impact of climate change/variability events on the occurrence of dengue fever in parts of the Caribbean: a retrospective study for the period 1980-2002. West Indian Medical Journal Suppl. 2005;53:54.

32. Soper FL. Dynamics of *Aedes aegypti* distribution and density. Seasonal fluctuations in the Americas. Bull World Health Organ. 1967;36:536–8.

33. Bar-Zeev M. The Effect of Temperature on the Growth Rate and Survival of the Immature Stages of Aëdes Aegypti (L.). Bulletin of Entomological Research. 1958;49:157–63.

34. Rueda LM, Patel KJ, Axtell RC, Stinner RE. Temperature-Dependent Development and Survival Rates of Culex quinquefasciatus and *Aedes aegypti* (Diptera: Culicidae). Journal of Medical Entomology. 1990;27:892–8.

35. Tun-Lin W, Burkot TR, Kay BH. Effects of temperature and larval diet on development rates and survival of the dengue vector *Aedes aegypti* in north Queensland, Australia. Medical and Veterinary Entomology. 2000;14:31–7.

36. Pant CP, Yasuno M. Field studies on the gonotrophic cycle of *Aedes aegypti* in Bangkok, Thailand. Journal of Medical Entomology. 1973;10:219–23.

37. Yasuno M, Tonn RJ. A study of biting habits of *Aedes aegypti* in Bangkok, Thailand. Bull World Health Organ. 1970;43:319–25.

38. Watts DM, Burke DS, Harrison BA, Whitmire RE, Nisalak A. Effect of Temperature on the Vector Efficiency of Aedes aegypti for Dengue 2 Virus. American Journal of Tropical Medicine and Hygiene. 1986;36:143–52.

39. Hayden MH, Uejio CK, Walker K, Ramberg F, Moreno R, Rosales C, et al. Microclimate and Human Factors in the Divergent Ecology of *Aedes aegypti* along the Arizona, US/Sonora, MX Border. EcoHealth. 2010;7:64–77.

40. Pontes RJ, Freeman J, Oliveira-Lima JW, Hodgson JC, Spielman A. Vector densities that potentiate dengue outbreaks in a Brazilian city. The American Journal of Tropical Medicine and Hygiene. 2000;62:378–83.

41. Rawlins SC. Spatial distribution of insecticide resistance in Caribbean populations of *Aedes aegypti* and its significance. Rev Panam Salud Publica. 1998 Oct;4(4):243-51.

42. Scott TW, Amerasinghe PH, Morrison AC, Lorenz LH, Clark GG, Strickman D, et al. Longitudinal Studies of *Aedes aegypti* (Diptera: Culicidae) in Thailand and Puerto Rico: Blood Feeding Frequency. Journal of Medical Entomology. 2000;37:89–101.

43. Nagao Y, Thavara U, Chitnumsup P, Tawatsin A, Chansang C, Campbell-Lendrum D. Climatic and social risk factors for *Aedes* infestation in rural Thailand. Tropical Medicine & International Health. 2003;8:650–659.

44. Quintero J, Carrasquilla G, Suárez R, Gonz'alez C, Olano V. An ecosystemic approach to evaluating ecological, socioeconomic and group dynamics affecting the prevalence of *Aedes aegypti* in two Colombian towns. Cad. Saúde P'ublica. 2009;25:S93–S103.

45. Spiegel JM, Bonet M, Ibarra A-M, Pagliccia N, Ouellette V, Yassi A. Social and environmental determinants of *Aedes aegypti* infestation in Central Havana: results of a case-control study nested in an integrated dengue surveillance programme in Cuba. Tropical Medicine & International Health. 2007;12:503–10.

46. Aldstadt J, Koenraadt CJM, Fansiri T, Kijchalao U, Richardson J, Jones JW, et al. Ecological Modeling of *Aedes aegypti* (L.) Pupal Production in Rural Kamphaeng Phet, Thailand. PLoS Negl Trop Dis. 2011;5:e940.

47. Padmanabha H, Durham D, Correa F, Diuk-Wasser M, Galvani A. The Interactive Roles of *Aedes aegypti* Super-Production and Human Density in Dengue Transmission. PLoS Negl Trop Dis. 2012;6:e1799.

48. Depradine CA, Lovell EH. Climatological variables and the incidence of Dengue fever in Barbados. International Journal of Environmental Health Research. 2004;14:429–41.

49. Hamilton, I. Analysis of dengue cases in Barbados (2004-2013). Final analysis report V1.3. 20 March 2014.

50. Verret M, Berry P, Fook TCT, Lal A. Assessment of Climate Change and Health Vulnerability and Adaptation in Dominica. 2016 p. 144.

51. Lowe R, Bailey TC, Stephenson DB, Graham RJ, Coelho CAS, Sá Carvalho M, et al. Spatio-temporal modelling of climate-sensitive disease risk: Towards an early warning system for dengue in Brazil. Computers & Geosciences. 2011;37:371–81.

52. Lowe R, Bailey TC, Stephenson DB, Jupp TE, Graham RJ, Barcellos C, et al. The development of an early warning system for climate-sensitive disease risk with a focus on dengue epidemics in Southeast Brazil. Statistics in medicine. 2013;32:864–883.

53. Lowe R, Barcellos C, Coelho CA, Bailey TC, Coelho GE, Graham R, et al. Dengue outlook for the World Cup in Brazil: an early warning model framework driven by real-time seasonal climate forecasts. The Lancet Infectious Diseases. 2014;14:619–626.

54. Lowe R, Rodo X, Barcellos C, Carvalho MS, Coelho CA, Bailey TC, et al. Dengue epidemic early warning system for Brazil. 2015; Available from: https://ore.exeter.ac.uk/repository/handle/10871/16630

55. Lowe R, Coelho CA, Barcellos C, Carvalho MS, Catao RDC, Coelho GE, et al. Evaluating probabilistic dengue risk forecasts from a prototype early warning system for Brazil. Elife. 2016;5:e11285.

56. Lowe R, Stewart-Ibarra AM, Petrova D, García-Díez M, Borbor-Cordova MJ, Mejía R, et al. Climate services for health: predicting the evolution of the 2016 dengue season in Machala, Ecuador. The Lancet Planetary Health. 2017;1:e142–51.

57. Schreiber KV. An investigation of relationships between climate and dengue using a water budgeting technique. International Journal of Biometeorology. 2001;45:81–9.

58. Yu H-L, Yang S-J, Yen H-J, Christakos G. A spatio-temporal climate-based model of early dengue fever warning in southern Taiwan. Stochastic Environmental Research and Risk Assessment. 2011;25:485–94.

59. Ortiz PL, Rivero A, Linares Y, Pérez A, Vázquez JR. Spatial models for prediction and early warning of *Aedes aegypti* proliferation from data on climate change and variability in Cuba. MEDICC review. 2015;17:20–28.

60. Exemplar to the user interface platform of the Global Framework for Climate Services (GFCS). Geneva, Switzerland: World Meteorological Association; 2014.

61. Climate change adaptation to protect human health: Barbados [Internet]. Public Health and Environment Department (PHE) of the World Health Organization; Available from: http://www.who.int/globalchange/projects/adaptation/PHE-adaptation-final-Barbados.pdf?ua=1

62. Chen AA, Chadee DD, Rawlins SC. Climate Change Impact on Dengue: The Caribbean Experience: University of the West Indies. Phoenix Printery Ltd., Kingston, Jamaica. 2006;

63. Ziervogel G, Downing TE. Stakeholder Networks: Improving Seasonal Climate Forecasts. Climatic Change. 2004;65:73–101.

64. Morss RE, Wilhelmi OV, Downton MW, Gruntfest E. Flood risk, uncertainty, and scientific information for decision making: lessons from an interdisciplinary project. Bulletin of the American Meteorological Society. 2005;86:1593.

65. Handel AS, Ayala EB, Borbor-Cordova MJ, Fessler AG, Finkelstein JL, Espinoza RXR, et al. Knowledge, attitudes, and practices regarding dengue infection among public sector healthcare providers in Machala, Ecuador. Tropical Diseases, Travel Medicine and Vaccines. 2016;2:8.

66. Implementation Plan of the Global Framework for Climate Services [Internet]. World Meteorological Association; 2014. Available from: http://www.wmo.int/gfcs/sites/default/files/implementation-plan//GFCS-IMPLEMENTATION-PLAN-FINAL-14211_en.pdf

67. Aligica PD. Institutional and stakeholder mapping: frameworks for policy analysis and institutional change. Public Organization Review. 2006;6:79–90.

68. Newcombe R. From client to project stakeholders: a stakeholder mapping approach. Construction Management and Economics. 2003;21:841–848.

69. Rawlins SC, Chen A, Rawlins JM, Chadee DD, Legall G. A knowledge, attitude and practices study of the issues of climate change/variability impacts and public health in Trinidad and Tobago, and St Kitts and Nevis. West indian medical journal. 2007;56:115–121.

70. Huang C, Vaneckova P, Wang X, FitzGerald G, Guo Y, Tong S. Constraints and barriers to public health adaptation to climate change: a review of the literature. American journal of preventive medicine. 2011;40:183–190.

71. Paterson JA, Ford JD, Ford LB, Lesnikowski A, Berry P, Henderson J, et al. Adaptation to climate change in the Ontario public health sector. BMC Public Health. 2012;12:452.

72. Gould S, Rudolph L. Challenges and Opportunities for Advancing Work on Climate Change and Public Health. International journal of environmental research and public health. 2015;12:15649–15672.

73. Maibach EW, Chadwick A, McBride D, Chuk M, Ebi KL, Balbus J. Climate Change and Local Public Health in the United States: Preparedness, Programs and Perceptions of Local Public Health Department Directors. PLOS ONE. 2008;3:e2838.

74. Balbus J, Ebi K, Finzer L, Malina C, Chadwick A, McBride D, et al. Are we ready? Preparing for the public health challenges of climate change. Environmental Defense Fund. 2008;

75. Are We Ready? Report 2: Preparing for the Public Health Challenges of Climate Change [Internet]. US Climate and Health Alliance. [cited 2017 Mar 16]. Available from: http://usclimateandhealthalliance.org/post_resource/are-we-ready-report-2-preparing-for-the-public-health-challenges-of-climate-change/

76. Saldana J. An introduction to codes and coding. The coding manual for qualitative researchers. 2009;1–31.

77. Saldaña J. The Coding Manual for Qualitative Researchers. Second Edition edition. Los Angeles: SAGE Publications Ltd; 2012.

78. Jupp TE, Lowe R, Coelho CA., Stephenson DB. On the visualization, verification and recalibration of ternary probabilistic forecasts. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences. 2012;370:1100–1120.

79. Street R, Jacob D, Parry M, Runge T, Scott J. A European research and innovation roadmap for climate services. European Commission. 2015;

80. Kraemer MU, Sinka ME, Duda KA, Mylne AQ, Shearer FM, Barker CM, et al. The global distribution of the arbovirus vectors *Aedes aegypti* and Ae. albopictus. eLife. 2015;4:e08347.

81. Benedict MQ, Levine RS, Hawley WA, Lounibos LP. Spread of the tiger: global risk of invasion by the mosquito Aedes albopictus. Vector-borne and zoonotic diseases. 2007;7:76–85.

82. Brady OJ, Gething PW, Bhatt S, Messina JP, Brownstein JS, Hoen AG, et al. Refining the Global Spatial Limits of Dengue Virus Transmission by Evidence-Based Consensus. Reithinger R, editor. PLoS Neglected Tropical Diseases. 2012;6:e1760.

83. Brady OJ, Golding N, Pigott DM, Kraemer MU, Messina JP, Reiner Jr RC, et al. Global temperature constraints on *Aedes aegypti* and Ae. albopictus persistence and competence for dengue virus transmission. Parasites & Vectors. 2014;7:338.

84. Nsoesie EO, Kraemer MU, Golding N, Pigott DM, Brady OJ, Moyes CL, et al. Global distribution and environmental suitability for chikungunya virus, 1952 to 2015. Euro Surveill. 2016 May 19;21(20).

85. Carlson CJ, Dougherty ER, Getz W. An ecological assessment of the pandemic threat of Zika virus. PLoS Negl Trop Dis. 2016;10:e0004968.

86. Messina JP, Kraemer MU, Brady OJ, Pigott DM, Shearer FM, Weiss DJ, et al. Mapping global environmental suitability for Zika virus. Elife. 2016;5:e15272.

87. Samy AM, Thomas SM, Wahed AAE, Cohoon KP, Peterson AT. Mapping the global geographic potential of Zika virus spread. Memórias do Instituto Oswaldo Cruz. 2016;111:559–560.

88. Kraemer MU, Sinka ME, Duda KA, Mylne AQ, Shearer FM, Barker CM, et al. The global distribution of the arbovirus vectors *Aedes aegypti* and *Ae. albopictus*. Elife. 2015;4:e08347.

89. Carlson CJ, Dougherty ER, Getz W. An ecological assessment of the pandemic threat of Zika virus. PLoS Negl Trop Dis. 2016;10:e0004968.

90. Messina JP, Kraemer MU, Brady OJ, Pigott DM, Shearer FM, Weiss DJ, et al. Mapping global environmental suitability for Zika virus. Elife. 2016;5:e15272.

91. Samy AM, Thomas SM, Wahed AAE, Cohoon KP, Peterson AT. Mapping the global geographic potential of Zika virus spread. Memórias do Instituto Oswaldo Cruz. 2016;111:559–560.

92. Johnson LR, Ben-Horin T, Lafferty KD, McNally A, Mordecai E, Paaijmans KP, et al. Understanding uncertainty in temperature effects on vector-borne disease: a Bayesian approach. Ecology. 2015;96:203–213.

93. Escobar LE, Qiao H, Peterson AT. Forecasting Chikungunya spread in the Americas via data-driven empirical approaches. Parasites & vectors. 2016;9:112.

94. Brasil P, Pereira Jr JP, Moreira ME, Ribeiro Nogueira RM, Damasceno L, Wakimoto M, et al. Zika virus infection in pregnant women in Rio de Janeiro. New England Journal of Medicine. 2016;375:2321–2334.

95. Rodrigues LC. Microcephaly and Zika virus infection. The Lancet. 2016;387:2070–2072.

96. Pan-American Health Organization / World Health Organization. Zika-Epidemiological Report Puerto Rico. Washington, D.C.: PAHO/WHO; 2017 Mar.

97. Pacheco O, Beltrán M, Nelson CA, Valencia D, Tolosa N, Farr SL, et al. Zika virus disease in Colombia—preliminary report. New England Journal of Medicine. 2016;

98. Viennet E, Harley D. Climate services for health: cooperation for climate informed dengue surveillance. The Lancet Planetary Health. 2017;1:e126–7.

99. Climate Prediction Center. Cold and Warm Episodes by Season (1951-present) [Internet]. NOAA/National Weather Service; 2012. Available from: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

Appendix 1. Climate and Health Sector Mandates and Competencies

Climate sector

The Caribbean Institute of Meteorology and Hydrology (CIMH) is mandated to support national meteorological services in the Caribbean region (16 member states) on topics related to weather, climate, and water. CIMH is the technical arm of the Caribbean Meteorological Organization (CMO). The ministers responsible for meteorology in the CMO states are represented on the counsel of CIMH, providing guidance and direction for the region. CIMH was recently designated as the World Meteorological Organization (WMO) Regional Climate Center for the Caribbean, expanding their role in the region and the countries that they serve. The applied meteorology and climatology group of CIMH has become the core of the RCC, aiming to provide products and services for sectors and the public, to move from data to information to services. They are guided by the Global Framework for Climate Services (GFCS). CIMH works in 6 key sectors: disaster risk management, health, water, agriculture, food security, and tourism, an additional sector that is not part of the GFCS. It is CIMH's responsibility to build the capacity of the national meteorological services in the region, but it is the responsibility of the national meteorological services to implement the climate services in their respective countries. As CIMH has increased their climate services portfolio, they have increased engagement with sectoral key stakeholders. This has required an analysis of sectoral needs through social science research. Climate services are now the biggest group at CIMH, and the group is attracting funding from donors interested in climate change adaptation. Health, and specifically VBDs, is a priority for CIMH because it falls within the GFCS, and because health is priority for society and has been identified as a priority by CARPHA. The role of CIMH is to determine whether they can provide climate services that help the health sector to solve urgent health problems. CIMH places most of their emphasis on the near future (climate variability) time scale as opposed to the climate change time scale. Funding for projects at CIMH depends on whether or not they can convince funders and decision makers that the climate services that they provide have a social or economic benefit for a given sector.

CIMH provides climate outlooks and monitoring information at the seasonal timescale, as well as twice a year at the Caribbean climate outlook forums (CariCOF). This information is published on the Caribbean RCC website as well as distributed via email to those who attended CariCOF meetings in the past. The information is also distributed via targeted bulletins for the sectors and through a bulletin focused on drought. The national meteorological services in the region receive the seasonal climate forecasts for their country, and are responsible for reviewing the forecast and distributing to their national stakeholders. The CIMH also supports regional meetings such as the EWISACTs (Early Warning Information System Across Climate Timescales) with sectoral stakeholders.

In the Caribbean, the national meteorological services have historically has focused on aviation meteorology. Their focus has been more operational than research oriented. However, in the last 10 years, they have begun to develop climate services and seasonal forecasts with support from CIMH, and this is an area that they would like to grow and develop. Currently, the national met services of Barbados and Dominica do not have a mandate to work on climate and health.

The Barbados national meteorological service produces weather forecasts three times each day for Barbados, St. Vincent, Dominica. On Barbados there are 11 stations with long-term rainfall data (1 per parish) and two complete weather stations with long-term data including temperature, relative humidity, and other parameters. They recently installed new stations in the Bell, Grahame Hall, and St. Phillip. On Dominica, there are two long term weather stations located at the airports (Canefield and Douglas Charles). A network of hydrometerological stations are being installed to improve coverage across the island. There are also 10 Domex rain gages, through a project with Yale University. Each month the national meteorological offices submit rainfall and temperature data from their long-term stations to Carigen, online platform that supports a centralized database operated by CIMH. These data are used by CIMH to generate the seasonal climate forecasts for the region.

Health sector

In Barbados, climate and health is a relatively high priority, but it is not a mandate. VBDs are a high priority because of the high burden of disease. There is a need to strengthen the competencies in this area. The mandates of the Barbados vector control unit are to map and analyze the data, and do targeted investigations or interventions when needed. They also conduct vector surveillance and control in ports (ovitrapping) and are responsible for purchaseing insecticides. The mandate of the environmental health officers, who are located at the polyclinics, is to conduct routine vector control and surveillance, and to visit each home 3-4 times per year.

In Dominica, climate and health is a priority area, and VBDs are also important because of the high burden of disease. The MoH has put emphasis on mainstreaming climate change adaptation within its overall activities. The environmental health department (EHD) in the Ministry of Health in Dominica has a very broad mandate, working in nine program areas including vector control, food safety, occupational health, port health, school health, institutional hygiene, among others. The EHD have the mandate to monitor and to ensure that the activities of the public do not impact have a negative impact on the environment, and that the environment does not have a negative impact on the health of the population.

The Caribbean Public Health Agency (CARPHA) is a relatively new organization. It is the combination of five pre-existing regional health institutions. The institutions associated with climate and health are the Caribbean Environmental Health Institute (CEHI) and the Caribbean Epidemiological Center. Climate and health are now part of CARPHA's mandate. CARPHA has twenty-four member states. They are responsible for providing assistance to member states to deal with any public health issue. Their role is to help national Ministries of Health to build capacity through trainings and other resources, to respond to outbreaks, to mobilize resources from donors, and to purchase needed equipment. An EWS for VBDs fits within CARPHA's mandate, because it would allow them to better serve their member states and would help them to reduce the risk of arboviral diseases in the future.

Th Pan American Health Organization's (PAHO) office in Barbados works with ten countries in the Eastern Caribbean. PAHO develops biannual work programs with each country, and supports the implementation of the plans. Their role is to ensure that the Ministries of Health have response plans that are current with scientific information and best practices, and they provide capacity building and training to strengthen surveillance. Climate and health has been mandated as a high priority for PAHO, as it is a central part of the World Health Organization's (WHO) global strategic plan.

Disease surveillance

In Dominica, serum samples from suspected dengue patients are sent to CARPHA in Trinidad for laboratory confirmation, which often takes three weeks. There is no national reference laboratory in Dominica for diagnostics of arboviruses. Most surveillance is syndromic. Key informants reported that there is fairly high health care seeking behavior, except among men. People seek health care in both private and public clinics. When a patient is diagnosed with dengue, the clinical nurse at the clinic is responsible for filling out a paper form, and sending the form each week to the Health Information Unit (HIU). At the same time, the EHD officer in the district is directly notified of the case to ensure a rapid intervention. There have been no cases of severe dengue fever (e.g., dengue hemorrhagic fever – DHF) and no known deaths due to dengue fever. Underreporting of dengue cases is a major problem, especially from the private sector. Since the CHIKV epidemic, the EHD began georeferencing cases of arboviral disease. Dominica is currently setting up a surveillance system whereby the EHD officers would have handheld units (e.g., tablets or phones) that would allow them to input vector surveillance data into an online system in real time. The data would be accessed by central EHD office and the Health Information Unit. The EHD has the hardware, and they are working with PAHO to develop software to support this surveillance platform.

In Barbados, the surveillance unit in the EHD of the Ministry of Health is responsible for disease surveillance. They work with thirteen sentinel sites including the hospital (QEH), the geriatric hospital, psychiatric hospital, and the network of polyclinics. In 2016 a new polyclinic was added. Physicians or nurses are required to fill out a paper notification form and send the form to the epidemiological unit, where the data are entered into a cenral database. The surveillance unit liaises with the Leptospirosis lab (national reference lab) to record laboratory confirmed cases. As in Dominica, this is a passive surveillance system, and there is significant underreporting of suspected cases of dengue fever by private physicians. There are also private laboratories that conduct diagnostic testing, but it is not required that their results are reported to the MoH. Physicians are using a system called MedData for electronic patient records. They generate weekly syndromic surveillance reports that come to the epidemiology unit, with for example, the number of undifferentiated fever cases. The surveillance unit compares weekly cases from the past 2 years to current cases to determine visually if there is "above normal" transmission

In Barbados, the Leptospirosis laboratory is the national reference laboratory. They conduct DENV, CHIKV, and ZIKV diagnostics for any individual with a suspected infection. Diagnostics include DENV IgM/IgG and CHIKV IgM/IgG using commercial ELISA kits. They also conduct real time PCR using the

CDC triplex assay (since Sept 2016) for DENV, CHIKV, and ZIKV, and they also serotyping of DENV. Serum samples are used for DENV, CHIKV and ZIKV diagnostics, and urine samples are also used for ZIKV. PCR is used for individuals within 5 days of infection, and IgM is used if the individual has been sick for more than 5 days. They also use IgM as a confirmatory test for anyone who is PCR negative. Other diseases that might be confused with dengue fever include hanta and parvovirus In Barbados, DENV/CHIKV/ZIKV case data have been mapped to the enumeration district level (census districts) since 2013. About 90% of suspected and confirmed cases are mapped, except when there is an outbreak, because there are too many cases to map. Mapping is done by the Vector Control Unit of the MoH

Entomological control and surveillance

In Barbados, the EHD in the MoH is responsible for vector surveillance and control. The epidemiological surveillance unit liaises with the Leptospirosis lab to send confirmed cases to the vector control unit, who are responsible for control along with the polyclincs. The polyclinics send entomology surveillance data each day to the vector control unit, who map the data to areas where targeted intervention is needed. The EHD officers at the polyclinics are also contacted directly by the physicians in the polyclinic when there is a suspected case, so that they can intervene quickly. The vector control unit of the EHD is responsible for vector surveillance and control in ports of entry, and they do this by ovitrapping in ports and within a 100-yard radius, as per international health regulations, and vector control preceding mass gathering events. Chemical larvicides used include temefos (5% granular form; main larvicide used), Aquatain (silicone based compound), Methoprene (juvenile growth inhibitor); larvivorous fish are also used in some cases. The adulticide used for fogging is 95% malathion with 5% diesel. Mosquito eggs are sent to CARPHA periodically for insecticide resistance testing. Vector control is decentralized to the polyclinics across the island. The most common breeding sites are 5 gallon white buckets. *Aedes albopictus* has not been detected. One of the major issues mentioned in Barbados was that companies and high-income communities use private vector control companies, which are not well regulated. The MoH doesn't know what chemicals they are using, at what frequency, or where, potentially increasing the risk of insecticide resistance.

In Dominica, since 2006, the EH department of the MoH has outsourced vector control and surveillance to the company National Pest, who provide monthly data to the EHD. The EHD also does its own surveillance and control on a quarterly basis; they sample 30% of homes in a cross sectional and representative sample. The EHD monitors and supervises National Pest. The EHD can also prosecute homes that have chronic mosquito breeding sites. *Aedes albopictus* has not been detected. When there is a case, the EHD officer, Community health nurse (CHN), and National Pest work together to intervene in all homes around the case within 200 meters. The EHD also does health promotion through schools, health facilities, ad weekly radio program. They also have a port surveillance program, where they conduct ovitrapping and vector control when needed. Each home across the island is visited about four times per year by the EHD officer and National Pest. National Pest does larviciding using bacillus thuringiensis israelensis (BTI), because of temefos resistance, and they use permethrin and malathion for fogging during outbreaks and mass gatherings. They also use larvivorious fish as a form of biological control. CARPHA conducts insecticide resistance testing with the EHD each year, and resistance to permethrin was recently documented. EHD planning for vector control occurs on the fiscal budgetary calendar, from July to June. Vector control is decentralized as EHD officers and National Pest officers are based in the local communities where they work across the island, but supervision is centralized in the EHD office in Roseau.

Appendix 2: Results of the theme analysis of interviews with key climate and health stakeholders.

Pillar 1: Communications and partnerships

Strategy for collaboration	Barbados	Dominica	Regional
Top level engagement and support are needed bring climate and health to the MoH agenda	x	x	
Create project implementation processes and identify internal and external funding sources	x		
Sign MOUs between the climate and health sectors, with a framework that indicates the work to be done jointly, roles of each, SOPs, and a timeline for the operational plan. This indicates that there is a strong commitment from the heads of the institutions and an understanding of mutual benefit.	x		x
Climate, health, risk forums and regional meetings to bring together stakeholders from the different sectors	x		
Include the planning unit of the MoH in meetings/forums regarding climate and health, since they control resources and influence policy	x		
Create a framework for communication, for bi-directional flow of information. Create an ad-hoc or standing committee. Terms of reference. Clear reporting guidelines, timelines, formats, content.	x	x	
Create an online data portal for the region or country	x		
Joint education/training/demonstration activities with the health and climate sectors to raise awareness and interest	x	x	
Develop data sharing protocols	x	x	
Link climate and health to tourism, which is the driver of the economy. This will garner greater political interest.	x		
MoH should coordinate with met services to ensure that new stations are placed in areas that are strategic for both climate and health surveillance		x	
Develop a closer working relationship between the heads of climate and health sectors, so that each group knows that the other is doing, what information can be shared, and what resources are available to help each other.		x	
Frame climate services for health as a development and economic issue. There is a high economic and social cost of VBDs. Show how an EWS can provide information early enough and reliable enough to be cost saving, show added value by making interventions more efficient and targeted.		x	x
Publish collaborative scientific publications on climate and health with co-authors across different sectors to facilitate data sharing and to build the evidence base			x
Strengthen the evidence base for the linkages between climate and health. Conduct case studies in the region.			x
Learn how to communicate climate science to the health sector, build personal relationships, create a dialogue, build trust, and understand the perspectives and needs of the end users.			x

Focus on the effect of extreme climate events or climate variability on health instead of climate change, which is polemic.			x
Train and support a critical mass of climate-health specialists to provide long-term sustainability for a program on climate and health. Focus on supporting, retaining, nurturing this cohort so that they are successful and stay for a while.			x
Include representatives from the met services in regular meetings related to disease surveillance	x	x	

Pillar 2: Research and evidence linking climate and health

Effects of climate on health (issues other than *Aedes aegypti* transmitted diseases)	Barbados	Dominica
Heat stress and discomfort due to hotter days and nights, may exacerbate diabetes	x	x
Lack of water affects hygiene and sanitation	x	
Salt water intrusion into the groundwater supply can increase the risk of hypertension	x	
Sea level rise can increase the expanse of wetlands, increasing habitat for mosquito vectors	x	
Flooding increases the risk of leptospirosis	x	x
Extreme climate events (e.g., hurricanes) result in relocation of people to shelters and crowding, increasing the risk of communicable diseases (respiratory infections, skin infections).	x	x
Water shortages increase water storage. Contamination of water stored with *Pseudomonas* bacterium increases the risk of Pseudomonas infections in eye/ear/skin.	x	
UV exposure increases the risk of skin cancer	x	
Climate affects nutrition and food security: Droughts reduce crop yields, warming ocean temperatures result in fish kills.	x	x
Flooding can cause in contamination of drinking water systems and recreational areas with fecal matter, increasing the risk of gastroenteritis, salmonella	x	
Dry weather and air pollution (e.g., due to vehicle exhaust, Saharan dust and grass fires) can increase the risk of respiratory problems, such as asthma	x	x
Extreme climate events (e.g., Tropical Storm Erica) result in destruction of homes, loss of lives, infrastructure damage.		x
Extreme climate events result in mental health problems for vulnerable populations, such as the elderly who were relocated post-disaster		x
Dry weather conditions increase the risk of gastroenteritis		x
Extreme climate events increase the risk of gastroenteritis and cholera		x

Risk factors for *Aedes aegypti* transmitted diseases	Barbados	Dominica
Water scarcity due to drought conditions increases household water storage, which increases breeding sites for *Aedes aegypti* mosquitoes	x	
Rainfall increases breeding sites for *Aedes aegypti* mosquitoes.	x	x
High rainfall, temperature and humidity during the rainy season increases the risk of disease transmission	x	x
Warming temperatures speed up the life cycle of the mosquito	x	x
Lack of public awareness/knowledge of proper water storage practices	x	
Improper management of public utilities and infrastructure, which can become mosquito breeding sites (e.g., telephone junction boxes, manhole covers, public wells, drains), and the difficulty in finding these cryptic (nontraditional) breeding sites	x	
Legislation by Town and Country Planning, which was enacted to increase drought resilience, that requires all buildings over a certain size to store water. Lack of standards to ensure that these don't become mosquito-breeding sites.	x	
Unclear connection between temperature and *Aedes aegypti*	x	
Introduction of new diseases and vectors due to trade and travel between the islands, and a large influx of tourists	x	x
Attitudes of community members that vector control is not their responsibility. It is the job of the Ministry of Health.	x	x
Sanitation practices of the community (e.g., littering)	x	
The link between rainfall and dengue has become less clear, due to increased water storage	x	x
Many microclimates which affect vector proliferation		x
The distribution of *Aedes aegypti* has increased into higher elevation areas; may be due in part to changing climate conditions.		x
Water scarcity due to extreme climate events. Following Tropical Storm Erika, water systems were damaged and rivers were contaminated. There was a scarcity of potable water. Homes began storing water in drums, and this practice continues today even though most homes have access to piped water (>90%)		x
Movement from rural (low risk) to urban areas (high risk) across the island results in disease spread		x
Community members are reactive. Low risk perception in between epidemics. They take actions only once there is an outbreak.		x
High degree of insecticide resistance to temefos (larvicide)		x
Difficulties with solid waste management result in increased number of breeding sites		x

Past projects on climate and health	Barbados	Dominica	Regional
Barbados was selected as the country in the western hemisphere for the WHO piloting climate change adaptations strategies for human health project (GEF), which ran from 2011 to 2015. As a result, Barbados set up a climate change and health point person in the MoH. One of the recommendations was the development of an EWS for dengue. Outcomes of the climate change project: showing the MoH that there are factors outside of the traditional public health spheres that affect health, linkages with CIMH, knowledge of other programs from other countries that can be adapted	x		
PAHO did a statistical time series analysis of dengue and climate in Barbados from 2003 to 2014 but were not able to show much predictive power with climate info	x		
PAHO supported projects to develop environmental health information systems, but they were not widely used. Now there are new initiatives to use handheld devices like cell phones for field data collection.			x
There was an IPCCC project led by investigators from the University of West Indies on climate and dengue in the Caribbean in the early 2000s. There was a book published.			x
The Environmental Health department in Dominica is working on a PAHO-funded project to cover water drums. Trying to do a demonstration in each community to get buy-in and sustainability. They recently sent a proposal to PAHO to do a community empowerment and mobilization project.		x	
The climate and health program in Dominica began in 2013. Dominica was selected as the health exemplar for the GFCS. There was a national consultation for the GFCS from 2015-2016, which focused on the health sector. They evaluated VBDs, food safety and water, and the impact of Tropical Storm Erika. The study provided evidence that gastroenteritis was linked to climate. This made the work much more interesting for the staff of the EHD and enhanced their work.		x	
Ongoing project in Dominica to develop climate smart health care facilities, funded by DFID, with UK overseas development programme, and PAHO		x	
With WMO/WHO and Health Canada, Dominica is developing a methodology for climate change adaptation planning for health in small island states		x	

Pillar 3: Capacity Development

Health sector needs	Barbados	Dominica	Regional
Training on the general knowledge about climate and health, climate and VBDs, early warning systems (for managers/decision makers and for everyone)	x	x	x
A better understanding of what climate services are available	x		x
Specialized training in GIS for technical specialists	x	x	x
Training in entomology and creation of entomology specialists		x	
Training should be interactive and practical, e.g., simulations	x		
Training on use of climate information for health during emergencies/disasters			x
Training in modeling, data analysis	x	x	
Training on how to write proposals to attract funding for new projects on climate and health	x		
Training in scientific research and tools (e.g., GIS tools). Include a research component to the health sector plan	x	x	
New research to strengthen the evidence base linking climate and health	x	x	x
Increase staffing to be able to take on a new area, e.g., climate services for health	x	x	x
EH staff want to be trained in how to collect weather station data, so they can increase the capacity of the local met service		x	
Improve data collection from the field using hand held devices		x	
Better data recording practices in the health sector to have reliable long-term records			x
Strengthen the relationship between the climate/health sectors to better understand needs and resources/data available	x	x	x

Climate sector needs			
Increase their number of staff to be able to take on a new area, e.g., climate services for health	x	x	x
Training on the general knowledge about climate and health, climate and VBDs, early warning systems (for managers/decision makers and for everyone)	x	x	x
A better understand of the needs of the health sector		x	
Better security for the met stations		x	
Transportation and security to be able to download data from weather stations		x	
Financial resources		x	
Strengthen the relationship between the climate/health sectors to better understand needs and resources/data available	x		x
Increase meteorology/forecasting capacity	x		

Pillar 4: Mainstreaming climate services for health operations

Current use of climate/weather information in VBD planning and interventions	Barbados	Dominica	Regional
MoH does not use climate info for planning VBD reduction intervention. There is no climate-driven EWS.	x	x	x
The MoH receives met data from the Barbados Met Service upon request as an excel spreadsheet. Very informal. No system in place to send data regularly.			
MoH planning for vector control revolves around the rainy or dry seasons	x	x	
Weather/climate info is not used to implement vector control, but the EH department does receive info, such as the CIMH drought bulletin and the met service weather bulletins. These reports to be more user-friendly and less technical so that the health sector can access them. Need to simplify the climate data so that health professionals, especially decision makers, can use the information to make decisions about control programs. Need climate-health bulletins		x	
CARPHA doesn't receive climate info currently, but they would want to in the future			x
There is no EWS for VBDs, except that the case surveillance data are monitored, and alerts are issued if cases surpass a threshold determined by historical cases	x	x	x
PAHO receives climate data from CIMH when requested			x

Ideas for climate services	Barbados	Dominica	Regional
Maps showing the spatial distribution of mosquito vectors in relation to climate conditions	x	x	
Data platform (ideally GIS) to integrate data on entomology, epidemiology and climate to be used by technical staff	x		
Climate and health bulletin with information about future VBD risk for decision makers	x		
Forecast of vector abundance and/or disease incidence using rainfall/temperature	x		
Wind speed and direction data could be used to inform fogging (adult insecticides)	x	x	
Develop a system that converts epidemic forecasts into color alert codes that are projected in space (maps) and time.			
Regular sharing of current climate/weather forecasts and past data to see trends with those involved in VBD surveillance and control		x	
For an EWS you need to have information systems with the research component, operations component, platform for data sharing and knowledge sharing, outreach/awareness/education, and an in-country response and mitigation plans and policies			x
Effective climate services are anything that moves beyond the tercile forecast to explain what will happen with disease risk if there is above/below normal rainfall, temperature, etc.			x

Issues to address in developing a climate service
Develop standardized data collection, sharing, and storage protocols
Collect entomological, disease, and climate data in compatible spatio-temporal scales and data formats
Identify the institution responsible for data storage and running the forecast models
Develop the infrastructure, hardware, and software needed for this platform

Sensitivities with sharing and disseminating human health data, especially for tourism based economies

Appendix 3. Climate and health interview for decision makers and managers

SECTION 1: BACKGROUND INFORMATION
Professional Background:______________

What is the name of the institution where you work? ___________

What is your position at your institution?______________

Time working in the sector ________years ________months

Indicate the jurisdiction of your institution (check all that apply)
☐ Regional (Caribbean) ☐ National ☐ Community

What is the approximate number of technical staff in your department?

What is the principal function of your department/office in your institution? *Prompts: vector borne diseases, disease and vector control/surveillance, climate, climate change, climate-health linkages, climate-health communications, Disaster Risk Reduction (DRR).*

SECTION 2. CLIMATE AND RELATED INFORMATION FOR VECTOR BORNE DISEASES
In your experience, how does climate affect directly and indirectly the health of people in your jurisdiction? *Prompts: water-borne diseases, vector-borne diseases, respiratory diseases, heat waves, hurricanes, droughts, floods, fires, mental health (depression, anxiety), air quality, water quality, unsafe sewerage, food security*

In your jurisdiction, what are the key factors that increase the risk of epidemics of diseases transmitted by *Aedes aegypti* (dengue fever, chikungunya, and Zika fever)? *Prompts: human movement, insecticide resistance, lack of community engagement/mobilization, lack of public health education, emergence of a new virus, insufficient staff/resources for vector control and diagnostics, high social vulnerability (e.g., urban poverty), climate conditions, basic services to the communities (drinkable water, sewage treatment).* In your jurisdiction, what climate factors trigger epidemics of diseases transmitted by *Aedes aegypti* (dengue fever, chikungunya, and Zika fever)? *Prompts: rainfall, air temperature, relative humidity, El Niño indices (ENSO)*.*

**(ENSO) is a naturally occurring phenomenon that involves fluctuating ocean temperatures in the equatorial Pacific. When sea surface temperatures are warmer than average (+0.5 deg C from the long term average), this is referred to as an El Niño event. When sea surface temperatures are cooler than average (-0.5 deg C from the long term average), this is referred to as a La Niña event.*

Does your department/office use weather or climate information to plan or implement sector interventions that may benefit or lead to the reduction of VBDs? Or specifically for *Aedes aegypti*?

Do you know if there are early warning systems for *Aedes aegypti* transmitted diseases in your jurisdiction? Do these early warning systems use climate information?

Do you know if your National Climate Change Team/Committee or National Disaster Management Committee address public health measures related to vector borne diseases? Have you been directly involved?

SECTION 3. CO-DEVELOPMENT OF CLIMATE SERVICES

From what institutions and in what format do you receive climate information? *Prompts: Caribbean Institute of Meteorology and Hydrology (CIMH), National Met Service, other public institutions, NGOs, academia, private sector, technical advisors, program directors, WHO/PAHO/WMO, CARPHA, Scientific advisor, Scientific journals*

What would you like to see as climate services (final products) that result from a collaboration between your sector and the climate & health sector? How would you use these products in your daily work? *Prompts: Training* *workshops, interactive GIS platform online, interactive excel spreadsheets, Climate and health bulletins, climate and health forums (quarterly), annual climate-health regional meetings, internal meetings between directors (bimonthly, quarterly), website*

What factors **limit** or **enable** your department to work more closely with the climate & health sector?

- Modeling capacity: human capacity, software, hardware
- Trained personnel and technical capacity
- Evidence of knowledge about climate & vector borne diseases (VBDs) interactions
- Prior experience with early warning systems or other climate services.
- Availability of financial resources
- Efficiency in the management and distribution of financial resources
- Coordination for cross cutting interventions for VBDs management
- Mobilization and coordination with local communities (Community-Based interventions)
- Strong leadership (vision)
- Organizational structure

What can be done to make your sector more interested or engaged in climate services for health? *Prompts: More information and understanding (training), time, expert advisory (scientific, operative), funding, leadership, peer support academia collaboration partnerships with NGOs, private sector, community leaders*

What kind of activities or trainings would be most useful for your institution?

SECTION 4. MULTI-SECTOR ENGAGEMENT FOR CLIMATE AND HEALTH (VBDs)

What other sectors/organizations do you currently partner with on work related to VBDs? *Prompts: National Met Service, environment, risk management, education, NGOs, private sector, community-based organizations.*

What other sectors/organizations/stakeholders would you like to partner with to improve the control of *Aedes aegypti* transmitted diseases? *Prompts: National Met Service, civil society, private sector, NGOs, academia, community organizations.*

How does climate and health (vector proliferation) fit within their institutional priorities/mandates/competencies?

What strategies would improve the collaborations between institutions working in the area of climate and VBDs? *Prompts: Institutional Agreement (MOU); Climate, Risk and Health Forums; Specific protocols of collaboration; Climate and health bulletins; data sharing agreements*

SECTION 5. NETWORKING

Would you mind sharing the names of others who you think would be useful to interview on this subject? We are looking for other key stakeholders with some awareness or interest, and who may be able to increase their agency's engagement. (Get contact information)

Would you be interested in receiving information from the results of this project by email?

Do you have any questions for me/us? Is there anything else you'd like to share?

You've been so helpful; I really appreciate the time you've taken to talk with me today. Do you mind if we contact you in the future with any follow-up questions that may emerge? Thank you very much.

References

Are We Ready? Report 2: Preparing for the Public Health Challenges of Climate Change | Rural Climate Network. http://www.ruralclimatenetwork.org/content/are-we-ready-report-2-preparing-public-health-challenges-climate-change, accessed March 16, 2017.

Climate Services for Health - Case Studies. 2016. World Meteorological Organization. https://public.wmo.int/en/resources/library/climate-services-health-case-studies, accessed February 21, 2017.

Exemplar to the User Interface Platform of the Global Framework for Climate Services (GFCS). 2014. Geneva, Switzerland: World Meteorological Association.

Gould, Solange, and Linda Rudolph. 2015. Challenges and Opportunities for Advancing Work on Climate Change and Public Health. International Journal of Environmental Research and Public Health 12(12): 15649–15672.

Paterson, Jaclyn A., James D. Ford, Lea B. Ford, et al. 2012. Adaptation to Climate Change in the Ontario Public Health Sector. BMC Public Health 12(1): 452.

Appendix 4: Climate and health data inventory questions

Question for key informants in health and climate sectors.

Please share an organizational diagram of the Ministry of Health of your country.

Please share links or copies of the laws and regulations that govern health care and the provision of health services related to vector-borne diseases in your country.

- Health Services Act

Please share links or copies of the laws and regulations that govern climate services for public health in your country.

- Global Framework for Climate Services
- No national legislation

Are there data sharing agreements between the public health sector and other agencies, such as the National Meteorological Services, Caribbean Institute of Meteorology and Hydrology, others?
No

Disease case reports and surveillance

1. What institution is responsible for disease surveillance?
2. How are cases of dengue fever, chikungunya and Zika reported (most likely passive surveillance?
3. How are cases diagnosed (clinical diagnosis, laboratory diagnosis)?
4. How are patients referred for laboratory testing? Do the patients come here or are blood/serum samples sent from the clinic?
5. Who conducts laboratory diagnoses of dengue/Zika/chikungunya cases?
6. What lab methods are used?
7. Is there historical data available on the prevalence of different DENV serotypes?
8. Is there targeted surveillance of ZIKV in pregnant women and congenital complications in infants?
9. Is there active surveillance of infections in the community?
10. Is there a community surveillance/detection system in place?
11. What is the spatial and temporal resolution of existing case records?
12. Are there electronic patient records or another electronic epidemiological database centralized for the country?
13. Are cases georeferenced? By whom?

Vector surveillance and control

1. What institution is responsible for vector surveillance and control?
2. How does the public health sector decide where to intervene for vector control and surveillance? Examples: Houses of suspected/confirmed cases, door to door vector control, high risk neighborhoods, requested by the communities
3. What are the most important factors that are considered when planning vector control/surveillance for the coming year? The following season? Weeks or days?
4. Is vector control and surveillance decentralized or centralized?
5. What vector surveillance tools are used? Larval surveys, pupal surveys, ovitraps, CDC light traps, prokopack backpack aspirators, other?
6. How frequently are homes visited for vector surveillance control?
7. Is there focal control (in and around presumed positive cases)?
8. What are the primary control methods for *Aedes aegypti*? Larvicide (temefos or BTI), indoor residual spraying (what chemical?), ultra low volume fogging (what chemical?), elimination of containers, use of petroleum products in standing water, biological control (copepods or larvivorous fish)?
9. Do you conduct surveillance of insecticide resistance? If yes, when? Where? How often?
10. Is there a national electronic database with historical vector surveillance data? What spatial and temporal resolution?
11. Has the vector surveillance data been georeferenced? By whom?

12. What is the timing (schedule) of vector control interventions (e.g., seasonal, monthly, random)?

13. Surveillance of *Aedes aegypti*, includes which of the following variables and what is the frequency (weekly, monthly, seasonal, random) of the data collected:

- GPS points (geographic location)
- Specific Address
- Elevation
- Local precipitation
- Local Temperature
- Breteau Index
- House Index
- Pupal indices
- Container indices
- Adult indices
- Housing characteristics
- Presence of febrile infections
- Household demographics
- Insecticide resistance
- Indoor versus outdoor location of adult mosquitoes

National census data

1. When was the last national household census conducted?
2. Are the census records geoferenced? At what spatial resolution?
3. Have vulnerability maps been created to identify the characteristics of high-risk communities (using census data)?

Climate data (CIMH/National Meteorology Service)

1. Who generates weather forecasts, seasonal forecasts, climate change projections?
2. How does your institution distribute their climate information?
3. How do CIMH and the NMS interact to support the forecast operations of the Caribbean Outlook Forum?
4. Is there a standardized database?
5. Spatial and temporal scale of meteorological data?
6. Location of met stations?
7. Automatic/manual stations?
8. What are the barriers/limitations and resources available for forecasting?

Climate and health capacity for supporting an early warning system:

1. Current resources and needed resources: human personnel (modelers), soft/hardware.
2. Who are the key technical personnel involved in future capacity building for the development and implementation of an EWS?

Appendix 5: Climate and health survey for public health practitioners

SECTION 1: BACKGROUND INFORMATION

Country:__________

Institution:__________

Department/unit:___________

What is your position at your institution?______________

Time working in the sector ________years ________months

Indicate the jurisdiction of your institution (check all that apply). Your jurisdiction refers to the geographic area (e.g., country, district, parish) which your department and institution serves.

☐ Regional (Caribbean) ☐ National ☐ Community ☐ Other:___________

Age: ☐ 18-30 ☐ 30-40 ☐ 40-50 ☐ 50-65 ☐ >65 ☐ Prefer not to reply

Gender: ☐ Male ☐ Female ☐ Other ☐ Prefer not to reply

Highest level of education completed:

☐ Primary education ☐ High School ☐ Bachelor's Degree ☐ Master's Degree ☐ Ph. D. ☐ Other:____

Professional Background:

☐ Public health
☐ Medical
☐ Management/administration
☐ Environment
☐ Engineering
☐ Entomology
☐ Risk
☐ Social Work
☐ Other:________________

SECTION 2. CLIMATE INFORMATION FOR VECTOR BORNE DISEASES

In your experience, which of the following factors are important in triggering epidemics of diseases transmitted by *Aedes aegypti* (dengue fever, chikungunya, and Zika fever) in your jurisdiction?

Risk factors	**Not important**	**Slightly important**	**Moderately important**	**Important**	**Very important**	**I don't know**
Introduction of a new virus to a susceptible population						
Mosquitoes that are resistant to insecticides						
Limited community engagement/mobilization						
Lack of community knowledge and awareness						
Insufficient staff/resources for vector control						
High-risk housing conditions						
Human movement						
Heavy rainfall						
Drought conditions						
Warmer air temperatures						
El Niño or La Niña events*						
Water storage behavior						
Economic barriers to mosquito control by households (e.g., cost of screens or insecticide)						
Low risk perception by communities						

**The El Niño Southern Oscillation (ENSO) is a naturally occurring phenomenon that involves ups in downs in ocean temperatures for 6 to 18 months in the east of the equatorial Pacific. When those temperatures are significantly warmer than average, this is referred to as an El Niño event, which in much of the Caribbean is linked to droughts. When the temperatures are significantly cooler than average, this is referred to as a La Niña event, which is linked to heavy rainfall and flooding*

Please describe any other risk factors not included in the prior question:_______________________________

Have you received information on the effects of climate on vector-borne diseases?
☐ Yes ☐ No ☐ I don't know

Does your health department use climate information to plan or implement disease and vector control interventions? ☐ Yes ☐ No ☐ I don't know

If your answer is YES, what is the source of the climate information (mark all that apply and specify)?
☐ Caribbean Institute of Meteorology and Hydrology (CIMH) ☐ National Meteorological Service: ______
☐ Universities ☐ Private institutions ☐ Others_______

If you had access to additional climate information, (1) what information would be helpful and (2) how could you use this information in your daily work to reduce the risk of vector-borne diseases?

SECTION 3: CLIMATE PERCEPTIONS AND PUBLIC HEALTH RESPONSES

"Climate variability" refers to fluctuations in climate around the long-term average, which occur over months, to seasons, to years. El Niño and La Niña are good examples of features of climate variability that affect weather and our society in the Caribbean. Examples of impacts of climate variability include long-term flooding and recurrent flash floods, droughts, heat waves, amongst others.
How much do you agree or disagree with the following statements?

	1 Strongly Disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly Agree	6 Don't know
My jurisdiction is currently experiencing one or more serious public health problems as a result of climate variability.						
My jurisdiction is currently experiencing an increased risk of diseases transmitted by *Aedes aegypti* due to climate variability.						
In the next 20 years, my jurisdiction will experience increasing risk of diseases transmitted by *Aedes aegypti* due to climate variability.						
I am worried about the impact of climate variability on the health and well-being of people in my jurisdiction.						
The effects of climate variability on the health of people in my jurisdiction is an urgent problem.						
There are options/solutions to reduce the effects of climate variability and to improve the health of people in my jurisdiction.						
The people in my jurisdiction are worried about the effects of climate variability on their health and well-being.						
My health department currently has ample expertise to assess the potential public health impacts associated with climate variability that could occur in my jurisdiction.						
Dealing with the public health effects of climate variability is an important priority for my health department.						
I am knowledgeable about the potential public health impacts of climate variability.						
The other relevant senior managers in my health department are knowledgeable about the potential public health impacts of climate variability.						
My health department currently has ample expertise to create an effective plan to protect local residents from the health impacts of climate variability.						
My health department currently has sufficient resources to effectively protect local residents from the health impacts of climate variability.						
My health department is able to effectively communicate the health impacts of climate variability to local communities.						

SECTION 4: EARLY WARNING SYSTEMS FOR VECTOR-BORNE DISEASES

Do you know what is an early warning system for disease epidemics? ☐ Yes ☐ No ☐ I don't know

Do you know if there are early warning systems for *Aedes aegypti* transmitted diseases in your jurisdiction? ☐ Yes ☐ No ☐ I don't know

Do these early warning systems use climate information? ☐ Yes ☐ No ☐ I don't know

In your words, describe an optimal early warning system to predict and prevent local epidemics of mosquito-borne diseases, like dengue fever:

____

____

If there was an early warning system created to predict epidemics of dengue fever, chikungunya and Zika fever, how would you prefer to receive the warnings or alerts (mark all that apply)?

☐ Climate and health bulletins (PDF) by email
☐ Climate and health forums (quarterly)
☐ Annual climate-health regional meetings
☐ Internal meetings within your department
☐ Interactive GIS platform online
☐ Interactive excel spreadsheets

What are the strengths of your health department, **which would enable** the implementation an early warning system for *Aedes aegypti* transmitted diseases? (mark all that apply)

☐ Computer programming expertise
☐ Geographic information system (GIS) expertise
☐ Statistical and/or modeling expertise
☐ Computing hardware to operate the early warning system (computers, data servers)
☐ General knowledge of climate and vector borne diseases
☐ Organizational structure
☐ Prior experience with early warning systems or other climate services
☐ Availability of financial resources
☐ Efficiency in the management and distribution of financial resources
☐ Effective vector and disease surveillance infrastructure
☐ Effective public health messaging/education
☐ Mobilization and coordination with local communities
☐ Strong coordination with other institutions/NGOs/private sector
☐ Strong leadership

Which areas would be **need to be strengthened** in order to implement an early warning system for *Aedes aegypti* transmitted diseases? (mark all that apply)

☐ Computer programming expertise
☐ Geographic information system (GIS) expertise
☐ Statistical and/or modeling expertise
☐ Computing hardware to operate the early warning system (computers, data servers)
☐ General knowledge
☐ Organizational structure
☐ Prior experience with early warning systems or other climate services
☐ Availability of financial resources
☐ Efficiency in the management and distribution of financial resources
☐ Effective vector and disease surveillance infrastructure
☐ Effective public health messaging/education
☐ Mobilization and coordination with local communities
☐ Strong coordination with other institutions/NGOs/private sector
☐ Strong leadership

SECTION 5. CAPACITY BUILDING

In your department, are there people with expertise in the following GIS, statistical, programming, or database software? (mark all that apply)

- ☐ ArcGIS
- ☐ QGIS
- ☐ Tableau
- ☐ Epi Info
- ☐ R
- ☐ SPSS
- ☐ SAS
- ☐ Google Earth
- ☐ Microsoft Excel
- ☐ Microsoft Access
- ☐ SQL
- ☐ Visual Basic
- ☐ Java
- ☐ Other:_____

What kind of activities or trainings would be useful for your institution? (mark all that apply)

- ☐ Climate forums: information and data for seasonal forecasts
- ☐ Climate forums: data and models for 5 years – scenarios, outlooks, and other tools.
- ☐ Technical workshop on how to use climate information to predict epidemics)
- ☐ Use of GIS (digital maps) to identify areas at risk of vector-borne diseases.
- ☐ Time series analysis of health and climate data
- ☐ How to communicate the effects of climate on health to local communities
- ☐ Simulations of an early warning system for epidemics
- ☐ Other:____

Thank you for taking the time to complete this survey!
Would you like to receive a summary report of the results? ☐ No ☐ Yes. Email:____________________

Appendix 6: Forecast scenarios discussed in the Barbados stakeholder workshop

What actions would your sector take in response to the following alerts?

Short term (2 week forecast):	**Results**
• In two weeks there is a high probability that *Aedes aegypti* larval indices will increase. • In two weeks, there is a high probability of a dengue outbreak.	• At this time scale, the health sector would use the same strategies as always, but would increase education and mobilization, especially in the known hot spots • Short-term forecasts are important. They provide some lead-time to respond to a dengue outbreak. • Informants engaged in vector control indicated that alerts even at 2 weeks would be sufficient to allow them to implement source reduction programs in high risk areas and to prepare the population.
Medium term (3 month forecast):	
• In the next three months (May-July), there is a high probability that *Aedes aegypti* larval indices will increase. • In the next three months (May-July), there is a high probability of a dengue outbreak.	• At this time scale, the health sector would be better able to plan with stakeholders, mobilize the field team, look at trends, and create bulletins for community mobilization. • Quote: "a year can feel like a long time away. With 3 months, there will be a sense of urgency and you can do meaningful activities, although there might not be new resources". • Informants from the national reference laboratory, responsible for arbovirus diagnostics, indicated that they would need at least 6 months of lead-time in order to effectively procure diagnostic reagents in Barbados.
Long term (1 year forecast):	
• Next year, during May to July, 2018, there is a high probability that *Aedes aegypti* larval indices will increase. • Next year, during May to July, 2018, there is a high probability of a dengue outbreak.	• At this time scale the health sector could better lobby for the needed financial support, allowing for more effective budgeting. They would also be able to better mobilize and train community members. They would able to monitor and evaluate interventions, and conduct a needs assessment to inform plans. • They suggest focusing on engaging critical stakeholders, such as policy makers and leaders in the MoH and Minister of Finance.

Instructions:

- Break into 3 groups (will count off). In each group, one representative of CIMH and the national meteorological service.
- Assign a note taker, a moderator, and a presenter.
- 30 minutes to discuss in small groups. Record key points on flipchart paper.
- 30 minutes (7-10 min per group) to present and discuss with everyone.

Note: This activity was conducted at a national consultation at PAHO in Bridgetown, Barbados, in April 2017, with approximately 25-30 representative from the national Ministry of Health (MoH) of Barbados, the National Meteorological Service of Barbados, CIMH, and PAHO.

Appendix 7. Databases for modeling the spatiotemporal distribution of *Aedes aegypti* using climate information in Barbados and Dominica

Data	Source	Temporal	Spatial	Variables
Climate records from meteorological stations.	CIMH	Daily historical data (+15 years)	Point locations of weather stations	Precipitation; air temperature, relative humidity
			Point locations of weather stations	**Barbados (received):** 11 stations historical monthly rainfall 2 stations monthly mean/max/min temperature
			Point locations of weather stations (Canefield and Douglas Charles/Melville Hall)	**Dominica (received):** 2 stations historical monthly rainfall 2 stations monthly mean/max/min temperature
Satellite/reanalysis climate products.	CIMH	As available	As from the Satellite	Pre-existing classification mapping products (e.g. urban-rural, vegetated/not, agricultural vs. residential, etc.). Existing broad products like GIMMs that have been ground-truthed. Repositories of compiled cloud-free imagery from e.g. MODIS/LandSat products and derivatives (NDVI, Tcap, etc) Specific private, or acquired products, such as IKONOS, QuickBird, SuperBird, etc. Gridded satellite climate products that have been ground-truthed, such as TRIM, CHIRPS, or any others.
Socio-demographic information from the latest national census	Census bureau	2010 (or most recent)	Disaggregated (census-block level)	Age, population, education levels and employment of the head of the household, housing density, type of housing, access to services (garbage collection, piped water)
		2010	Enumeration district (ED)	**Barbados:** Received data on population and numbers of homes occupied per ED from the 2010 census.
		2011	Parish	**Dominica:** Access to most recent census data from online report by the census bureau. Received data on population, access to piped water

				and sewerage.
GIS maps of census blocks.	Census bureau	2010 (or most recent)	Census blocks	
Historical entomological information from vector control and surveillance	Ministry of health	+15 years, monthly	Neighborhood, census block level, or district level (with corresponding GIS polygon shapefiles); or GPS coordinates.	*Ae. aegypti* larval indices (House Index = % of homes with *Ae. aegypti* juveniles, Breteau Index = number of containers with *Ae. aegypti* juveniles per 100 homes; Container Index = % of water-bearing containers inspected with *Ae. aegypti* juveniles) Vector control effort (number of field worker days, kg of larvicide applied per unit time) Other entomological indices (e.g., adult mosquito densities, ovitrap data)
		weekly data from 2013 to present.	district level (n=64)	**Barbados:** Entomological data include epidemiological week, polyclinic, date, inspector, locality, district, homes visited, homes inspected, homes closed, homes positive for *Aedes aegypti* larvae or pupae, containers inspected, containers positive for *Aedes aegypti* larvae or pupae, homes rechecked, House Index, Breteau Index, Container index.
		Weekly, 2007-present	Health district level	**Dominica (received)** Entomological data include epidemiological week, district, homes visited, homes inspected, homes closed, homes positive for *Aedes aegypti* larvae or pupae, containers inspected, containers positive for *Aedes aegypti* larvae or pupae, homes rechecked, House Index, Breteau Index, Container index.
Not yet georeferenced				***Barbados (not received):*** *Historical paper records of entomological surveys since the mid-1990s, to be digitized and mapped to the district level. These data are the same as the currently mapped entomological records*

				Long-term ovitrap records from several sentinel sites in Barbados (ports and hospitals). Variables include presence/absence of eggs, egg counts, and the location (latitude/longitude) of the ovitraps.
Historical de-identified epidemiological records	Ministry of Health	Weekly or monthly cases	Neighborhood, census block level, or district level (with corresponding GIS polygon shapefiles); or GPS coordinates.	Dengue fever, Zika, chikungunya cases with clinical diagnosis or laboratory confirmation. Additional data if available: Disaggregated case records with exact data, patient age, gender, location (municipality), and diagnostics conducted. Historical records on the prevalence and distribution of the dengue serotypes in circulation.
		Total national monthly, 1999-2016; Georeferenced cases from 2013 to present	enumeration district (ED) (n = several hundred).	**Barbados (received):** Epidemiological data include monthly laboratory confirmed cases of dengue fever, chikungunya and Zika fever. Cases are georeferenced from 2013 to present.]
		Weekly, 2008-2016	National level	Barbados Total undifferentiated febrile illness cases
Not georeferenced		Individual patient records and weekly cases from 1993 to present	Health district level	**Dominica (received):** A database of individual patient records since 1993 with cases of dengue fever, chikungunya, and Zika fever. Weekly cases of dengue fever from 2000 to present.

Appendix 8. Survey results (Tables 8.1-8.6).

Table 8.1. Background on survey participants

Characteristics	**% (n)**
Total number of respondents	32
Female (%)	71.9 (23)
Jurisdiction	
Barbados	62.5 (20)
Dominica	31.3 (10)
Regional	6.3 (2)
Range Age	
18 - 30	9.4 (3)
31 - 40	25 (8)
41 -50	31.3 (10
51-65	25 (8)
> 65	3.1 (1)
No response	6.3 (2)
Level of Education	
Associate's degree	15.6 (5)
Bachelor's degree	21.9 (7)
Master's degree	59.4 (19)
No response	3.1 (1)
Organizations	
Ministry of Health	87.5 (28)
PAHO/WHO	6.3 (2)
National Pest (private sector, Dominica)	3.1 (1)
No response	3.1 (1)
Time working in sector	
1- 5 years	3.1 (1)
6 -11 years	12.5 (4)
12- 15 years	15.6 (5)
> 15 years	62.5 (20)
No response	6.3 (2)

Table 8.2. Strengths and weaknesses of the health sector with respect to the implementation of an early warning system for *Aedes aegypti* transmitted diseases

Categories	Strength	Weakness
Availability of financial resources	12.5 (4)	71.9 (23)
Efficiency in the management and distribution of financial resources	15.6 (5)	28.1 (9)
Statistical and/or modeling expertise	18.8 (6)	59.4 (19)
Prior experience with early warning systems or other climate services	21.9 (7)	34.4 (11)
Computer programming expertise	25 (8)	46.9 (15)
Computing hardware to operate the early warning system (computers, data servers)	28.1 (9)	34.4 (11)
Organizational structure	34.4 (11)	18.8 (6)
Geographic information system (GIS) expertise	40.6 (13)	65.6 (21)
Strong leadership	43.8 (14)	31.3 (10)
Mobilization and coordination with local communities	59.4 (19)	18.8 (6)
Strong coordination with other institutions/NGOs/private sector	62.5 (20)	31.3 (10)
General knowledge of climate and VBDs	62.5 (20)	34.4 (11)
Effective vector and disease surveillance infrastructure	65.6 (21)	34.4 (11)
Effective public health messaging/education	68.8 (22)	37.5 (12)

Table 8.3. Types of software currently used in health departments.

Categories	% (n)
Microsoft Excel	75 (24)
Epi Info	62.5 (20)
Google Earth	56.3 (18)
Microsoft Access	50 (16)
ArcGIS	28.1 (9)
QGIS	21.9 (7)
SPSS	21.9 (7)
Java	9.4 (3)
Visual Basic	3.1 (1)
Stata	3.1 (1)

Table 8.4. Preferred training activities for the health sector

Categories	% (n)
Technical workshop on how to use climate information, data & models and other tools to predict epidemics)	78.1 (25)
Use of GIS (digital maps) to identify areas at risk of vector borne diseases.	75 (24)
How to communicate the effects of climate on health to local communities	75 (24)
No response	6.3 (2)

Table 8.5. Current use of climate information and early warning systems. Results shown as % (n).

Questions	No response	Don't know	No	Yes
Have you received information on the effects of climate on vector-borne diseases?	0 (0)	0 (0)	31.3 (10)	68.8 (22)
Does your health department use climate information to plan or implement disease and vector control interventions?	0 (0)	18.8 (6)	31.3 (10)	50 (16)
Do you know what is an early warning system for disease epidemics?	3.1 (1)	0 (0)	18.8 (6)	78.1 (25)
Are there early warning systems for *Aedes aegypti* transmitted diseases in your jurisdiction?	6.3 (2)	12.5 (4)	40.6 (13)	40.6 (13)
Do these early warning systems use climate information?	28.1 (9)	37.5 (12)	21.9 (7)	12.5 (4)

Table 8.6. Preferred way of receiving information from an early warning system that predicts epidemics of dengue fever, chikungunya and Zika fever.

Categories	% (n)
Climate and health bulletins (PDF) by email	90.6 (29)
Interactive GIS plataform online	65.6 (21)
Internal meetings within your department	59.4 (19)
Climate and health forums (quarterly)	34.4 (11)
Annual climate-health regional meetings	25 (8)
Interactive excel spreadsheets	25 (8)