Intersecting vulnerabilities: Climatic and demographic contributions to future population exposure to Aedes-borne viruses in the United States

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***** Supplementary Material *****

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Table S1 – List of general circulation models (GCMs) used to project future cumulative monthly transmission risk of Aedes-borne viruses (see Ryan et al., 2019).

| Institute & Model | Acronym          |
|-------------------|------------------|
| Beijing Climate Center Climate System Model | BCC-CSM1.1 |
| Hadley Center GCM | HadGEM2-AO       |
| Hadley Center GCM | HadGEM2-ES       |
| National Center for Atmospheric Research’s Community Climate System Model | CCSM4 |

Table S2 – Occupations considered as “outdoor workers”, with the associated percentage of jobs requiring work outdoors at some point in the day (BLS, 2016). Note that no statistics exist for farming, fishery, and forestry.

| Occupation                                      | Percentage of jobs requiring work outdoors at some point in the day (%) |
|------------------------------------------------|-------------------------------------------------------------------------|
| Transportation and material moving              | 73                                                                      |
| Personal care service                           | 74                                                                      |
| Building and grounds cleaning and maintenance   | 77                                                                      |
| Installation, maintenance, and repair           | 87                                                                      |
| Protective service                              | 91                                                                      |
| Construction and extraction                     | 95                                                                      |
| Farming, fishing, and forestry                  | -                                                                       |
Table S3 – Cumulative monthly transmission risk of *Aedes*-borne viruses, for baseline and future (2050 and 2080) time-periods, under RCP2.6 and RCP8.5. County-level results are averaged at the regional scale and country (CONUS) scale and separated for *Ae. aegypti* and *Ae. albopictus*.

| Ae. spp | Region   | Scenario | Year   | Mean (IQR) | Min (IQR) | Max (IQR) |
|---------|----------|----------|--------|------------|-----------|-----------|
|         | CONUS    | Baseline | 1960-90 | 2.8 (0)    | 0.0 (0)   | 9.4 (0)   |
|         |          | RCP2.6   | 2050   | 2.8 (0.1)  | 0.0 (0)   | 9.4 (0.2) |
|         |          |          | 2080   | 2.9 (0.3)  | 0.0 (0)   | 9.3 (0.4) |
|         |          | RCP8.5   | 2050   | 3.5 (0.3)  | 0.0 (0)   | 10.1 (0.7) |
|         |          |          | 2080   | 4.0 (0.1)  | 0.0 (0)   | 11.8 (0.2) |
|         | Mid-West | Baseline | 1960-90 | 3.0 (0)    | 0.0 (0)   | 5.0 (0)   |
|         |          | RCP2.6   | 2050   | 3.0 (0.2)  | 0.0 (0)   | 5.0 (0)   |
|         |          |          | 2080   | 3.1 (0.3)  | 0.0 (0)   | 5.0 (0)   |
|         |          | RCP8.5   | 2050   | 3.7 (0.3)  | 0.8 (0.7) | 5.0 (0)   |
|         |          |          | 2080   | 4.1 (0.1)  | 2.0 (0.1) | 5.7 (0.3) |
|         | North-East| Baseline | 1960-90 | 1.9 (0)    | 0.0 (0)   | 4.0 (0)   |
|         |          | RCP2.6   | 2050   | 1.9 (0.2)  | 0.0 (0)   | 4.0 (0)   |
|         |          |          | 2080   | 2.0 (0.4)  | 0.0 (0)   | 4.0 (0)   |
|         |          | RCP8.5   | 2050   | 2.9 (0.5)  | 0.0 (0)   | 4.0 (0)   |
|         |          |          | 2080   | 3.5 (0.2)  | 0.0 (0)   | 5.3 (0.3) |
|         | South    | Baseline | 1960-90 | 4.8 (0)    | 1.1 (0)   | 9.4 (0)   |
|         |          | RCP2.6   | 2050   | 4.8 (0.1)  | 1.0 (0.3) | 9.4 (0.2) |
|         |          |          | 2080   | 4.9 (0.3)  | 1.3 (0.7) | 9.3 (0.4) |
|         |          | RCP8.5   | 2050   | 5.4 (0.1)  | 2.3 (0.2) | 10.1 (0.7) |
|         |          |          | 2080   | 5.7 (0.3)  | 2.7 (0.4) | 11.8 (0.2) |
|         | West     | Baseline | 1960-90 | 1.4 (0)    | 0.0 (0)   | 5.7 (0)   |
|         |          | RCP2.6   | 2050   | 1.4 (0.1)  | 0.0 (0)   | 5.7 (0)   |
|         |          |          | 2080   | 1.5 (0.2)  | 0.0 (0)   | 5.7 (0.2) |
|         |          | RCP8.5   | 2050   | 2.1 (0.4)  | 0.0 (0)   | 5.8 (0.4) |
|         |          |          | 2080   | 2.8 (0.2)  | 0.0 (0)   | 6.2 (0.2) |
|         | CONUS    | Baseline | 1960-90 | 3.1 (0)    | 0.0 (0)   | 8.3 (0)   |
|         |          | RCP2.6   | 2050   | 3.2 (0.1)  | 0.0 (0)   | 11.1 (0.8) |
|         |          |          | 2080   | 3.3 (0.1)  | 0.0 (0)   | 11.0 (0.6) |
|         |          | RCP8.5   | 2050   | 3.4 (0.1)  | 0.0 (0)   | 9.1 (1.0) |
|         |          |          | 2080   | 3.4 (0.2)  | 0.0 (0)   | 7.8 (0.2) |
|         | Mid-West | Baseline | 1960-90 | 3.3 (0)    | 0.4 (0)   | 4.6 (0)   |
|         |          | RCP2.6   | 2050   | 3.5 (0.1)  | 0.4 (0.3) | 4.9 (0.1) |
|         |          |          | 2080   | 3.6 (0.1)  | 0.4 (0.4) | 5.0 (0)   |
|         |          | RCP8.5   | 2050   | 3.6 (0.2)  | 1.9 (0.2) | 4.8 (0.3) |
|         |          |          | 2080   | 3.5 (0.3)  | 2.0 (0)   | 4.8 (0.3) |
|         | North-East| Baseline | 1960-90 | 2.7 (0)    | 0.0 (0)   | 4.0 (0)   |
|         |          | RCP2.6   | 2050   | 2.7 (0.2)  | 0.0 (0)   | 4.0 (0)   |
|         |          |          | 2080   | 2.8 (0.5)  | 0.0 (0)   | 4.0 (0)   |
|         |          | RCP8.5   | 2050   | 3.4 (0.4)  | 0.0 (0)   | 4.6 (0.2) |
|         |          |          | 2080   | 3.6 (0.2)  | 0.0 (0)   | 4.7 (0.3) |
|         | South    | Baseline | 1960-90 | 4.4 (0)    | 2.2 (0)   | 8.3 (0)   |
|         |          | RCP2.6   | 2050   | 4.9 (0.3)  | 2.2 (0.2) | 11.1 (0.8) |
|         |          |          | 2080   | 4.8 (0.4)  | 2.2 (0.4) | 11.0 (0.6) |
|         |          | RCP8.5   | 2050   | 4.2 (0.7)  | 2.3 (0.3) | 9.1 (1.0) |
|         |          |          | 2080   | 3.8 (0.4)  | 2.2 (0.3) | 7.8 (0.3) |
|         | West     | Baseline | 1960-90 | 1.8 (0)    | 0.0 (0)   | 5.6 (0)   |
|         |          | RCP2.6   | 2050   | 1.8 (0.2)  | 0.0 (0)   | 5.9 (0)   |
|         |          |          | 2080   | 1.9 (0.2)  | 0.0 (0)   | 5.9 (0)   |
|         |          | RCP8.5   | 2050   | 2.5 (0.3)  | 0.0 (0)   | 5.9 (0)   |
|         |          |          | 2080   | 2.9 (0.1)  | 0.0 (0)   | 6.2 (0.4) |

*Note: IQ = interquartile range.*
**Text S1 – Main caveats of the projections of vulnerable population groups**

Outdoor workers projections: By using constant county-level ratio of outdoor workers over the total working age population (20-64 years) of the county population, our projections of outdoor workers account only for demographic changes (population and age-structure). Other changes are likely to influence to future number of outdoor workers at the county level, such as changes in the structure and repartition of the labor force across the different occupations, economic development, technological development, lifestyle changes, etc. Accounting for these changes – which would likely differ across the SSPs – remains challenging and is not the main aim of this study. Furthermore, existing occupational projections are limited to short time-horizon projections, e.g. 2026 for the projections of the Bureau of Labor Statistics (BLS, 2017).

Low-income population projections: Rao et al. (2018) employed three different thresholds of poverty from the World Bank, with the highest threshold being $5.5/cap/day (in $2015 PPP). This threshold is not aligned with the poverty threshold used by the US census bureau (and ACS estimates), which varies between ~$15 and $25/cap/day, depending on the number of persons living in the household. The highest threshold of the World Bank used by Rao et al. (2018) is more representative of extreme poverty in the US than it is of poverty. By aligning our projections of low-income population with the projections of Rao et al. (2018), we assumed the poverty in the US to increase/decrease with the same pace as that of the extreme poverty. This may not be the case. For instance, the large decrease in extreme poverty observed under SSP1 and SSP5 could be associated with only a moderate increase in poverty/low-income communities.

Finally, our projections of the different population groups heavily relies on the county-level population projections depicted in Hauer (2019). Once different sets of county-level population projections for the United-States becomes available, it would be interesting to explore the uncertainty due to population projections, as these have proved significantly influence future population exposure to climate-related hazards in other regions (e.g. Rohat et al., 2019).

**References**

Bureau of Labor Statistics, US Department of Labor 2017 Over 90 percent of protective service and construction and extraction jobs require work outdoors : The Economics Daily: U.S. Bureau of Labor Statistics The Economics Daily Online: [https://www.bls.gov/opub/ted/2017/over-90-percent-of-protective-service-and-construction-and-extraction-jobs-require-work-outdoors.htm](https://www.bls.gov/opub/ted/2017/over-90-percent-of-protective-service-and-construction-and-extraction-jobs-require-work-outdoors.htm)

Kc S and Lutz W 2017 The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100 Global Environmental Change 42 181–92

Rohat G, Flacke J, Dosio A, Dao H and van Maarseveen M 2019 Projections of Human Exposure to Dangerous Heat in African Cities Under Multiple Socioeconomic and Climate Scenarios Earth’s Future 7 528–46

Ryan S J, Carlson C J, Mordecai E A and Johnson L R 2019 Global expansion and redistribution of Aedes-borne virus transmission risk with climate change PLoS Negl Trop Dis 13 Online: [https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6438455/](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6438455/)