ACTUARIES CLIMATE INDEX

SAMPLE CALCULATIONS

ACTUARIES CLIMATE INDEX
INDICE ACTUARIEL CLIMATIQUE

AMERICAN ACADEMY *of* ACTUARIES
Objective. Independent. Effective.™

Canadian Institute of Actuaries
Institut canadien des actuaires

CAS

SOCIETY OF ACTUARIES

Contents

Actuaries Climate Index

Sample Calculations

The purpose of this document is to present sample calculations for each component of the Actuaries Climate Index (ACI) at a particular geographic location. The sample calculations illustrate the magnitudes of the values by component and the implications of some of the intermediate calculations underlying the index.

The **Methodology** behind the ACI is detailed in the document *Actuaries Climate Index—Development and Design*. The Actuaries Climate Index has six components (presented in order of formula complexity):

DROUGHT	$MaxCDD_{std}(j,k)$	Maximum consecutive dry days (<1 mm) in year
SEA LEVEL	$S_{std}(j,k)$	Sea level
PRECIPITATION	$MaxP^{(5\text{-}day)}_{std}(j,k)$	Maximum five-day precipitation in month
WARM TEMPERATURES	$F\ T{:}warm_{std}(j,k)$	Frequency of temperatures above the 90th percentile
COOL TEMPERATURES	$F\ T{:}cool_{std}(j,k)$	Frequency of temperatures below the 10th percentile
WIND POWER	$F\ WP_{std}(j,k)$	Frequency of strongest wind power

where "j" indicates the month and "k" indicates the year.

The index calculations for each component measure the change relative to the 30-year reference period, 1961–1990, in a standardized format. The length of the reference period has been selected as the span of conditions that commonly defines climate. For each component, the standardized anomaly is calculated as the difference between the current period and the reference period, and then scaled by the division of its reference period standard deviation. An algebraic way to write this is: $(X-\mu)/\sigma$. The main reason we choose to express each component as a standardized anomaly is to combine figures of widely disparate phenomena—in terms of their units of measurement and variability among locations—on a compatible basis. Variations are counted by standard deviations from a centralized mean as the unit for all the components that comprise the Actuaries Climate Index—namely temperatures, sea level, wind power, drought, and precipitation. The index is defined by the average of the standardized components, such that it measures an average departure from the mean in terms of the number of standard deviations.

The Actuaries Climate Index is calculated on a monthly basis, as well as on a seasonal basis, following similar methodologies. Note that the seasonal indices are determined by simply taking averages of the unscaled monthly regional values and applying the same standardization methodology as mentioned in the prior paragraph. The seasonal ACI uses meteorological seasons, which are by full calendar months, rather than astronomical seasons, which are based on the dates of the solstices and equinoxes. For example, winter comprises the calendar months of December, January, and February. To simplify this document, the sample calculations focus on the monthly series only. A key metric, the five-year moving average, is also presented because it helps visualize trends.

The index is computed using a gridded dataset, aggregated for regions within Canada and the United States. Each grid measures a surface area 2.5 degrees latitude by 2.5 degrees longitude. At the equator, a grid covers an area of approximately 275 km by 275 km; at 50 degrees latitude, about the middle latitude of Canada and the United States, a grid covers an area of 275 km latitude by 180 km longitude. Values for each grid are based on the average of the weather or tide stations within the grid.[1] The sample calculations that follow detail the calculation as if a region contained only a single grid or a single location within a grid.

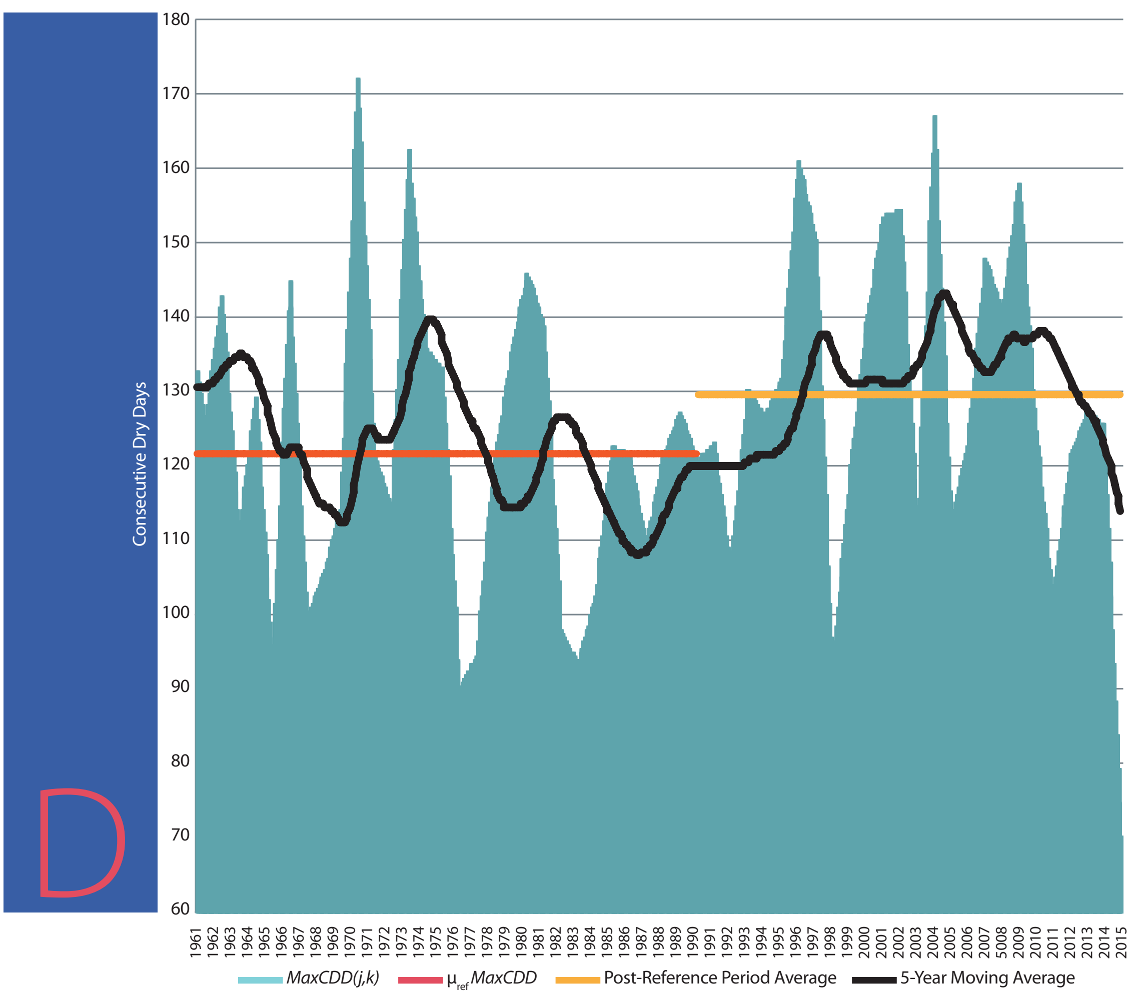
1 The process for calculating regional indices varies slightly by component. For other than sea level, the component values for stations within each grid are averaged together to obtain grid cell means. Then the grid cell means for the grids in each region are averaged together using grid size as weights. (Grid size is proportional to the cosine of the latitude of the center point of the grid, and these cosines are used as weights). Reference period standard deviations are then calculated at the region level from the mean regional observations, and the index is calculated from the anomalies of the monthly or seasonal means (vs. the reference period mean) and the reference period standard deviations. Following this procedure, we do not presently calculate index values at the grid level, though we are considering that as a future enhancement. For sea level, the stations within each region are all averaged together to get the regional means. Standard deviations and index values are then calculated at the regional level as for the other components.

1. Drought

The following figures represent a sample grid ACI calculation for the drought component, centered near Barstow, West San Bernardino County in south central California (located at 35 degrees north latitude and 117.5 degrees west longitude). Drought is measured by the maximum number of consecutive dry days in each year k, *MaxCDD(k)*, where a dry day is counted when precipitation is less than 1 millimeter. Monthly values are obtained for each month j, year k, by linear interpolation, where *MaxCDD(12,k) = MaxCDD(k)*. For other values of j, *MaxCDD(j,k)* = (12-j)/12 * *MaxCDD(12,k-1)* + j/12 * *MaxCDD(12,k)*. Anomalies are measured by the departure in a month's maximum consecutive dry days from the average across the monthly reference period values from 1961–1990.

Figure 1.1. Maximum Consecutive Dry Days

Barstow, West San Bernadino County, South Central California



The maximum number of consecutive dry days in each month j, year k, *MaxCDD(j,k)*, is shown in Figure 1.1 for the years 1961–2015; also shown is the average for the reference period 1961–1990, μ_{ref} *MaxCDD(j)*, as well as the average for the post-reference period 1991–2015, and a five-year moving average in black.

Next shown is CDD anomaly, Δ*MaxCDD(j,k)*, which is the difference between *MaxCDD(j,k)* and the average for the reference period 1961–1990, μ_{ref} *MaxCDD*. Adjusting the *MaxCCD(j,k)* data by the reference period mean μ_{ref} *MaxCDD* results in an average reference period anomaly of zero. The calculation is given by:

$$\Delta\, MaxCDD(j,k) \quad = \quad MaxCDD(j,k) - \mu_{ref}\, MaxCDD$$

Also shown is the five-year moving average of Δ*MaxCDD(j,k)*.

Figure 1.2. Consecutive Dry Days Anomaly

Barstow, West San Bernadino County, South Central California

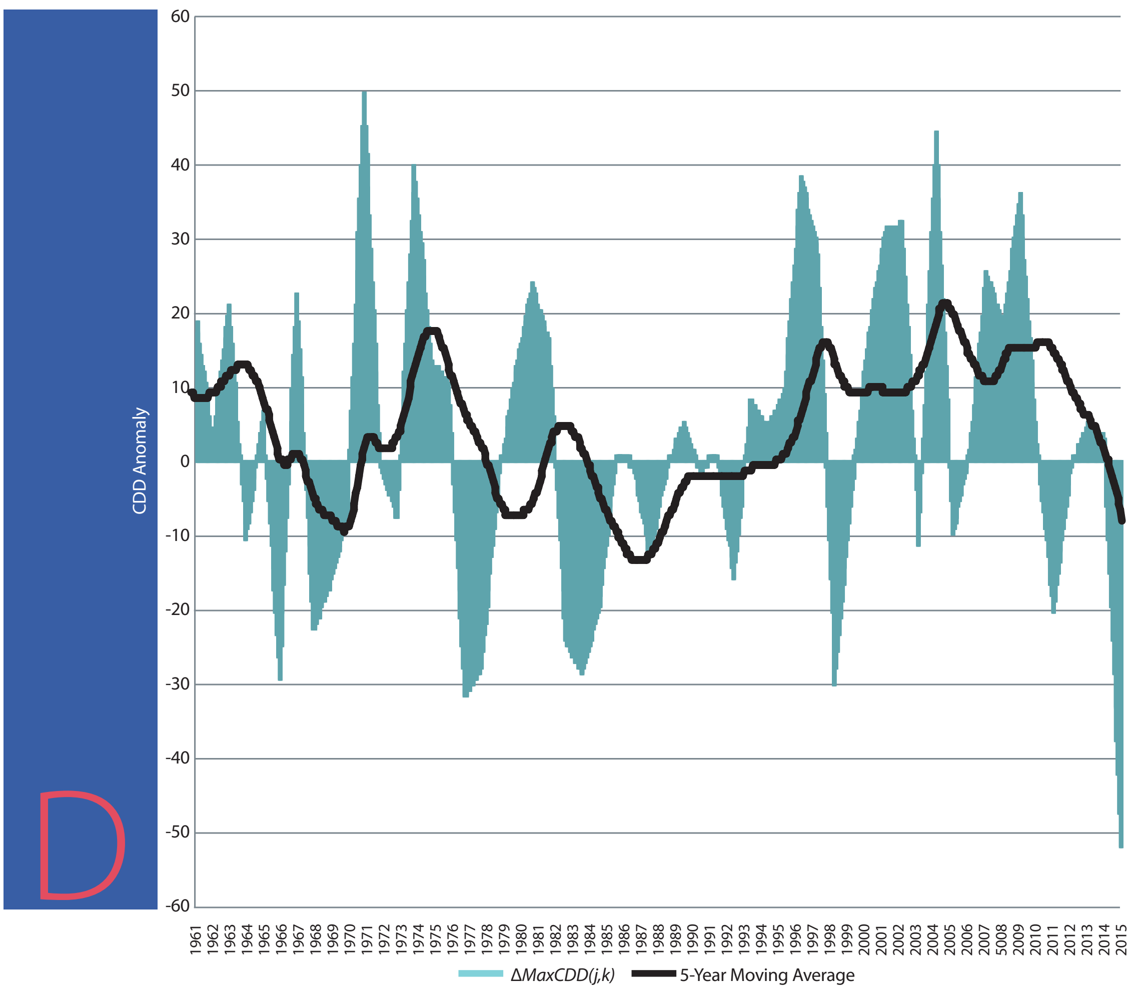


Figure 1.3. Standardized Consecutive Dry Days Anomaly

Barstow, West San Bernadino County, South Central California

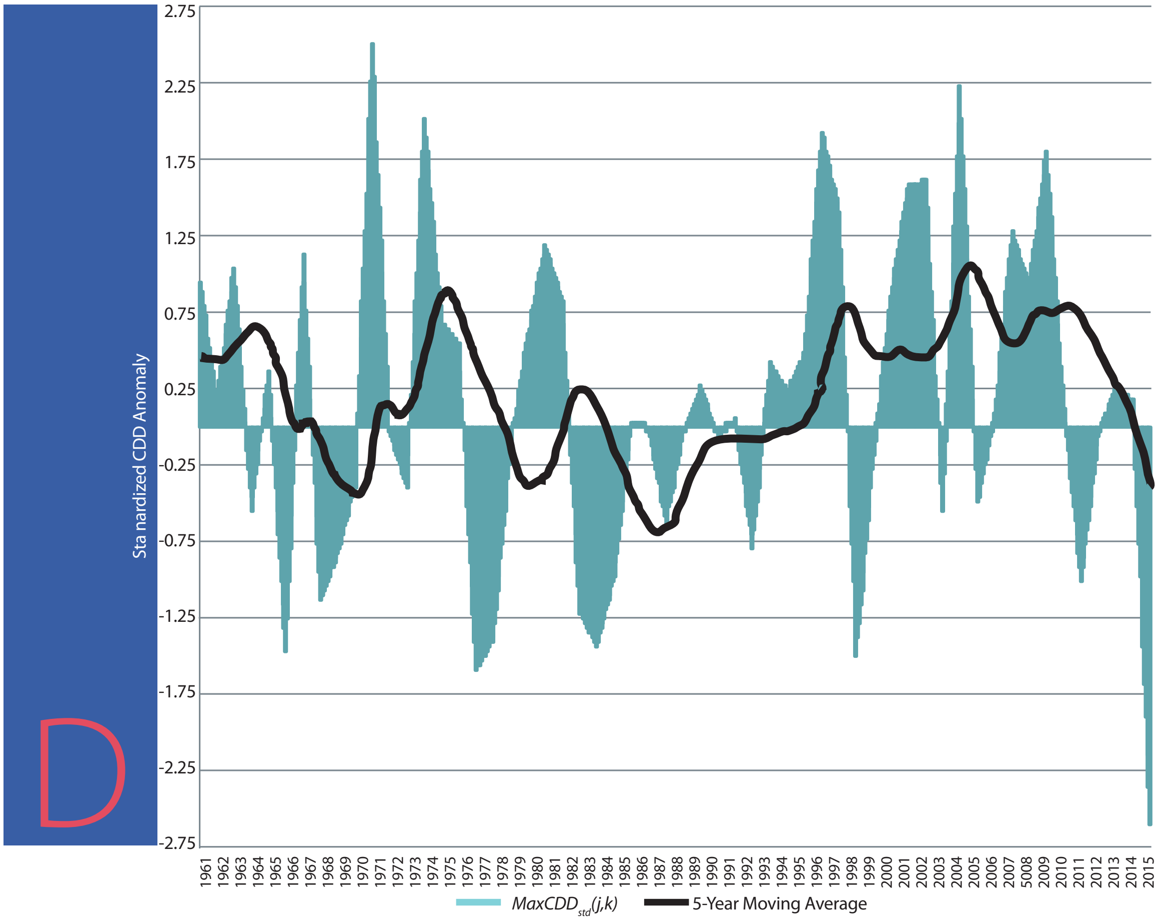


Figure 1.3 shows the standardized CDD anomaly, which is the CDD anomaly, $\Delta MaxCDD(j,k)$, divided by the standard deviation for the reference period, σ_{ref} *MaxCDD*.

The calculations are notated as follows:

$$MaxCDD_{std}(j,k) = [MaxCDD(j,k) - \mu_{ref} MaxCDD] / \sigma_{ref} MaxCDD$$

The standardized anomalies as well as the five-year moving averages displayed in the figures above show the impact of the California drought frequently discussed in recent years. The increase in precipitation in 2015 has not been sufficient to alleviate concerns over the drought while new problems of mudslides and floods have arisen. Still, intense storms have been helpful in bringing reservoir levels up.

2. Sea Level

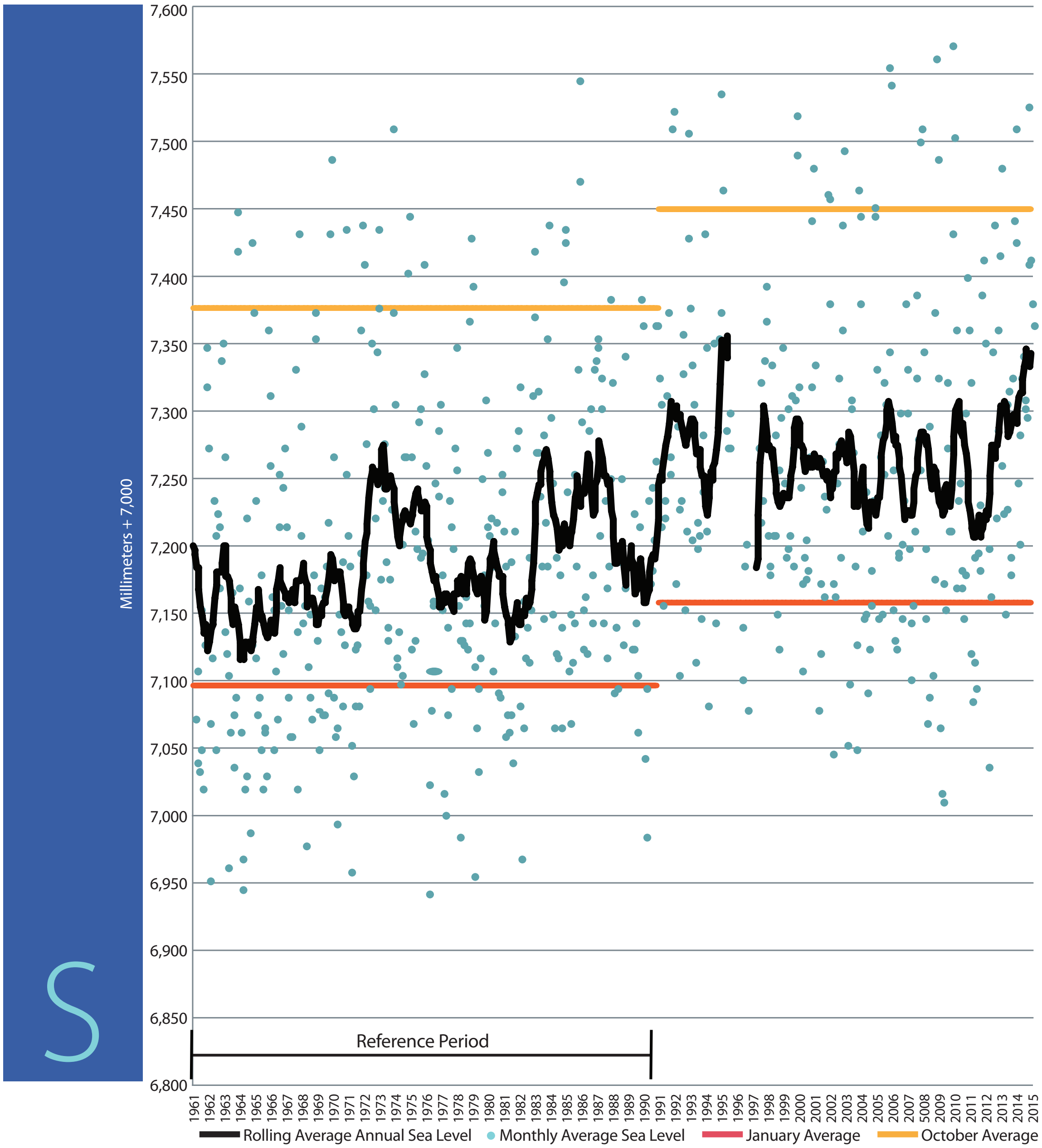
Sea level (*S*) measurements are available on a monthly average basis via tide gauges located at over 100 permanent coastal stations in Canada and the United States.[2] The monthly averages are based on hourly readings throughout the month. A quality control procedure eliminated many of these coastal stations on the basis of incomplete data (records starting after 1970, or more than a third of the monthly average values missing), leaving 76 stations with reliable time series for further analysis. Station 112 at Fernandina Beach, Florida, is an example location having adequate data and will be used to illustrate this component. Data for the ACI is compiled monthly. Twelve distinct sea level reference means, $\mu_{ref} S(j)$, and 12 standard deviations, $\sigma_{ref} S(j)$, are calculated from the reference period values of $S(j)$, (e.g., 30 values for January over 1961–1990), similar to what was done for the drought component.

The tide gauges measure sea level relative to the land below. This measurement includes the impact of land movement. Land mass itself may be rising or falling and affects sea level rise. Sea level is given in millimeters, with 7,000 mm added to avoid negative values. Figure 2.1 shows actual sea level data points as blue circles—12 values per year. The averages are shown for the months in which sea level is lowest and highest at this location, January and October, respectively. Seasonal changes in sea level occur with changes in water temperature and salinity, and vary with land movements, ocean currents, precipitation, evaporation, and the water's slow absorption and release of heat.

2 Permanent Service for Mean Sea Level, "Obtaining Tide Gauge Data," accessed Nov. 11, 2016.

Figure 2.1. Average Annual Sea Level

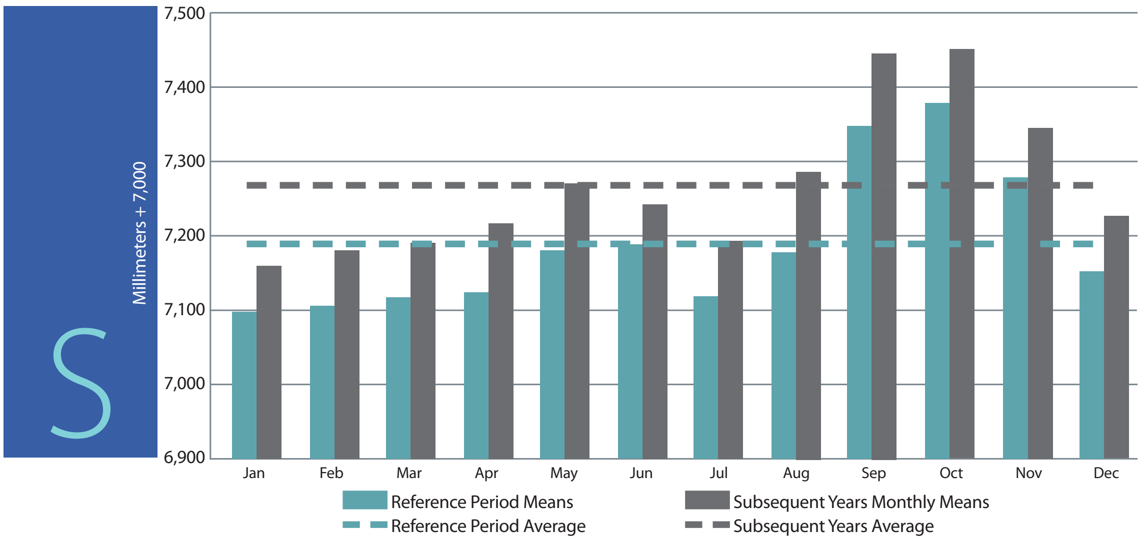
Fernandina Beach, Florida



The monthly sea level reference means, $\mu_{ref}\,S(i)$, and standard deviations, $\sigma_{ref}\,S(i)$, are shown in Figure 2.2. The graph shows the reference period means by month and overall compared to the subsequent years, which are higher in every month for this location.

Figure 2.2. Sea Level Monthly Means

Fernandina Beach, Florida



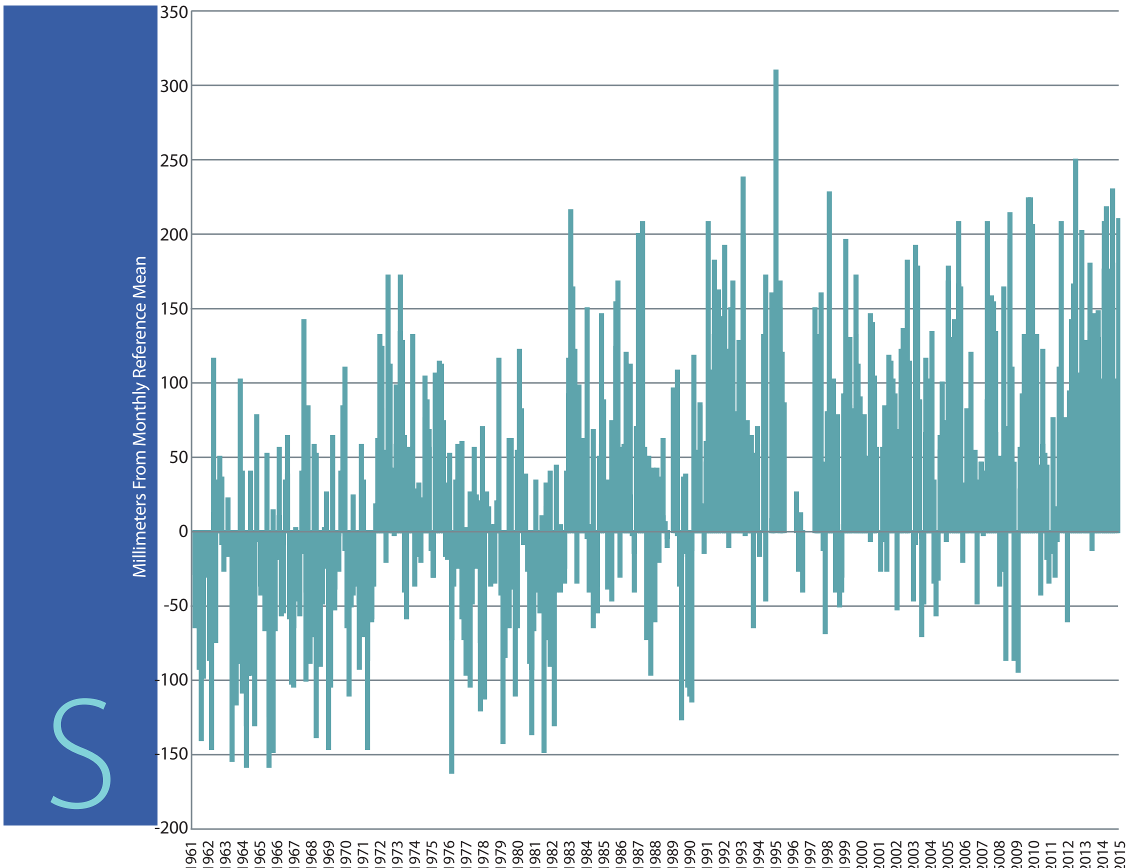
Month(j):	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$\mu_{ref} S(j)$	7097.4	7104.6	7115.0	7124.4	7179.5	7189.0	7119.0	7177.3	7346.1	7377.6	7277.4	7152.8
$\sigma_{ref} S(j)$	93.9	90.1	82.3	53.8	64.7	81.1	60.5	59.8	60.8	77.2	75.7	71.2

For $S(j,k)$, the sea level in month j and year k, the anomaly $\Delta S(j,k)$ is given by:

$$\Delta S(j,k) \quad = \quad S(j,k) - \mu_{ref} S(j) \qquad \text{for months j = Jan, Feb, Mar, …, Dec.}$$

Figure 2.3. Sea Level Monthly Anomalies

Fernandina Beach, Florida



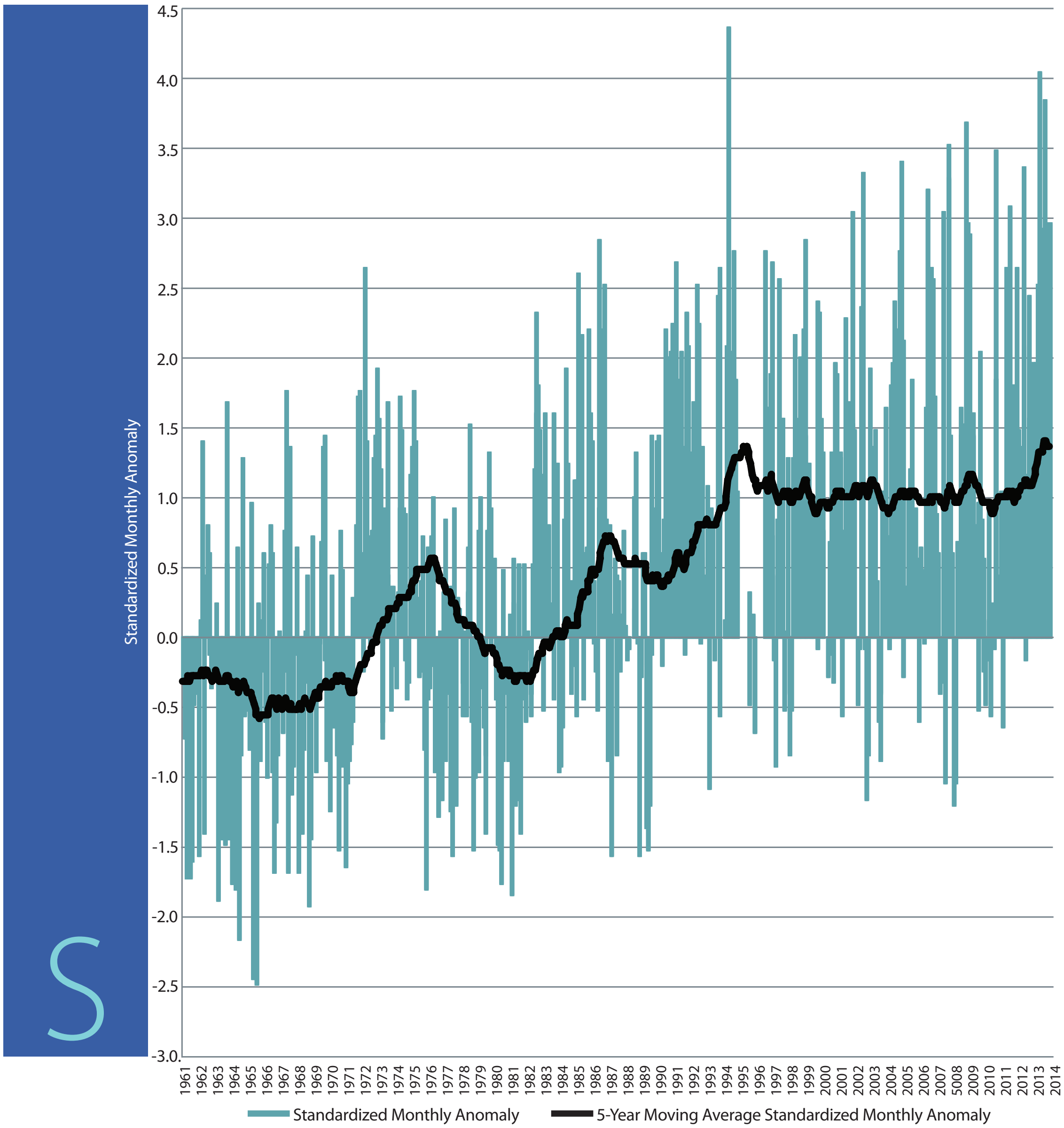
Sea level anomalies $\Delta S(j,k)$ are then standardized by the equation:

$$S_{std}(j,k) = [S(j,k) - \mu_{ref} S(j)] / \sigma_{ref} S(j)$$

$$= \Delta S(j,k) / \sigma_{ref} S(j)$$

Figure 2.4. Sea Level Monthly Standardized Anomalies

Fernandina Beach, Florida



3. Precipitation

The precipitation component focuses on extreme rather than average precipitation by using the maximum 5-day precipitation time series from GHCNDEX.[3] GHCNDEX provides gridded, station-based indices of temperature- and precipitation-related climate extremes.

The probability distribution function (PDF) of precipitation is not normal, but is instead right-skewed, because the left tail of the distribution must always be anchored at zero. The maximum five-day precipitation in a given month (in units of mm precipitation) was chosen to represent the changes to the right, high-value tail of the precipitation PDF. The left side of the PDF is addressed through a complementary ACI component focusing on meteorological drought.

The calculations for this component are almost the same as for sea level. The maximum consecutive five days of precipitation form the basis for the data, notated as $MaxP^{(5\text{-}day)}$.

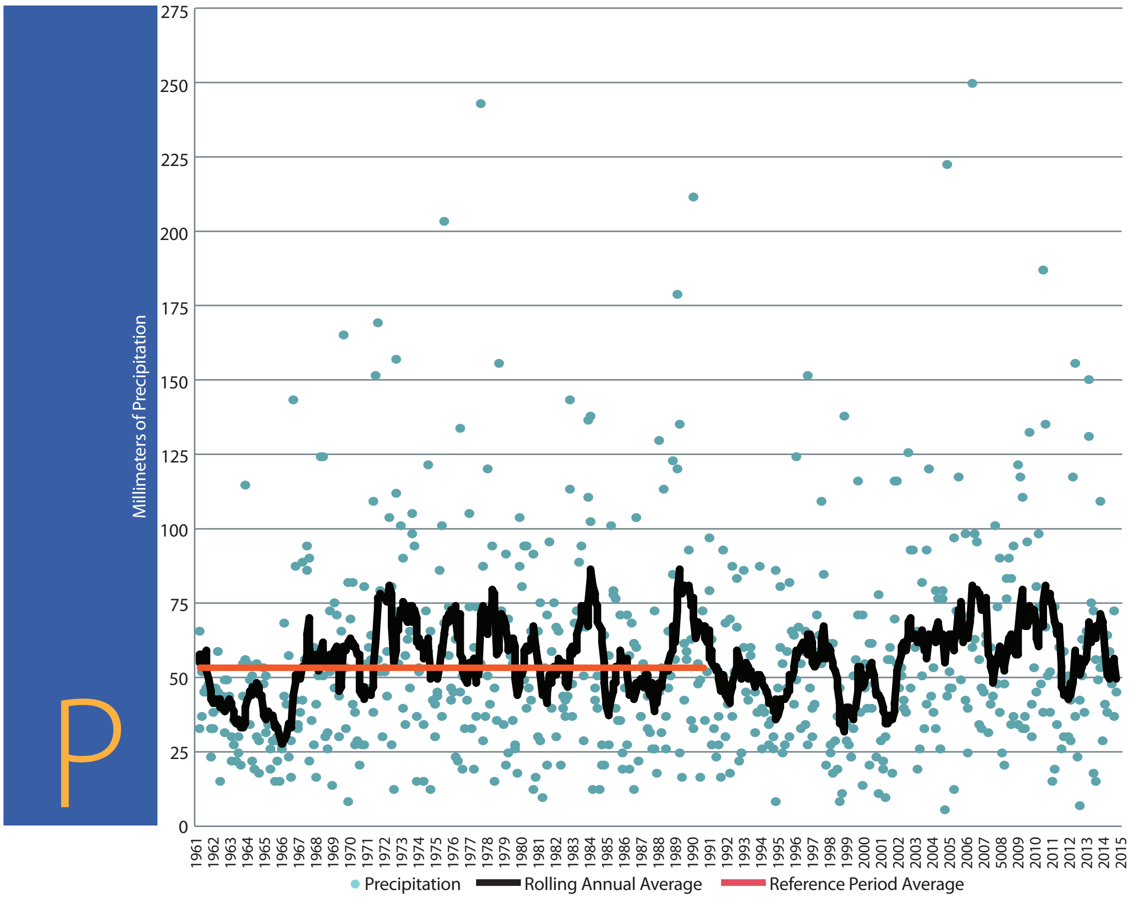
The station selected to illustrate the $MaxP^{(5\text{-}day)}$ anomaly is from the New York Central Park Tower.

Because precipitation is measured by maximum values, the distribution is more skewed than sea level. Some months are extreme outliers, far above the average five-day maximums.

3 National Center for Atmospheric Research/University Corporation for Atmospheric Research, "Climate Data Guide," accessed Nov. 11, 2016.

Figure 3.1. Maximum Five-Day Precipitation

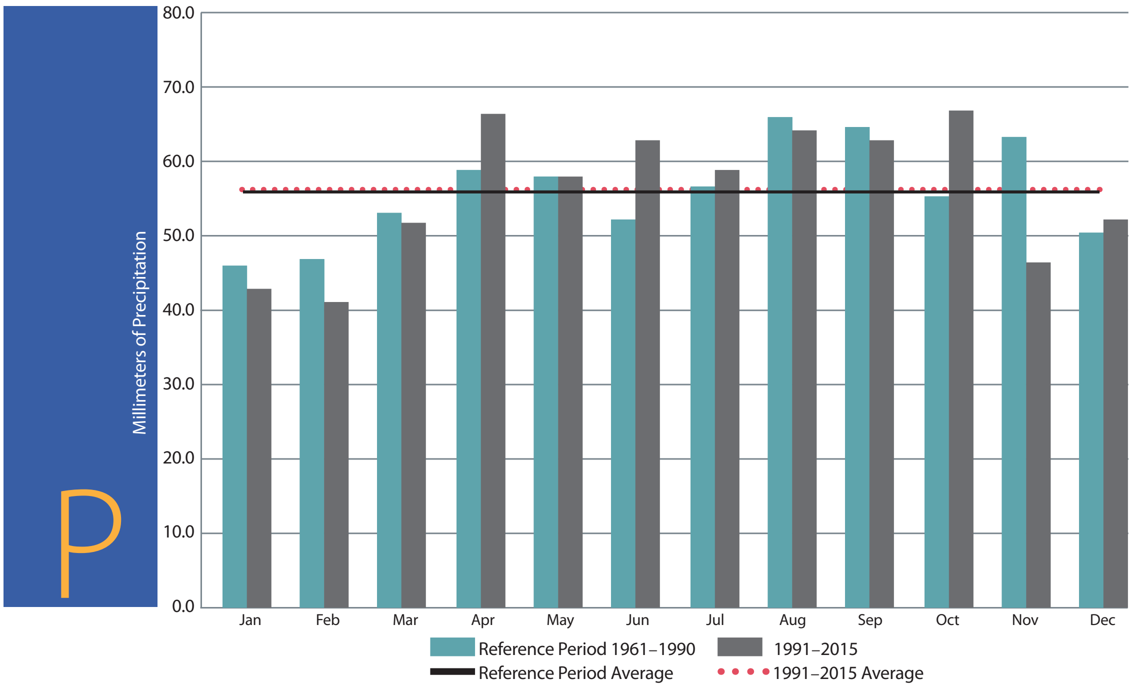
NYC Central Park



This monthly data is translated by an average of the five-day maximums over the 30-year reference period, creating a set of 12 means. The standard deviations are calculated monthly over the same reference period, to scale and standardize the distribution. The means for the reference period are shown in the figure below, along with the monthly means for subsequent years. There is no shift in the overall averages between periods for this location, although there are changes in the average five-day maximums by month.

Figure 3.2. Mean *MaxP*$^{(5\text{-}day)}$ *(j,k)* Precipitation by Month

NYC Central Park



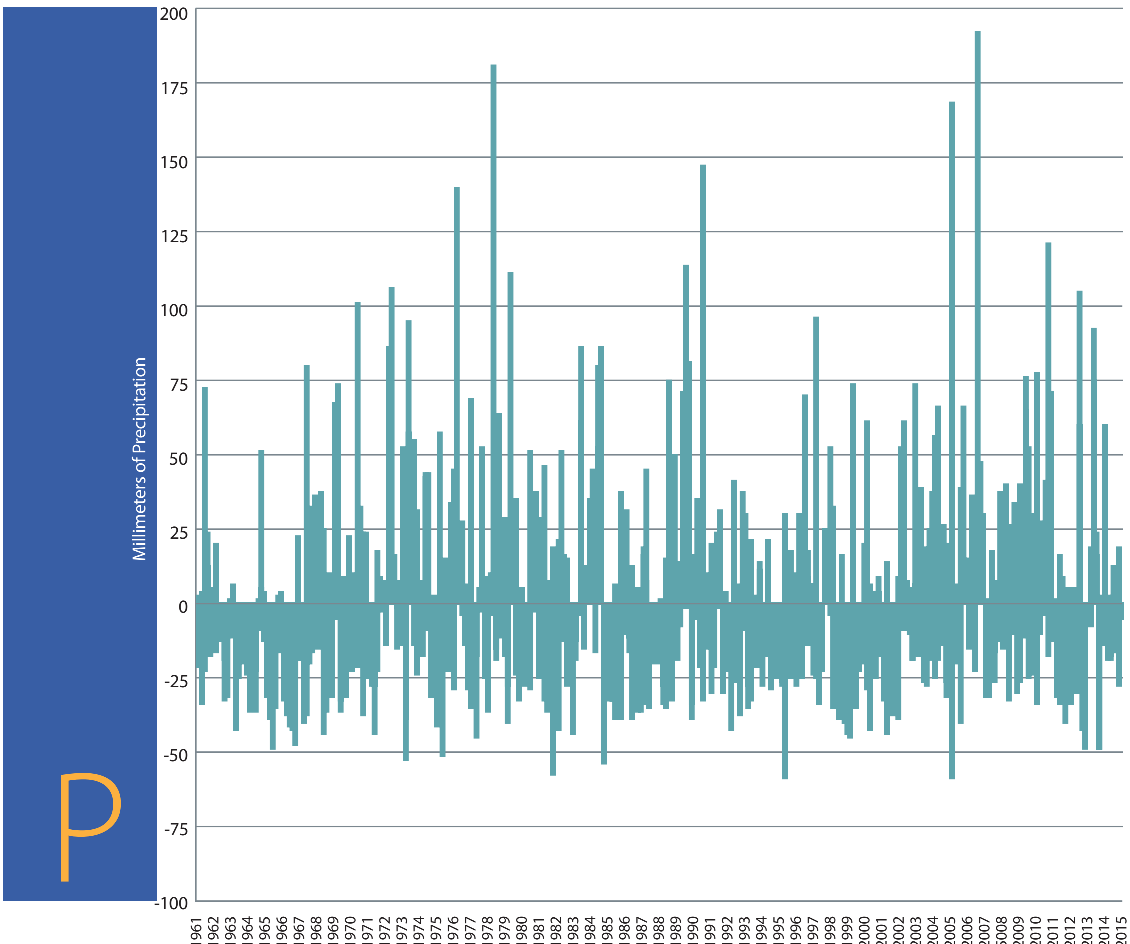
Month(j):	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$\mu_{ref}\,MaxP^{(5\text{-}day)}(j)$	45.9	46.9	53.1	58.8	57.9	52.4	56.7	66.3	64.8	55.2	63.5	50.4
$\sigma_{ref}\,MaxP^{(5\text{-}day)}(j)$	30.0	20.7	24.6	27.8	31.8	32.7	31.0	47.3	50.0	27.3	46.6	19.4

For the ACI, values for each month in each year of the observation period are used. Thus for each single month over the observation period, the anomalies are determined by comparing the current monthly value with the values for the reference period. The anomaly of $MaxP^{(5\text{-}day)}$ relative to the reference period value for a given month is given by:

$$\Delta MaxP^{(5\text{-}day)}(j,k) \quad = \quad MaxP^{(5\text{-}day)}(j,k) - \mu_{ref}\, MaxP^{(5\text{-}day)}(j)$$

Figure 3.3. $\Delta MaxP^{(5\text{-}day)}(j,k)$

NYC Central Park



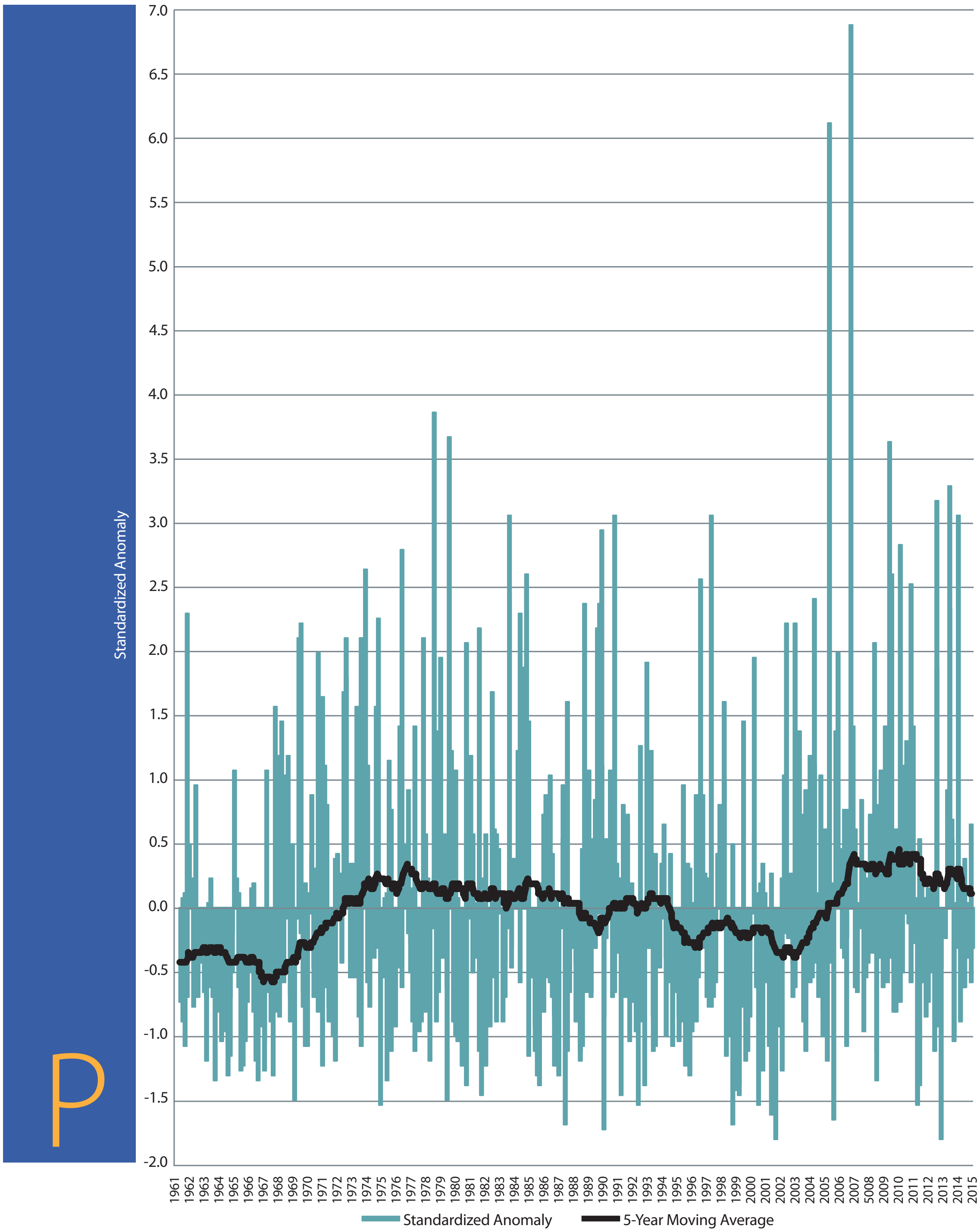
For the purpose of combining the six components of the ACI, the deviations $\Delta MaxP^{(5\text{-}day)}$ have again been converted to ratios to standard deviations using the formula:

$$MaxP^{(5\text{-}day)}_{std}(j,k) \quad = \quad [MaxP^{(5\text{-}day)}(j,k) - \mu_{ref} MaxP^{(5\text{-}day)}(j)\,] \,/\, \sigma_{ref} MaxP^{(5\text{-}day)}(j)$$

$$= \quad \Delta MaxP^{(5\text{-}day)}(j,k) \,/\, \sigma_{ref} MaxP^{(5\text{-}day)}(j)$$

Figure 3.4. *MaxP*$^{(5\text{-}day)}_{std}$

NYC Central Park



4. Warm Temperatures

One of the more important measures of the index is warm temperatures, as warmer temperatures are a foundational indicator of climate risk. “Warm temperatures” are established by calendar day thresholds, which are set during the reference period by the top 10 percent of temperatures for the surrounding five calendar days. Because temperatures fluctuate seasonally and daily throughout the year, the thresholds are smoothed by moving five calendar days centered at each calendar day calculation, taken over 30 years, for a basis of 150 values.

The definition of warm temperatures is comparative, not absolute, and is established not only in the summer months, but throughout the year. A warm temperature in the summer can point to extreme heat, which can cause excess morbidity and mortality. Warm temperatures in the spring, fall, and winter can point to a changing climate, which affects the ecology of flora and fauna, agriculture, weather patterns, and storms. Both warm maximums and warm minimums are considered by the component, where maximums typically correspond to daytime high temperatures and minimums to the nighttime high temperatures. Sometimes the highest temperature occurs at night and the lowest temperature during sunlight hours, due to changes in cloud cover and frontal movements. For this reason, these measures are referred to by the daily “maximum” and “minimum” rather than by “daytime” and “nighttime.”

This example will show how the warm temperature component of the Actuaries Climate Index is calculated for one weather station, in Toronto, Ontario.[4] Note that the GHCNDEX[5] data already contains the frequency of temperatures that are above the warmest 10 percent of temperatures for each grid cell. To avoid possible inhomogeneity across the in-base and out-base periods, the GHCNDEX calculation for the base period (1961–1990) makes use of a bootstrap process. Details are described in Zhang et al. (2005).[6] A Monte Carlo simulation demonstrates that the threshold temperatures calculated during the base period is affected by sampling error, which the bootstrap resampling procedure corrects. This example walks through what the calculation would look like within the GHCNDEX program, but without the bootstrapping technique.

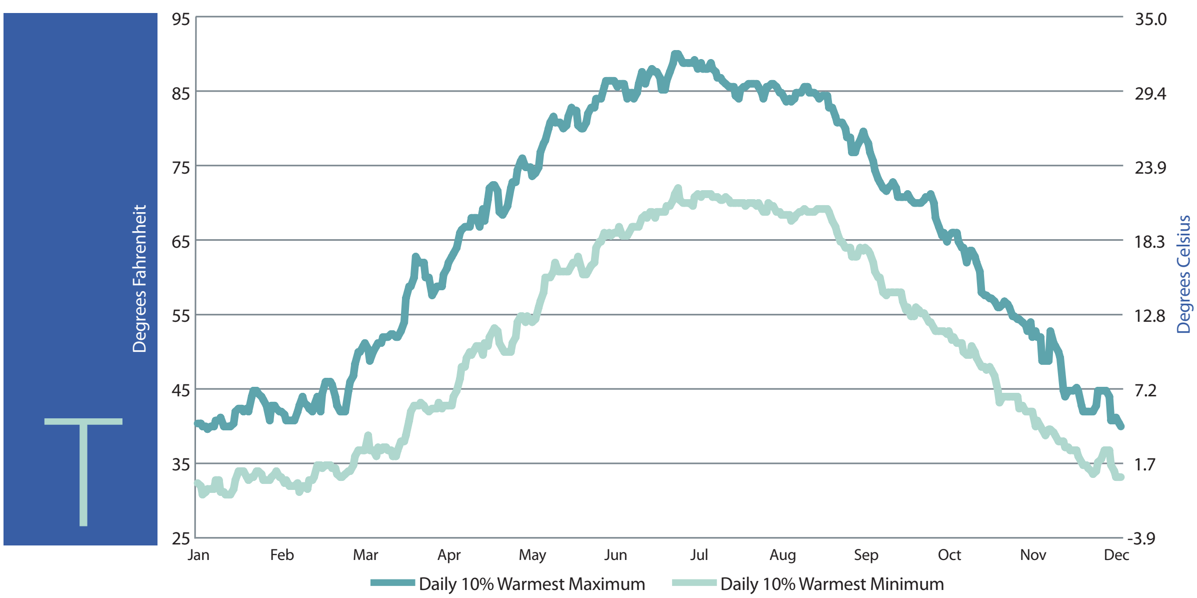
4 Daily data was obtained for Toronto City Centre from the government of Canada’s “Historical Data” website.
5 M.G. Donat, L.V. Alexander, H. Yang, I. Durre, R. Vose, J. Caesar, 2013: “Global Land-Based Datasets for Monitoring Climatic Extremes,” *Bull. Amer. Meteor. Soc.*, 94, 997–1006.
6 X. Zhang, et al., 2005: “Avoiding Inhomogeneity in Percentile-Based Indices of Temperature Extremes,” *J. Climate*, 18, 1641-1651.

Figure 4.1 shows the calendar day thresholds set according to the warmest 10 percent of temperatures in the reference period. These thresholds were adjusted from the initial calculation to correct for sampling errors, so that the exceedance frequency during the reference period is 10 percent. The sampling errors result because the 30 values used to determine the exceedance frequency for each calendar day during the reference period is a subset of the 150 values used to determine the threshold temperature, and therefore, the exceedance frequency is close to but not necessarily equal to 10 percent. The axis on the left shows degrees Fahrenheit (˚F), while the one on the right shows degrees Celsius (˚C). The warmest 10 percent curve for daily maximums is shown in dark teal, while the warmest 10 percent line for daily minimums is shown in light teal.

To illustrate, the figure's highest threshold value for daily maximum temperatures occurs on July 9, when the 10 percent warmest temperature is 90.0˚F (32.2˚C). This means that on July 9 in Toronto, one would expect the maximum temperature that day to be higher than 90.0˚ F (32.2˚C) only one year in 10. The high point for the warmest 10 percent minimum temperature threshold occurs on the very same calendar day, July 9, with a value of 72.0˚F (22.2˚C). That means that on July 9, we would only expect the minimum temperature to be higher than 72.0 ˚F (22.2˚C) one year in 10. If a day is chosen in March—for example March 15—the 10 percent warmest maximum temperature threshold is 52.2˚ F (11.2˚C) while the 10 percent warmest minimum temperature threshold is 37.4˚F (3.0˚C).

Figure 4.1. Warmest 10% Temperature Thresholds

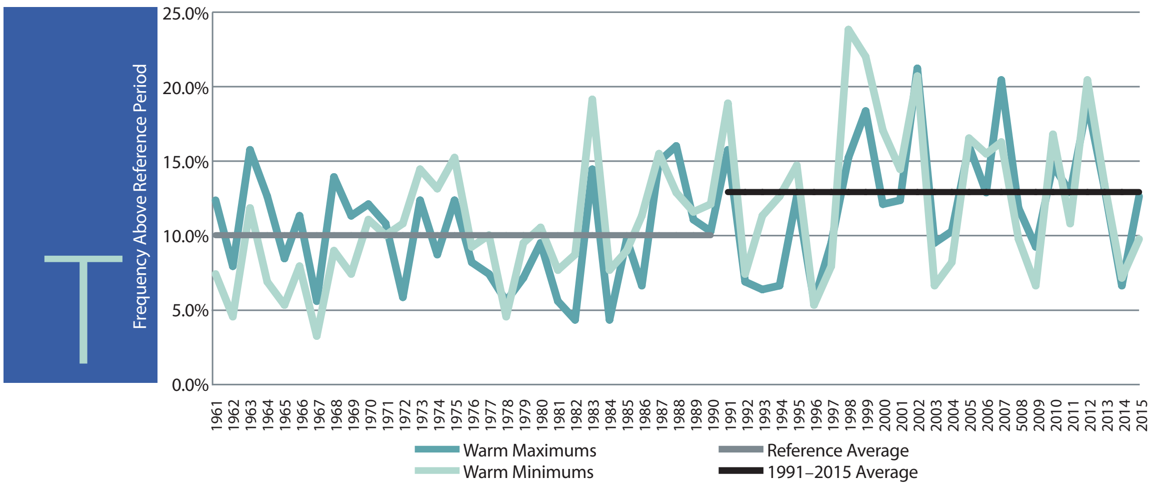
Toronto, Canada



Using the thresholds established over five rolling calendar days across the reference period, the frequency at which temperatures exceed these values is compiled. Daily maximum and minimum temperatures tend to move beyond thresholds in unison, as can be seen in the Figure 4.2:

Figure 4.2. Annual Frequency of Warm Temperatures

Toronto, Canada

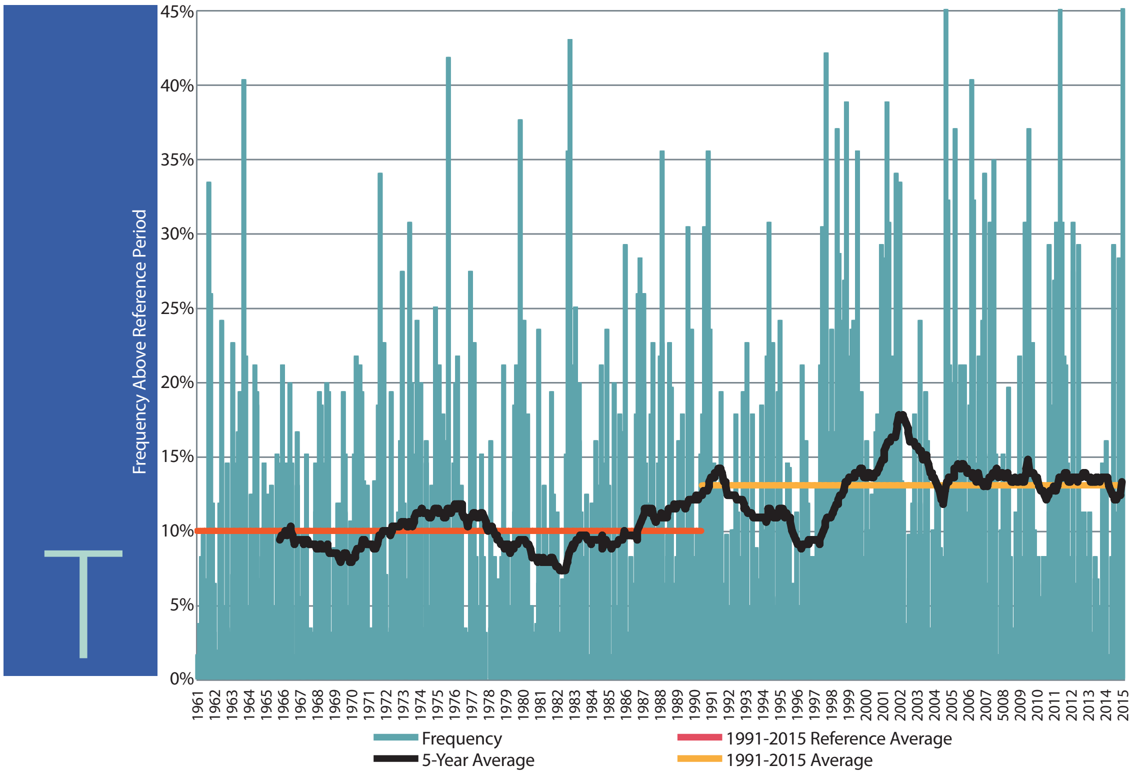


The gray line shows the average warm temperature frequencies in the reference period, which by definition is 10 percent, compared to the 25-year period after the reference period (black line), which averaged 13.0 percent. The dark teal line is the frequency of warm maximum daily temperatures, while the light teal line shows the frequency of warm minimum temperatures. The monthly frequencies have been averaged into annual frequency figures for clarity of presentation.

In the Actuaries Climate Index, to avoid double counting, we average the frequencies of daily minimum and daily maximum warm extremes, as the two frequencies are strongly correlated. Figure 4.3 shows the frequency of daily minimum plus daily maximum warm extremes, divided by 2. Figure 4.3 spans 55 years in total, i.e., the 30-year reference period, followed by the next 25 years.

Figure 4.3. Monthly Frequency of Warm Temperatures

Toronto, Canada



As can be seen in Figure 4.3, temperature frequencies are quite variable. One way to help distinguish the signal from the noise in the observations is by using an averaging technique, such as the five-year average shown above.

The standardized anomalies are then calculated as:

$$F\,T{:}warm\,(j,k) \quad = \quad [\,F\,T{:}warm_{max}\,(j,k) + F\,T{:}warm_{min}(j,k)\,]\;/\;2$$

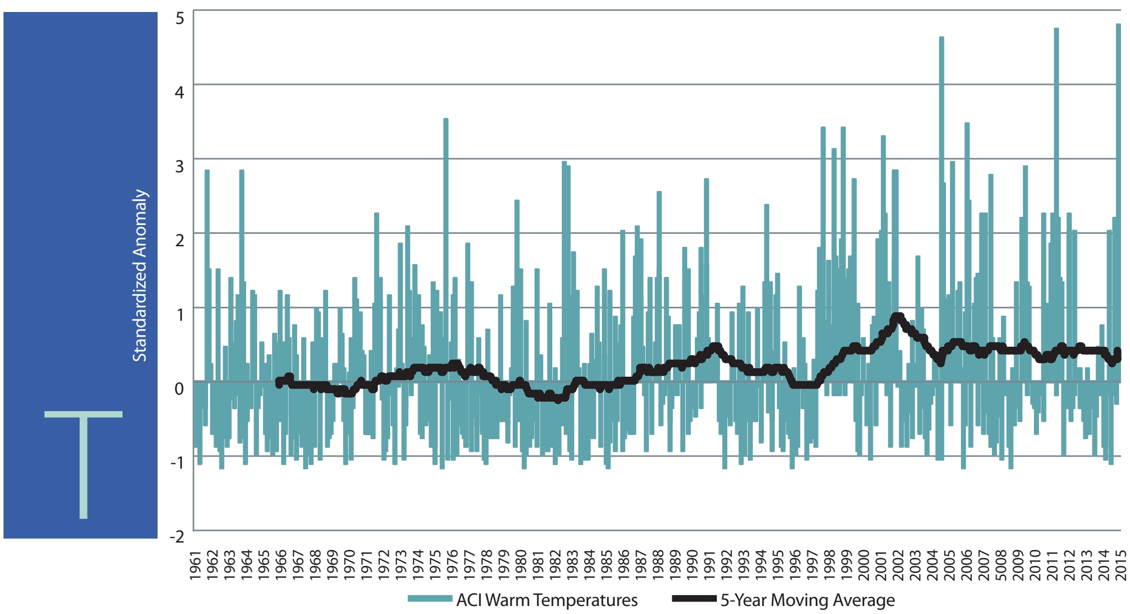
$$\sigma_{\text{ref}}\,F\,T{:}warm\,(j) \quad = \quad \sigma_{\text{ref}}[\,F\,T{:}warm_{max}\,(j) + \sigma_{\text{ref}}F\,T{:}warm_{min}\,(j)\,]\;/\;2$$

$$F\,T{:}warm_{std}\,(j,k) \quad = \quad \frac{[\,F\,T{:}warm\,(j,k) - \mu_{\text{ref}}\,F\,T{:}warm\,(j)\,]}{\sigma_{\text{ref}}\,F\,T{:}warm\,(j)}$$

Where $F\ T{:}warm_{max}(j,k)$ represents the monthly frequency of warm daily maximum temperatures, and $F\ T{:}warm_{min}(j,k)$ the monthly frequency of warm daily minimum temperatures. The average monthly frequencies for all months during the reference period, $\mu_{ref}\ F\ T{:}warm\ (j)$, is 10 percent, for j = Jan, Feb … Dec.

Figure 4.4 Standardized Anomalies—Warm Temperatures

Toronto, Canada



5. Cool Temperatures

The next measure used in the index is the frequency of cooler temperatures, as a decrease in the occurrence of cooler temperatures is indicative that the temperature distribution has shifted to the right. Because a decrease in the occurrence of cooler temperature extremes is indicative of a warming climate, the *F T:cool(j,k)* component is subtracted from the ACI. The methodology is the same as for warm temperatures, with the cooler temperature thresholds similarly set according to moving five calendar days across the reference period. "Cool temperatures" are defined as daily temperatures in the lowest 10 percent as measured for the particular calendar day across the reference period. The definition of cool temperatures is comparative, not absolute, so that a cool temperature can happen not only in the winter months but throughout the year. A lack of cool temperatures can point to a changing climate, which affects the ecology of flora and fauna, agriculture, weather patterns, and storms. For example, a lack of cool temperatures could affect fruit production, as fruit trees need a certain amount of cold in the winter to set fruit. Maple syrup production requires a good balance between nights below freezing, followed by days above freezing for the sap to run.

Figure 5.1. Coolest 10% Temperature Thresholds

Toronto, Canada

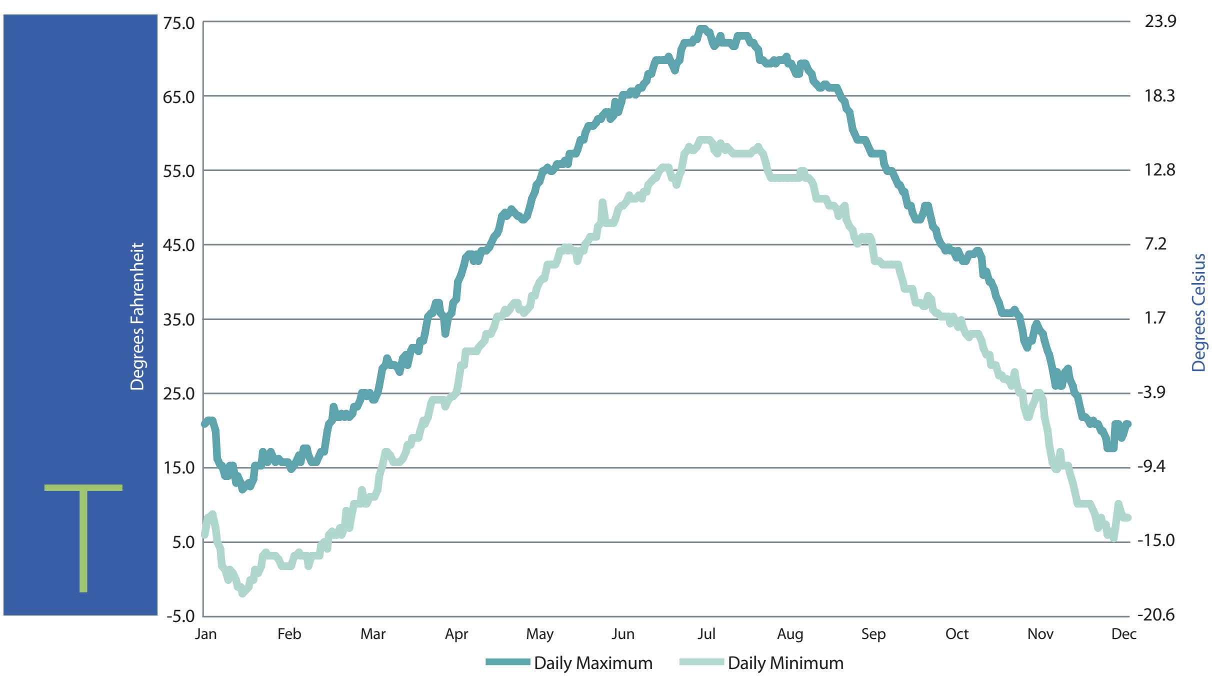
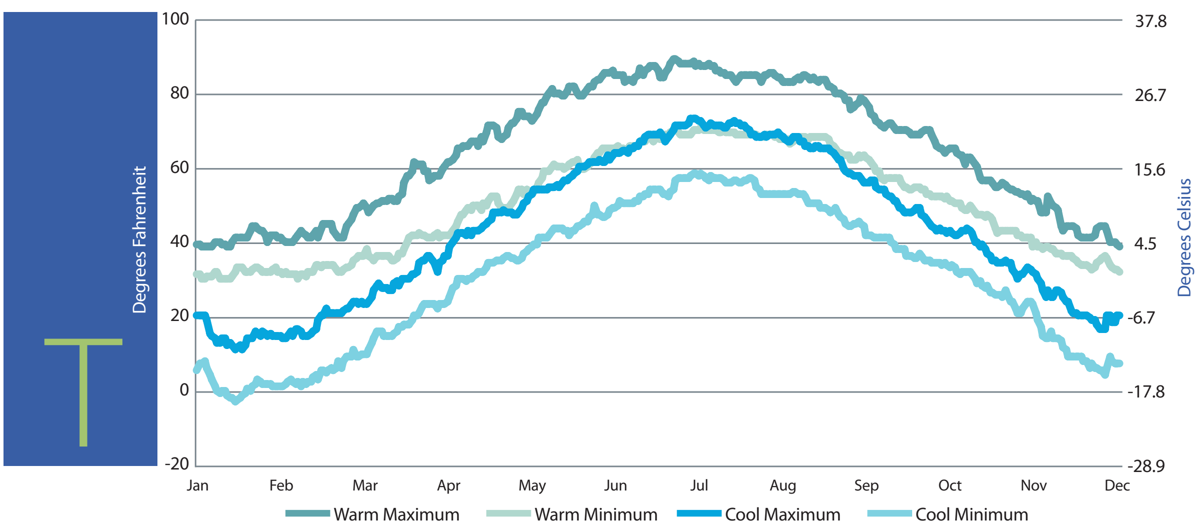


Figure 5.1 shows the coolest 10 percent temperature threshold curves for Toronto, the upper curve for the daily 10 percent coolest maximum temperature thresholds, and the lower for daily 10 percent coolest minimum temperature thresholds. The mean coldest calendar day of the year in Toronto occurred centered at January 16 in the reference period, where the minimum temperatures were below -1.9˚F (-18.8˚C) 10 percent of the time. The mean coolest maximum temperature occurred at the same calendar day, January 16, where the highest low temperatures were below 12.1˚F (-11.1˚C) 10 percent of the time. The highest point on this figure is July 17, the calendar day where the coolest maximum temperature is expected to be below 74.1˚F (23.4˚C) 10 percent of the time. Another way to think of this is that 90 percent of the time, we expect a temperature of at least 74.1˚F (23.4˚C) on July 17 for the daily coolest maximum, and 90 percent of the time, no colder than 59.2˚F (15.1˚C) for the coolest minimum.

The following figure shows how the warmest 10 percent temperature thresholds compare to the coolest 10 percent temperature thresholds for Toronto.

Figure 5.2. 10% Warmest and Coolest Temperature Thresholds

Toronto, Canada

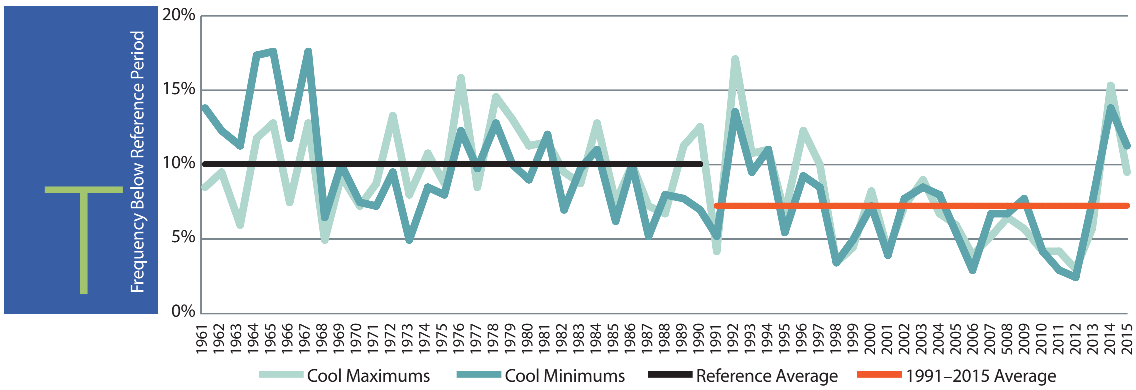


There appears to be more overlap between the maximum and minimum temperatures in the summer months. From October to April, the warmer minimum temperatures are above the cool maximum temperatures.

Daily 10 percent maximum and minimum coolest temperatures tend to move together, as can be seen in Figure 5.3.

Figure 5.3. Annual Frequency of Cool Temperatures

Toronto, Canada

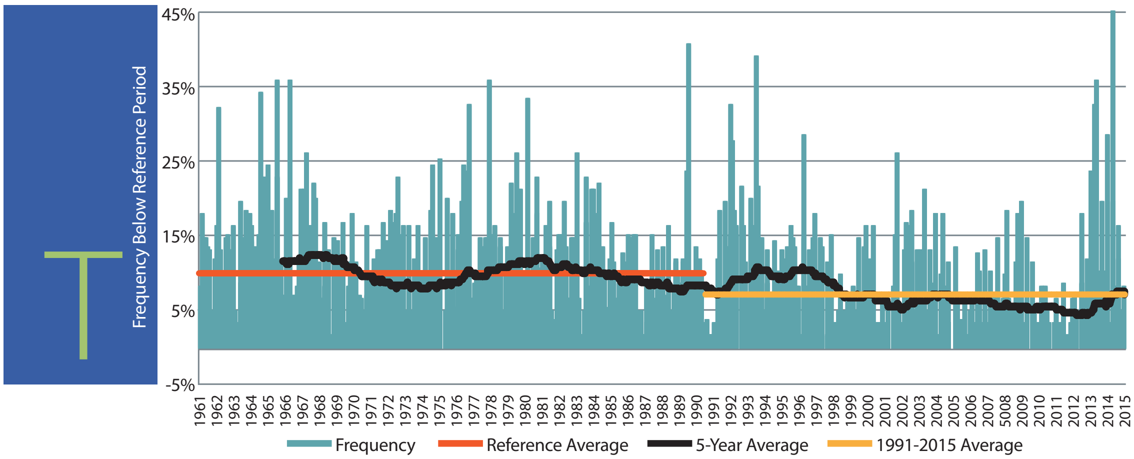


The black line shows the average cool temperature frequencies in the reference period, which by definition is 10 percent, compared to the 25-year period after the reference period (red line), which averaged 7.2 percent. This shows that, in Toronto, cooler temperatures have been less frequent after the reference period. The lighter teal line is the frequency of cool maximum daily temperatures, while the dark teal line shows the frequency of cool minimum temperatures.

Similar to the calculations for warm temperatures, we average the frequencies of daily minimum and daily maximum cool extremes, as the two temperatures are strongly correlated. Figure 5.4 shows the frequency of daily minimum plus daily maximum cool extremes, divided by 2. Figure 5.4 spans 55 years in total, i.e., the 30-year reference period, followed by the next 25 years.

Figure 5.4. Monthly Frequency of Cool Temperatures

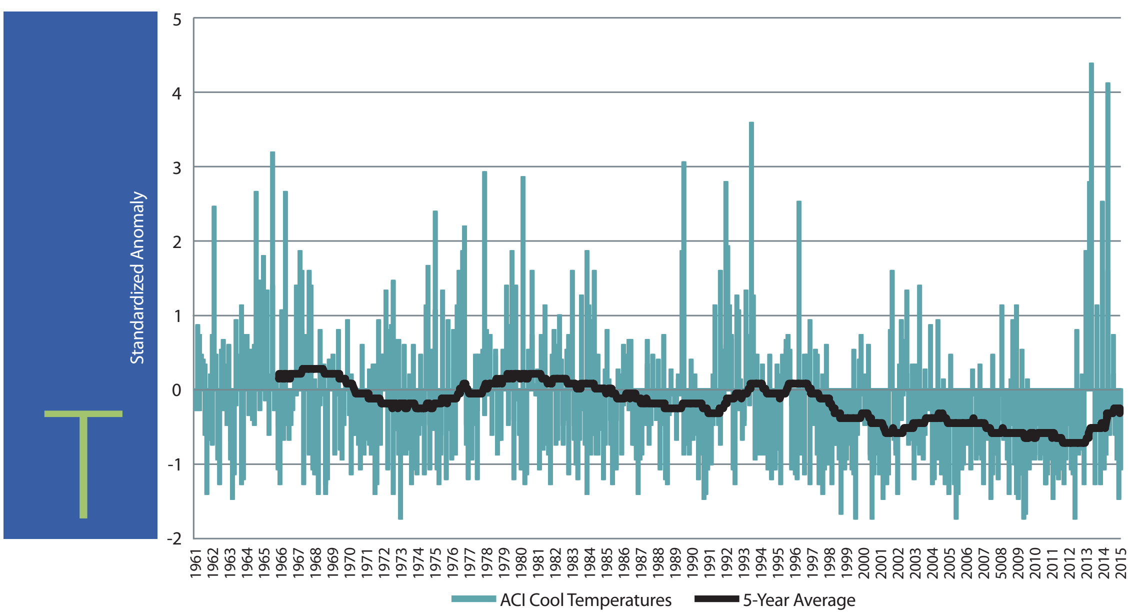
Toronto, Canada



Similar to what was done for the other components, the standardized anomalies are calculated, shown in Figure 5.5:

Figure 5.5. Standardized Anomalies—Cool Temperatures

Toronto, Canada



Over the past 15 years, the five-year average in Toronto shows fewer cool temperature extremes, with a slight upward movement in cool temperatures in the past few years.

6. Wind Power

Like precipitation, the PDF of daily mean wind speed is right-skewed, and the changes of most interest occur in the high-value tail of the distribution. Daily mean wind speed measurements[7] are converted to wind power *WP*, using the relationship $WP = (1/2)\,\rho w^3$, where *w* is the daily mean wind speed and ρ is the air density (taken to be constant at 1.23 kg/m^3). Wind power is used because damages from high winds have been shown to be proportional to *WP*, rather than to *w* (see *Phase I Report*,[8] Sec. 5.6). The wind power thresholds are determined for each day and month in the reference period, $WP_{ref}(i,j)$, for each day *i* and month *j* (*j* = Jan, Feb … Dec), at each grid point separately. The $WP_{ref}(i,j)$ value is determined as the mean plus 1.28 standard deviations of $WP(i,j,k)$ for all 30 values of year *k* in the reference period. The count of days where mean winds exceed $WP_{ref}(i,j)$ is then stated as a percentage of the number of days in the month, providing an exceedance frequency measure for every month of every year for the full period. Note that 1.28 standard deviations above the mean was chosen to isolate the top 10 percent of wind speeds (and equivalently, wind power). Due to sampling error, the frequency of the extreme wind speeds during the reference period is 13 percent. We plan to change how the threshold wind speeds are calculated during the reference period in a future release of the ACI, so that the frequency of exceedance of the threshold during the reference period is 10 percent, which is consistent with other ACI components that use exceedance frequencies. The current methodology still provides useful information, as it still measures the exceedance frequencies during the current period, compared to that in the reference period, and standardizes it by dividing by the standard deviation of the exceedance frequencies during the reference period:

$$F\,WP_{std}\,(j,k) \quad = \quad [\,F\,WP\,(j,k) - \mu_{ref}(j)\,]\,/\,\sigma_{ref}(j)$$

Note that damageability does not enter the ACI calculation; the threshold wind power will occur at the same point as the threshold for wind speed, so these frequencies are identical for wind speed and wind power. The frequencies are standardized by subtracting the mean and dividing by the standard deviation of the reference period. Using an Excel formula notation that gives a count of 1 when the inequality in parentheses is true, the initial frequency calculation is given by the sum:

7 National Centers for Environmental Information, "Measurements," accessed Nov. 15, 2016.
8 Solterra Solutions, *Determining the Impact of Climate Change on Insurance Risk and the Global Community—Phase I: Key Climate Indicators*, Nov. 1, 2012.

$$F\ WP\ (j,k) \quad = \quad [\sum_{i=1}^{n(j)} ((\ WP(i,j,k)\ \text{-}\ WP_{ref}(j)) > 0\ ) * 1]\ \ /\ \ n(j)$$

where i represents the day, j the month, k the year, and n(j) the number of days in month j.

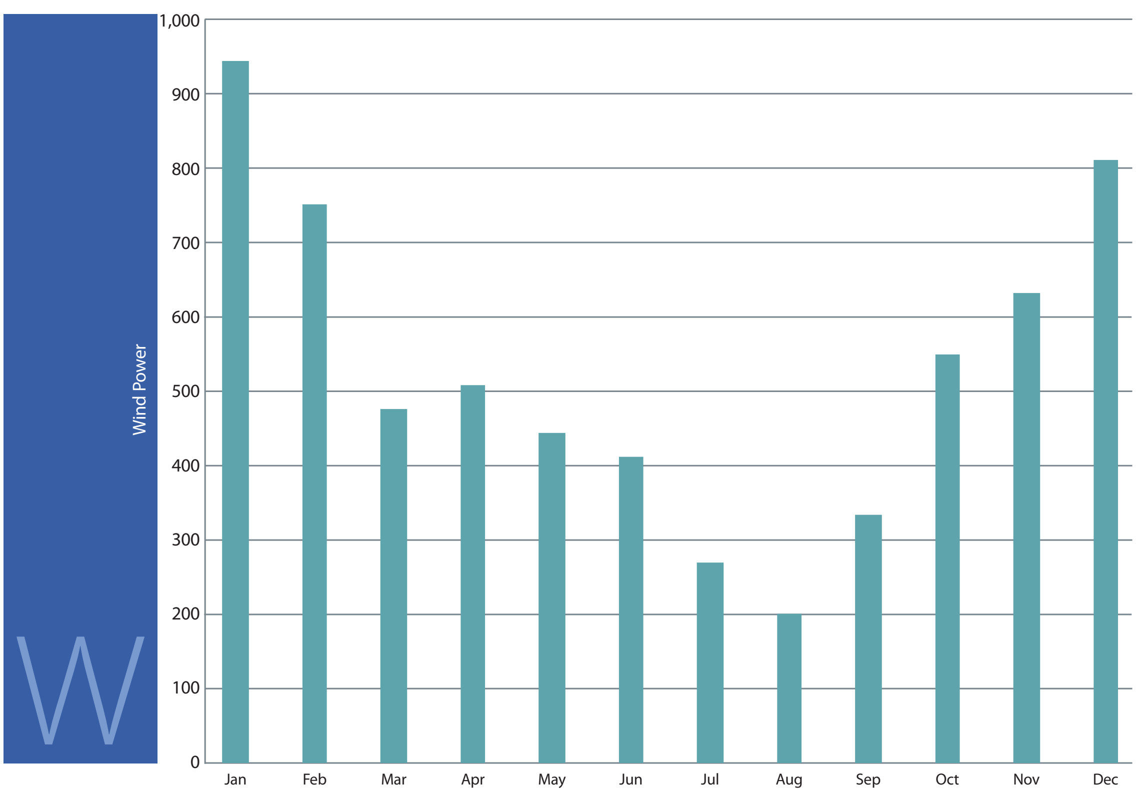
$$F\ WP_{std}\ (j,k) \quad = \quad [\ F\ WP\ (j,k) - \mu_{\mathrm{ref}}(j)\ ]\ /\ \sigma_{\mathrm{ref}}(j)$$

The sample calculation will be for the grid containing Lethbridge, Alberta. The grid region is between latitudes 47.5 and 50 degrees north, and by longitudes 110 to 112.5 degrees west. In the Lethbridge grid region, the daily mean wind speeds from 1961 to 2011 range from 0 to 24.4 meters per second, such that wind power values range from 0 to 8919.2. The average of daily mean wind speeds by month over the 30-year reference period comprises a narrow range, from a minimum of 4.25 mps for August to a maximum 6.02 mps for January. The threshold wind power by month spans a broad range, from $WP_{ref}(Aug)$ = 202.0 mps to $WP_{ref}(Jan)$ = 945.5 mps.

The thresholds of wind power for the reference period are shown in Figure 6.1.

Figure 6.1. Wind Power $WP_{ref}(j)$ Thresholds—Reference Periods

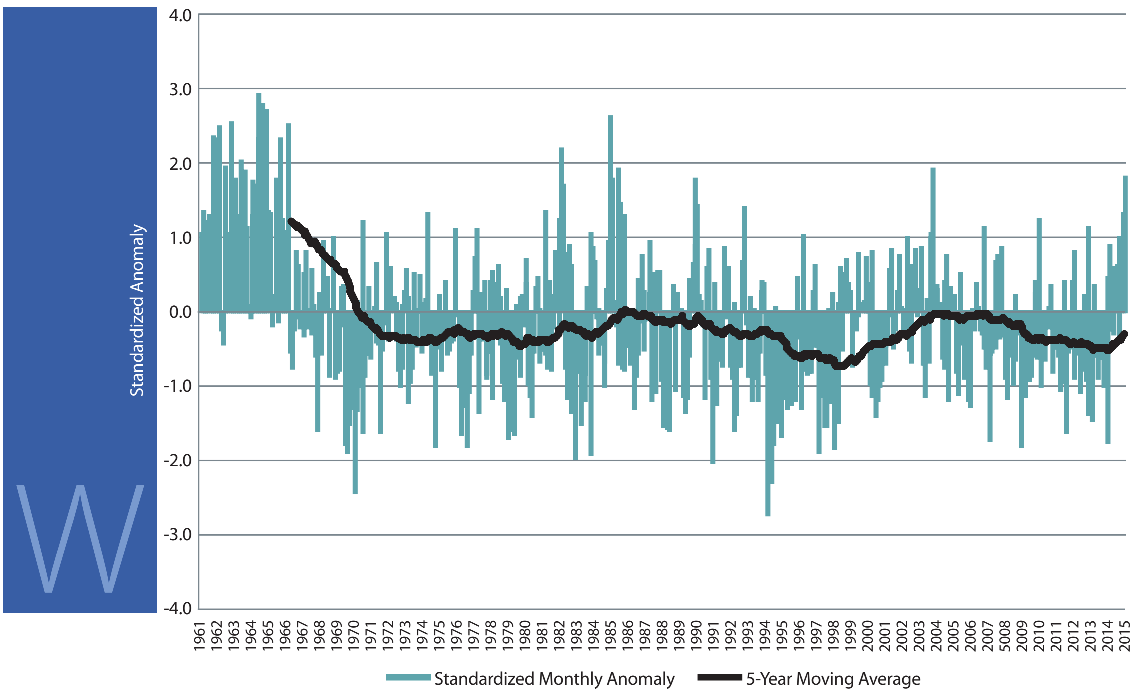
Lethbridge, Alberta, Canada



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$WP_{ref}(j)$	945.5	750.8	477.3	508.8	445.6	410.5	269.3	202.0	332.7	547.4	632.5	810.1
Wind speed thresh., mps:	11.5	10.7	9.2	9.4	9.0	8.7	7.6	6.9	8.1	9.6	10.1	11.0
Wind speed thresh., kph:	41.4	38.5	33.1	33.8	32.4	31.3	27.4	24.8	29.2	34.6	36.4	39.6
Wind speed thresh., mph:	25.7	23.9	20.6	21.0	20.1	19.5	17.0	15.4	18.1	21.5	22.6	24.6

The time series of $F\ WP_{std}$ is shown in Figure 6.2.

Figure 6.2. ΔWP_{std}
Lethbridge, Alberta, Canada



Note that the wind speeds seem to be much higher in the early part of the reference period at this particular location. It is possible that this increase is related to improvement in anemometer measurements in the mid-1960s for this particular location. This anomaly does not appear to be an issue for the wind data overall.

The Actuaries Climate Index

The standardized anomalies are averaged when combined into the Actuaries Climate Index. Note that the cool temperature component, $F\,T{:}cool_{std}$ (j,k), is subtracted in the index, counting fewer cool extremes as evidence of the shift of the temperature probability distribution curve to the right.

$$ACI\,(j,k) = \frac{MaxCDD_{std}\,(j,k) + S_{std}\,(j,k) + Max\,P^{(5\text{-}day)}{}_{std}\,(j,k) + F\,T{:}warm_{std}\,(j,k) - F\,T{:}cool_{std}\,(j,k) + F\,WP_{std}\,(j,k)}{6^{\dagger}}$$

† Note that the Central Arctic Region (CAR) does not have a sea level component due to a lack of complete sea level data, and that the Midwest does not have a sea level component because it has no ocean coastline. For these regions, the sea level component is omitted from the ACI, and a divisor of 5 is used to average the remaining five components.

ACTUARIES CLIMATE INDEX

INDICE ACTUARIEL CLIMATIQUE

ACTUARIESCLIMATEINDEX.ORG