**Supplemental Material**

**Climate Change influences on the annual onset of Lyme disease in the United States**

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**Detailed methodology for climate data**

In this section a more detailed description for the calculation of GDDW20, SDM5, and PRCPAW8 is provided.

The GDDW20 for each future period was calculated from the downscaled AOGCM data by 1) linearly interpolating, for each of the three periods, the 16-year daily average TMAX and TMIN from the 16-year monthly averages (assuming the monthly averages occur on the 15th day of each month), 2) calculating the GDDs for each day with respect to a base of 10 oC as in Moore et al. (2014), 3) Accumulating the GDDs over the first 140 days of the year (there are 140 days through week 20), 4) dividing the 2025-2040 or 2065-2080 GDDW20 by the 1992-2007 GDDW20 to calculate the fractional change in GDDW20 between the historical and future periods, and 5) multiplying this fractional change signal by the observed 1992-2007 GDDW20 values from NLDAS-2 that were used in Moore et al. (2014) to yield the future GDDW20 values for 2025-2040 or 2065-2080 for each AOGCM and RCP scenario.

The SDM5 is a function of temperature and relative humidity and was calculated from the downscaled AOGCM data using the 16-year average of TMAX and TMIN for the present and future periods for the months of April and May, and by assuming relative humidity remains constant in the future, because projected humidity data are not available from the AOGCM database. The assumption that relative humidity remains constant as climate changes is consistent with observation- and AOGCM-based studies (Held and Soden 2000; Willett et al. 2008). Notably, saturation deficit (the amount that atmospheric water vapor must be increased to achieve saturation, measured in terms of vapor pressure in mmHg) increases as temperature increases for a given constant value of relative humidity, because more humidity is required to achieve saturation from an absolute perspective for warmer conditions. The months of April and May were chosen because they approximately encompass the 5-week period leading up to the onset week across the 12 States. First, the April-May saturation deficit (SDAPR-MAY) for both periods was calculated from TMAX and TMIN and relative humidity. The fractional change between current and future SDM5 was then computed by dividing the 2025-2040 or 2065-2080 SDAPR-MAY by the 1992-2007 SDAPR-MAY. The fractional change was then multiplied by the observed SDM5 values for 1992-2007 from NLDAS-2 that were used in Moore et al. (2014), to yield the future SDM5 values for 2025-2040 or 2065-2080 for each AOGCM and RCP scenario.

The future PRCPAW8 was calculated from the downscaled AOGCM PRCP data averaged for the months of March, April and May (“PRCPMAR-MAY”) in a manner identical to that described above for SDM5. March was chosen as the start month because the beginning of March approximates the end of week 8 of the calendar year. May was chosen as the end month because the end of May approximates the national average Lyme disease onset week (~week 21—22).

A sensitivity analysis was performed to determine whether the calculated values of SDM5 and PRCPAW8 are sensitive shifts of LOW. To explain, if LOW shifts forward from week 20 in the present to week 18 in the future, week 8—18 would represent PRCPAW8 rather than week 8—20; these subtle shifts are neglected in order to simplify computations. The sensitivity analysis indicates that if shifts in the calculation dates of SDM5 and PRCPAW8 were accounted for, the impact would be to enhance the climate-induced shift in LOW toward earlier onset in the 21st century by about 15% for SDM% and 20% for PRCPAW8, because both variables would increase less (and increases in both variables are associated with later LOW). Therefore, the results for changes in LOW presented within are likely conservative.

**State and national change statistics for all RCP scenarios and time periods**

In Tables 3 and 4 of the manuscript the State- and national-level differences between the AOGCM multi-model mean future (2065-2080) and historical (1992-2007) values of LOW and associated climate variables are shown the RCP2.6 and RCP8.5 scenarios. Here, the differences for the other six combinations of scenarios and time periods are shown: For 2025-2040: RCP2.6 (Table S1), RCP4.5 (Table S2), RCP6.0 (Table S3) and RCP8.5 (Table S4). For 2065-2080: RCP4.5 (Table S5) and RCP 6.0 (Table S6).

Table S1. The 2025-2040 minus 1992-2007 differences of RCP2.6 AOGCM multi-model mean values of LOW, and the differences and contributions of associated climate variables.\*

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Change: 2025-2040 minus 1992-2007 | | | | | Contribution of change to ΔLOW | | |
| REGION | STATE | ΔLOW | ΔTJAN-MAY | ΔGDDW20 | ΔSDM5 | ΔPRCPAW8 | of ΔGDDW20 | of ΔSDM5 | of ΔPRCPAW8 |
|  |  | (Weeks) | (oC) | (GDDs) | (mmHg) | (mm) | (Weeks) | (Weeks) | (Weeks) |
| MIDWEST | MN | -0.5 | 1.6 | 80 | 0.49 | 14 | -1.1 | 0.5 | 0.1 |
|  | WI | -0.6 | 1.6 | 76 | 0.35 | 16 | -1.1 | 0.3 | 0.1 |
| NORTH | ME | 0.1 | 1.5 | 34 | 0.20 | 43 | -0.5 | 0.2 | 0.4 |
|  | MA | -0.1 | 1.3 | 42 | 0.23 | 34 | -0.6 | 0.2 | 0.3 |
|  | NH | -0.1 | 1.5 | 51 | 0.26 | 40 | -0.7 | 0.2 | 0.4 |
| EAST | CT | -0.1 | 1.3 | 52 | 0.25 | 43 | -0.7 | 0.2 | 0.4 |
|  | RI | -0.1 | 1.1 | 42 | 0.19 | 31 | -0.6 | 0.2 | 0.3 |
|  | NJ | -0.4 | 1.3 | 71 | 0.27 | 33 | -1.0 | 0.3 | 0.3 |
|  | NY | -0.2 | 1.3 | 52 | 0.25 | 37 | -0.7 | 0.2 | 0.3 |
|  | PA | -0.7 | 1.4 | 84 | 0.29 | 27 | -1.2 | 0.3 | 0.2 |
| MID-ATL | MD | -0.6 | 1.2 | 71 | 0.24 | 18 | -1.0 | 0.2 | 0.2 |
|  | VA | -1.1 | 1.4 | 105 | 0.30 | 15 | -1.5 | 0.3 | 0.1 |
| NATIONAL | -- | -0.4 | 1.4 | 63 | 0.28 | 29 | -0.9 | 0.3 | 0.3 |

\*Future values with statistically significant change (p<0.05) compared to 1992-2007 are underlined.

Table S2. As in Table S1, but for the RCP4.5 scenario for 2025-2040.\*

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Change: 2025-2040 minus 1992-2007 | | | | | Contribution of change to ΔLOW | | |
| REGION | STATE | ΔLOW | ΔTJAN-MAY | ΔGDDW20 | ΔSDM5 | ΔPRCPAW8 | of ΔGDDW20 | of ΔSDM5 | of ΔPRCPAW8 |
|  |  | (Weeks) | (oC) | (GDDs) | (mmHg) | (mm) | (Weeks) | (Weeks) | (Weeks) |
| MIDWEST | MN | -0.5 | 2.0 | 96 | 0.59 | 28 | -1.3 | 0.6 | 0.2 |
|  | WI | -0.7 | 1.9 | 95 | 0.44 | 20 | -1.3 | 0.4 | 0.2 |
| NORTH | ME | 0.0 | 1.6 | 43 | 0.25 | 44 | -0.6 | 0.2 | 0.4 |
|  | MA | -0.1 | 1.3 | 50 | 0.28 | 35 | -0.7 | 0.3 | 0.3 |
|  | NH | -0.2 | 1.6 | 64 | 0.32 | 41 | -0.9 | 0.3 | 0.4 |
| EAST | CT | -0.2 | 1.3 | 62 | 0.30 | 39 | -0.9 | 0.3 | 0.4 |
|  | RI | -0.2 | 1.1 | 48 | 0.23 | 31 | -0.7 | 0.2 | 0.3 |
|  | NJ | -0.6 | 1.3 | 85 | 0.33 | 35 | -1.2 | 0.3 | 0.3 |
|  | NY | -0.3 | 1.4 | 65 | 0.31 | 33 | -0.9 | 0.3 | 0.3 |
|  | PA | -0.8 | 1.5 | 101 | 0.35 | 32 | -1.4 | 0.3 | 0.3 |
| MID-ATL | MD | -0.6 | 1.2 | 82 | 0.29 | 26 | -1.2 | 0.3 | 0.2 |
|  | VA | -1.1 | 1.4 | 120 | 0.35 | 22 | -1.7 | 0.3 | 0.2 |
| NATIONAL | -- | -0.5 | 1.5 | 76 | 0.34 | 32 | -1.1 | 0.3 | 0.3 |

\*Future values with statistically significant change (p<0.05) compared to 1992-2007 are underlined.

Table S3. As in Table S1, but for the RCP6.0 scenario for 2025-2040.\*

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Change: 2025-2040 minus 1992-2007 | | | | | Contribution of change to ΔLOW | | |
| REGION | STATE | ΔLOW | ΔTJAN-MAY | ΔGDDW20 | ΔSDM5 | ΔPRCPAW8 | of ΔGDDW20 | of ΔSDM5 | of ΔPRCPAW8 |
|  |  | (Weeks) | (oC) | (GDDs) | (mmHg) | (mm) | (Weeks) | (Weeks) | (Weeks) |
| MIDWEST | MN | -0.3 | 1.4 | 69 | 0.46 | 30 | -1.0 | 0.4 | 0.3 |
|  | WI | -0.3 | 1.4 | 65 | 0.33 | 28 | -0.9 | 0.3 | 0.3 |
| NORTH | ME | -0.1 | 1.2 | 30 | 0.18 | 13 | -0.4 | 0.2 | 0.1 |
|  | MA | -0.3 | 1.0 | 36 | 0.20 | 5 | -0.5 | 0.2 | 0.0 |
|  | NH | -0.3 | 1.2 | 46 | 0.24 | 10 | -0.6 | 0.2 | 0.1 |
| EAST | CT | -0.2 | 1.0 | 41 | 0.20 | 18 | -0.6 | 0.2 | 0.2 |
|  | RI | -0.2 | 0.7 | 29 | 0.14 | 4 | -0.4 | 0.1 | 0.0 |
|  | NJ | -0.4 | 1.0 | 61 | 0.24 | 24 | -0.9 | 0.2 | 0.2 |
|  | NY | -0.2 | 1.0 | 44 | 0.22 | 19 | -0.6 | 0.2 | 0.2 |
|  | PA | -0.6 | 1.1 | 74 | 0.27 | 25 | -1.0 | 0.3 | 0.2 |
| MID-ATL | MD | -0.4 | 0.9 | 59 | 0.21 | 23 | -0.8 | 0.2 | 0.2 |
|  | VA | -0.8 | 1.1 | 91 | 0.27 | 20 | -1.3 | 0.3 | 0.2 |
| NATIONAL | -- | -0.4 | 1.1 | 54 | 0.25 | 18 | -0.8 | 0.2 | 0.2 |

\*Future values with statistically significant change (p<0.05) compared to 1992-2007 are underlined.

Table S4. As in Table S1, but for the RCP8.5 scenario for 2025-2040.\*

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Change: 2025-2040 minus 1992-2007 | | | | | Contribution of change to ΔLOW | | |
| REGION | STATE | ΔLOW | ΔTJAN-MAY | ΔGDDW20 | ΔSDM5 | ΔPRCPAW8 | of ΔGDDW20 | of ΔSDM5 | of ΔPRCPAW8 |
|  |  | (Weeks) | (oC) | (GDDs) | (mmHg) | (mm) | (Weeks) | (Weeks) | (Weeks) |
| MIDWEST | MN | -0.4 | 2.0 | 89 | 0.58 | 33 | -1.2 | 0.5 | 0.3 |
|  | WI | -0.6 | 2.1 | 92 | 0.45 | 29 | -1.3 | 0.4 | 0.3 |
| NORTH | ME | 0.0 | 1.8 | 41 | 0.25 | 37 | -0.6 | 0.2 | 0.3 |
|  | MA | -0.1 | 1.5 | 47 | 0.26 | 29 | -0.7 | 0.3 | 0.3 |
|  | NH | -0.2 | 1.8 | 60 | 0.32 | 35 | -0.8 | 0.3 | 0.3 |
| EAST | CT | -0.2 | 1.4 | 55 | 0.27 | 40 | -0.8 | 0.3 | 0.4 |
|  | RI | -0.1 | 1.1 | 41 | 0.20 | 29 | -0.6 | 0.2 | 0.3 |
|  | NJ | -0.6 | 1.4 | 83 | 0.31 | 35 | -1.2 | 0.3 | 0.3 |
|  | NY | -0.2 | 1.5 | 60 | 0.29 | 36 | -0.8 | 0.3 | 0.3 |
|  | PA | -0.8 | 1.5 | 102 | 0.35 | 30 | -1.4 | 0.3 | 0.3 |
| MID-ATL | MD | -0.7 | 1.3 | 86 | 0.29 | 20 | -1.2 | 0.3 | 0.2 |
|  | VA | -1.3 | 1.5 | 127 | 0.37 | 18 | -1.8 | 0.3 | 0.2 |
| NATIONAL | -- | -0.4 | 1.6 | 74 | 0.33 | 31 | -1.0 | 0.3 | 0.3 |

\*Future values with statistically significant change (p<0.05) compared to 1992-2007 are underlined.

Table S5. As in Table S1, but for the RCP4.5 scenario for 2065-2080.\*

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Change: 2065-2080 minus 1992-2007 | | | | | Contribution of change to ΔLOW | | |
| REGION | STATE | ΔLOW | ΔTJAN-MAY | ΔGDDW20 | ΔSDM5 | ΔPRCPAW8 | of ΔGDDW20 | of ΔSDM5 | of ΔPRCPAW8 |
|  |  | (Weeks) | (oC) | (GDDs) | (mmHg) | (mm) | (Weeks) | (Weeks) | (Weeks) |
| MIDWEST | MN | -1.3 | 3.7 | 187 | 1.03 | 39 | -2.6 | 1.0 | 0.4 |
|  | WI | -1.5 | 3.7 | 184 | 0.77 | 40 | -2.6 | 0.7 | 0.4 |
| NORTH | ME | -0.4 | 3.2 | 96 | 0.49 | 56 | -1.3 | 0.5 | 0.5 |
|  | MA | -0.7 | 2.8 | 110 | 0.55 | 35 | -1.5 | 0.5 | 0.3 |
|  | NH | -0.9 | 3.2 | 135 | 0.62 | 45 | -1.9 | 0.6 | 0.4 |
| EAST | CT | -1.0 | 2.9 | 138 | 0.61 | 41 | -1.9 | 0.6 | 0.4 |
|  | RI | -0.8 | 2.6 | 117 | 0.51 | 36 | -1.6 | 0.5 | 0.3 |
|  | NJ | -1.5 | 2.8 | 170 | 0.63 | 29 | -2.4 | 0.6 | 0.3 |
|  | NY | -1.0 | 3.0 | 134 | 0.61 | 33 | -1.9 | 0.6 | 0.3 |
|  | PA | -1.9 | 2.9 | 195 | 0.66 | 25 | -2.7 | 0.6 | 0.2 |
| MID-ATL | MD | -1.6 | 2.6 | 166 | 0.58 | 15 | -2.3 | 0.5 | 0.1 |
|  | VA | -2.3 | 2.8 | 219 | 0.65 | 15 | -3.1 | 0.6 | 0.1 |
| NATIONAL | -- | -1.2 | 3.0 | 154 | 0.64 | 34 | -2.2 | 0.6 | 0.3 |

\*Future values with statistically significant change (p<0.05) compared to 1992-2007 are underlined.

Table S6. As in Table S1, but for the RCP6.0 scenario for 2065-2080.\*

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Change: 2065-2080 minus 1992-2007 | | | | | Contribution of change to ΔLOW | | |
| REGION | STATE | ΔLOW | ΔTJAN-MAY | ΔGDDW20 | ΔSDM5 | ΔPRCPAW8 | of ΔGDDW20 | of ΔSDM5 | of ΔPRCPAW8 |
|  |  | (Weeks) | (oC) | (GDDs) | (mmHg) | (mm) | (Weeks) | (Weeks) | (Weeks) |
| MIDWEST | MN | -1.0 | 3.4 | 164 | 0.91 | 44 | -2.3 | 0.9 | 0.4 |
|  | WI | -1.2 | 3.3 | 162 | 0.67 | 46 | -2.3 | 0.6 | 0.4 |
| NORTH | ME | -0.3 | 2.8 | 79 | 0.42 | 41 | -1.1 | 0.4 | 0.4 |
|  | MA | -0.6 | 2.4 | 89 | 0.46 | 24 | -1.2 | 0.4 | 0.2 |
|  | NH | -0.8 | 2.8 | 113 | 0.53 | 37 | -1.6 | 0.5 | 0.3 |
| EAST | CT | -0.8 | 2.4 | 109 | 0.50 | 33 | -1.5 | 0.5 | 0.3 |
|  | RI | -0.7 | 2.1 | 87 | 0.39 | 17 | -1.2 | 0.4 | 0.1 |
|  | NJ | -1.3 | 2.4 | 146 | 0.54 | 24 | -2.0 | 0.5 | 0.2 |
|  | NY | -0.8 | 2.6 | 110 | 0.51 | 33 | -1.5 | 0.5 | 0.3 |
|  | PA | -1.7 | 2.6 | 174 | 0.58 | 25 | -2.4 | 0.6 | 0.2 |
| MID-ATL | MD | -1.5 | 2.4 | 154 | 0.52 | 19 | -2.2 | 0.5 | 0.2 |
|  | VA | -2.2 | 2.5 | 207 | 0.59 | 17 | -2.9 | 0.6 | 0.2 |
| NATIONAL | -- | -1.1 | 2.6 | 133 | 0.55 | 30 | -1.9 | 0.5 | 0.3 |

\*Future values with statistically significant change (p<0.05) compared to 1992-2007 are underlined.

**References**

Held, I.M., Soden, B.J., 2000. Water vapor feedback and global warming. Annual Rev. Energy Environ. 25, 441-475.

Moore, S.M., Eisen, R.J., Monaghan, A.J., Mead, P., 2014. Meteorological influences on the seasonality of Lyme disease in the United States. Am. J. Trop. Med. Hyg. 90, 486-496.

Willett, K.M., Jones, P.D., Gillett, N.P., Thorne, P.W., 2008. Recent changes in surface humidity: development of the HadCRUH dataset. J. Clim. 21, 5364-5383.