A 30-Year Heat Wave Analysis in New Jersey

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Introduction

New Jersey is the third-fastest warming state in the country since 1970 (Climate Central, 2024) and has experienced a 3.5°F rise since the beginning of the 20th century (Runkle et al., 2022). The warming recorded in New Jersey is part of a broader, region-wide trend that has seen the Northeast United States warm faster than many other regions in the US (Marvel et al., 2023). Unlike much of mid-latitude North America, the coastal Northeastern United States has experienced significant warming in both summer and winter, leading to a high increase in the annual mean temperature. This has resulted in an increase of over 4°F (2°C) in the Northern Hemisphere since 1902 (Karmalkar & Horton, 2021). Rapid warming leads to a higher baseline temperature for the region, increasing the likelihood of extreme heat events occurring. Additionally, climate change impacts atmospheric circulation, resulting in alterations to weather patterns. For example, shifts in the jet stream can trap hot air in one place for longer periods, resulting in prolonged heat waves (Coumou et al., 2018). A heat wave is a stretch of at least three days with temperatures of 90°F or greater (NOAA, 2018), and alterations in localized weather can lead to more frequent and persistent heat waves within the region.

This significant warming trend is projected to continue (Runkle et al., 2017). Heat waves are expected to become more intense (Runkle et al., 2022) and impact larger areas with more frequency and longer duration by 2050 (Lyon et al., 2019). A multi-model analysis of 100°F heat index found that by midcentury, the frequency of heat index, or apparent temperature, values over 100°F is projected to increase threefold in the Northeast under an intermediate emissions scenario (RCP4.5) (Dahl et al., 2019).

Extreme heat, such as that experienced during heat waves, can be dangerous to human health. Prolonged exposure to high temperatures can result in ineffective body temperature regulation, with excessive sweating causing dehydration without proper fluid replenishment and rest. Heat exhaustion and heat stroke are severe outcomes of exposure to extreme heat, and ultimately, heat waves act as threat multipliers, as high temperatures put stress on the cardiovascular, respiratory, and renal systems. In order to better understand the long-term impacts the projected warming trend will have on human health, an analysis of heat wave trends is important in discerning if and how they are changing. A recent study found that "heat-related mortality rates in the US increased from 1999 to 2023, especially during the last 7 years (of the study) (Howard et al., 2024)." The potential for increased mortality is most notable in heavily populated areas such as the Northeast region of New Jersey, due in part to the increased ratio of the built environment (e.g., concrete buildings, roadways, etc.) compared to green space. It has been shown that cement and asphalt-dominated areas enhance the urban heat island effect (i.e., when an urban area experiences warmer temperatures than a nearby rural area). In contrast, areas with a more natural setting negatively correlate with urban heat islands (Yin et al., 2023). In addition to increasing the localized temperatures of more urbanized environments, the urban heat island effect also contributes to higher overnight temperatures. The number of warm nights in New Jersey has consistently been above the long-term state average since the early 2000s, with the highest 5-year average occurring during the 2010–2014 period (Runkle et al., 2022). The difference between daytime and nighttime temperatures, i.e., the loss of the cooling effect afforded in the overnight period, will exacerbate the potential for longer and hotter heatwaves and heat-related illnesses.

This study of heat wave temperature data aims to determine whether there has been a significant increase in the frequency and duration of heat waves statewide and at individual stations (Figure 1) over the 30-year period from 1994 to 2023. Furthermore, trends in the range between the daily high and low temperatures during heat waves were evaluated. The 30-year period (1994-2023) represents the minimum period required by the World Meteorological Organization to calculate the average climate and is known as a climate period (NOAA, 2021).

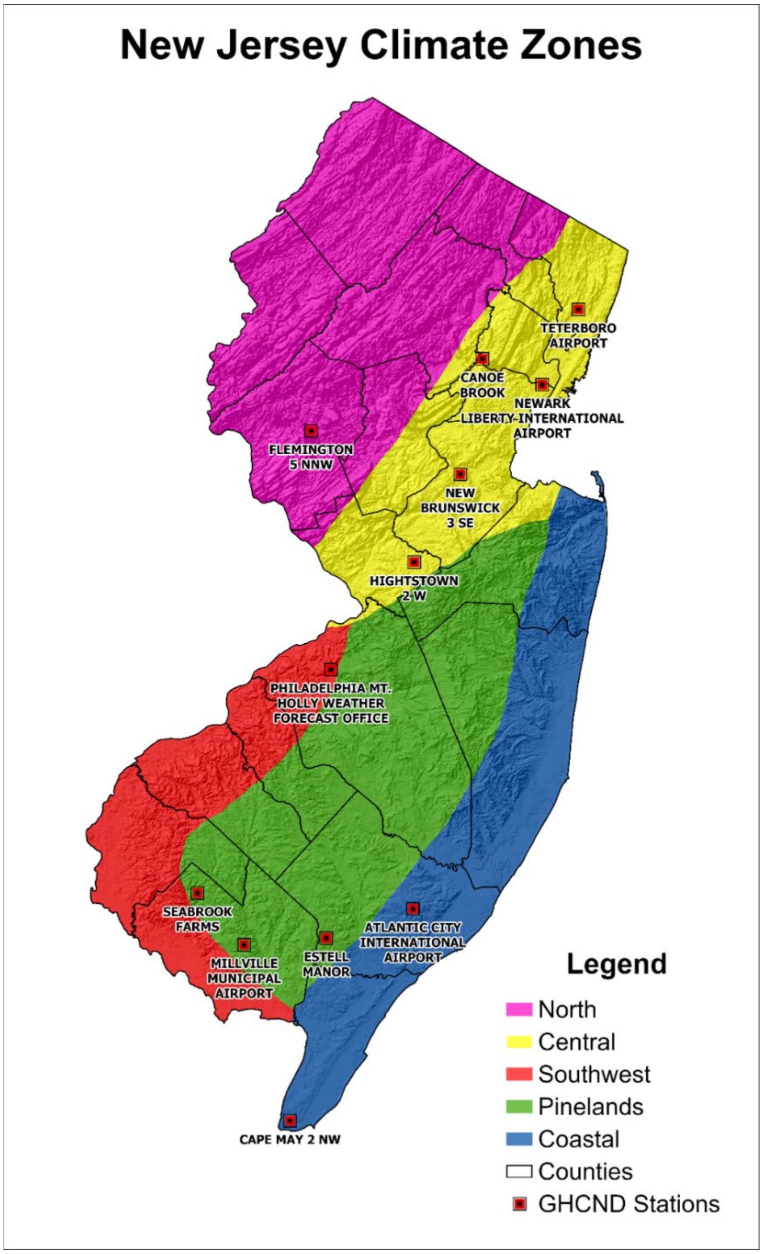

Figure 1. Global Historical Climatological Network Daily (GHCND) stations where data were analyzed for this study and the New Jersey Climate Zones for reference.

Methods

In this study, data were acquired from Global Historical Climatological Network Daily (GHCND) stations that were chosen for their consistency of location, completeness of record, and location to assure representation from the North (1 station), Central (5 stations), Southwest (1 station), Pine Barrens (3 stations), and Coastal (2 stations) New Jersey Climate Zones (Office of the NJ State Climatologist, 2024). For the purposes of this analysis, there are key distinctions among these zones. The Northern Zone is part of the Appalachian Uplands and is characterized by a continental climate with minimal Atlantic Ocean influence, whereas the Coastal Zone is influenced by both oceanic and continental climates and experiences milder temperature fluctuations. The Central Zone is heavily urbanized, causing a "heat island" effect with higher nighttime temperatures. At the same time, the Pine Barrens Zone's sandy soils lead to rapid temperature drops at night and a wide temperature range. The Southwest Zone is influenced by maritime conditions, resulting in higher average temperatures and high humidity (Ludlum, 1983). In this study, the selected Pine Barrens stations are located near the border with the Southwest Climate Zone. With these factors under consideration, 12 stations were selected (Figure 1). These stations and their associated data were pulled from the NOAA's National Centers for Environmental Information (NCEI), using the "select a location" data tool (NOAA, 2025.).

Initially, the data sets were downloaded from NCEI and filtered by dates with high temperatures of 90°F or greater. Then, periods of three consecutive dates or greater of these high temperatures were identified, as consistent with the definition of a heat wave (NOAA, 2018). Next, the five-year average heat wave length (i.e., the average number of days that heat waves lasted) was calculated for five-year increments from 1994 to 2023. Yearly average heat wave frequency (i.e., the average number of heat waves recorded in a year) was also calculated. Finally, the heat wave temperature range was calculated by determining the average high and average low temperatures of all the heat wave days each year and then taking the difference between these two values.

The three metrics, five-year average heat wave length, yearly average heat wave frequency, and heat wave temperature range, were plotted in °F over a 30-year period. Heat wave length was assessed in five-year intervals in order to include temporal variability where some stations may include zero or one heat wave in a given year. To assess whether the metrics changed over time, one-way Analysis of Variance (ANOVA) tests were performed on the five-year average heat wave length, whereas Kendall Tau tests were performed on the other two metrics to assess temporal trends.

All statistical analyses were performed in RStudio (version 2023.12.1). Statistical significance was assumed when *p*-values were less than or equal to 0.1. When a significant trend was detected with the Kendall Tau Test, a Theil-Sen line was plotted to display the change in the heat wave metrics from 1994 to 2023. The equation of the Theil-Sen line was utilized to estimate the change in metric over the 30-year period.

Results and Discussion

Five-Year Average Heat Wave Length

The five-year average heat wave length was calculated as the average number of days that heat waves lasted over five-year-long periods. Over the 30-year period from 1994 to 2023, there was not a statistically significant trend in five-year average heat wave length at the statewide level (Figure 2; one-way ANOVA; $p \geq 0.1$). Thus, no difference was found in the length of heat waves from 1994 to 2023. At the station level, there was no difference in the length of heat waves from 1994 to 2023 (Figure 3; Table 1; one-way ANOVA; all p-values ≥ 0.1) at all stations with the exception of Canoe Brook. For Canoe Brook, the mean heat wave length was higher in 2009-2013 than in other periods (one-way ANOVA; $p = 0.08$). During this 30-year period, heat waves averaged 4.3 days in length (see Table 2).

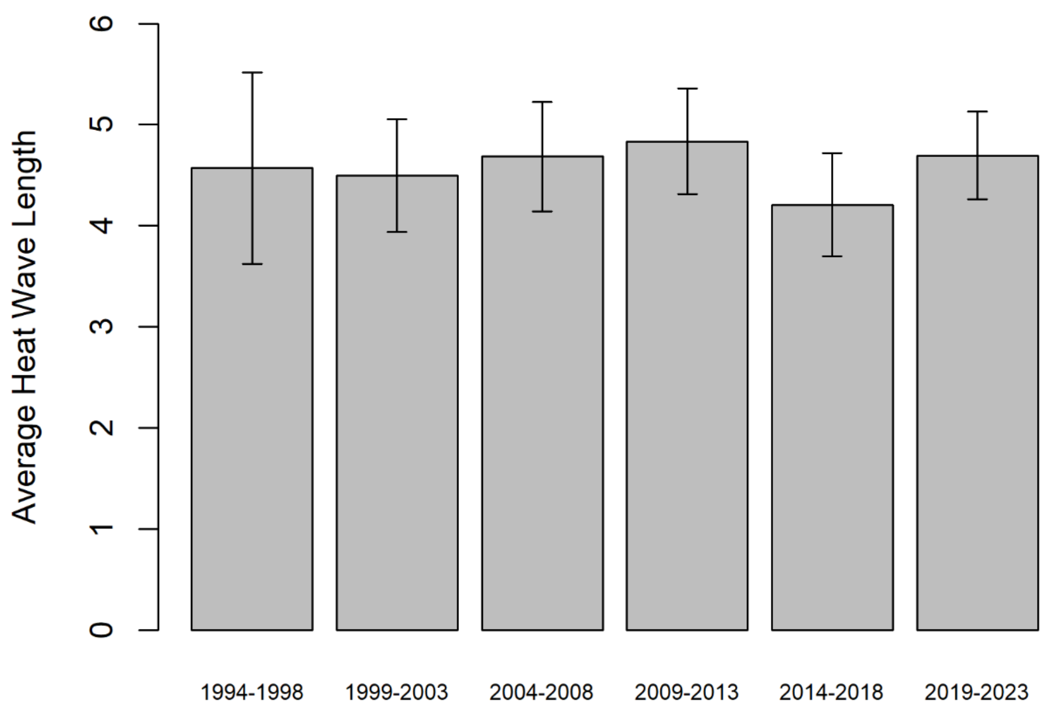

Figure 2. Five-year average heat wave length was calculated from 12 stations in New Jersey. A heat wave was defined as three or more days of high temperatures exceeding 90°F. The mean length of the heat waves (# days) was calculated during each five-year period. There was no significant change in average heat wave length over time (one-way ANOVA, all *p*-values ≥ 0.1). Error bars display ± 1 standard deviation.

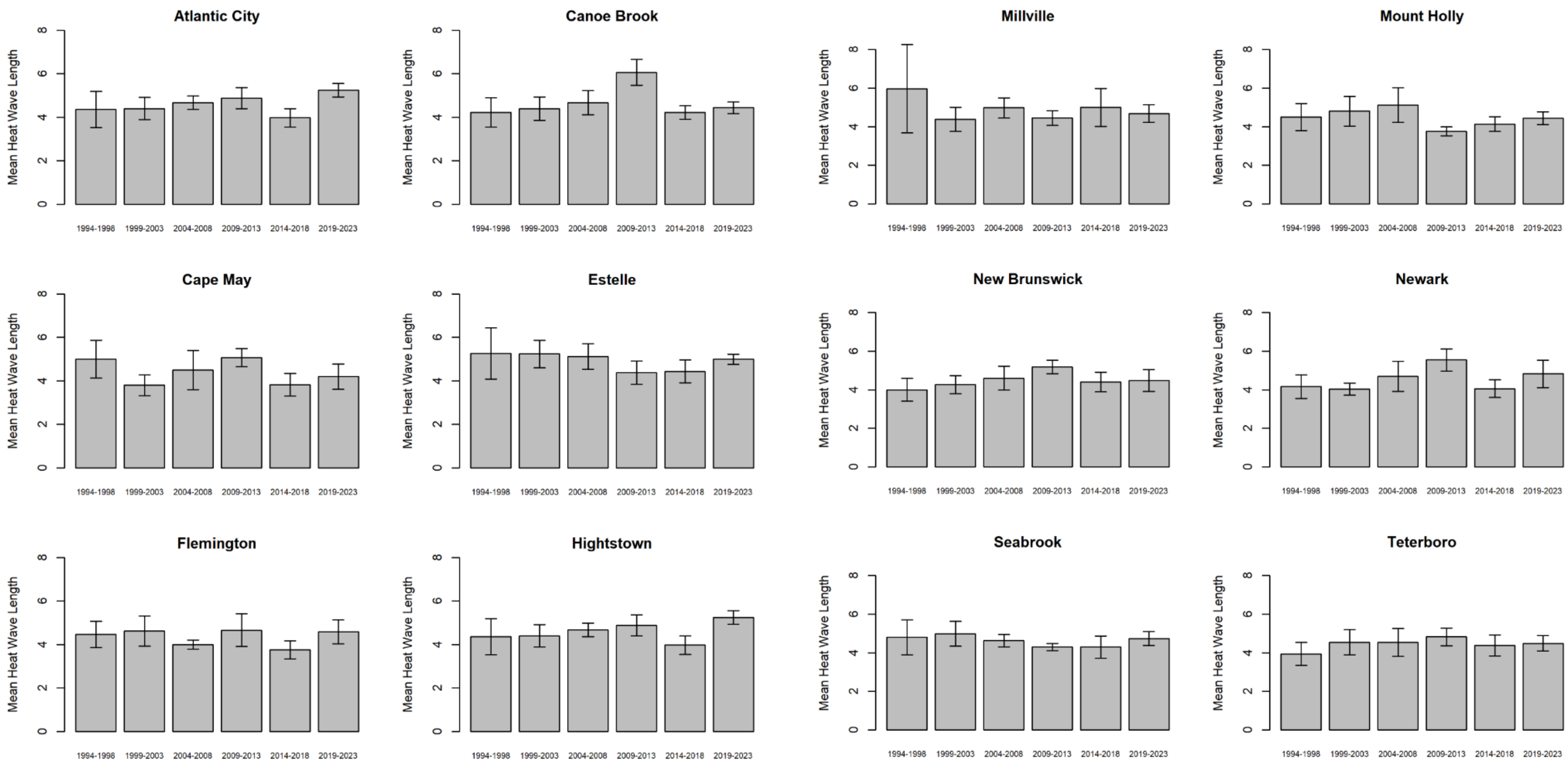

Figure 3. Five-year average heat wave length. A heat wave was defined as three or more days of high temperatures exceeding 90°F. During each five-year period, the mean length of the heat waves (days) was calculated to determine whether heat wave length changed over time. For Canoe Brook, the mean heat wave length was higher in 2009-2013 than in the other time periods (one-way ANOVA; $p = 0.08$). In the other locations, no significant change was detected in mean heat wave length from 1994 to 2023 (all p-values ≥ 0.1). Error bars show ± 1 standard deviation. See Table 1 for summary statistics.

Yearly Average Heat Wave Frequency

The yearly average heat wave frequency was calculated as the number of heat waves recorded in a year. At the statewide level, the yearly average heat wave frequency significantly increased from 1994 to 2023 (Figure 4; Kendall Tau Test; p-value = 0.03). In 1994, the average number of heat waves was 2.0, but this average increased to 4.1 by 2023 (Theil-Sen line). At the station level, there was a statistically significant increase in yearly average heat wave frequency at six of the 12 stations analyzed (Figure 5; Kendall Tau Test; p-values ≤ 0.1). The stations with significant increases in heat wave frequency included Canoe Brook, Hightstown, New Brunswick, and Teterboro Airport in the Central climate zone, and Atlantic City and Cape May in the Coastal climate region. These increases are consistent with the significant national and international increases in heat wave frequency since the 1950s (Perkins-Kirkpatrick & Lewis, 2020).

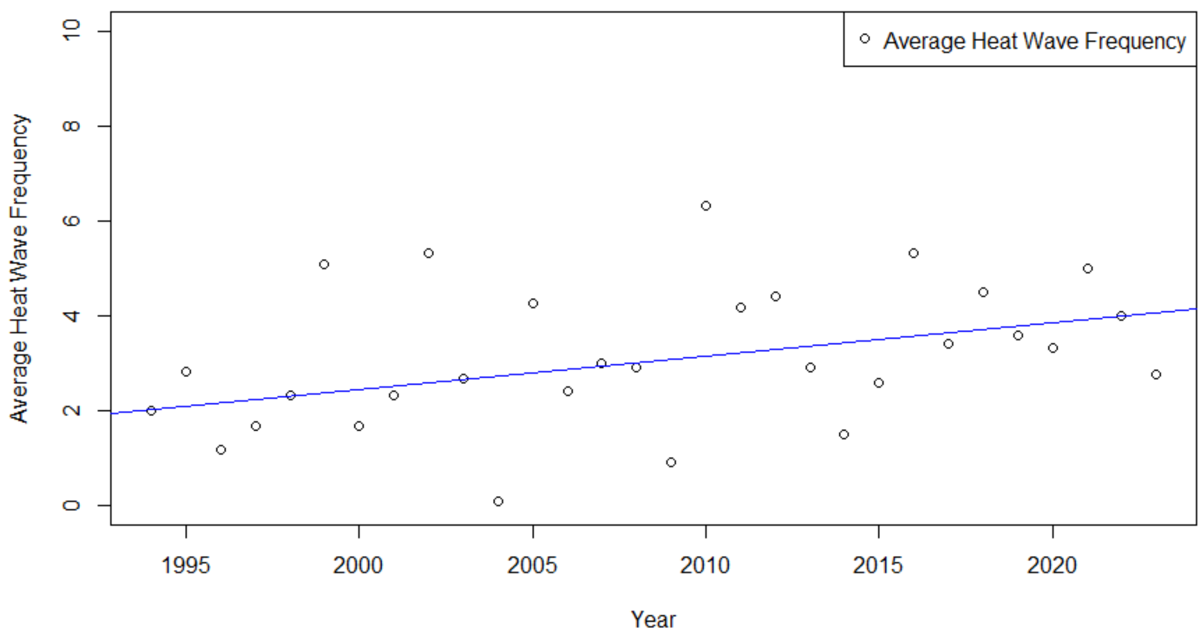

Figure 4. Statewide yearly average heat wave frequency calculated from 12 stations in New Jersey. The average number of heat waves increased from 2.0 in 1994 to 4.1 in 2023 (Kendall Tau; tau = 0.28; *p* = 0.03).

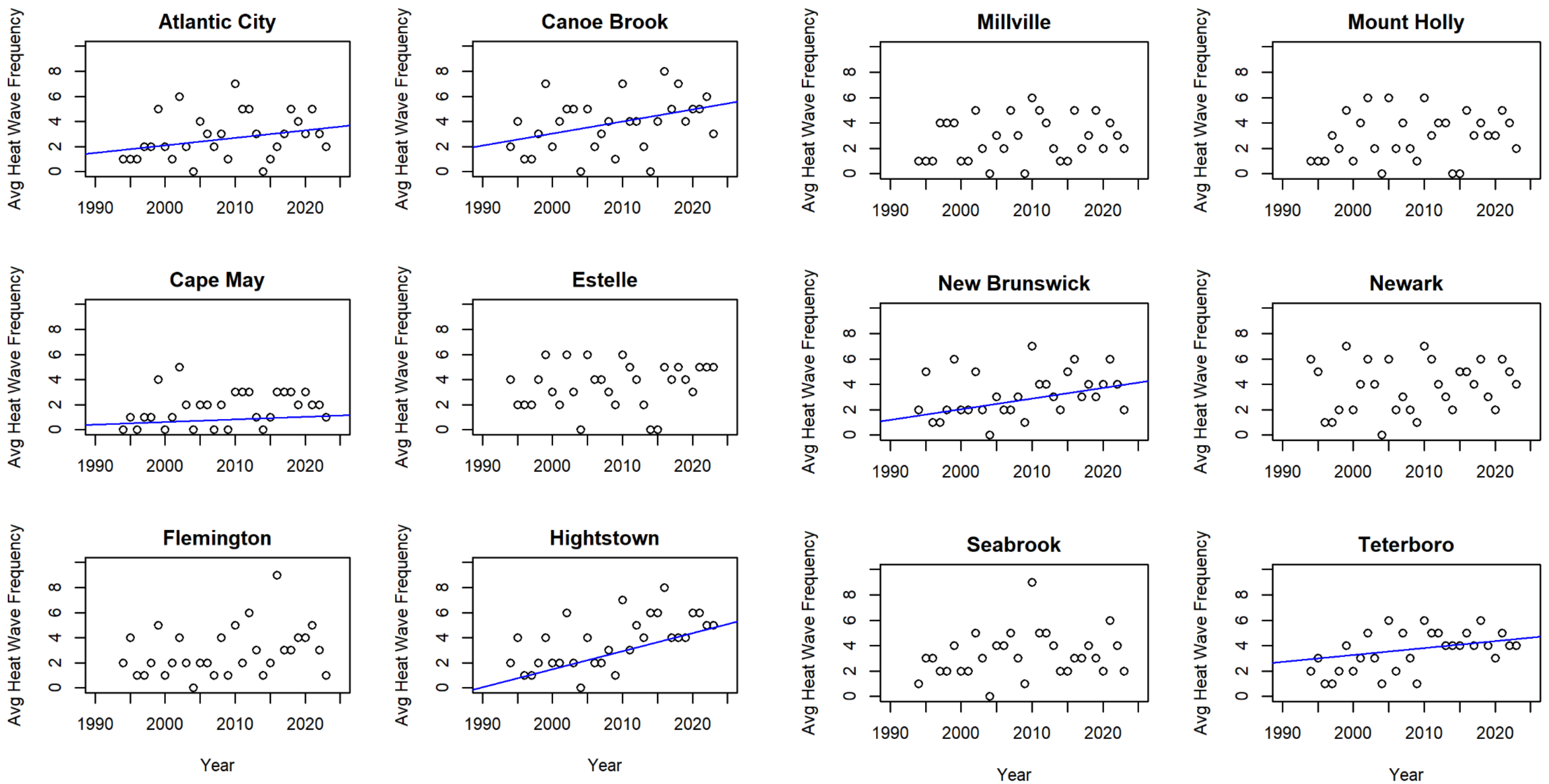

Figure 5. Yearly average heat wave frequency in New Jersey. The yearly average heat wave frequency was calculated by counting all groupings of three or more days of 90°F or greater recorded in a year. A Theil-Sen line is displayed when a significant trend was detected via a Kendall Tau Test (p-value ≤ 0.1, see Table 3 for statistical results) and is designated by the blue trend line.

Yearly Average Heat Wave Temperature Range

The yearly average heat wave temperature range metric was calculated by subtracting the average high and average low temperatures of all the days in a year included in a heat wave. A decrease in the range between high and low temperatures during a heat wave suggests there is less cooling overnight and thus less relief from the daytime heat. Yearly average heat wave temperature range has seen a statistically significant decrease from 1994 to 2023 at the statewide level (Figure 6; Kendall Tau Test; p-value = 0.01). The average heat wave temperature range decreased from 24.8°F in 1994 to 21.7°F in 2023. More noticeable still is a decrease in the yearly average heat wave temperature range at the station level. At seven of the 12 stations, there was a statistically significant decrease in the temperature range (Figure 7; p-values ≤ 0.1). A decrease is especially pronounced at five stations in the Southwest, Pinelands, and Coastal regions, where four of the top five minimal station-specific temperature ranges occurred. Considerable changes were noted at Estelle Manor and Atlantic City Airport (see Table 3). This metric was calculated to consider the daily temperature range, rather than only the high temperatures, as warming low temperatures allow for less recovery from the extreme heat. The results may point to a measured confirmation of the observed warming trend of summer low temperatures in a warmer climate (Climate Central, 2023).

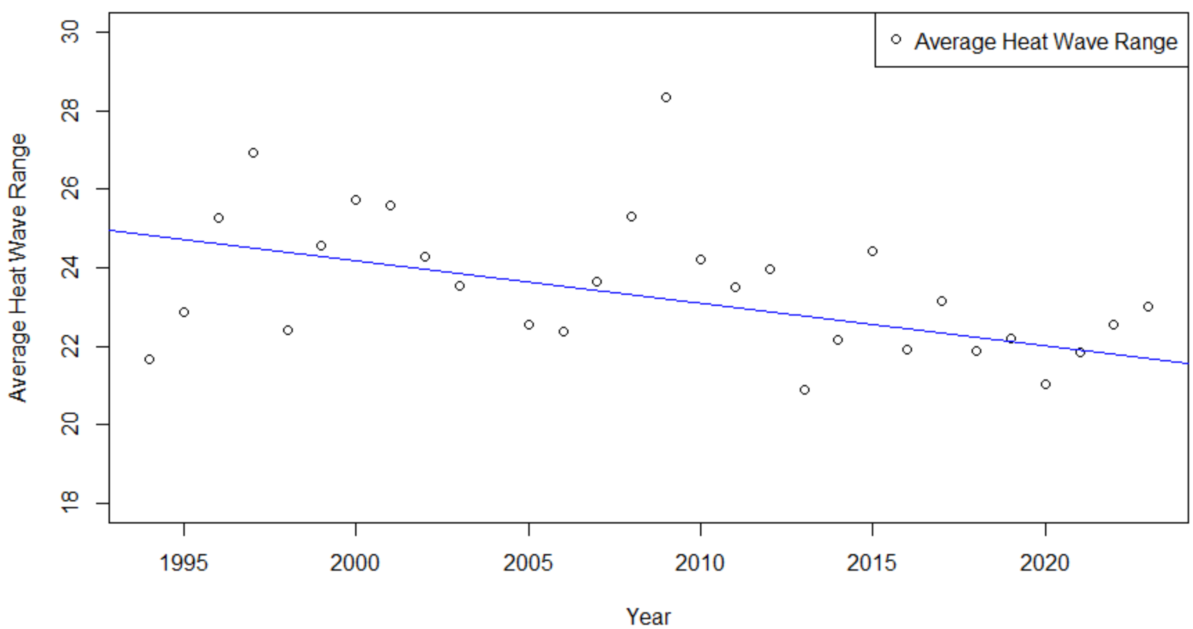

Figure 6. Statewide yearly average heat wave temperature range (°F) calculated from 12 stations in New Jersey. The average heat wave range decreased from 24.8°F in 1994 to 21.7°F in 2023 (Kendall tau test; tau = -0.32; *p* = 0.01).

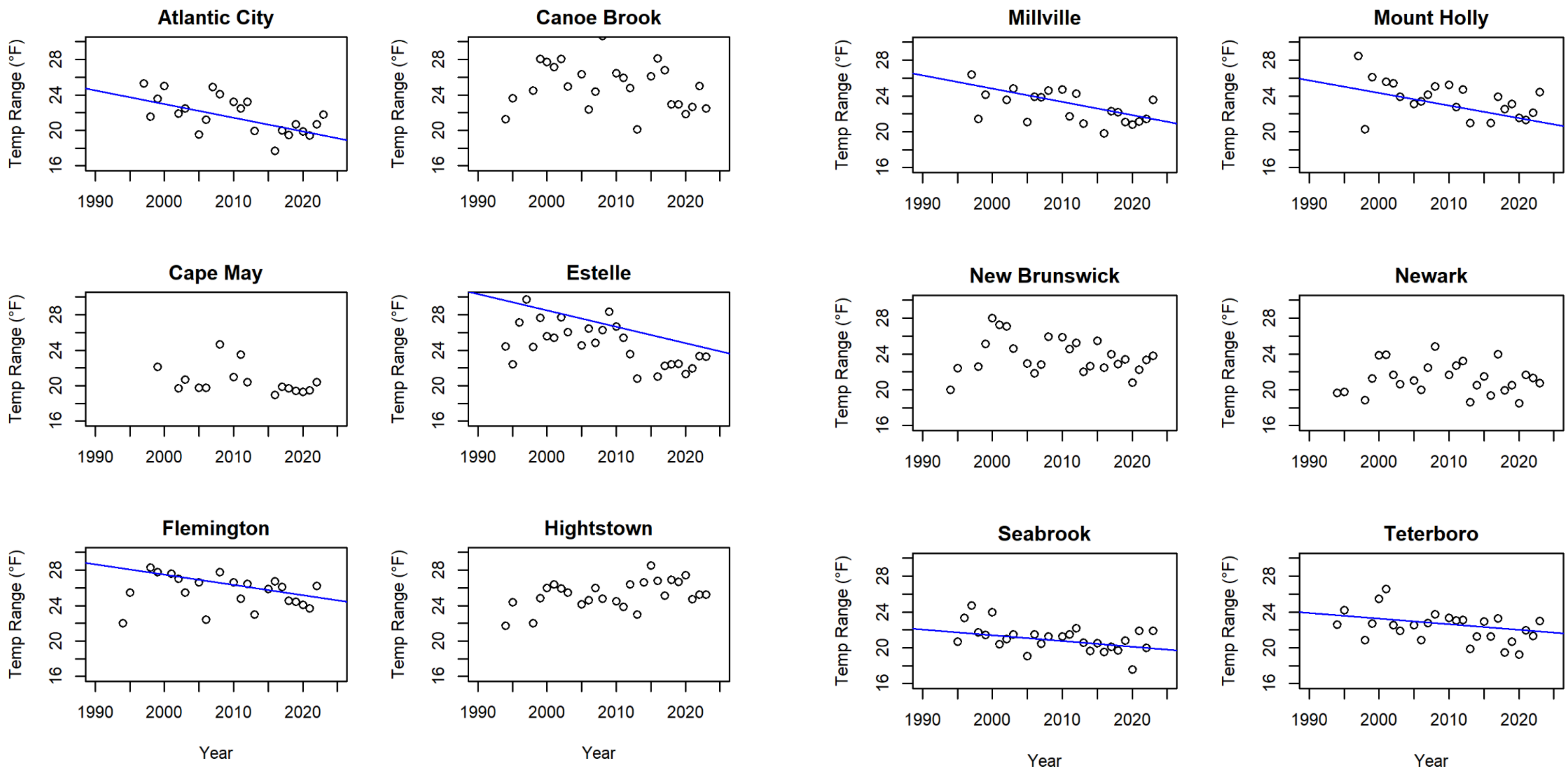

Figure 7. Yearly average temperature range (°F) in New Jersey. The average range of temperatures in heat wave days by year was calculated by finding the average high and average low temperatures in a given year and then taking the difference between these two figures. A Theil-Sen line is displayed when a significant trend was detected via a Kendall Tau Test (p-value ≤0.1, see Table 3 for statistical results).

Conclusions and Future Research

The purpose of this study was to analyze the recent heat wave trends in the state of New Jersey. Three measures were used to do this: heat wave length, heat wave frequency, and heat wave temperature range. Twelve stations were chosen for their completeness of record and location to get as even a distribution throughout the state as possible. From the results, it was found that heat wave frequency and heat wave temperature range have experienced significant changes (an increase and decrease, respectively). When the heat wave temperature range decreases, the difference between high and low temperatures is smaller which means that conditions stay warmer. Heat wave length did not experience a significant change over the 30-year period of the analysis. Therefore, there is a trend toward more heat waves in recent years and less daily cooling associated with each one.

Incorporation of another 30 years of heat wave data from these stations and additional stations, if data are available, could create a more balanced station distribution and extend the time series over two full climate periods. Further analyses could be scaled to look at individual heat wave events, giving higher or lower weight based on the duration of the event during the year. This would allow for the creation of a heat wave intensity score, which could be used in parallel to the frequency metric summarized in this report.

In addition, it may be useful to calculate heat index trends by incorporating dew points measured at each station. Dew point is the temperature at which air must be cooled in order to form condensation and can be used to determine humidity. According to the National Weather Service, the heat index (or apparent temperature) is how the air feels when temperature and humidity are combined (NOAA, 2023). Humidity is important as an exacerbating factor that when combined with surface temperature, is the most predictive of lethal heat conditions (NJDEP, 2022). While the NCEI dataset does not contain humidity, the heat index can be calculated via dew point temperature. Calculating and assessing this trend would complement the current analyses and provide more insight into the intensity of heat waves observed over the past several decades.

Table 1. This table contains all five-year statistics (averages and 1 standard deviation) for heat wave length (days) assessed at 12 stations in New Jersey. Heat wave length was averaged over a period of five years to include individual years at stations that contained zero or one heat wave. To assess whether the metrics changed over time, one-way ANOVAs were performed on the five-year average heat wave length.

Station	Year	Avg Heat Wave Length (days)	1 Standard Deviation
Atlantic City International Airport	1994-1998	4.4	1.7
Atlantic City International Airport	1999-2003	4.4	1.0
Atlantic City International Airport	2004-2008	4.7	0.6
Atlantic City International Airport	2009-2013	4.9	1.0
Atlantic City International Airport	2014-2018	4.0	0.9
Atlantic City International Airport	2019-2023	5.2	0.6
Canoe Brook	1994-1998	4.2	1.3
Canoe Brook	1999-2003	4.4	1.1
Canoe Brook	2004-2008	4.7	1.1
Canoe Brook	2009-2013	6.1	1.2
Canoe Brook	2014-2018	4.2	0.6
Canoe Brook	2019-2023	4.4	0.5
Cape May 2 NW	1994-1998	5.0	1.7
Cape May 2 NW	1999-2003	3.8	0.9
Cape May 2 NW	2004-2008	4.5	1.8
Cape May 2 NW	2009-2013	5.1	0.8
Cape May 2 NW	2014-2018	3.8	1.0
Cape May 2 NW	2019-2023	4.2	1.2
Estelle Manor	1994-1998	5.3	2.4
Estelle Manor	1999-2003	5.2	1.3
Estelle Manor	2004-2008	5.1	1.2
Estelle Manor	2009-2013	4.4	1.1
Estelle Manor	2014-2018	4.4	1.1
Estelle Manor	2019-2023	5.0	0.5
Flemington 5 NNW	1994-1998	4.5	1.2
Flemington 5 NNW	1999-2003	4.6	1.4
Flemington 5 NNW	2004-2008	4.0	0.4
Flemington 5 NNW	2009-2013	4.7	1.5
Flemington 5 NNW	2014-2018	3.8	0.8
Flemington 5 NNW	2019-2023	4.6	1.1
Hightstown 2 W	1994-1998	4.4	1.7
Hightstown 2 W	1999-2003	4.4	1.0
Hightstown 2 W	2004-2008	4.7	0.6
Hightstown 2 W	2009-2013	4.9	1.0

Station	Year	Avg Heat Wave Length (days)	1 Standard Deviation
Hightstown 2 W	2014-2018	4.0	0.9
Hightstown 2 W	2019-2023	5.2	0.6
Millville Municipal Airport	1994-1998	6.0	4.6
Millville Municipal Airport	1999-2003	4.4	1.3
Millville Municipal Airport	2004-2008	5.0	1.0
Millville Municipal Airport	2009-2013	4.5	0.8
Millville Municipal Airport	2014-2018	5.0	2.0
Millville Municipal Airport	2019-2023	4.7	0.9
Philadelphia Mt. Holly Weather Forecast Office	1994-1998	4.5	1.4
Philadelphia Mt. Holly Weather Forecast Office	1999-2003	4.8	1.6
Philadelphia Mt. Holly Weather Forecast Office	2004-2008	5.1	1.8
Philadelphia Mt. Holly Weather Forecast Office	2009-2013	3.8	0.5
Philadelphia Mt. Holly Weather Forecast Office	2014-2018	4.1	0.8
Philadelphia Mt. Holly Weather Forecast Office	2019-2023	4.4	0.7
New Brunswick 3 SE	1994-1998	4.0	1.2
New Brunswick 3 SE	1999-2003	4.3	0.9
New Brunswick 3 SE	2004-2008	4.6	1.2
New Brunswick 3 SE	2009-2013	5.2	0.7
New Brunswick 3 SE	2014-2018	4.4	1.0
New Brunswick 3 SE	2019-2023	4.5	1.1
Newark International Airport	1994-1998	4.2	1.2
Newark International Airport	1999-2003	4.0	0.6
Newark International Airport	2004-2008	4.7	1.6
Newark International Airport	2009-2013	5.5	1.2
Newark International Airport	2014-2018	4.1	0.9
Newark International Airport	2019-2023	4.8	1.4
Seabrook Farms	1994-1998	4.8	1.8
Seabrook Farms	1999-2003	5.0	1.3
Seabrook Farms	2004-2008	4.6	0.6
Seabrook Farms	2009-2013	4.3	0.4
Seabrook Farms	2014-2018	4.3	1.2
Seabrook Farms	2019-2023	4.7	0.7
Teterboro Airport	1994-1998	3.9	1.2
Teterboro Airport	1999-2003	4.5	1.3
Teterboro Airport	2004-2008	4.5	1.4
Teterboro Airport	2009-2013	4.8	0.9
Teterboro Airport	2014-2018	4.4	1.1
Teterboro Airport	2019-2023	4.5	0.8

Table 2. This table shows the average heat wave length and 1 standard deviation for the entire period (1994-2023) for all 12 stations used in this study. The statewide average and standard deviation can be found at the bottom of the table.

Station	County	Region	Average Heat Wave Length (days)	1 Standard Deviation
Atlantic City International Airport	Atlantic	Coastal	4.5	2.3
Canoe Brook	Essex	Central	4.4	1.6
Cape May 2 NW	Cape May	Coastal	3.3	2.1
Estelle Manor	Atlantic	Pinelands	4.4	1.9
Flemington 5 NNW	Hunterdon	North	4.2	1.3
Hightstown 2 W	Mercer	Central	4.4	1.3
Millville Municipal Airport	Cumberland	Pinelands	4.6	2.4
Philadelphia Mt. Holly Weather Forecast Office	Burlington	Southwest	4.0	1.8
New Brunswick 3 SE	Middlesex	Central	4.3	1.3
Newark International Airport	Union	Central	4.4	1.4
Seabrook Farms	Cumberland	Pinelands	4.5	1.3
Teterboro Airport	Bergen	Central	4.5	1.1
--	--	Statewide	4.3	0.3

Table 3. This table contains summary statistics for the heat wave metrics assessed at 12 stations in New Jersey. Kendall's Tau was calculated for heat wave frequency and heat wave range in order to determine if there was a significant trend. A Theil-Sen line was used to determine the change in median from the beginning of the study period (1994) to the end (2023) for stations with a significant trend. Analyses without a significant trend at $p < 0.1$ are marked as NS (not significant) and Tau as -.

			Heat Wave Frequency (Heat Waves/Year)				Heat Wave Temperature Range (°F)			
Station	**County**	**Region**	**Number of Heat Waves per Year Over 30 yr Period (1994-2023) ± 1 SD**	**Change in Median Number of Heat Waves from Beginning to End of 30 yr Period (1994 to 2023)**	**Tau**	***p***	**30 yr Avg ± 1 SD**	**Change in Median Temperature Range from Beginning to End of 30 yr period (1994 to 2023)**	**Tau**	***p***
Atlantic City International Airport	Atlantic	Coastal	2.8 ± 1.8	1.7 to 3.5	0.23	0.087	21.7 ± 2.1	23.4 to 19.4	-0.41	0.007
Canoe Brook	Essex	Central	3.8 ± 2.1	2.5 to 5.2	0.26	0.057	25.0 ± 2.6	-	-	NS
Cape May 2 NW	Cape May	Coastal	1.7 ± 1.3	0.5 to 1.1	0.24	0.081	20.6 ± 1.6	-	-	NS
Estelle Manor	Atlantic	Pinelands	3.5 ± 1.8	-	-	NS	24.7 ± 2.4	29.6 to 24.3	-0.37	0.007
Flemington 5 NNW	Hunterdon	North	2.8 ± 1.9	-	-	NS	25.6 ± 1.8	28.2 to 24.9	-0.29	0.063
Hightstown 2 W	Mercer	Central	3.7 ± 2.0	0.6 to 4.8	0.46	0.001	25.3 ± 1.6	-	-	NS
Millville Municipal Airport	Cumberland	Pinelands	2.7 ± 1.7	-	-	NS	22.8 ± 1.8	25.3 to 21.5	-0.34	0.030
Philadelphia Mt. Holly Weather Forecast Office	Burlington	Southwest	2.9 ± 1.8	-	-	NS	23.6 ± 2.0	24.7 to 21.1	-0.39	0.010
New Brunswick 3 SE	Middlesex	Central	3.2 ± 1.8	1.5 to 4.0	0.28	0.041	23.8 ± 2.0	-	-	NS
Newark International Airport	Union	Central	3.8 ± 2.0	-	-	NS	21.2 ± 1.7	-	-	NS
Seabrook Farms	Cumberland	Pinelands	3.3 ± 1.8	-	-	NS	21.1 ± 1.5	21.7 to 19.9	-0.28	0.039
Teterboro Airport	Bergen	Central	3.6 ± 1.6	3.0 to 4.5	0.34	0.013	22.3 ± 1.7	23.6 to 21.8	-0.23	0.094

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