Title: The impact of climate change on transmission season length: West Nile virus as a case study

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Keywords: West Nile virus, climate change, season length, vector-borne diseases, temperature

Summary

Background — Climate change is accelerating the spread of temperature-sensitive vector-borne diseases such as West Nile virus (WNV), the most widespread mosquito-borne disease in the United States, with 2,400 reported cases in 2024. In New York State (NYS), where WNV first emerged in the U.S., mean temperatures have increased by 1.4°C since the early 1900s. Although temperature is a well-established driver of WNV transmission, its effect on transmission season length remains poorly quantified. This study examines whether WNV transmission seasons have lengthened in NYS and

whether these changes are associated with increased disease risk, shifts in seasonal timing, and anthropogenic climate change.

Methods — We integrated daily county-level observational data from 1999–2024, including temperature, mosquito surveillance, and human case data, with climate model simulations spanning 1850–2024 to assess trends in transmission season length.

Findings — Based on observed temperature suitability, the WNV transmission season in NYS has lengthened by an average of 20 days over the past 25 years, beginning 3.8 days earlier and ending 16.3 days later. Longer transmission seasons are positively associated with higher WNV prevalence in both mosquito vectors and humans. While such changes could occur in the absence of global warming, climate model analyses indicate that the observed increase in season length is 6.4 times more likely under historical climate forcing since 1900 than under pre-industrial conditions.

Interpretation — These findings demonstrate that climate change is reshaping the phenology and burden of WNV transmission.

Funding — Supported by NIH, NSF, Stanford University, and the Fogarty International Center.

Research in Context

Evidence before this study – We searched Google Scholar for publications from 1999 to 2024 using the term “West Nile virus and season length,” yielding 18,200 results. Previous studies focused on how climatic factors affect transmission and its seasonality in the United States, but none assessed how climate change influences transmission season duration. We analyzed over two decades of data to link extended WNV transmission seasons with increased vector and human prevalence. Additionally, we evaluated the causal role of climate warming using simulated climate data and counterfactual analyses.

Added value of this study – Using daily temperature and WNV case data from 1999–2024, we found that the WNV transmission season in NYS has lengthened by an average of 20 days. The season now begins 3.8 days earlier and ends 16.3 days later. Longer seasons were associated with higher prevalence in mosquitoes and humans. Climate model simulations indicate that human-driven greenhouse gas emissions have significantly extended the WNV season, making observed trends in season length, onset, and conclusion 6, 2, and 16 times more likely, with implications for mosquito infection and human disease risk.

Implications of all available evidence – Our findings suggest that climate change is lengthening WNV transmission seasons, a phenomenon likely relevant to other temperature-sensitive vector-borne diseases. As warming continues, extended transmission seasons may amplify risks for WNV and other vector-borne diseases, underscoring the need for climate-adaptive public health surveillance and intervention strategies.

Introduction

Across the globe, surface air temperature is increasing. Global warming since the 19th century has reached 1.4°C[1], and since 1999, there has been a global average increase of 0.4°C[2]. Climate change has been shown to affect many infectious diseases, and vector-borne diseases are particularly susceptible to thermal changes because mosquitoes are ectothermic organisms[3]. Temperature affects several key mosquito life history traits—such as survival, blood feeding, vector competence, and development—as well as pathogen replication, all of which are essential for disease transmission[4]. Vector-borne diseases account for more than 17% of all infectious diseases, causing more than 700,000 deaths annually[5]. Vector-borne diseases are especially responsive to anthropogenic changes, and rising temperatures can influence disease risk[6]. Although a large body of research has documented impacts of temperature on vector-borne disease transmission[6–9], very few studies have investigated how climate warming has affected the transmission season in temperate environments[10–12], where transmission is limited by cool temperatures in the spring and fall. As a result, seasonal epidemics that start earlier and last longer can increase the overall disease burden.

West Nile virus (WNV), a mosquito-borne arbovirus, emerged in the Western Hemisphere in 1999, with New York State (NYS) at the epicenter of the outbreak. In NYS, the average temperature has increased by nearly 1.4°C from 1901 to 2022[13,14]. Based on mathematical models parameterized using data from lab experiments, the thermal suitability range for WNV transmission by *Culex pipiens***,** the primary vector in NYS, is between 16.7°C and 33.9°C[15]. This implies that the time at which seasonal temperatures

become suitable for WNV transmission governs the outer bound on the transmission season, and that these seasonal thermal suitability limits may be sensitive to climate warming.

Climatic factors such as temperature, precipitation, and relative humidity are known drivers of WNV transmission under weather variability and climate change[6,8,15–19]. Warmer temperatures, elevated humidity, and heavy precipitation contributed to an increased rate of human WNV infection in the United States (U.S.) during the early 2000s[20]. Drought has also been identified as a key driver of WNV transmission dynamics in the U.S.[21]. In the Southeastern U.S., dry and hot spring/summer conditions, along with increased temperature and rainfall in late summer/fall, have been shown to lengthen the WNV transmission season[22]. In the Northeastern U.S., WNV is predicted to become more geographically widespread due to climate change[12,23]. Although the impact of temperature on WNV transmission is well described[9,15,21], its effect on the length of the WNV transmission season and association with human incidence remain unclear in NYS or elsewhere. Extended virus activity could influence public health responses, including surveillance duration and resource allocation.

In this study, we examine the impact of climate change on the transmission dynamics and seasonal duration of vector-borne diseases using WNV in NYS as a case study. Using temperature, mosquito surveillance, and human case data from 1999 to 2024, spanning the entire time since WNV was introduced to the US, we assess the influence of recent temperature trends on WNV transmission season length in NYS. Specifically, we address four questions: (1) Has the WNV transmission season length increased in NYS? (2) Are longer transmission seasons associated with increased WNV

incidence in mosquitoes and humans? (3) Are these changes associated with shifts in the timing of infection onset and termination in hosts? and (4) Can these observed changes in NYS WNV season be linked to human-caused climate change? The goal of this study is to outline the effect of rising temperatures on WNV transmission season length, which may help public health officials better prepare for future transmission seasons by adjusting the timing of surveillance and vector control activities. Our results illustrate the broad potential for climate warming to extend vector-borne disease transmission seasons, particularly in temperate regions where they are limited by cool temperatures.

Methods

Temperature Data

Daily temperature data were derived from GridMET[24] a gridded surface meteorological dataset that covers the continental U.S. and mapped surface weather variables at a ~4-km horizontal resolution. This dataset combines two sources: temporally rich data from the North American Land Data Assimilation System Phase 2 (NLDAS) and spatially rich data from Parameter-elevation Regression on Independent Slopes Model (PRISM). We downloaded this dataset from https://www.climatologylab.org/ and calculated daily, county-wide mean temperatures for the period 1999–2024 using NYS county boundaries provided by https://www.ny.gov/. Data analysis was performed in R version 4.3.2[25] and Python 3.12.9[26] , and visualization was conducted in R, Python, and Prism 10.4.1.

To calculate season length, temperature data were filtered to include days when the average daily temperature was ≥16.7°C—the thermal minimum for WNV transmission

estimated by previous studies[19,27]—and were within a 13-day window of another day ≥16.7°C. This filtering removed isolated single-day temperature outliers and accounted for the mosquito development time. Season length was measured as the number of days between the first and last days within this filtered period. We did not apply an upper temperature bound since average temperatures generally do not reach the WNV transmission maximum of 33.9°C[9].

To evaluate changes in temperature-suitable transmission dynamics, we fit three linear regressions per county: (1) temperature-suitable season length by year, (2) temperature-suitable first day of the transmission season by year, and (3) temperature-suitable last day of the transmission season by year (e.g., Eq. 1).

$$Y = \beta_0 + \beta_1 Year + \varepsilon \qquad \text{Eq. 1}$$

We used linear regression to estimate the y-intercept (β_0) and the average rate of change (β_1) over time (in years) for each response variable Y (i.e., season length, first day, and last day of transmission season). For each county, we used the fitted regression model to predict the values of each transmission variable in 1999 and 2024. We then calculated the total change over time by taking the difference between these two predicted values. We used model-based predictions rather than raw observed values to ensure that our estimates of change reflected long-term trends and were not overly influenced by outlier years or transient fluctuations at either endpoint.

The GridMET[24] dataset included historical temperature data from 1979 to 1998. These data were analyzed and visualized in R[25] to determine the average historical temperature in each NYS county. The code used for these analyses, as well as

subsequent analyses, can be found at https://github.com/Rachellfay/WNV-Season-Length.

Mosquito Surveillance Data

Mosquito trapping and testing data across NYS were compiled as part of the Arbovirology surveillance program, which received samples from 45 of the 62 counties, although participating counties varied by year. These data excluded Bronx, Kings, New York, Queens, and Richmond counties, which conducted their own mosquito surveillance annually. Mosquito surveillance was completed as previously reported[28–30] (see supplemental methods).

Human WNV Data

Human WNV case data were obtained from the NYS Department of Health Bureau of Communicable Disease Control and the Centers for Disease Control annual county data records[31], excluding Bronx, Kings, New York, Queens, and Richmond counties, where mosquito surveillance data were unavailable. Details on human WNV data are provided in the supplemental methods. Data analysis was performed in R, and visualization was conducted in R[25] and Prism 10.4.1.

Climate model simulations

To investigate the influence of anthropogenic climate forcing on the duration of the WNV transmission season, we analyzed climate model simulations from Phase 6 of the Coupled Model Intercomparison Project (CMIP6). In particular, we analyzed 37

simulations of the 1850-2025 period from 37 different climate models (1 simulation per climate model). Although CMIP6 is the most recent CMIP iteration and represents the current state of the science in the international community, the simulations with actual historical forcing were only run through the year 2014, after which the simulations were forced by various future scenarios. Therefore, the climate model simulations we analyzed used historical climate forcing (including historical anthropogenic emissions) from 1850-2014 and projected future emissions from the shared socioeconomic pathway SSP2-4.5 scenario (which is a moderate forcing scenario) for the 2015-2025 period.

Since WNV transmission rates are highly dependent on absolute temperature thresholds (e.g., with 16.7°C representing the thermal minimum for WNV transmission[15]), biases in daily temperature between the GridMET dataset and the climate model simulations could substantially impact our results[32]. Therefore, we first bias-corrected and downscaled the climate model simulations to the GridMET 4km grid using the bias-correction and spatial disaggregation (BCSD) method[33]. For each climate model simulation, we used detrended quantile mapping[34] to correct each daily grid cell temperature value to the corresponding quantile in the GridMET dataset (bilinearly interpolated to match the climate model grid). To preserve the long-term temperature trends in the climate model simulations, the long-term trends were removed (using a 30-day sliding window) from each climate model simulation and added back after the quantile mapping procedure was complete. Finally, we spatially disaggregated the climate model simulations to the 4km GridMET grid by removing the bias-corrected climatology, bilinearly interpolating the daily residual fields from the native climate model grid to the

4km GridMET grid, and adding the 4km GridMET climatology back in, yielding the final bias-corrected and downscaled daily temperature data for each climate model simulation.

For each of the 37 bias-corrected and downscaled climate model simulations, we calculated timeseries of daily mean temperature for each county in NYS using the county shapefiles provided by https://www.ny.gov/. We then calculated the WNV season characteristics (season length, season start date, and season end date) for both the pre-industrial period (1850-1900[35]) and the recent period (1999-2024) using the same methodology as for the GridMET dataset (described in section 1 of Methods). By averaging our results across 37 simulations from different climate models, we filtered out the noise of internal variability in the climate system (and trends specific to any individual climate model), making it more likely that any long-term trends are caused by anthropogenic climate forcing.

Results

Temperature Data

To assess temperature effects on WNV transmission season length, temperature data were filtered by days ≥16.7°C (See Methods), which falls within the thermal suitability for WNV transmission by *Cx. pipiens* populations in NYS[15]. Hereafter, we refer to the number of days above the thermal suitability threshold as the 'transmission season'. The average transmission season length has significantly increased since 1999 (Fig. 1A and B; simple linear regression, $p < 0.05$). Although the increase varies by county (Fig. 1C), on average, the transmission season has extended by 20 days from 1999 to 2024.

Over the past 25 years, the transmission season has begun significantly earlier and ended significantly later statewide (Fig. 2A, 2C; simple linear regression, $p < 0.05$). Although the extent of transmission season advance varies across counties, the season started an average of 3.8 days earlier from 1999 to 2024 (Fig. 2B). Additionally, the transmission season in 2024 ended an average of 16.3 days later than in 1999 (Fig. 2D). However, the length of the extension varies by county. To determine if historically cooler counties had larger differences in season length, we analyzed mean historical temperature data from 1978-1998 and plotted this against changes in season length. Historical mean temperatures (1978–1998) were quadratically related to changes in season length, with the greatest increase in counties averaging 11.2°C (Fig. 2E; quadratic regression, $p < 0.05$).

Mosquito Infection Data

Longer transmission seasons were hypothesized to increase WNV prevalence in mosquitoes. To test this relationship, county-level mosquito surveillance data were analyzed and compared with the state-wide average transmission season length. WNV prevalence was calculated using maximum likelihood estimation for all *Culex* spp. mosquito pools (Fig. 3A; simple linear regression, $p < 0.05$). We calculated the season length for each county with at least 10 years of surveillance data and compared these lengths to the prevalence of WNV-positive mosquito pools. Longer transmission seasons were associated with an increased number of WNV-positive mosquito pools statewide (Fig. 3A) and in Suffolk County (Fig. 3B; simple linear regression, $p < 0.05$), but not in six other counties analyzed (Fig. S1; $p > 0.05$).

Given that longer transmission seasons are associated with increased WNV prevalence in mosquitoes, we next investigated whether the first WNV-positive mosquito pool occurs earlier in the year. Statewide, longer transmission seasons were significantly associated with earlier detection of the first WNV-positive mosquito pool of the season (Fig. 3C; simple linear regression, $p < 0.05$). Moreover, a significant negative association between the timing of the first WNV-positive pool and the length of the season was observed in Suffolk County (Fig. 3D; simple linear regression, $p < 0.05$), while no such relationship was found in six other counties analyzed (Fig. S2; $p > 0.05$). Contrary to our expectations, we found no significant trend in the timing of the last WNV-positive mosquito pool annually, nor was there a significant association between longer transmission seasons and later mosquito transmission activity (Fig. S3; $p > 0.05$). However, because cessation of seasonal WNV surveillance is contingent on resource allocation rather than WNV activity or temperature, it is likely that late-season WNV positivity of mosquitoes has been missed.

Human Case Data

To investigate the relationship between the duration of the WNV transmission season and the occurrence of human infections, we used statewide human WNV case data obtained from the CDC. Through a simple linear regression, we identified a statistically significant positive correlation between the length of the transmission season and the number of reported human WNV cases statewide (Fig. 4A; $p < 0.05$). We found that the first human WNV cases tended to occur earlier during longer transmission seasons, though this trend was not significant, with cases diagnosed an average of 10

days earlier in 2024 than in 1999 (Fig. 4B; $p > 0.05$). We found a significant relationship between longer transmission seasons and later last human WNV cases statewide, with cases occurring 17 days later in 2024 than in 1999 (Fig. 4C; $p < 0.05$). Together, these findings indicate that extended transmission seasons are linked to increased WNV activity in humans.

Climate change attribution analysis

To investigate the sensitivity of the duration of the WNV transmission season to human emissions of greenhouse gases, we analyzed 37 climate model simulations from the CMIP6 archive. When analyzing WNV season characteristics in each of these climate model simulations during the recent period relative to the 1850-1900 period, we found robust changes in WNV season length, onset date, and termination date, with most of these changes occurring since 1990 (Fig. 5A-C). We also found statistically significant ($p < 0.01$) changes in the distribution of WNV season length, first day, and last day over the last 15 years (2010-2024) of the climate model simulations compared to the preindustrial period (1850-1900) (Fig. S4). In particular, we found that on average across climate model simulations and all NYS counties, WNV season length increased by ~16 days (98% of values > 0), onset date decreased by ~8 days (94% of values < 0), and termination date increased by ~8 days (97% of values > 0) (Fig. S4). This indicates that changes similar to those observed empirically are captured within the climate model simulations when comparing the preindustrial baseline period (1850-1900) to the recent period (2010-2024).

Although we cannot claim that global warming is solely responsible for the recent observed trends in WNV season characteristics, we can analyze trends in the climate model simulations to determine whether global warming increased the likelihood of the observed trends in season length, onset, and termination. We compared the gridMET trends (i.e., those shown in Figs. 1a, 2b, and 2c) to the distribution of 26-year trends in the climate model simulations calculated from the preindustrial period (1850-1900; which we split into two adjacent 26-year periods) and the recent period (1999-2024) (Figs. 5D-F and S5). We found that the probability of trends in WNV season length as extreme as the gridMET trend has increased from 4.8% (3.1%-7.9%) in the preindustrial period to 30.5% (24.3%-38.8%) in the recent period, suggesting that the observed trend was 6.4 times more likely to occur because of global warming (Fig. 5D). Similarly, we found that the global warming since 1850 has increased the likelihood of the observed trends in season onset and termination dates, suggesting that the observed trend in WNV season start date was 2.2 times more likely to occur because of global warming, and the observed trend in WNV season end date was 16.0 times more likely (Figs. 5E-F).

Discussion

Temperature is a key driver of vector-borne pathogen transmission, yet its influence on transmission season length remains poorly characterized for many diseases, including WNV. Using county-level temperature data and the lower thermal limit for WNV transmission in *Cx. pipiens*, we show that the WNV transmission season in NYS increased by an average of 20 days from 1999 to 2024 (Fig. 1A). This expansion varies by county and is greatest in historically warmer areas (Fig. 1B–C, Fig. 2E). The season

now begins earlier and ends later, with larger shifts at the season's end; statewide, the last day occurs 16.3 days later on average, while onset occurs 3.8 days earlier (Fig. 2).

These changes have measurable epidemiological consequences. Longer transmission seasons are associated with higher WNV prevalence in mosquitoes and earlier detection of the first positive mosquito pool (Fig. 3A,D), as well as increased human case counts occurring both earlier and later in the year (Fig. 4). Although we cannot definitively attribute these trends to climate change alone, climate model simulations indicate that anthropogenic greenhouse gas emissions have substantially increased WNV season length since its emergence in 1999 (Fig. 5A). Observed trends in season length, onset, and termination are approximately 6, 2, and 16 times more likely under present-day climate conditions than in the absence of global warming (Fig. 5D–F). Together, these results support the conclusion that climate change has lengthened the WNV transmission season in NYS, with implications for mosquito infection dynamics and human disease risk.

Numerous weather factors influence WNV transmission[6,8,11,36–38], with temperature being a major driver of season length[11,20,39,40]. Studies in Europe show that warmer springs can extend the transmission season and increase WNV prevalence[10,41], and in the U.S., local temperature similarly shapes WNV seasonality[20,39,40]. Our study examines over two decades of data linking extended seasons with WNV prevalence in vectors and humans and uses climate model simulations to explore the causal role of global warming. Although temperature is critical, other factors—such as precipitation and humidity—also affect transmission, warranting future investigation[6,8,20,42]. While previous studies have

examined weather variability[11,15,20,21], this is the first to assess the impact of climate change on transmission duration and its implications for disease spread.

Climate change continues to accelerate, and mitigation efforts remain insufficient to stabilize the global temperature. Vector-borne diseases are sensitive to warming-driven extensions of the transmission season, which may alter thermal suitability, increase vulnerability to vector expansion, and allow vectors and viruses to evolve[43–46]. Surprisingly, we found no relationship between the last WNV-positive mosquito pool and extended seasons, likely because surveillance typically ends by late October for operational reasons, missing late-season transmission. Our finding of later human case reports in years with longer transmission season highlights the need to extend vector sampling and management later into the season.

Our mosquito surveillance dataset does not include data from the five boroughs of New York City, the area where WNV transmission was initially detected in the state, and where the largest human population resides. Although this does not bias our results, the inclusion of mosquito and human WNV prevalence data from this region could strengthen our analysis. In the remaining counties with surveillance data, we found a significant link between the timing of the first and last human WNV cases and the length of the transmission season. However, since reported case dates can vary with detection methods, analyzing data by detection type could reveal a stronger relationship. Additionally, while we know that avian hosts play a role in the WNV transmission cycle[47–50], we could not account for climate-driven changes in the avian community in this study due to a lack of WNV surveillance in avian populations.

This study highlights WNV as a compelling case study for understanding recent trends in the seasonality of vector-borne disease transmission and linking these observed changes to human-caused climate change. Our findings demonstrate that rising temperatures extended the WNV transmission season in NYS by nearly three weeks over the past 25 years, leading to earlier seasonal onset and later termination. This extension of the transmission window is strongly associated with increases in both WNV prevalence in mosquito vectors and human WNV cases, underscoring the tangible public health consequences that are already occurring from a warming climate. Our climate model analysis suggests that it is possible but highly unlikely (<5% probability) that this observed trend in WNV transmission season length could have occurred in the absence of global warming, and that this trend was more than 6 times more likely to occur because of global warming since 1900.

While temperature is a key driver, the complex interplay of other climatic factors, vector ecology, and host dynamics also shapes disease patterns. As climate change continues in the coming decades[51], similar shifts in thermal suitability and vector behavior are likely to facilitate the expansion and intensification of WNV and other vector-borne diseases.

Acknowledgments

We are grateful to the New York State Arbovirology Laboratory for their support and collaboration throughout this study. We thank the New York State Department of Health for kindly sharing their human WNV case data. We additionally thank both the New York State Bureau of Communicable Disease Control and county health departments for

their coordination and implementation of mosquito collections for surveillance testing. We also thank Dr. Alexander Keyel for his valuable assistance and insightful feedback. We acknowledge the World Climate Research Programme, which coordinated and promoted CMIP6, and thank the climate modeling groups for producing and making available their model output, the Earth System Grid Federation (ESGF) for archiving the data and providing access, and the multiple funding agencies that support CMIP6 and ESGF.

Contributions

RLF and EAM conceived and designed the study. RLF, CKG, JTT, and ATC collected and formatted the data utilized in the manuscript. RLF, CKG, and JTT conducted the results analysis. RLF, CKG, and JTT prepared the manuscript. NSD and EAM supervised the work. CKG, JTT, NSD, ATC, and EAM provided constructive comments to improve the manuscript and participated in revising the manuscript.

Declaration of interests

Data Sharing

Data was made available through the Freedom Of Information Law, Article 6 (Section 84-90), of the New York State Public Officers Law, providing the public the right to access records maintained by government agencies with certain exceptions. Due to confidentiality restrictions set by the New York State Department of Health (NYSDOH), mosquito surveillance and human case data cannot be made publicly available. However, these data can be requested directly from the NYSDOH Bureau of Communicable

Diseases at BCDC@health.ny.gov. Model output from Phase 6 of the Coupled Model Intercomparison Project is available from the Earth System Grid Federation through their website at https://esgf.github.io/. The GridMET data used in this analysis is available from their website at https://www.climatologylab.org/. The New York State County boundaries used in this analysis can be downloaded from https://www.ny.gov/.

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Figures

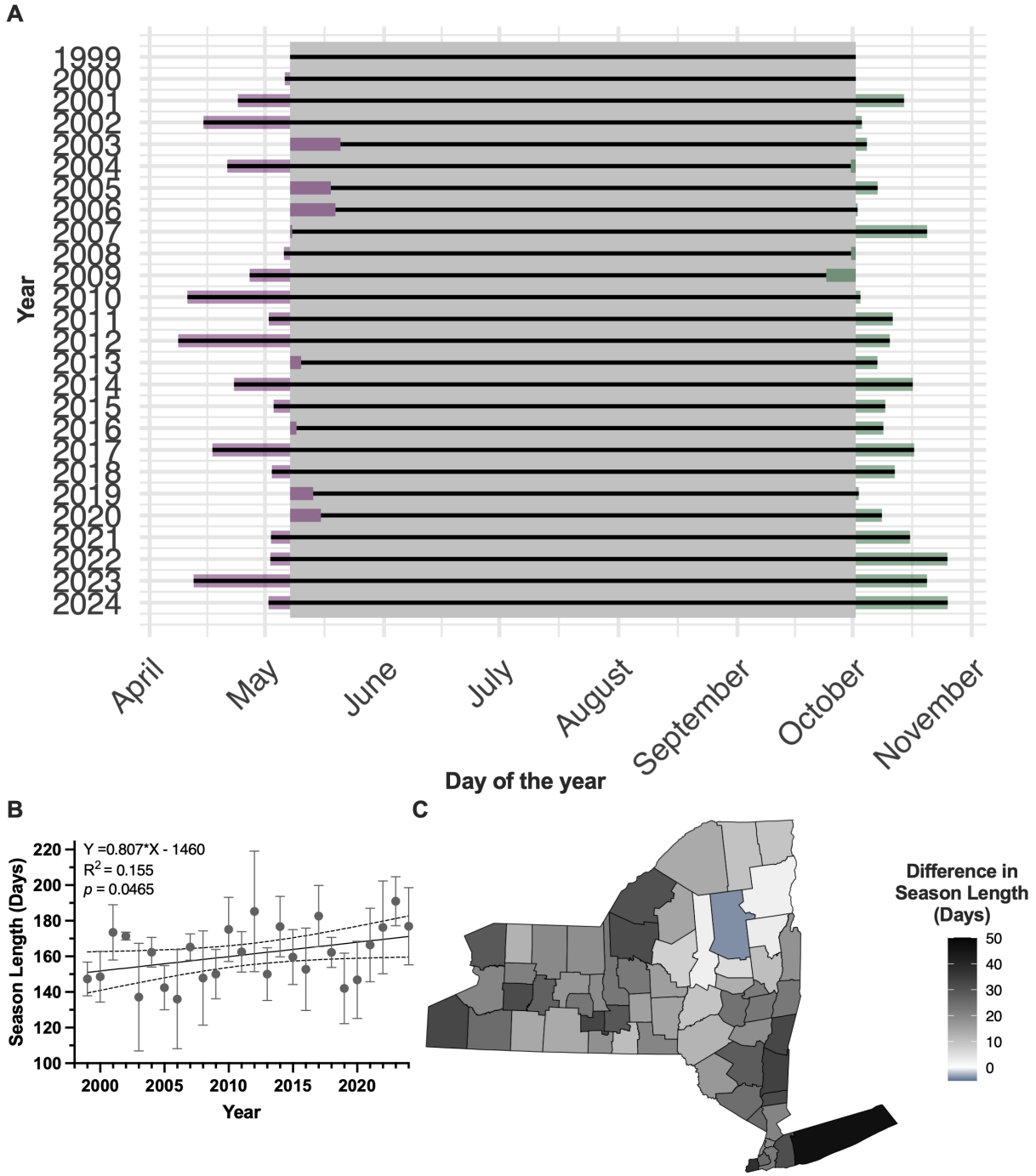

Fig 1. Change in WNV season length from 1999-2024. **A**) Summary of annual average season length across NYS across all counties. Gray denotes the 1999 season determined by filtering days ≥16.7°C, black denotes the season length that year, purple denotes the early season anomaly compared to the 1999 season, and green denotes the late season anomaly compared to the 1999 season. **B**) Average season length annually across NYS and the standard deviation in season length across all counties per year, showing the

mean, SD, and 95% confidence interval (simple linear regression p=0.0465). **C**) Map by county of the difference in season length between 1999 and 2024.

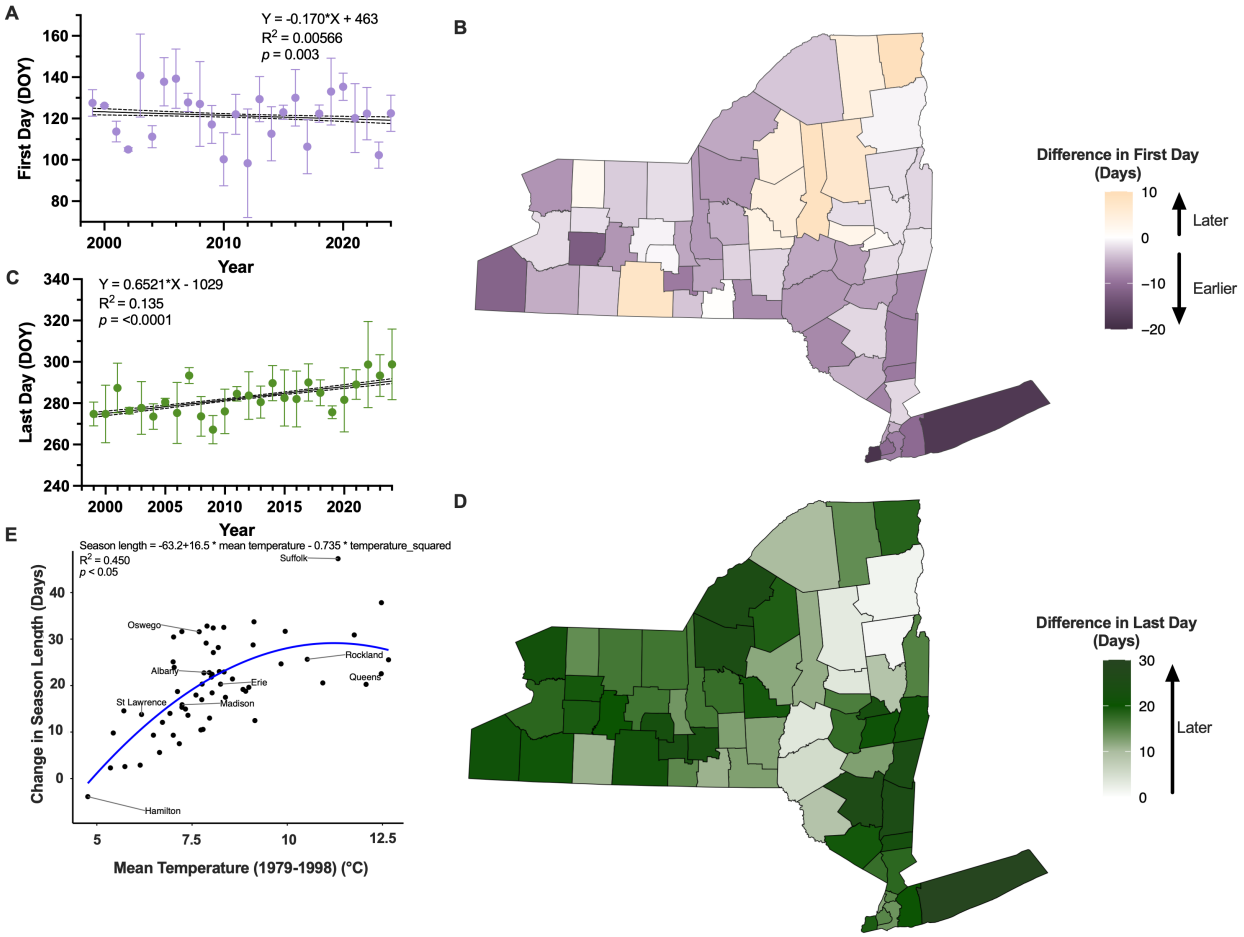

Fig 2. The difference in the first (**A**-**B**) and last (**C**-**D**) day of the season and total season length by historical temperature (**E**). (**A**) First day ≥16.7°C annually statewide, showing the mean, SD, and 95% confidence interval (simple linear regression p=0.003). (**B**) Map by county of the difference in the first day of the season from 1999 compared to 2024. (**C**) Last day ≥16.7°C annually statewide, showing the mean, SD, and 95% confidence interval (simple linear regression p <0.0001). (**D**) Map by county of the difference in the last day of the season from 1999 compared to 2024. **E**) Quadratic regression showing the relationship between season length and historical temperature on a county scale, with points labeled by county name (quadratic regression p < 0.05).

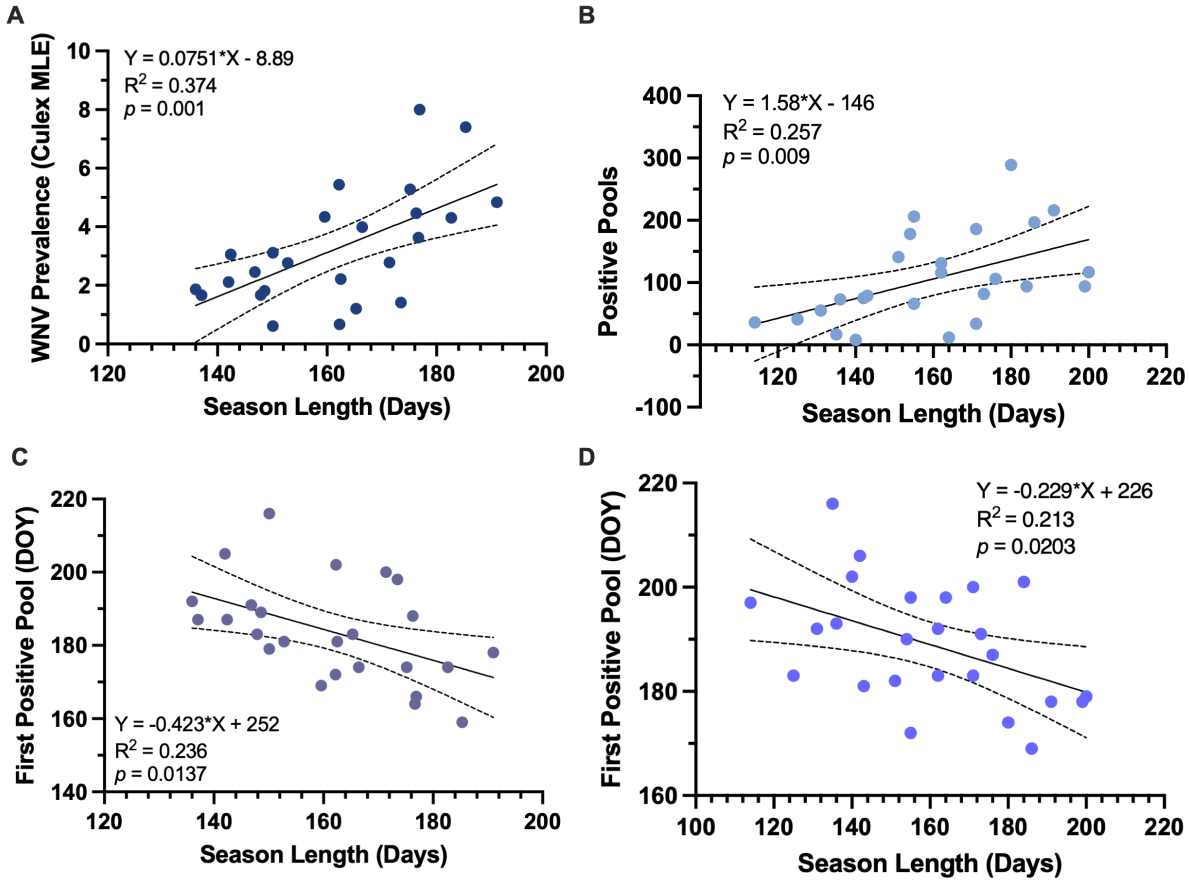

Fig 3. The relationship between WNV prevalence in mosquitoes and season length. **A**) Annual WNV prevalence (maximum likelihood estimation) versus average season length statewide (simple linear regression p=0.0011). **B**) Suffolk County number of WNV-positive mosquito pools versus transmission season length (simple linear regression p=0.0097). **C**) First positive mosquito pool statewide versus annual average statewide season length (simple linear regression p=0.0137). (**D**) Suffolk County number of WNV-positive mosquito pools versus transmission season length (simple linear regression p=0.0203). (Note that the y-axis differs among panels.)**.**

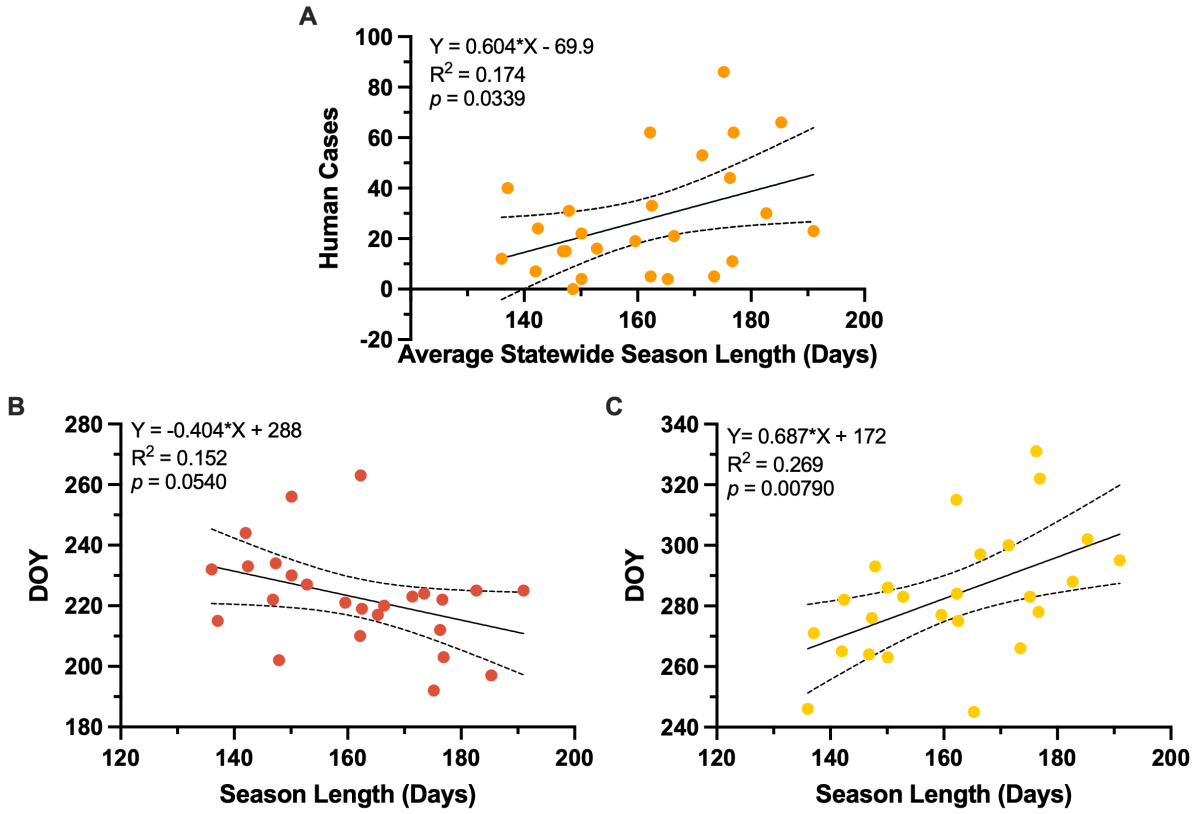

Fig 4. Human WNV cases versus season length in NYS. **A**) Total human WNV cases in New York State versus annual season length in New York State (simple linear regression *p*=0.0339). **B**) First human WNV case statewide versus annual average statewide season length (simple linear regression *p*=0.0540). **C**) Last human WNV case statewide versus annual average statewide season length (simple linear regression *p*=0.0079).

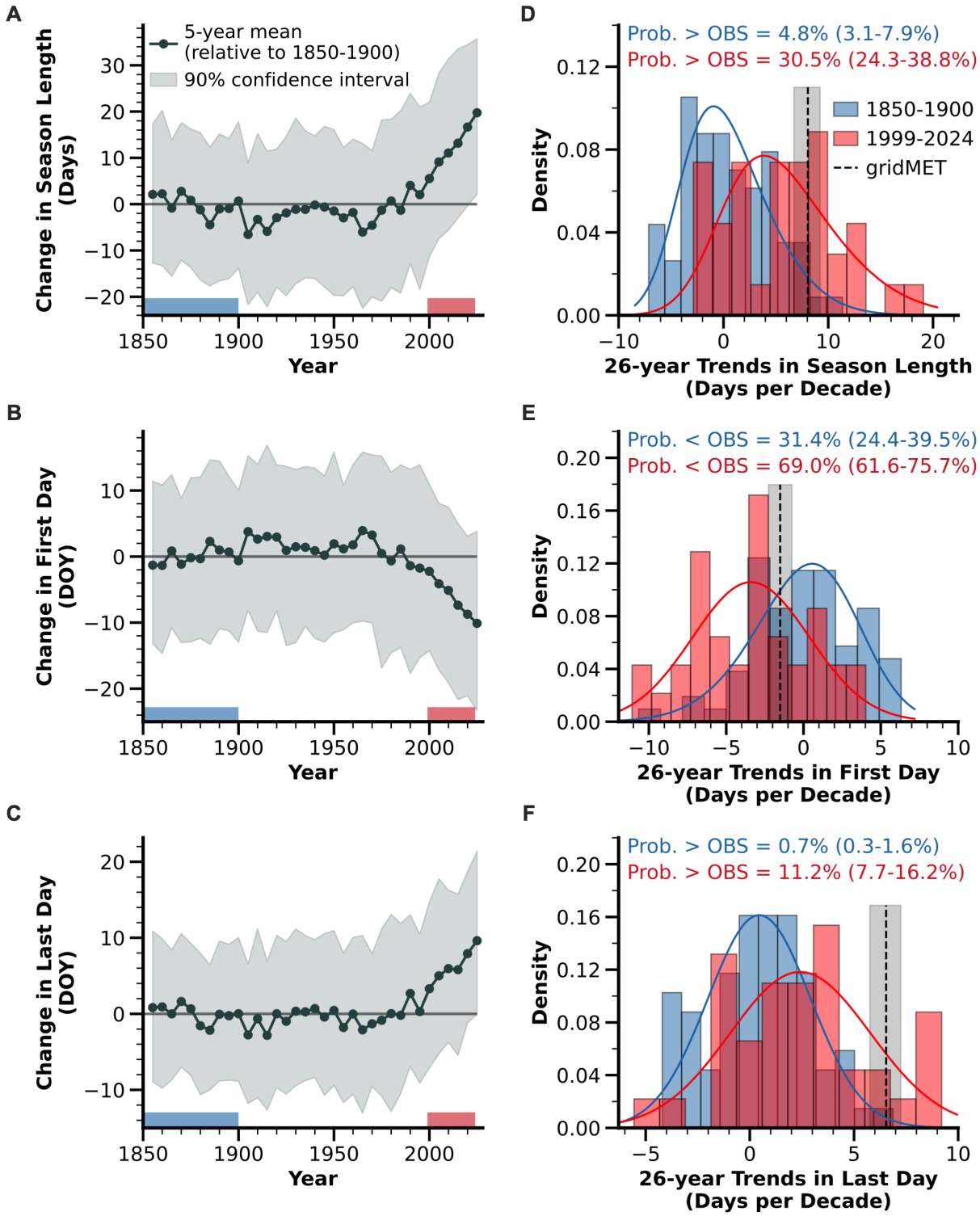

Fig 5. Influence of global warming on trends in the seasonality of WNV transmission. **A**) Change in WNV season length relative to the 1850-1900 period mean. For each 5-year bin, the solid line shows the mean across all NYS counties and all 37 climate model simulations, and the shading shows the range of the 5th-95th percentile values. Colored

bars indicate the preindustrial (blue; 1850-1900) and recent periods (red; 1999-2024). **B-C**) Same as A, but for changes in the first and last day of the WNV season, respectively. **D**) Distribution of 26-year trends in WNV season length calculated using gridMET 1999-2024 (black), climate model simulations from 1999-2024 (red), and climate model simulations from 1850-1900 (blue; which we split into two adjacent 26-year periods). Probability indicates the likelihood of observing the gridMET trend (i.e., Prob. > OBS) in the distribution of climate model trends from the preindustrial and recent periods calculated from skew-normal distributions fit to each period. Uncertainty range of gridMET trends is estimated using bootstrap resampling. **E-F**) Same as D, but for trends in the first and last day of the WNV season, respectively.