Seasonal Forecasts of the Dengue Vector

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**Introduction.** Dengue fever is considered the most important vector-borne viral disease in the world as it potentially affects 2.5 billion people in more than 100 tropical and sub-tropical countries (Fig. 1). Current estimates suggest that up to 50 million dengue cases occur annually, including 500,000 cases of the related illness, dengue hemorrhagic fever (DHF). As no vaccine presently exists, the only method of controlling or preventing dengue and DHF is to combat the mosquito vector. This research examines the relationship between climate, the dengue vector, and reported numbers of dengue/DHF cases. It also presents preliminary results for generating seasonal forecasts of the dengue vector, by using a general circulation model's (EHCAM3.6) output to drive the mosquito model.

Classical dengue fever, also known as breakbone fever, is characterized by sore joints and muscles, headache, a sudden onset of fever with occasional nausea/vomiting and rash; these symptoms may last for several days. Dengue hemorrhagic fever (DHF) is a more serious illness mainly affecting children and young adults; symptoms include a sudden onset of fever and hemorrhagic manifestations that result in significant fluid loss and may lead to shock. Approximately five percent of DHF cases are fatal. A prior infection with one of the four dengue viruses results in a greater probability of contracting DHF. The primary vector for dengue is *Aedes aegypti*, a peri domestic (living in and around human dwellings), day-biting mosquito, which feeds preferentially on human blood.

Environmental conditions strongly affect the geographic distribution and abundance of *Ae. aegypti*. Breeding habitats for the mosquito consist of any type of water-holding container ranging from cisterns and jars to discarded bottles and tires. These sites are typically found in abundance near urban populations, where the food supply for gravid female mosquitoes (human blood) is also plentiful. In these environments, climatic variables, such as temperature, humidity, and precipitation, can significantly influence mosquito development and survivorship.

Many factors have a significant effect on the magnitude of a dengue epidemic, including socioeconomic variables, such as the presence of mosquito monitoring and control programs, and the use of window screens and air conditioning. However, the presence and abundance of *Ae. aegypti*, the vector for dengue, is vital to the transmission of the disease.
Methods. **Global-scale mosquito model.** To examine the global-scale relationships between climate, *Ae. aegypti* populations, and cases of dengue/DHF, a numerical model of mosquito population dynamics is used. The mosquito model is driven by precipitation, temperature, relative humidity and solar radiation to describe the effects of global-scale climatic conditions on *Ae. aegypti*. The model is based on the CIMSiM mosquito model, which was originally designed to examine *Ae. aegypti* populations in specific cities. In this study, the model was simplified for use at the global scale.

The global-scale model simulates the relationship between climate and the development, population dynamics, and potential distribution of *Ae. aegypti*. The model uses a daily time step, and operates on a 1° by 1° latitude-longitude grid (-100 km on a side). By tracking the abundance, age, and development of the mosquito in its four life stages (specifically the egg, larval, pupal and adult stages), the model simulates a life table of 200 cohorts.

**Observed climate data.** The CRU05 historical climate dataset was used to drive the global mosquito model. This 0.5° by 0.5° latitude-longitude resolution (-50 km on a side) dataset consists of observed monthly climate data from 1901 to 1995 assembled by the Climatic Research Unit of the University of East Anglia (http://www.cru.uea.ac.uk/cru/data). The CRU05 data, interpolated to a 1.0° resolution, was used to run the model from 1950 to 1995. The monthly data were linearly interpolated to quasi-daily values.

**ECHAM3.6 climate data.** Data from the ECHAM3.6 general circulation model, developed by the Max Planck Institute, was also used to drive the mosquito model. This GCM was run from 1950-1998, and forced with observed sea surface temperatures. The model’s resolution is T42, approximately 2.8° by 2.8° latitude-longitude.

**Dengue Fever Case Reports.** To determine the relationship between the simulated variations in mosquito abundance and the variations in the reported number of dengue/DHF cases, we compared the annual case data with the modeled mosquitoes, by country, for the years 1958-1995. With the available case data from the Pan-American Health Organization (PAHO) and the Global Infectious Disease and Epidemiology Network (GIDEON) and the model resolution, our study included data for 20 countries in the Americas and 12 countries in Asia and the western Pacific.

Results. **Observed Climate Data.** There is good agreement between the observed (Fig. 1) and modeled (Fig. 2) global distribution of the mosquito. In comparing the mosquitoes to dengue/DHF cases, the analysis indicates that the majority of the countries (7 out of 12) in Southeast Asia and the western Pacific have statistically significant (p<0.05) positive correlations between simulated mosquito densities and the number of reported dengue cases. In fact, the year-to-year fluctuations in the modeled mosquitoes for these countries correspond well with the peaks in the reported dengue/DHF cases, e.g. Thailand (Fig. 4).
There also were statistically significant correlations between modeled mosquito
density and dengue/DHF cases for four of the 20 American countries.

It is evident, that on average, Asian countries have more years of dengue case
data than American countries, and the nations with statistically significant
relationships have more years of data than nations without significant results.
Since the Southeast Asian dengue pandemic began at the conclusion of World
War II, dengue has been an important infectious disease in Asia, in fact the
leading cause of childhood mortality in many countries. The pandemic did not
intensify in the Americas until the 1980s, following the termination of *Ae. aegypti*
eradication programs.

**ECHAM3.6 Climate Data.** One of the concerns in using output from the
ECHAM3.6 GCM to drive the mosquito model is the relatively low resolution of
the data. To determine the effect of resolution on the model output, I interpolated
the observed (CRU05) monthly climate data (1950-1995) to a T42 resolution and
ran the mosquito model with it. I also interpolated output modeled mosquito
densities (originally run at a 1.0° resolution) to T42. By comparing these outputs,
it was apparent that, in general, higher resolution input data resulted in higher
mosquito densities.

Preliminary analyses of the mosquito model driven with the ECHAM3.6 climate
data (from 1950-1995) show that the global distribution of the modeled mosquito
compares well with the results using the observed climate to drive the mosquito
model. The modeled densities compare well, though in some regions of the
world, such as east of the Andes and in northern Australia, ECHAM3.6 forced
densities are higher (Fig. 3). In comparing the ECHAM3.6 modeled mosquitoes
to reported dengue/DHF cases (Fig. 5), the correlations are lower than with the
observed climate data (Fig.4). One of the reasons for this decreased correlation
may be the resolution of the ECHAM3.6 data, and the resulting fewer grid cells
per country. For example, at 1.0° resolution, Indonesia consists of 156 grid cells
(r=0.78, Fig. 4), but only 45 grid cells at 2.8° resolution (r=0.71, Fig. 5). Thailand
consists of 43 grid cells at 1.0° resolution (r=0.69) and only 9 grid cells at 2.8°
resolution (r=0.32).

**Conclusion.** Given the correlations between the modeled mosquitoes (forced
with observed climate data) and reported dengue/DHF cases, there is a
possibility that forecast mosquito densities may be used to anticipate dengue
caseloads. Based on the preliminary results of driving the mosquito model with
the ECHAM3.6 climate data, a good potential exists for using seasonal climate
forecasts, however, further analyses of these initial results are needed. The
ability to forecast mosquito densities and potential dengue caseloads would be
very useful in many regions of the world where dengue is a serious threat both to
human health and the economy.
World Distribution of Dengue - 2000

Figure 1. Observed distribution of *Aedes aegypti* mosquito and dengue.

Figure 2. Modeled mosquito using observed climate data.

Figure 3. Difference between modeled mosquitoes using ECHAM3.6 climate data vs. observed climate data.

Figure 4. Modeled mosquito (obs. climate data) and reported DHF cases in Indonesia.

Figure 5. Modeled mosquito (ECHAM3.6 climate) and reported DHF cases in Indonesia.