CLIMATE INFORMATION FOR ARBOVIRUS RISK MONITORING

Opportunities and Challenges

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Arthropodborne viruses (arboviruses) have presented a health threat to humans throughout history. In recent years, however, high-profile arbovirus introductions and modifications of range areas of susceptibility have raised concern about our ability to anticipate new epidemics and to manage them after onset. These include the expanding threat presented by Lyme disease and West Nile virus in North America, dengue epidemics in cities across the tropics and subtropics, and dramatic outbreaks in the Western Hemisphere, such as that of Chikungunya virus in 2013/14 and the current Zika virus crisis (Ventura et al. 2016). These arboviruses present researchers with a host of complexities, ranging from pathogen genetics to human behavior.

THE NIH–FIOCRUZ ARBOVIRUS SEMINAR: GLOBAL HEALTH CHALLENGES AND COLLABORATIVE OPPORTUNITIES IN ARBOVIRUS RESEARCH

What: The 84 researchers and public health officials from universities, research institutes, and operational agencies discussed opportunities to apply climate information to arbovirus monitoring and prediction.
When: 30 November–3 December 2015
Where: Manaus, Brazil

Arbovirus dynamics also involve environmental and ecological systems in a manner that often leads to significant climate sensitivity (e.g., Chaves et al. 2012; Naish et al. 2014; Tabachnick 2010). This sensitivity presents opportunities for risk monitoring and early warning systems (Lowe et al. 2014). It also suggests that the range and dynamics of these diseases might be altered by a changing climate (Campbell et al. 2015), alongside changing socioeconomic and environmental conditions.

In this context, the U.S. National Institutes of Health (NIH) and Brazil's Fundação Oswaldo Cruz (Fiocruz) convened the NIH–Fiocruz Arbovirus Seminar: Global Health Challenges and Collaborative Opportunities in Arbovirus Research (https://respond.niaid.nih.gov/conferences/fiocruz/Pages/default.aspx). A key objective of the seminar was to establish new cross-disciplinary collaborations by engaging virologists, epidemiologists,

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entomologists, social scientists, geographers, and climate scientists, among others, in focused discussion of arbovirus risks and responses. Presentations and discussion addressed numerous arbovirus threats, but particular emphasis was placed on dengue, Zika virus, and Chikungunya virus on account of current burden and trends in the Western Hemisphere.

Within the seminar, a 1-day training workshop was held on the topic of climate and disease modeling. The workshop was motivated by the persistent challenge of establishing substantive collaboration between the climate science and arbovirus research communities. These collaborations are required to improve understanding of pathogen dynamics and to advance risk monitoring, prediction, and projection. Workshop participants identified a number of emerging themes and research needs at the interface of climate science and arbovirus control strategies.

NEW DATASETS. The workshop opened with a review of publicly available climate and ecological datasets, with an emphasis on Brazil. Participants noted that arbovirus dynamics often include processes in remote, poorly monitored sites and that risk modeling requires an understanding of environmental changes over space and time. This makes monitoring a significant challenge for disease control experts, who are not accustomed to working with advanced climate datasets; risk assessments often rely on sparse conventional meteorological stations that may not be representative of local conditions. Collaborative analysis between climate scientists and the health research community can address this problem, as the power of data assimilation–based reanalysis and forecast systems and, to some extent, satellite-based ecological monitoring has not been fully utilized in the arbovirus community. Websites that allow direct access to these datasets, including the National Aeronautics and Space Administration (NASA) Giovanni (http://giovanni.sci.gsfc.nasa.gov/), the International Research Institute for Climate and Society (IRI) map room and data library (http://iri.columbia.edu/resources/), and the Royal Netherlands Meteorological Office (KNMI) Climate Explorer (http://climexp.knmi.nl/), among others, are also valuable in that they empower nonexperts to access advanced climate analysis. Some participants did express reticence to utilize such sites, however, as they feel that active collaboration is required to ensure that they interpret and apply climate data appropriately. Climate science participants recognized this challenge while noting resources such as the National Center for Atmospheric Research (NCAR)–University Corporation for Atmospheric Research (UCAR) Climate Data Guide (https://climatedataguide.ucar.edu/), which helps nonexperts navigate available datasets.

For studies in Brazil, the recently launched Fiocruz Observatório Nacional de Clima e Saúde (National Observatory for Climate and Health; www.climasaude.icict.fiocruz.br/) provides a valuable resource for accessing climate and environmental data relevant to arbovirus risk. This data portal, maintained by the Fiocruz Institute of Communication and Information Science and Technology in Health (ICICT/Fiocruz) and the National School of Public Health Sérgio Arouca (ENSP/Fiocruz), along with the National Institute for Space Research (INPE), gathers and combines information on climate, hydrology, and environment and pairs it with epidemiological, socioeconomic, and health data to facilitate novel analysis. The portal is free, accessible, and intuitive so that it can be utilized by public health practitioners, members of civil society, and researchers.

LINKING CLIMATE DATA AND MODELS. Given the complexities of arbovirus dynamics, data on climate and environment are only useful insomuch as they can be integrated into multidisciplinary studies of pathogen dynamics and transmission risk. To this end, the workshop included several presentations on the state of the art in arbovirus risk modeling, with an eye to the fact that recent and future introduction events will make it necessary to model risk for arbovirus that does not have an observational history in affected areas. In such cases, process-based models can be critical for risk characterization and response. When developing these models, key elements include identifying questions to be considered, developing functions to describe relevant mechanisms, and designing sensitivity analyses to incorporate parameter and functional uncertainty into the models.

Workshop experts stressed that model development and analysis is cyclical, with initial results informing refinement and modification in subsequent analyses. As an example, workshop participants discussed how a multivector model of West Nile virus transmission dynamics could be adapted and applied to Chikungunya virus (Lord 2010; Lord and Day 2001). Identifying which factors should be modified depends on the biology of the system and also on the research questions. In this case, the host population structure was simplified while geographic variation was added by including variation in seasonal temperature. The relationship between mosquito mortality and temperature was modified to reflect the increased temperature range. In both models, differences between mosquito species affected virus transmission dynamics. The cycle of model development, analysis, and revision continues with the exploration of parameter ranges for mosquito population dynamics. These models included temperature only, although other aspects of climate are important in arbovirus systems. There is a need to include more extensive climate data in process-based arbovirus models to better understand epidemic and endemic transmission.

In another case study presented at the workshop, researchers at NCAR combined climate data with process-based models to study the expansion of the dengue vector *Aedes aegypti* to Puebla, Mexico, a city of 1.5 million people located at 2100 m MSL (Lozano-Fuentes et al. 2012). Because *Ae. aegypti* exploit a wide range of containers as sites for oviposition and development of the immature stages, a field-validated energy balance model was applied to link climate data to relevant environmental parameters (Steinhoff et al.

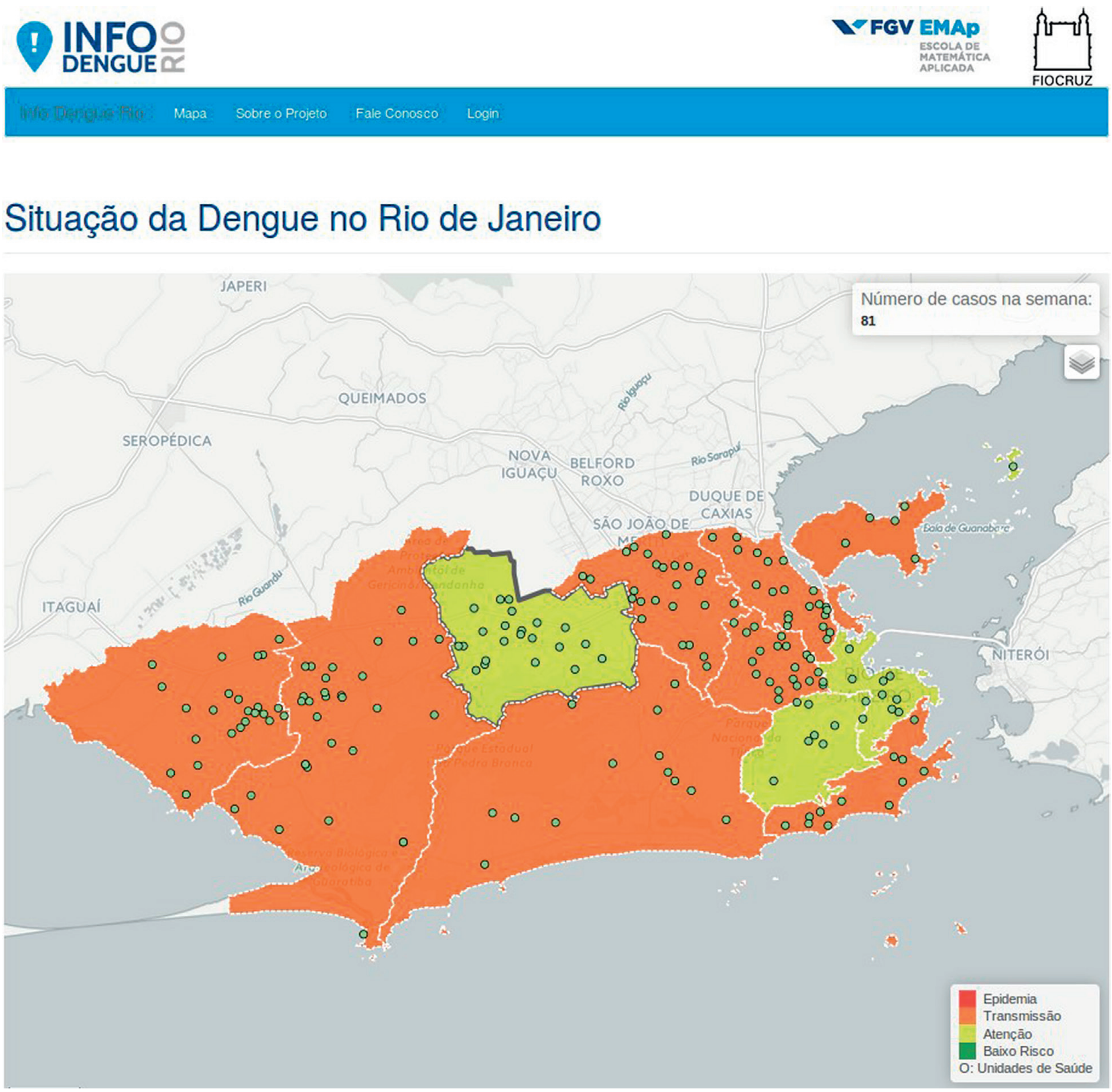

Fig. 1. Screenshot from the website of the Info Dengue project in Rio de Janeiro, Brazil. The city is divided by the health surveillance department into 10 monitoring areas called planning units, as shown by white borders. Both the estimation of the number of dengue cases and a weekly color code represent the risk associated with dengue in each of the areas. The color code varies between green (low risk), yellow (attention), orange (transmission), and red (epidemic). Dots show locations of health units where the population is assisted.

2016, manuscript submitted to *Earth Interact.*). Results indicate that simulated water temperatures are higher for containers that are larger, darker, and that receive more sunlight, indicating that microenvironmental conditions related to container characteristics play an important role in the proliferation of *Ae. aegypti*.

The spatial components of arbovirus ecology and risk modeling were also emphasized throughout the workshop. Spatial tools for ecoepidemiological research have facilitated new insights on landscape determinants of disease transmission and the effects of climate change. Opportunities and limitations in using spatial tools to capture natural and human systems in arbovirus transmission are evident in recent work on systems such as Chagas disease (Gürtler et al. 2014), West Nile virus (Ruiz et al. 2010), and dengue (Guagliardo et al. 2015). Challenges include addressing loss in heterogeneity across scales; consideration of social, economic, and institutional processes; and integration of finescale biotic factors with coarse-scale climatic and environmental factors. One important research question is how to decide which environmental and climate changes to monitor for maximum health relevance.

COMMUNICATION. In closing, the workshop identified needs and opportunities in communicating climate-based arbovirus risk analyses. One promising example from Brazil is the Info Dengue project (http://alerta.dengue.mat.br; Fig. 1), which continuously provides health surveillance teams and the general public of Rio de Janeiro with information on the current dengue situation in the city. The data and potential risks associated with a dengue epidemic are presented in weekly reports and a public website that contains a city map with the spatial distribution of the number of dengue cases, dengue time series in the city and each neighborhood, and estimates of the current number of new cases in each epidemiological week. Estimating the current number of cases (nowcasting) is an important challenge for systems like Info Dengue (Donker et al. 2011; Johansson et al. 2014), since new cases may take weeks to be reported. Use of social media, including Twitter, to track new cases is being tested to enhance real-time estimates.

Info Dengue uses data from meteorological stations located at airports in the city to evaluate the potential risk of a dengue epidemic. The project team is pursuing efforts to use climatic data at finer scales from different sources, since highly bv conditions affect the activity of *Ae. aegypti*. For example, temperature fluctuations may significantly alter the average length of the mosquito life cycle and reproduction rates.

While Info Dengue is making inroads into public awareness in Rio de Janeiro, the presence of known arbovirus risk does not always translate into public awareness. In a study of four North American cities, two with dengue transmission and two without, NCAR researchers found that although awareness of dengue was higher in Nogales and Hermosillo, Sonora, Mexico, and in Key West, Florida, than in Tucson, Arizona, a significant gap exists between universal implementation of key strategies and community practices in all four sites, highlighting the need for an evaluation of current education and outreach practices in these cities.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS. The workshop was designed to promote an open exchange of ideas and did not attempt to achieve consensus recommendations. Nevertheless, several key points emerged. These include the following:

While climate science institutions have made progress in disseminating their datasets through accessible data portals, there is still a data disconnect between the climate and arbovirus research communities. Many highly sophisticated pathogen transmission models rely on sparse or inconsistent in situ weather data, despite the availability of satellite-informed meteorology products and land data assimilation systems at global and regional scales. This results in suboptimal climate analysis within the arbovirus community and also deprives the climate community of the feedback needed to improve the value of their products for public health applications. One clear need identified at the workshop is for joint training sessions at which researchers learn analysis tools from both communities.

The recent emergence of Zika and Chikungunya viruses as serious health risks in the Americas demonstrates that human behavior, including human mobility, is driving the evermore frequent introduction and establishment of arbovirus pathogens into nonendemic regions, with the potential for unanticipated epidemics. In this context, it is important that researchers evaluate climate influence on the potential introduction and establishment of arbovirus pathogens in nonendemic regions, including emerging and neglected diseases. While the workshop specifically addressed the application of climate and biophysical data to transmission risk models, participants emphasized that human behavior is central to arbovirus transmission and that any risk model must take this into account. This requires multidisciplinary collaboration, often merging both quantitative and qualitative research methodologies.

Participants noted the health dimension of the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP; Warszawski et al. 2014) as a promising example of a multimodel approach to vectorborne disease. Similar initiatives should be considered for climate–arbovirus analyses, with the goals of characterizing uncertainties, understanding differences in assumptions between models, and identifying synergies between statistical and process-based transmission models.

Finally, participants stressed the need to engage public health practitioners and, where appropriate, community members as full partners in the research process. Their participation is required to ensure the usability of the generated data through designing the right modeling experiments and data initiatives, to define prediction time horizons of interest, and to generate realistic representations of human systems within models. Recent communications work by NCAR (www.ral.ucar.edu/csap/weather-climate-and-health) was identified as an example of success in this regard.

To advance these objectives, workshop participants are proposing participation in an informal consultation group to develop collaborative projects and training initiatives, as established in an agreed-on joint declaration of seminar participants. Ultimately, research progress on climate-mediated arbovirus dynamics in Brazil and the surrounding region will require a sustained, interdisciplinary effort that leverages expertise and experience across countries.

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