The Climate Sensitivity of Mosquito Habitats

Simulating Subseasonal Climate Impacts on Dengue Vector Breeding Sites

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1. Background

The Big Picture: Climate and Dengue

- Dengue is a major contributor to global disease burden, with an estimated 390 million infections annually **[1]**. Dengue incidence is tied to climate due to its mosquito vectors (*Ae. aegypti*, *Ae. albopictus*).
- There are ongoing efforts to develop climate-informed early warning systems for forecasting dengue risk **[e.g., 2, 3, 4]**.
- Can dengue risk forecasting be improved by modeling the intermediate processes that link climate and dengue (such as the climate-dependent suitability of mosquito breeding sites) **[Fig. 1]**?

Figure 1: A process chain linking climate and dengue. Variability in meteorology (e.g., rainfall, temperature) influences the suitability of mosquito breeding sites. This impacts mosquito population dynamics, which in turn determine the frequency of mosquito-human interactions (blood meals) that result in dengue infection.

This Work's Focus: Mosquito Breeding Sites in Sri Lanka

- Dengue vectors primarily breed in artificial container habitats (e.g., water tanks, tires). Habitat suitability depends on water height and temperature, which can be simulated by an (NCAR-developed) energy balance model, WHATCH'EM **[5] [Fig. 2]**.
- We apply WHATCH'EM for three cities in the dengue-impacted tropical country of Sri Lanka **[Fig. 3]**:
  - Negombo: high temperature, high rainfall, high dengue incidence
  - Jaffna: high temperature, low rainfall, high dengue incidence
  - Nuwara Eliya: low temperature, high rainfall, low dengue incidence

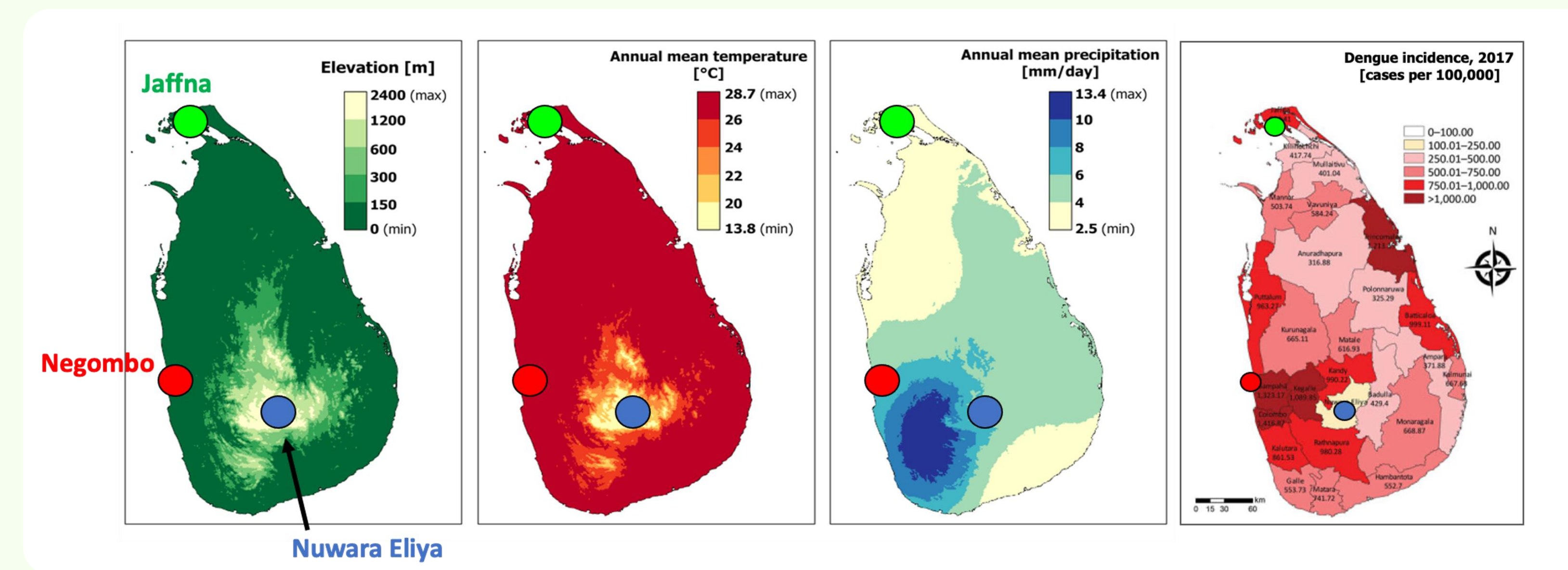

Figure 3: Maps of Sri Lanka showing (left to right) elevation, annual mean temperature, annual mean precipitation (data from WorldClim v2.1 **[6]**), and dengue incidence in an epidemic year (reproduced from **[7]**). Colored dots indicate cities of interest for this work: Negombo, Jaffna, Nuwara Eliya.

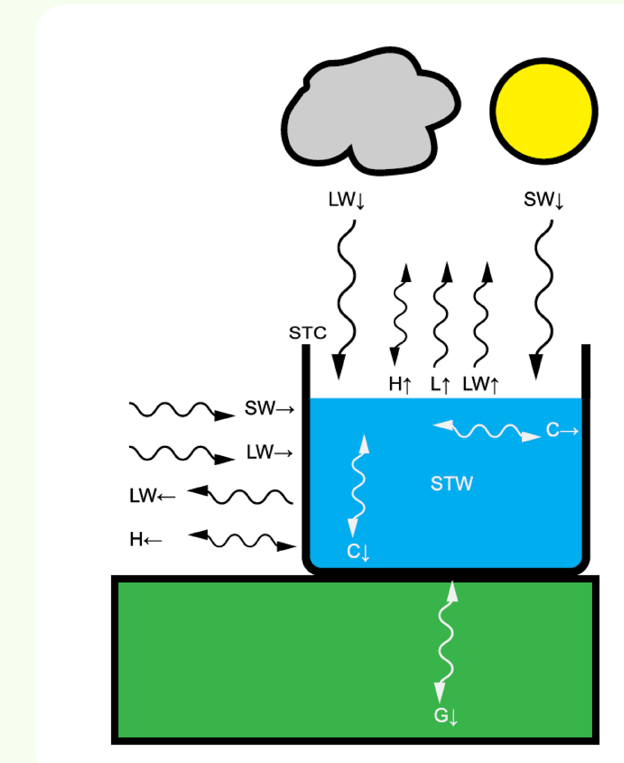

Figure 2: Schematic of the WHATCH'EM energy balance model. Arrows indicate modeled energy transfer processes: SW = shortwave radiation, LW = longwave radiation, H = sensible heat, L = latent heat, C = conduction between water and container, G = conduction between container and ground, STW = heat storage in water.

2. WHATCH'EM Model Setup

Meteorology: Meteorological data for the three cities of interest are from the MERRA-2 and IMERG reanalysis products **[Fig. 4]**. For this preliminary analysis we used data for one of Sri Lanka's southwest monsoon season (May–Sep 2017), corresponding to one of two peak dengue seasons each year.

Container Specifications: For each city, we simulated a range of containers to assess sensitivity to container specifications **[Fig. 5]**. In this preliminary analysis we show results for the "median" simulation: a half-shaded, gray, bucket-sized container.

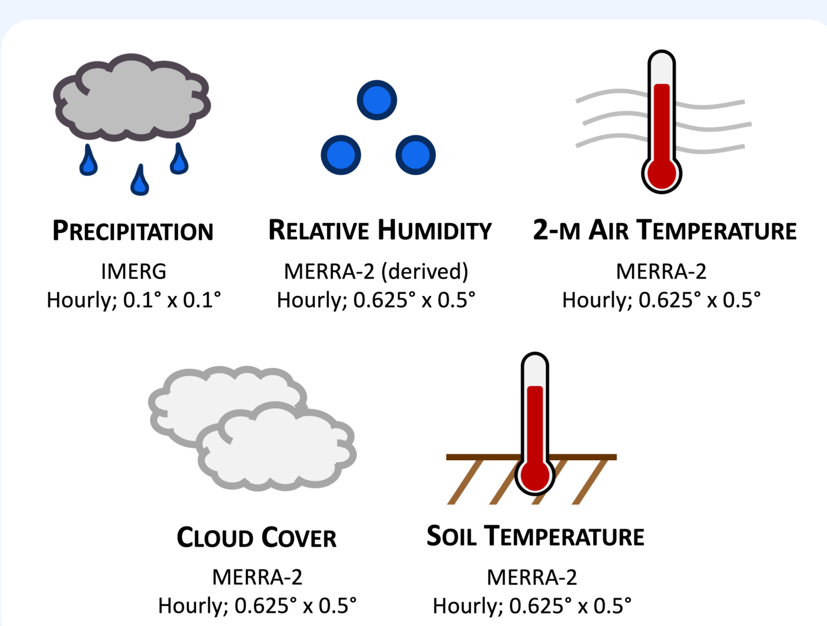

Figure 4: Meteorological data inputs for WHATCH'EM. Data are from the MERRA-2 and IMERG reanalysis products **[8, 9, 10]**.

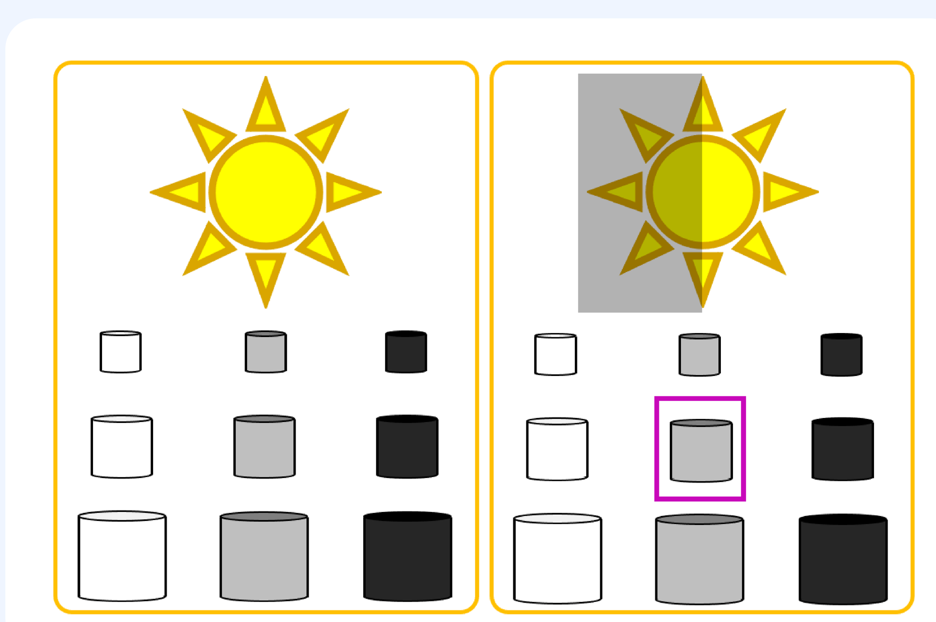

Figure 5: A schematic of WHATCH'EM container specifications: shading level (no shade, half shade), color (white, gray, black), size (coffee, bucket, barrel). Boxed in purple is the "median" simulation discussed here.

3. Preliminary Results

City Comparison

- **Water height:** Steady increase for Nuwara Eliya and Negombo (high rainfall cities), fluctuating for **Jaffna** (low rainfall city) **[Fig. 6A]**.
- **Water temperature:** Higher diurnal range early in season (low water height) **[Fig. 6B]**. Max daily temperatures in **Jaffna** suggest reduced mosquito survival **[Fig. 7]**.

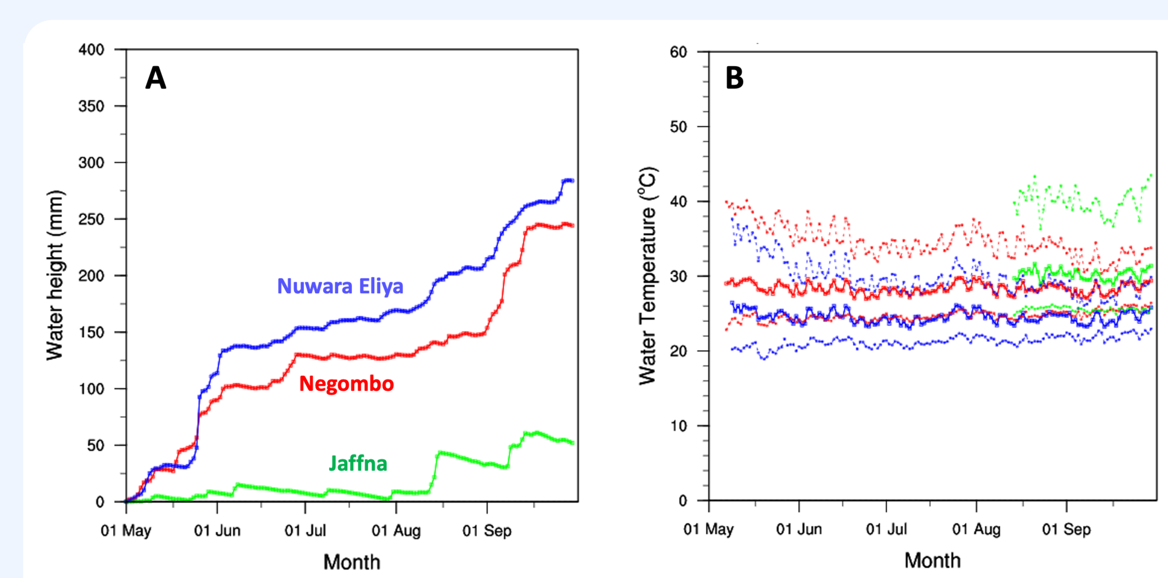

Figure 6: WHATCH'EM results for "median" simulation (half-shaded gray bucket) showing evolution of **(A)** water height and **(B)** water temperature for each of the three cities. In the latter, solid lines are mean daily temperature, dashed lines are maximum/minimum daily temperatures. Temperatures are undefined when water height is less than 15 mm.

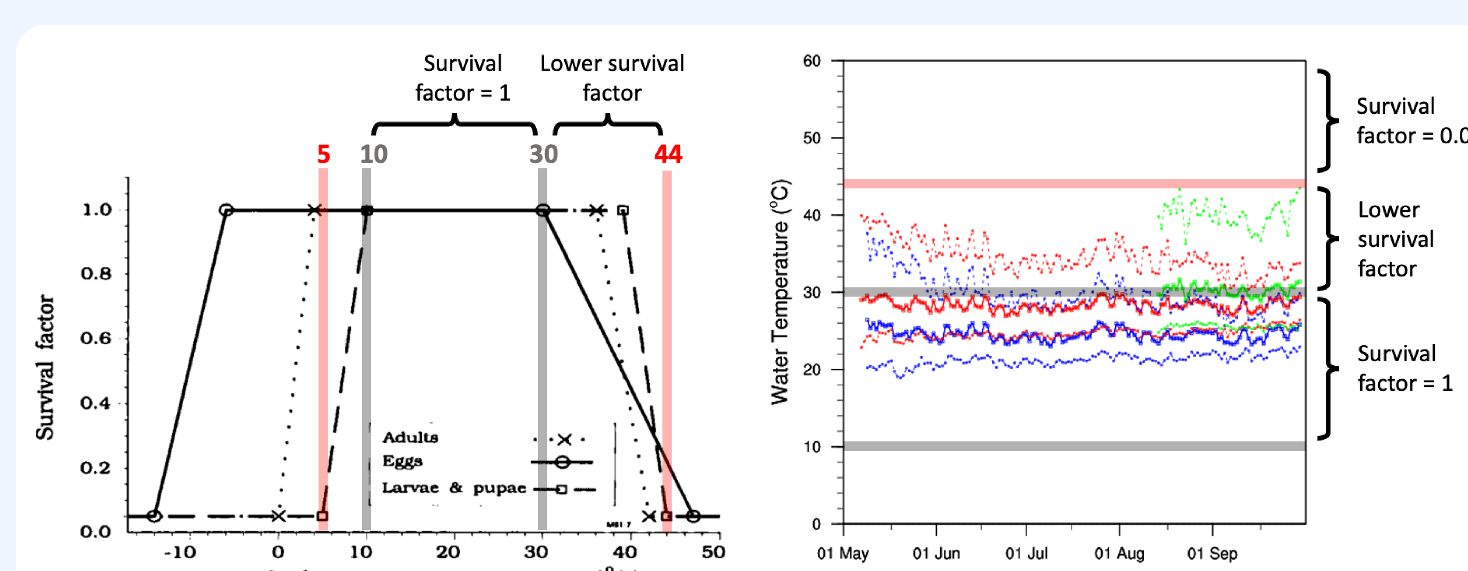

Figure 7: (left) A model of *Aedes aegypti* survival probability given temperature extremes (from **[11]**), and **(right)** the same plot as Fig. 6B, but with these survival thresholds overlaid.

4. Next Steps

Further Exploratory Work

- How sensitive are model results to container types? Explore the parameter space of **Fig. 5**.
- How do non-epidemic years compare to epidemic years?
- How does each city's model results change for other seasons **[Fig. 8]**?

Incorporation Into Statistical Model

What metrics can we derive from these models to associate with dengue incidence?

- Days with water height > 15 mm **[Fig. 6A]**
- Days with maximum water temperature > survival threshold **[Fig. 7]**

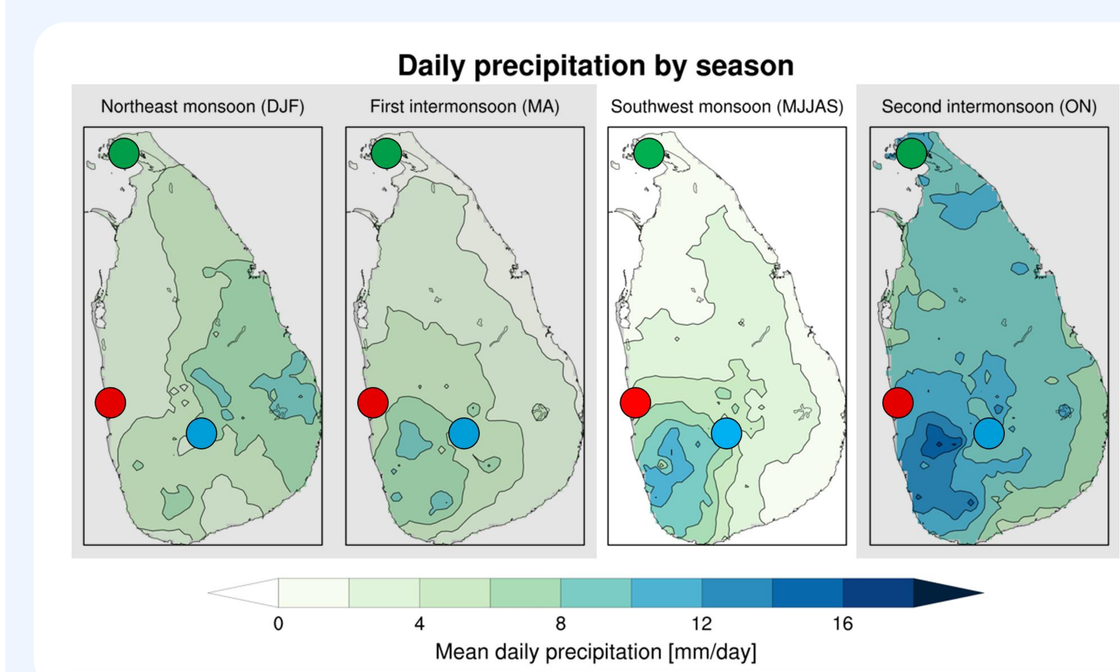

Figure 8: Mean daily rainfall in Sri Lanka by season (CHIRPS data averaged over 1981–2020 **[12]**). Colored dots indicate the three cities of interest. Grayed out seasons are those not yet considered in this work.

References/Acknowledgements:

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