Working Group 3: Environmental Suitability and Infectious Disease Risk

Report from the Climate Change and Infectious Disease Working Group: pre-Next Einstein Forum (NEF) Satellite Workshop on Modeling of Infectious Diseases with a focus on Ebola

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Executive Summary

Climate change will expose new populations to diseases, by altering the range of temperature, precipitation, and other key meteorological variables, changing the areas in which the environment is suitable for these diseases to persist. However, this is a relatively slow process in comparison to the ability of diseases to jump between *currently* suitable environments via migration and travel. Cataloging, understanding, and ultimately predicting the movement of pathogens into naïve suitable environments in the current climate is necessary to anticipate and work to prevent the next crisis situation, and is the critical first step to understanding how disease risks will change in a changing climate.

Working Group Background

Our working group of the DIMACS/pre-NEF workshop on modeling infectious diseases was tasked with identifying some key issues in intersection of climate change and disease modeling. Our group included mathematicians (data-free), mathematical biologists (data users ranging from parameter estimation to data fitting), a medical geographer/disease ecologist, and a climate scientist. Our group had members ranging from those conducting climate modeling of infectious diseases, to those who were interested in the way in which climate change might interact with their models.

This narrative is distilled from discussions over the two days, describing questions and challenges that emerged, with a few directions forward evolving from discussion. We describe the main sets of challenges we seek to engage with, and present several steps forward and recommendations. While our discussions were looking through a lens of climate forcing, we quickly discovered that we were in fact describing the larger environment, which comprises several types of factors at multiple spatial scales that mediate climate impacts on (a) disease introduction and (b) disease establishment and onward transmission.

Environmental Suitability and Infectious Disease Risk

Human activity is currently altering the climate system, and will continue to do so for the foreseeable future. Across the globe, temperatures are increasing and precipitation patterns are shifting. With these changes come changes in the habitats of every species on Earth, including those that are pathogenic to humans. The International Panel on Climate Change (IPCC) projects that climate change will substantially alter the global distribution of infectious disease over the next few decades. So-called 'tropical' infections may move into currently temperate areas, leading to seasonal outbreaks and potentially becoming endemic. Milder winters may lead to increased survival rates and population densities of multiple disease vectors, such as ticks and mosquitoes, increasing the likelihood of exposure to a number of different pathogens. Reductions in water security and quality may lead to increases in diarrheal illness. Reductions in food security may add the compounding effect of malnutrition to the morbidity and mortality from infectious disease. Changes in disease risk across the globe will likely expose many populations to novel pathogens, increasing morbidity and mortality and posing significant challenges for public health officials, and other decision makers.

Despite these real and significant risks posed by infectious diseases in a changing climate, we feel it is critical to recognize the more immediate threat posed by the rapid movement of pathogens and vectors amongst *currently* suitable environments, through global travel and migration. Humanity is in the midst of the greatest mass migration in history, with hundreds of millions of people moving from rural to urban areas. Modern travel networks allow pathogens and vectors to move between continents in a matter of hours. The consequences of the transport of pathogens between suitable environments, and the resulting introductions, are apparent throughout history, from bubonic plague in Europe to measles and smallpox in the Americas. In recent years, cases of dengue fever, chikungunya virus, and other serious vector-borne emerging infectious diseases (EIDs) have been reported in the southern US states, while outbreaks of West Nile virus and other environmentally-related EIDs have already spread across the entire continental US. The rapid global spread of Zika currently underway is merely the latest example in a long line of diseases that have been transported from their endemic region and have touched off epidemics in new populations. Risks associated with the global movement of pathogens and vectors can develop far more rapidly than those associated with climate change.

We thus argue that the most pressing concern is not understanding and quantifying the infectious disease risk in a changing climate, but rather understanding what defines a *suitable environment* for any given disease. Understanding the conditions that predispose an area to introduction and/or establishment of a novel pathogen is crucial to understanding the changing risk of infectious disease, whether in the current climate or in the future. For some diseases there is an obvious connection to the climate, where the range of the vector (for example) is prohibited because the temperature and precipitation range is unsuitable. However, it does not necessarily follow that if the climate changes and the temperature and precipitation ranges do become suitable that the disease will inevitably spread to these new areas.

As a concrete example, malaria was endemic to the United States in the first half of the 20th century, and was effectively eliminated in 1951 as a result of aggressive control measures. Isolated cases of local transmission, particularly in the areas around airports, occur with some regularity. Malaria has been endemic in the US in the past, and the climate is clearly suitable now and likely to remain so for decades to come. We have the continued presence of competent vectors, but malaria has not re-established itself in the US. Clearly more than just climate factors are playing a role. The example of malaria in the US stands in sharp contrast to that of the introduction of West Nile Virus, which took only four years to spread across the entire country. Likewise, the global Zika epidemic is a stark reminder of how rapidly a novel disease can spread under the proper conditions.

A main conclusion of our working group is that significant research efforts should be made to understand the factors that determine the success or failure of a disease introduction in the *current* climate, both for its own sake and as a critical first step to understanding the evolving risk under a changing climate. Some of the key and open research questions identified by the working group are as follows:

1. What defines environmental suitability?

The working group identified a number of open questions in terms of defining what creates a suitable environment for the introduction of a given disease. Are there key environmental variables in addition to temperature and precipitation that should be considered? Are the routine measurements of climatic variables currently in place sufficient for informing estimates of disease risk, or are specialized observations necessary? Can a given disease (or vector) exploit available microclimates to survive in regions that would appear to be inimical based on larger scale measurements of the surrounding environment? What is the role of the built environment in either enhancing or reducing environmental suitability?

2. Can we identify currently suitable environments?

The working group was in strong agreement that there is a CRITICAL need for rapid, accurate, and affordable surveillance and diagnostic tools. Such tools represent not only a research challenge, for the creation of the necessary sensor and diagnostic devices, but also a willingness to commit to systematic and long-term support of surveillance efforts. We need to conclusively establish evidence not only the presence of a pathogen during a crisis situation but also absence during quiet periods. Too often we have absence of observations in place of observations of absence. Without a full catalog of pathogens that occupy environmental conditions similar to those of the US mid-Atlantic region, we have no means of knowing the full risk posed to the Washington, DC, area by its three major airports. Likewise we cannot know what diseases may expand their ranges to encompass novel populations as the climate changes without fully understanding the distribution of diseases in the current climate.

With the benefits of hindsight, what data should we have been collecting prior to the recent Zika and Ebola epidemics? What data should we be collecting now to prepare for the next such outbreak? Can we extend the effective coverage of surveillance networks back in time by systematically identifying and digitizing historical data archives?

3. *What are the implications of environmental suitability?*

A key question identified by the group was how to distinguish *a priori* between the widely divergent outcomes of malaria and West Nile virus in the United States, or between Ebola and Zika. What are the factors that permit or prohibit a sudden jump from one area of the globe to another? Does the introduction of a new disease always begin with a large, noticeable epidemic, or is it possible that such transitions occur often and unnoticed? How strong a determining factor is the climate in the two regions? How important are initial control efforts? Was the presence of an animal reservoir the critical factor in the rapid spread of WNV? Are there potentially suitable animal reservoirs for Ebola outside of Africa?

4. How do we act on this information?

Ultimately our goal must be to understand, quantify, and predict risks from EID in both current and future climates. To do so requires models that incorporate information on the behavior of both the disease and climate systems, as well as their interactions. Challenging models with data is a critical element in not only demonstrating their accuracy and utility to decision makers, but also in driving model improvements. Communication of the results of these models, and their inherent uncertainties, is also a significant challenge we identified, requiring the participation of experts in the field of communication to be successful. We conclude by re-iterating that we can not hope to say anything conclusive about the potential for disease risk to change with climate change, without first fully documenting and describing the distribution of potential threats in the current climate.