ACTUARIES CLIMATE INDEX
DEVELOPMENT AND DESIGN

ACTUARIES CLIMATE INDEX
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Actuaries Climate Index

DEVELOPMENT AND DESIGN

The Actuaries Climate Index™ (ACI) is intended to provide a useful monitoring tool—a "*Climate at a Glance*" indicator. The Index has been developed collaboratively among four North American actuarial organizations—the Canadian Institute of Actuaries, the Society of Actuaries, the Casualty Actuarial Society, and the American Academy of Actuaries—with climate expertise and research provided by Solterra Solutions.

The ACI will be updated quarterly, and has been designed to be statistically robust, yet easy to understand. The Index tracks changes in a variety of climate-related variables over time. Because it is based on actual historical data, the Index is retrospective and does not provide projections about future events.

A second index, the Actuaries Climate Risk Index (ACRI), will be based on the historical correlations of economic losses, mortality, and injuries to the ACI data, and will be described in a separate report.

These two indices will help actuaries, public policy makers, and the general public learn more about extreme weather and its associated risks.

About the Actuaries Climate Index

The Actuaries Climate Index has six components, each of which is a monthly time series beginning in 1961 based on measurements from an extensive network of meteorological stations and coastal tide stations within the United States and Canada. Where possible, the components measure extremes, rather than averages, because extremes have the largest impact on people and property. All data is standardized to measurements over the 30-year reference period of 1961 to 1990, which was the earliest available 30-year period with good data, i.e., there were fewer quality-controlled stations in the source data prior to 1961. The key metric is a five-year moving average. This five-year period was carefully chosen as the most efficient time period to reduce the noise of the time series data and allow users to see a clear climate signal. The plan is to publish a seasonal Index, as well as monthly indices, each quarter by reporting on the most recent available meteorological season (three months ending February, May, August, and November) compared to the reference period. The Index will be launched for the United States and Canada on a website. Users will be able to follow changes in the seasonal ACI and its individual components, for Canada and the United States separately, the Canada-U.S. regions combined, as well as 12 sub-regions.

The six Actuaries Climate Index components are:

1. Frequency of temperatures above the 90th percentile (*T90*);
2. Frequency of temperatures below the 10th percentile (*T10*);
3. Maximum rainfall per month in five consecutive days (*P*);
4. Annual maximum consecutive dry days (*D*);
5. Frequency of wind speed above the 90th percentile (*W*); and
6. Sea level changes (*S*).

These components were selected because they are representative of the key impacts of climate on people and the economy.

The ACI reflects how these components can be expressed in terms of the statistics of weather and sea level. Of particular interest is how the shape of the probability distribution function (PDF) of a certain component changes with time. Often, looking at the behavior of mean quantities is considered sufficient; however, because an increased frequency or intensity of climate extremes has been known to have detrimental impacts on society (see the *Phase I Report,*[1] Chapter 4), the ACI prioritizes information on changing extremes.

The creation of an Index for the United States and Canada should not be taken as an indication that changes in this region are representative of changes globally. Movements of climate statistics, including those measured by the Actuaries Climate Index, vary significantly from place to place. The sponsors and developers of the ACI are hopeful that the geographical scope of the Index can be replicated and expanded so that more regions can be combined into a global index. The necessary good quality historical data exists in many other parts of the world; the sponsors and developers have been encouraged by the interest shown by leaders in other actuarial organizations to develop an adaptation of the Actuaries Climate Index in their regions.

1 Solterra Solutions, "*Determining the Impact of Climate Change on Insurance Risk and the Global Community—Phase I: Key Climate Indicators,*" Nov. 1, 2012.

The Temperature (T) components are defined as the frequency of temperatures above the 90th percentile and below the 10th percentile, relative to the reference period of 1961 to 1990.

The analysis of surface temperatures used in the ACI is based upon the GHCN-Daily[2] gridded data set. Specifically, the monthly frequency of daily maximum (i.e., generally daytime) and minimum (i.e., generally nighttime) temperatures lying below the 10th and above the 90th percentiles of the PDF is used, as provided in the related GHCNDEX dataset.[3] These are denoted by *TX10, TX90* (daily high temperatures) and *TN10, TN90* (daily low temperatures), which are expressed as percentages, and are provided as time series by station and grid from 1951 to present.[4] Within each grid, the GHCN index values are averaged over the selected weather stations, and within each ACI region, the GHCN index values are averaged over the grids in that region. For each region in the United States and Canada, the mean values of these percentile differences over the reference period 1961-1990 are calculated, giving 12 monthly values. In each case, and in accord with the above definitions, the values are very near 10 percent (small differences from the nominal values arise due to the use of robust sampling methods, i.e., the percentiles for each day are based on the surrounding five-day period). Next, the same quantities for the corresponding month of every member in the entire time series are calculated. Finally, the difference between each monthly exceedance frequency and the reference period value—approximately 10 percent—for the corresponding month at each grid point is calculated.

2 Global Historical Climatology Network (GHCN) Daily, from the NOAA Satellite and Information Service, is an integrated database of daily climate summaries from land surface stations across the globe. The grids each cover a surface area of 2.5 degrees longitude by 2.5 degrees latitude.

3 GHCNDEX is a dataset based on GHCN Daily. It provides gridded, station-based indices of temperature- and precipitation-related climate extremes and was developed by the Climate Change Research Centre and the Australian Research Council's Centre of Excellence for Climate System Science. (Donat, M.G., L.V. Alexander, H. Yang, I. Durre, R. Vose, J. Caesar, "Global Land-Based Datasets for Monitoring Climatic Extremes," *Bulletin of the American Meteorological Society*, July 2013.)

4 Graphs for the Actuaries Climate Index start at 1961, the beginning of the reference period.

These differences (i.e., anomalies) in exceedance frequency are denoted as follows:

$\Delta TX90$ (change in warmer daily temperatures),
$\Delta TN90$ (change in warmer nightly temperatures),
$\Delta TX10$ (change in cooler daily temperatures), and
$\Delta TN10$ (change in cooler nightly temperatures).

There is a correlation between *TX90* and *TN90*, because warmer days and warmer nights tend to occur together, and similarly between *TX10* (colder days) and *TN10* (colder nights). Therefore, included in the Index is a term for the change in warmer temperatures as:

$$\Delta T90 = ½\,(\Delta TX90 + \Delta TN90)$$

And a term for the change in cooler temperatures as:

$$\Delta T10 = ½\,(\Delta TX10 + \Delta TN10)$$

Because temperatures have been observed to be warming over most of the United States and Canada in recent decades, $\Delta T10$ is generally a negative number (see Figure 1) due to fewer cold minima falling below the *T10* threshold of the reference period. Because a coincident decrease in $\Delta T10$ and increase in $\Delta T90$ represent a shift of the PDF to warmer temperatures, the sign of $\Delta T10$ should be reversed to properly reflect its contribution to this shift. Otherwise, to the extent that the temperature PDF is symmetric around the mean and the standard deviation remains unchanged, the area removed under the colder half of the curve would offset the area added to the warmer half, resulting in a significant underestimate of the magnitude of the shift. An increased value of the Index due to the reduction in cold extremes is consistent with increased melting of permafrost, and increases in the propagation of diseases and the population of pests and insects that were previously less likely to survive in lower temperatures.

An alternative and useful way to describe the change in temperatures, or in any other indicator, is to compare the change since the reference period, ΔT, to its reference period standard deviation, $\sigma_{ref}(T)$. Specifically, by constructing the ratio of the two, a dimensionless quantity known as the *standardized anomaly* (*Phase I Report*,[5] Sec. 5.2) results, which is a common statistical technique for combining diverse quantities. The standardized anomaly

5 Solterra Solutions, op. cit.

consistently measures what level of change in the average readings is significant relative to the underlying level of variability for each quantity at the region level. Thus we have

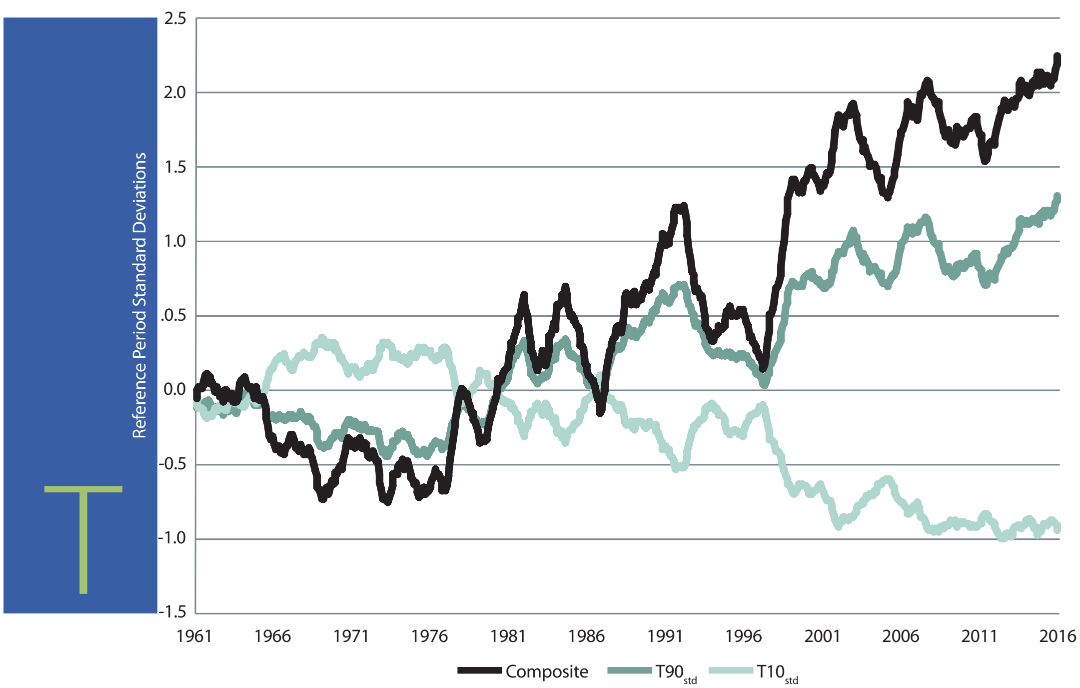
$$T90_{std} = 1/2(\Delta TX90/\ \sigma_{ref}(TX90) + \Delta TN90/\ \sigma_{ref}(TN90),$$

and

$$T10_{std} = 1/2(\Delta TX10/\ \sigma_{ref}(TX10) + \Delta TN10/\ \sigma_{ref}(TN10))$$

The black line in Figure 1 below shows $T90_{std}$ - $T10_{std}$. Each line in the graph is a five-year moving average.

Figure 1. Temperature seasonal standardized anomalies.



P

The Precipitation (P) component is defined as the maximum rainfall over any five consecutive days in the month.

In contrast to temperature, the PDF of precipitation is not normal, but is instead right-skewed (sometimes referred to as "heavy-tailed"). A wholesale shift of the PDF of precipitation is not realistic, because the left tail of the distribution must always be anchored at zero, but the shape of the PDF can still evolve. In order to account for the left side of the distribution, a component for meteorological drought is included, which is described later. For precipitation, the GHCNDEX[6] variable *Rx5day*, the maximum five-day precipitation in a given month (in units of mm H_2O) was chosen to represent the changes to the right, high-value tail of the precipitation PDF.

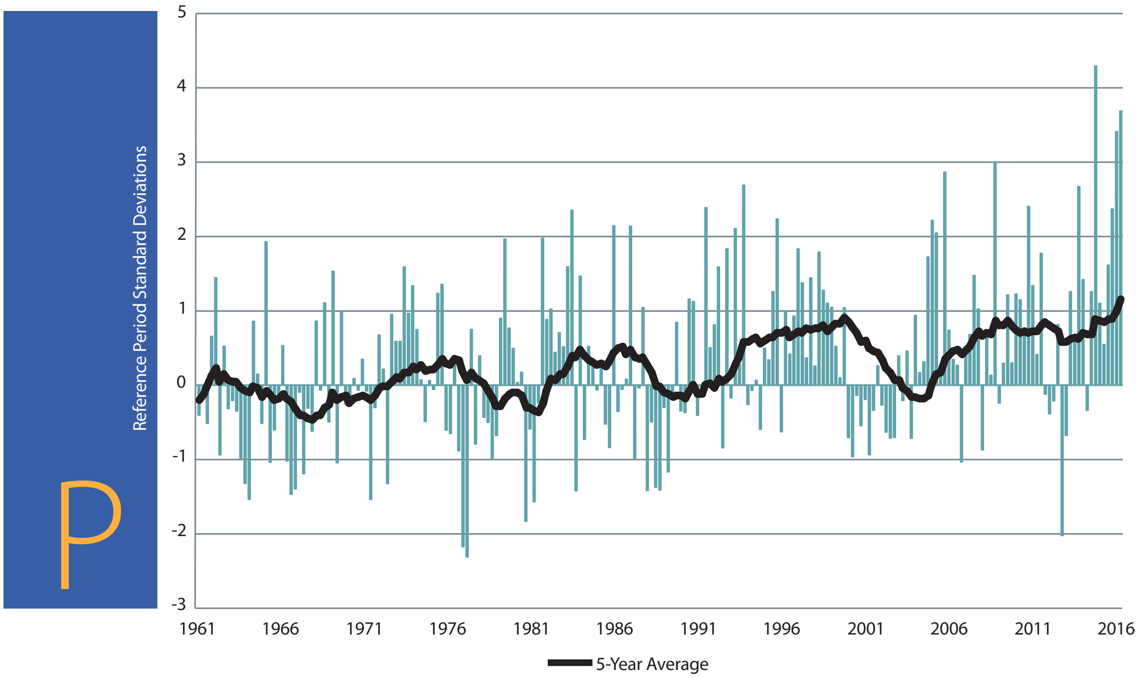
The percentage anomaly of *Rx5day* relative to the reference period value for a given month is given by

$$\Delta P = [(Rx5day - Rx5day_{ref})/Rx5day_{ref}]$$

Positive values of ΔP express an increase in multiple day, heavy-precipitation events compared to the reference period. As with temperatures, we have converted ΔP into standardized anomalies as shown in the graph below, and shown the five-year moving average.

6 GHCNDEX, op. cit.

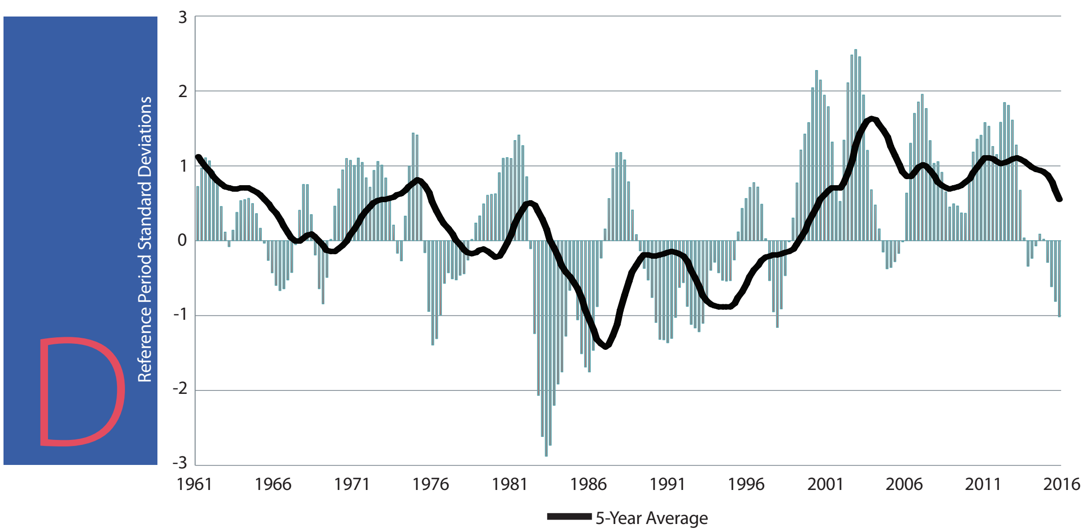
Figure 2. Maximum five-day rainfall seasonal standardized anomalies.



Changes in the left tail of the precipitation PDF are reflected in the GHCNDEX index **Consecutive Dry Days** (D), defined as the maximum number of consecutive days in a year with less than 1mm of daily precipitation.

Unlike the temperature and precipitation components of the ACI, only one value of consecutive dry days per year is provided in GHCNDEX. Monthly values are obtained by the linear interpolation of annual values. The conversion of consecutive dry days to a percentage anomaly (denoted by ΔD) was done in the same manner as for the other components and then converted to a standardized anomaly. The time series of D_{std} is shown in Figure 3 below.

Figure 3. Consecutive Dry Days seasonal standardized anomalies.



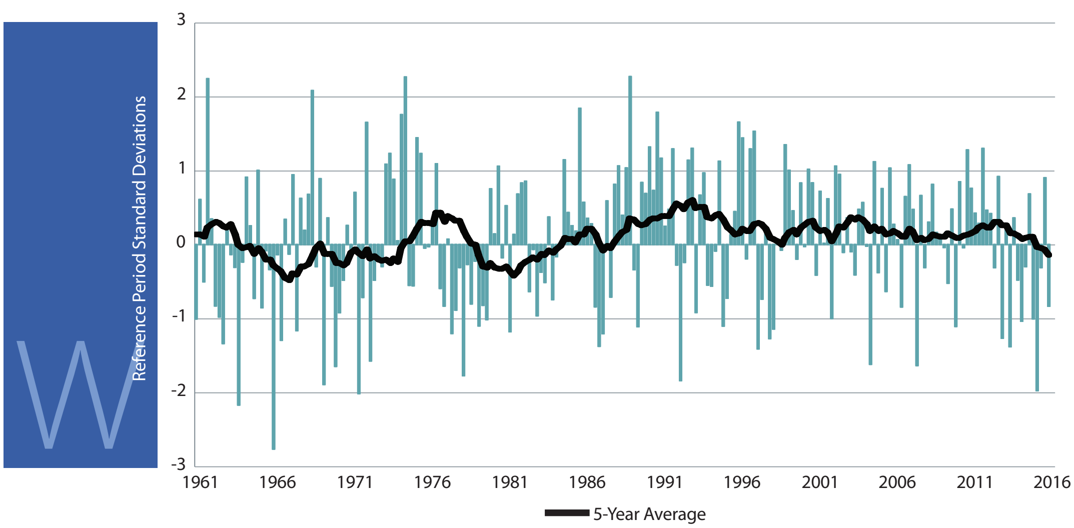
Like precipitation, the PDF of daily mean Wind (W) speed is right-skewed, and the changes of most interest occur in the high-value tail of the distribution.

Daily 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).[8] Wind Power is used because impacts from high winds (i.e., damages) have been shown to be proportional to *WP*, rather than to w (see *Phase I Report,*[9] *Sec. 5.6*). The GHCNDEX procedure is followed by finding the 90th percentile of wind power, *WP90*, over the reference period at each grid point and for each month. The change in the frequency of winds above *WP90* is then calculated for each month in the entire period, and expressed as a percent anomaly. That is, this componant is computed as

$$\Delta W = (\Delta WP90/WP90_{ref})$$

The time series of W_{std} is shown below.

Figure 4. Wind Power seasonal standardized anomalies.



7 The National Centers for Environmental Prediction (NCEP) reanalysis data, done in conjunction with the National Center for Atmospheric Research (NCAR), (Kalnay et al., "NCEP/NCAR 40-Year Reanalysis Project," *Bulletin of the American Meteorological Society*, 77, 437-470, 1996) is provided by the National Oceanic and Atmospheric Administration's Oceanic and Atmospheric Research/Earth System Research Laboratory Physical Sciences Division in Boulder, Colorado, USA.

8 A constant air density is used because the variance in air density is statistically insignificant when compared to the variations in wind speed cubed.

9 Solterra Solutions, op. cit.

S

Sea level (S) measurements are available on a monthly basis via tide gauges located at over 100 permanent coastal stations in Canada and the United States.[10]

A quality control procedure eliminated many of these on the basis of incomplete data (records starting after 1970 and/or more than one-third of the monthly values missing), leaving 76 stations with reliable time series for further analysis. The tide gauges measure sea level relative to the land below, but because the land may be moving, the ACI sea level component measures the combined effect on coastal shorelines of the generally rising seas and the rising or falling land.

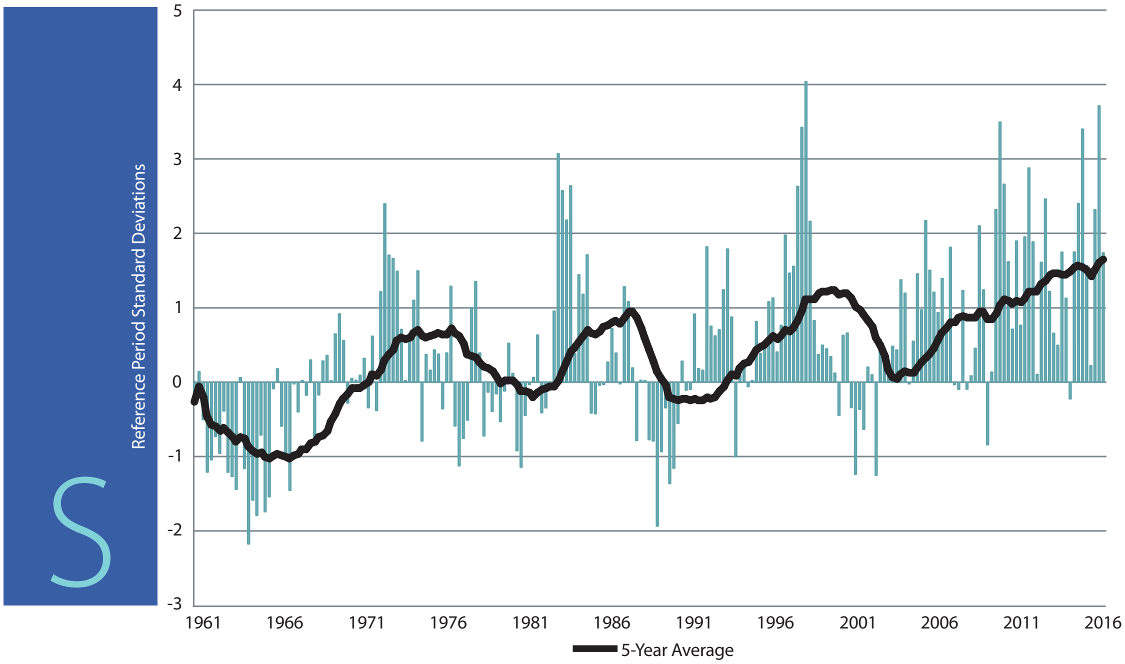
As for the other five components, sea level changes at each coastal station are converted to standardized anomalies per the equation

$$S_{std} = \Delta S / \sigma_{ref}(S)$$

Note that $\sigma_{ref}(S)$ is calculated on a monthly basis, from the reference period values of S (e.g., 30 values for January over 1961-90). Calculating the mean of S_{std} over all stations results in the time series shown in Figure 5.

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

Figure 5. Sea Level seasonal standardized anomalies.



Combining the Components

For the purpose of combining the six components, the use of standardized anomalies provides an effective means of combining these indicators in a straightforward and meaningful manner. The approach allows such inherently different quantities to be combined in a single index, while preserving the accuracy of the components. For any individual indicator, the standardized anomaly corresponds to how unusual that month's/season's value is, compared to the reference period mean and standard deviation for that month/season. Hence, each component is in units of the standard deviation of that quantity, and the notation used for sea level, i.e., S_{std}, is used for each component. This follows the strategy of Hansen et al.'s (1998) Common Sense Climate Index.[11]

As an example, consider the temperature component *T90*, which describes the upper tail of the distribution of daily temperatures. Because temperatures (and also the exceedances represented by *T10* and *T90*) are approximately normally distributed, about one-third of the time one expects that $T90_{std}$ will be outside the interval ±1, and one-sixth of the time it will be greater than +1. But if it exceeds +2, this is indicative of a rare event, because it is expected only 2.5 percent of the time. Values exceeding +3 are very rare, and expected only approximately 0.125 percent of the time. Hence, the value of $T90_{std}$ is a direct reflection of the rarity of the events it tracks.

When it comes to the ACI, constructed as a mean of the six components, the likelihood of a value exceeding 1 or less than -1 is much lower than for an individual component because the reference period standard deviation for the combined index is around 0.45 (depending on region) compared to 1 for each component. Nevertheless, for ease of comparison, the ACI and the five-year average are shown on the same scale as the components in Figure 6 (and Appendices 1 and 2). The number of standard deviations for the composite ACI is around 2.2 (1 / 0.45) times the number that the component scale would indicate. It should be kept in mind, however, that the exceedance probabilities (as discussed above) decrease much faster as values move further in the tail.

For all components, a positive variation reflects an increase in climate-related extremes and thus increases the value of the Index (except in the case of *T10*, whose sign is reversed as explained above). The final expression for the ACI is then:

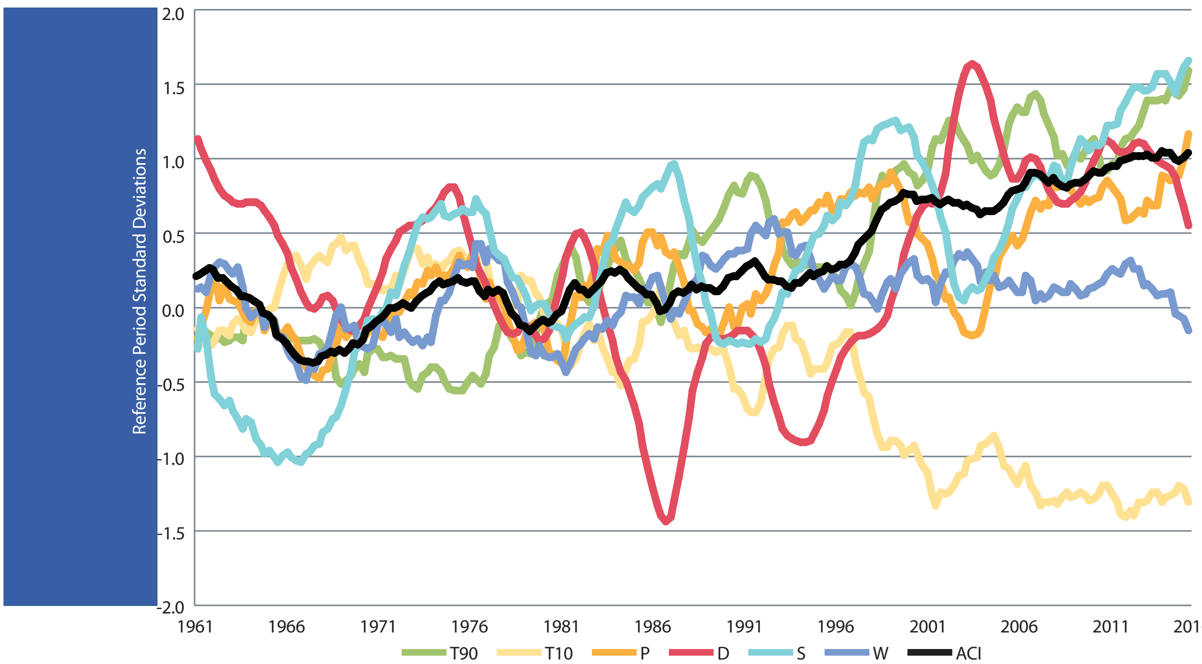
$$ACI = mean\ (T90_{std} - T10_{std} + P_{std} + D_{std} + W_{std} + S_{std})$$

11 Hansen, J., M. Sato, J. Glascoe, and R. Ruedy, "A common-sense climate index: Is climate changing noticeably?" *Proceedings of the National Academy of Sciences*, April 1998.

Please note that the Central Arctic Region (CAR) does not have a Sea Level component due to a lack of complete historical data, and the Midwest (MID) does not have a Sea Level component because it has no ocean coastline. For these regions, the ACI is calculated as the mean of the other five components.

Figure 6 below shows each of the components as a standardized anomaly.

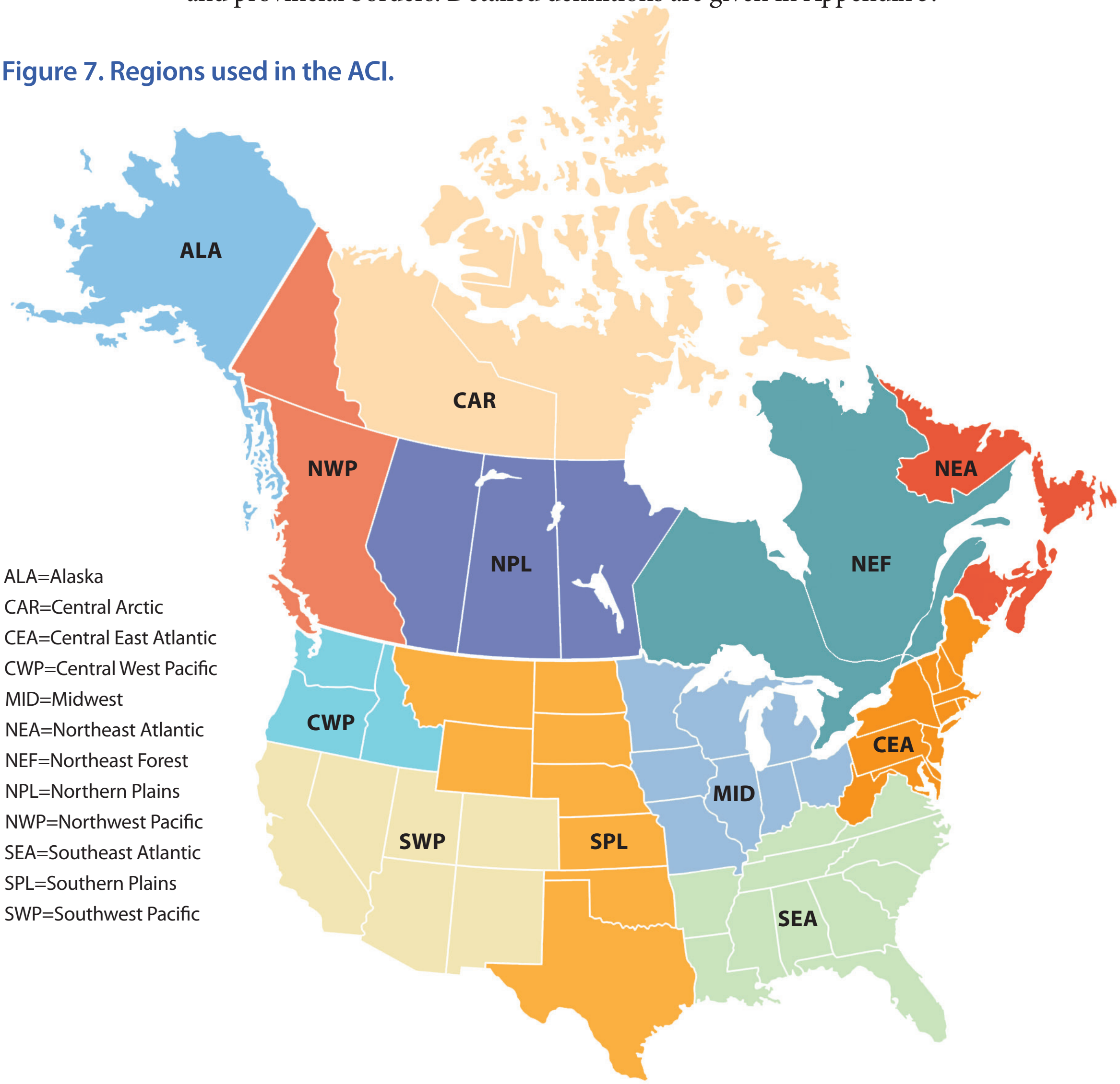
Figure 6. Seasonal five-year moving averages of components used in the ACI.



Region Map

Figure 7 below shows the 12 regions used for the ACI; these regions are defined along state and provincial borders. Detailed definitions are given in Appendix 3.

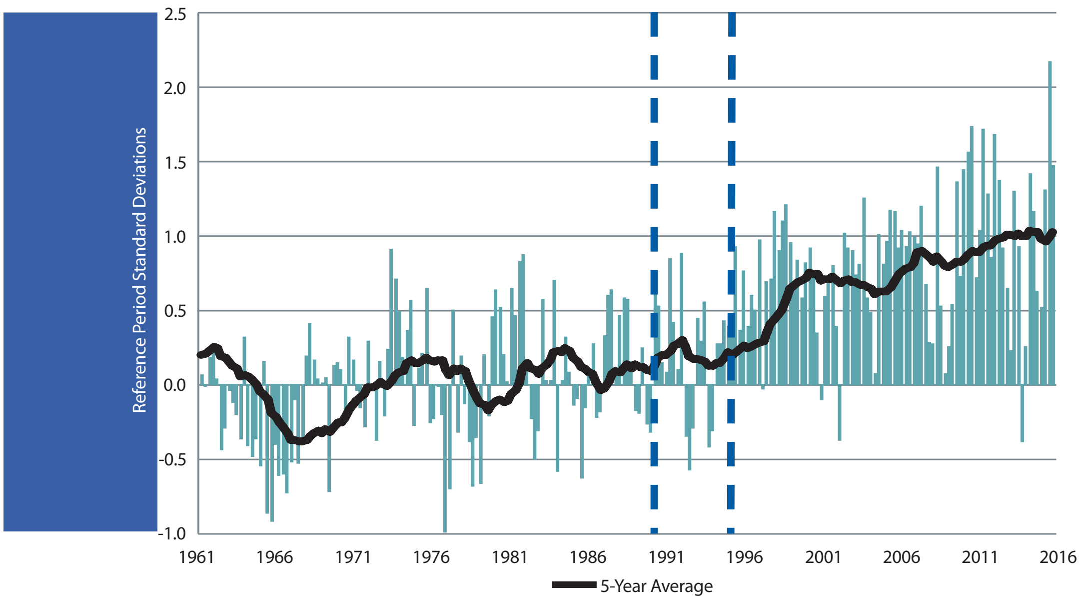
Figure 7. Regions used in the ACI.



Actuaries Climate Index Values

Figure 8 shows results for the Actuaries Climate Index by season for Canada and the United States. The most recent five-year moving average using data through winter 2016 (February) is at about one standard deviation above the mean.

Figure 8. The Actuaries Climate Index for the United States and Canada.



By definition, the ACI averages zero over the 1961-1990 reference period. The graph shows that the average ACI continued to be near zero until about 1995, after which all but four seasons have had a positive ACI. The dotted line at 1990 indicates the end of the reference period. The dotted line at 1995 is the first place where the moving five-year average is after the reference period. Note the frequency of positive bars, indicating more frequent climate extremes, after 1995.

Graphs by region similar to the above are shown in Appendix 1. These graphs show that the ACI has generally been higher in Canada than in the United States since 2012. The Index in Canada is driven upward primarily by the Northeast Atlantic (NEA) and the Northwest Pacific (NWP). In the United States, the highest Index values have been in the Southern Plains (SPL) and the Central East Atlantic (CEA), while the Alaska (ALA) region has had consistently negative ACI values since 2008, primarily due to falling sea levels there as the land rebounds upward from melting glaciers.

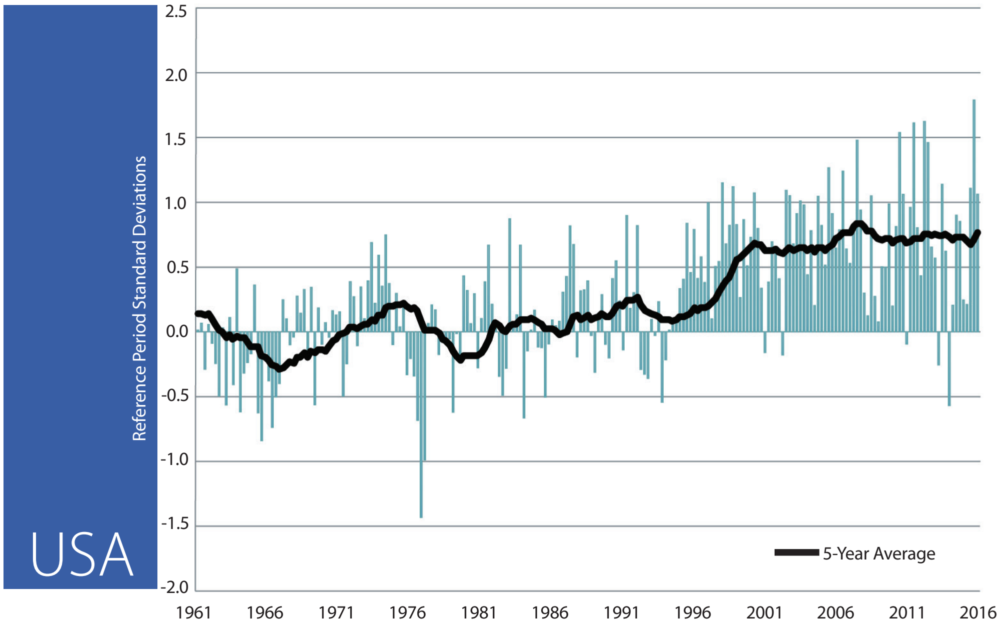
It should be noted that indices at the country and combined countries levels are calculated independently of the smaller regions, based on the standardized anomaly for the country or the combined countries. Due to averaging climate variability over such large areas, the standard deviation tends to be lower, resulting in standardized anomalies that can be larger than for any individual sub-region. For example, the latest five-year moving average in Figure 8 is higher than for any of the sub-regions shown in Appendices 1a-1g. It should also be noted that Alaska is only included at the combined country level; the Index for the United States is only for the contiguous lower 48 states (Hawaii is excluded due to its small size). Similarly, the seasonal Index is calculated independently of the monthly Index, and the standard deviations tend to be lower on a seasonal basis than on a monthly basis. As a result, the seasonal ACI tends to be higher than the monthly ACI, and the five-year averages are consistently higher for the seasonal ACI than for the monthly ACI since around 1990.

Graphs by region and component, similar to Figure 6, are shown in Appendix 2. These graphs show that the ACI in the past 20 years has been driven upward primarily by more warm temperatures (*T90*) and fewer cold temperatures (*T10*) in almost every region, and higher sea levels (*S*), especially along the Atlantic (*NEA, CEA, SEA*) and Gulf coasts (*SPL*), partially offset by falling sea levels in Alaska (*ALA*) and the Hudson Bay (*NPL*) due to the rising land in those places. Heavy precipitation (*P*) in many parts of Canada and drought (*D*) in many parts of the United States have also contributed to the higher index.

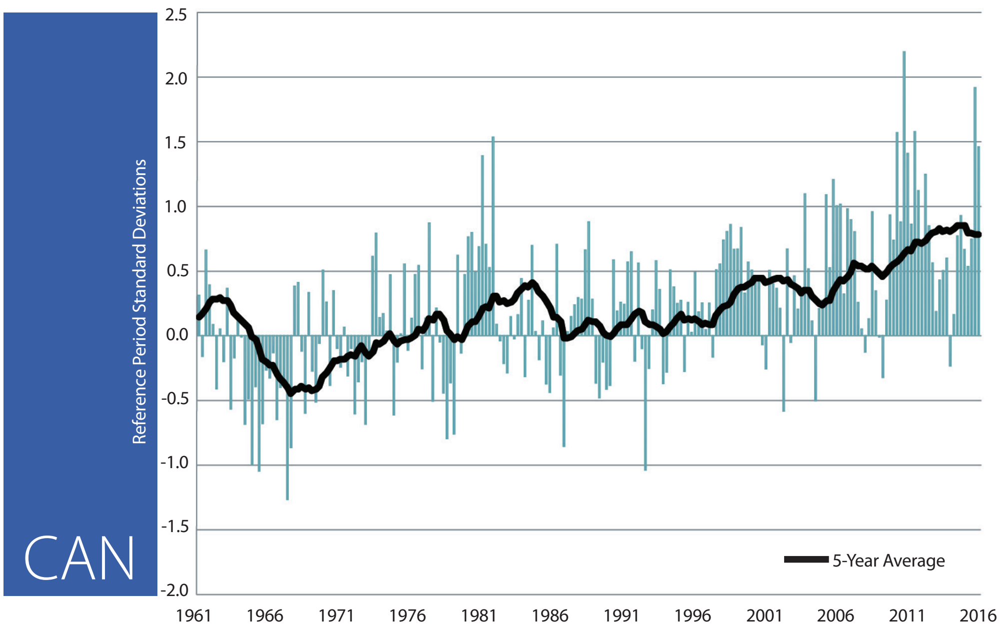
Appendix 4 provides further explanation of the considerations involved in defining the ACI methodology. Appendix 5 lists the participants in the Index development process. Appendix 6 summarizes the review by the National Oceanic and Atmospheric Administration of the Actuaries Climate Index datasets and methodology. Further details of the Index calculations can be found in the document, *Sample Calculations for the Actuaries Climate Index*, which illustrates the magnitudes of the values by component.

Appendix 1—ACI Graphs by Region

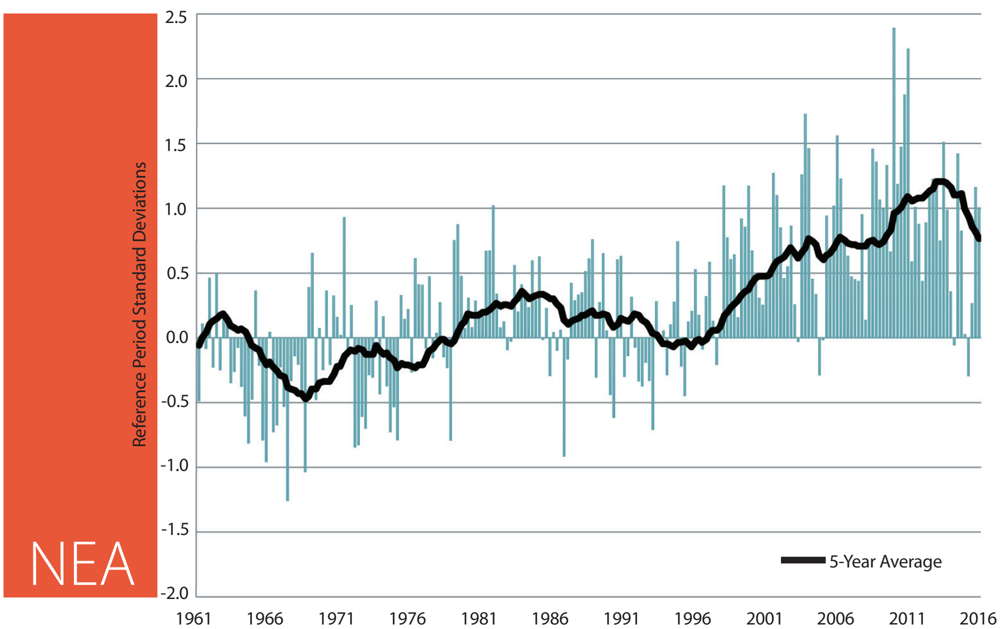
Appendix 1a. Actuaries Climate Index–United States.



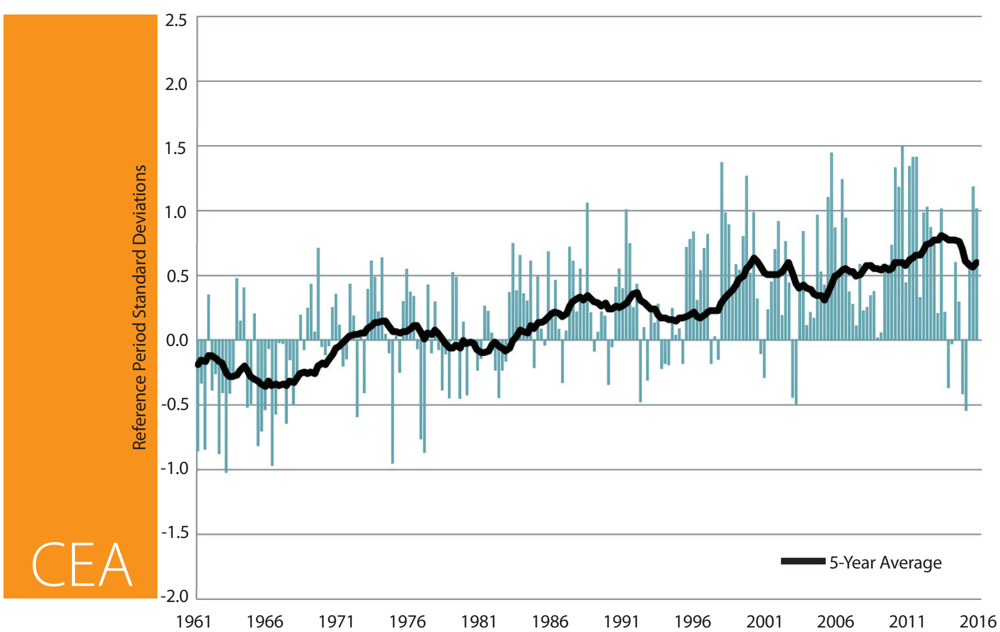
Appendix 1b. Actuaries Climate Index–Canada.



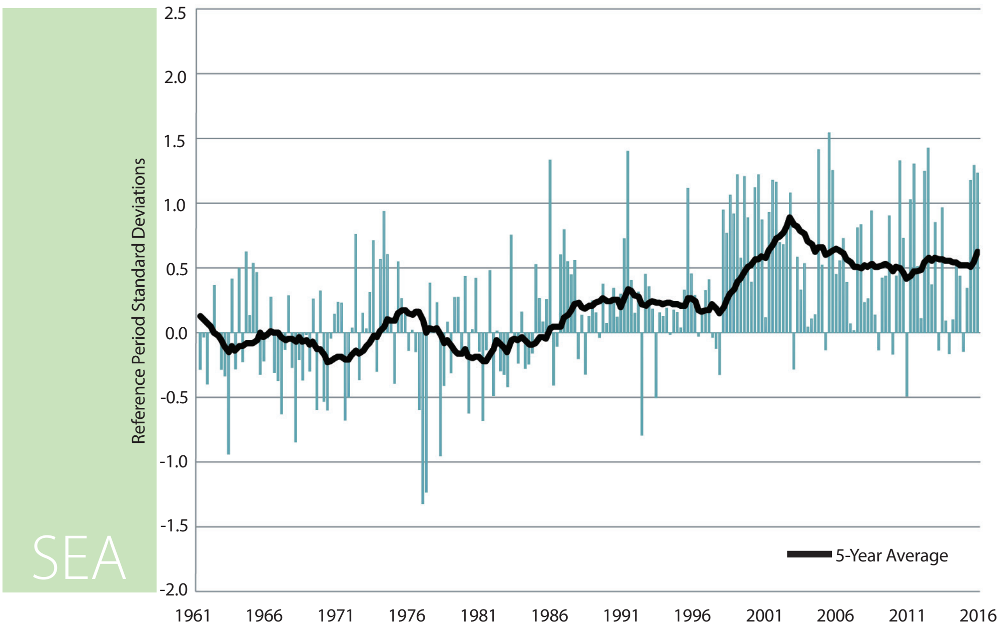
Appendix 1c. Actuaries Climate Index–Northeast Atlantic.



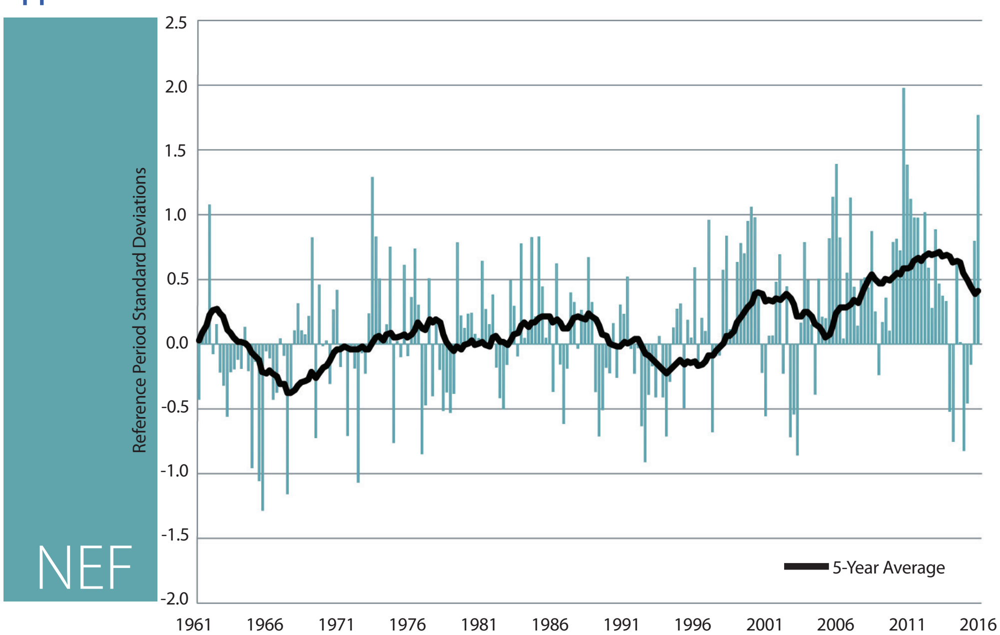
Appendix 1d. Actuaries Climate Index–Central East Atlantic.



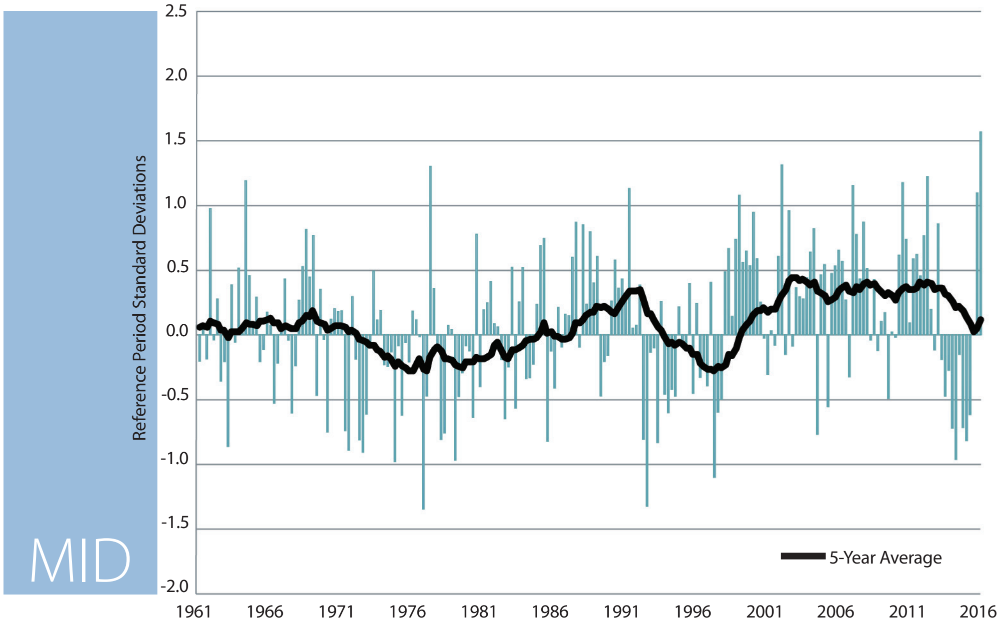
Appendix 1e. Actuaries Climate Index–Southeast Atlantic.



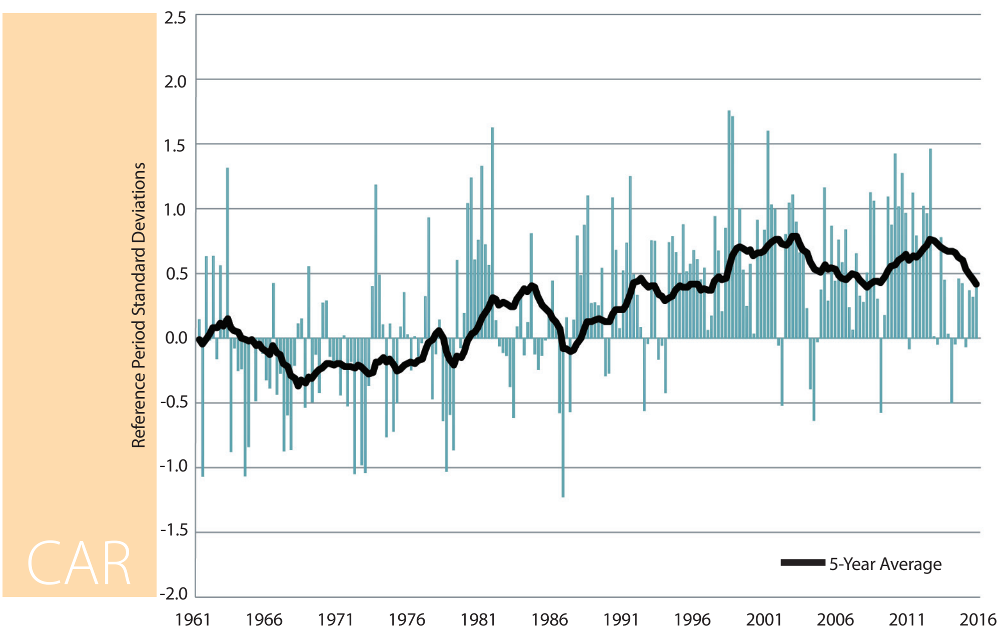
Appendix 1f. Actuaries Climate Index–Northeast Forest.



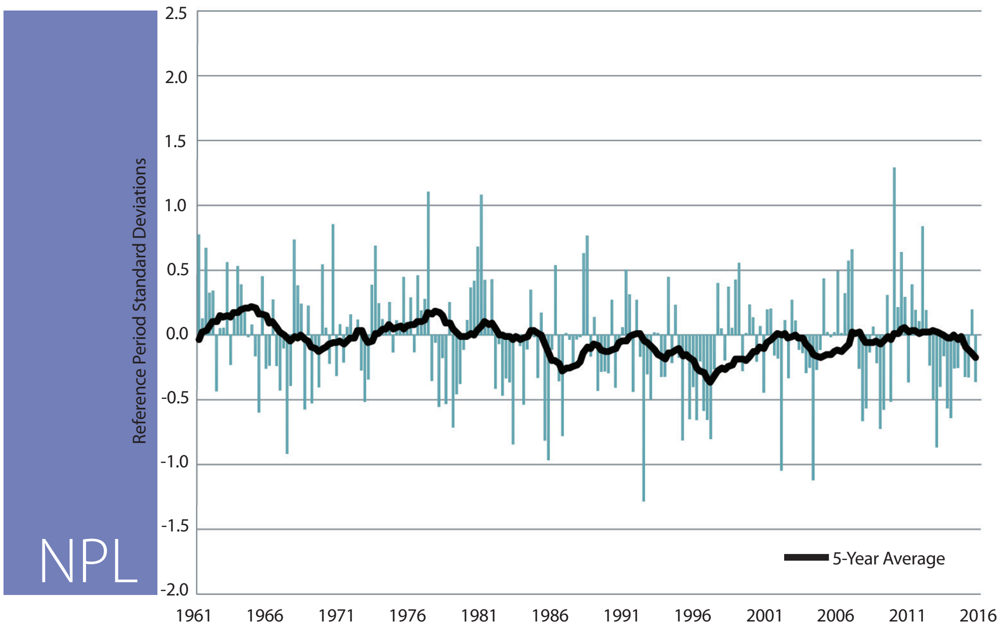
Appendix 1g. Actuaries Climate Index–Midwest.



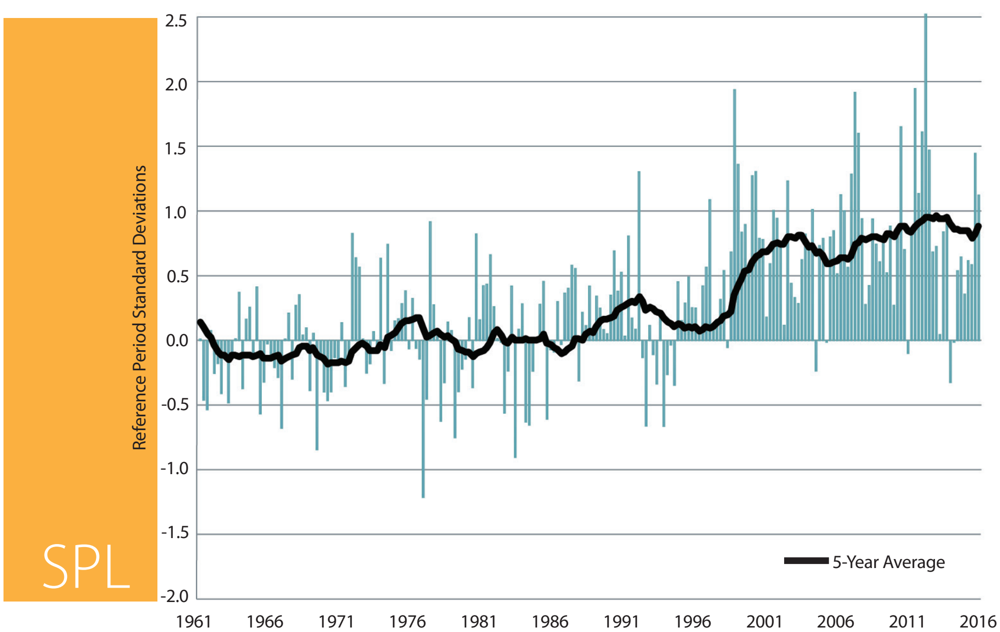
Appendix 1h. Actuaries Climate Index–Central Arctic.



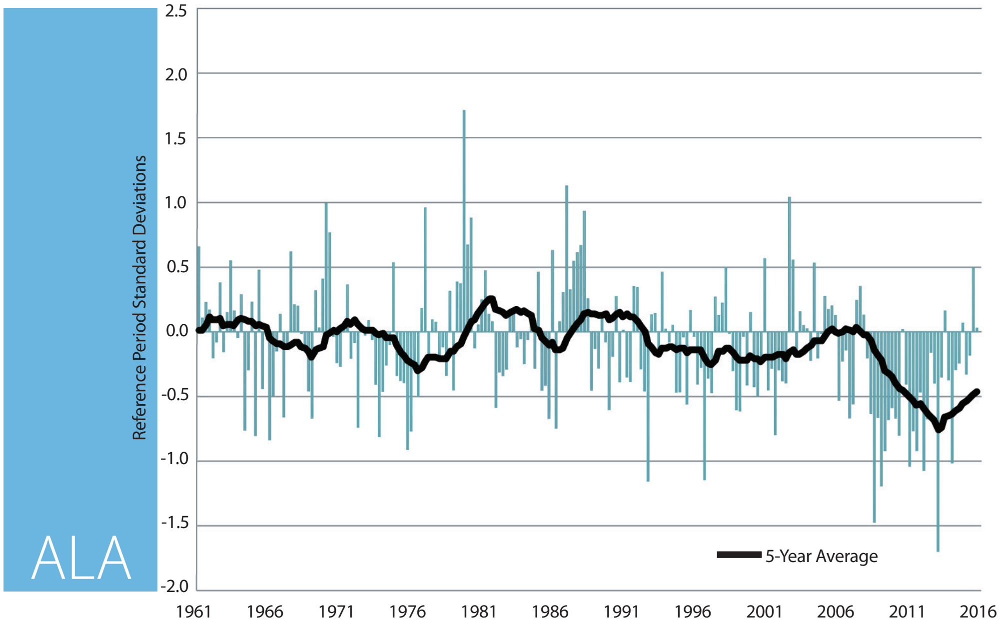
Appendix 1i. Actuaries Climate Index–Northern Plains.



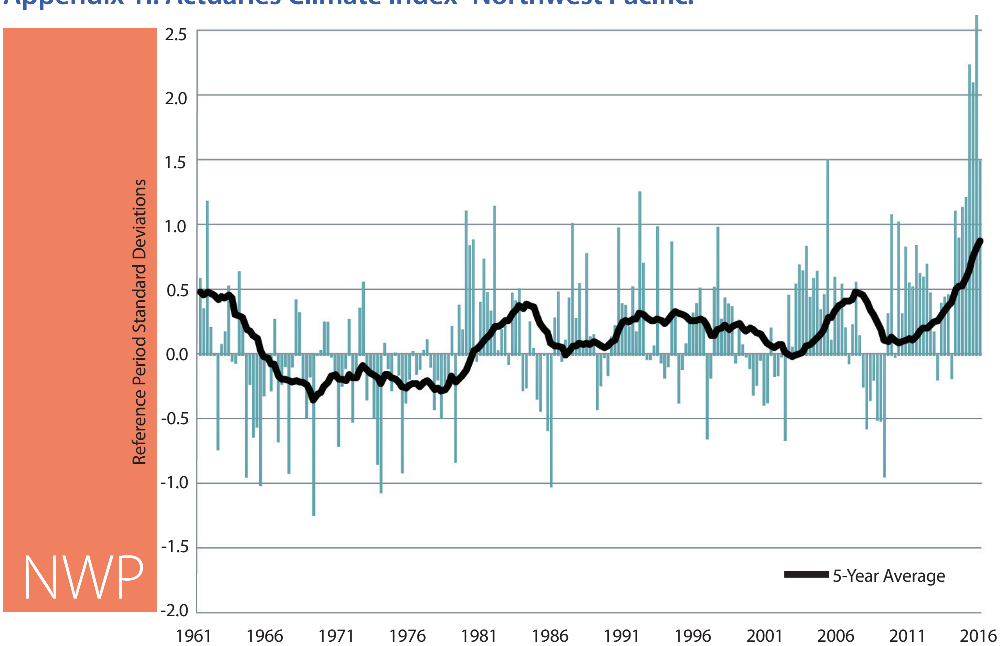
Appendix 1j. Actuaries Climate Index–Southern Plains.



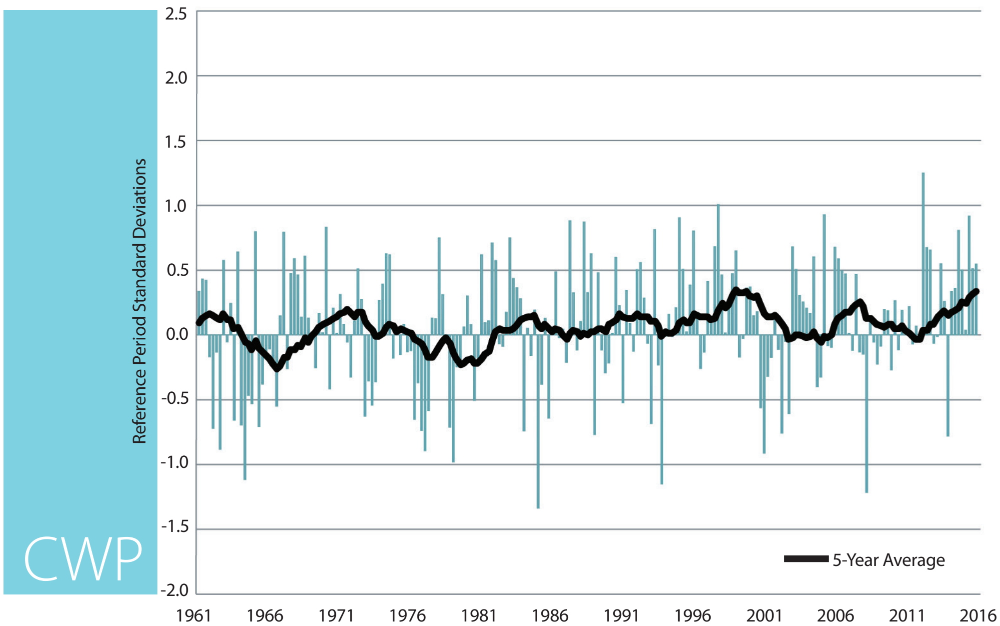
Appendix 1k. Actuaries Climate Index–Alaska.



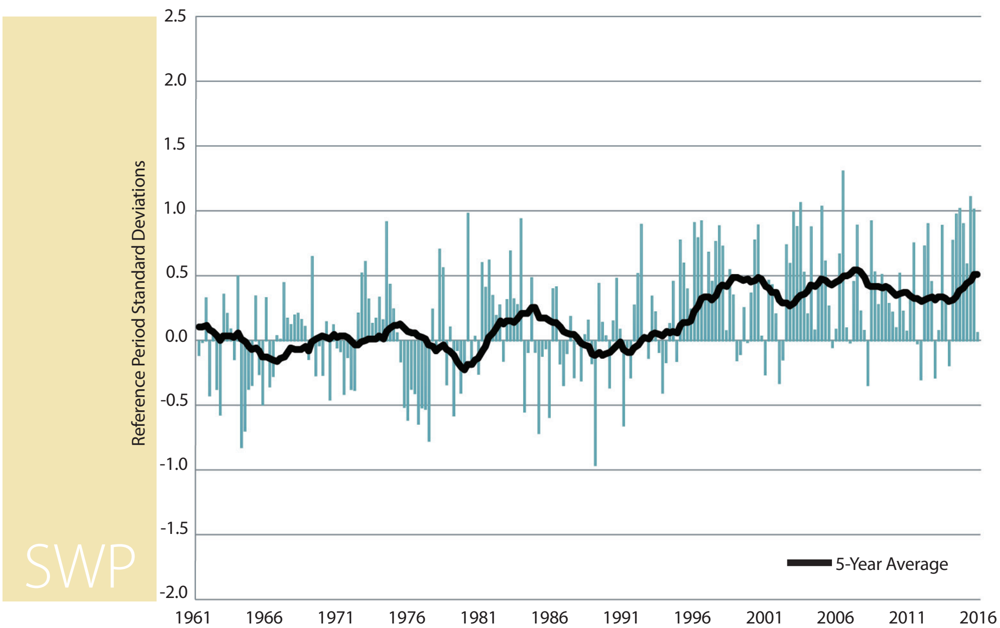
Appendix 1l. Actuaries Climate Index–Northwest Pacific.



Appendix 1m. Actuaries Climate Index–Central West Pacific.

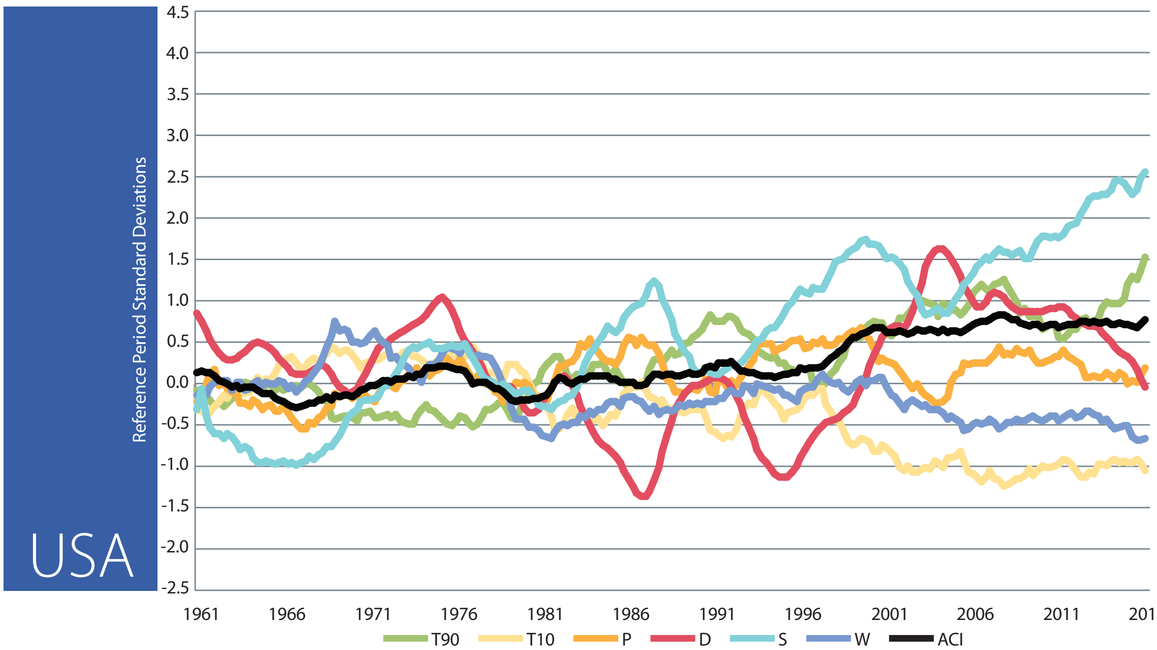


Appendix 1n. Actuaries Climate Index–Southwest Pacific.

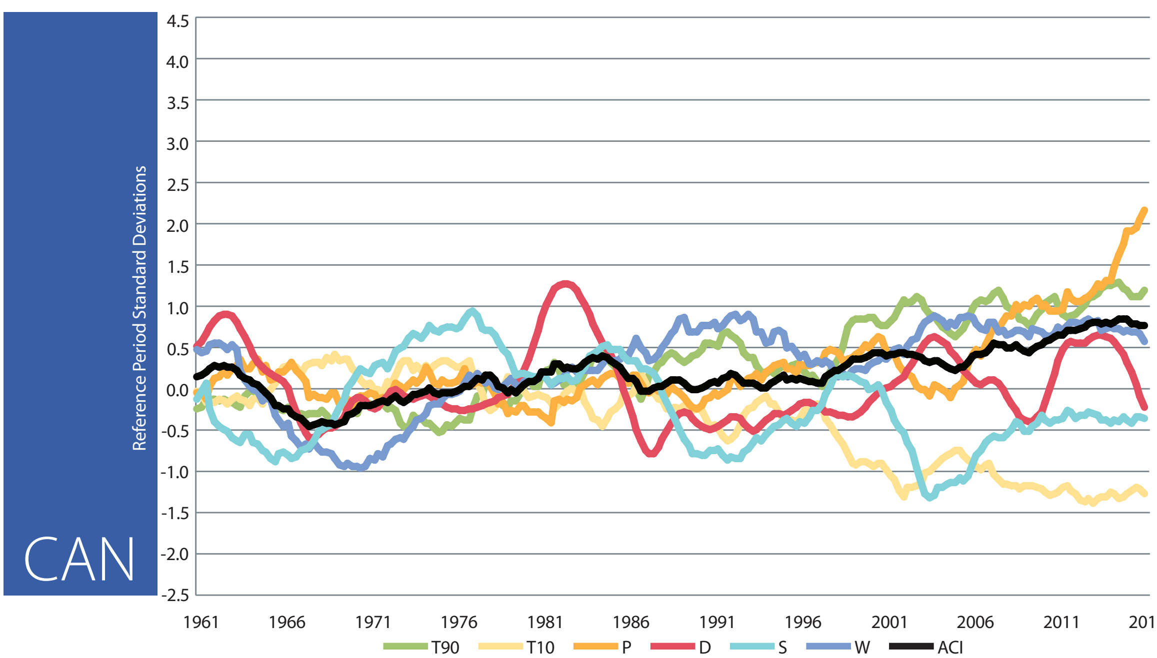


Appendix 2—ACI Graphs of Regions by Component: 5-Year Average

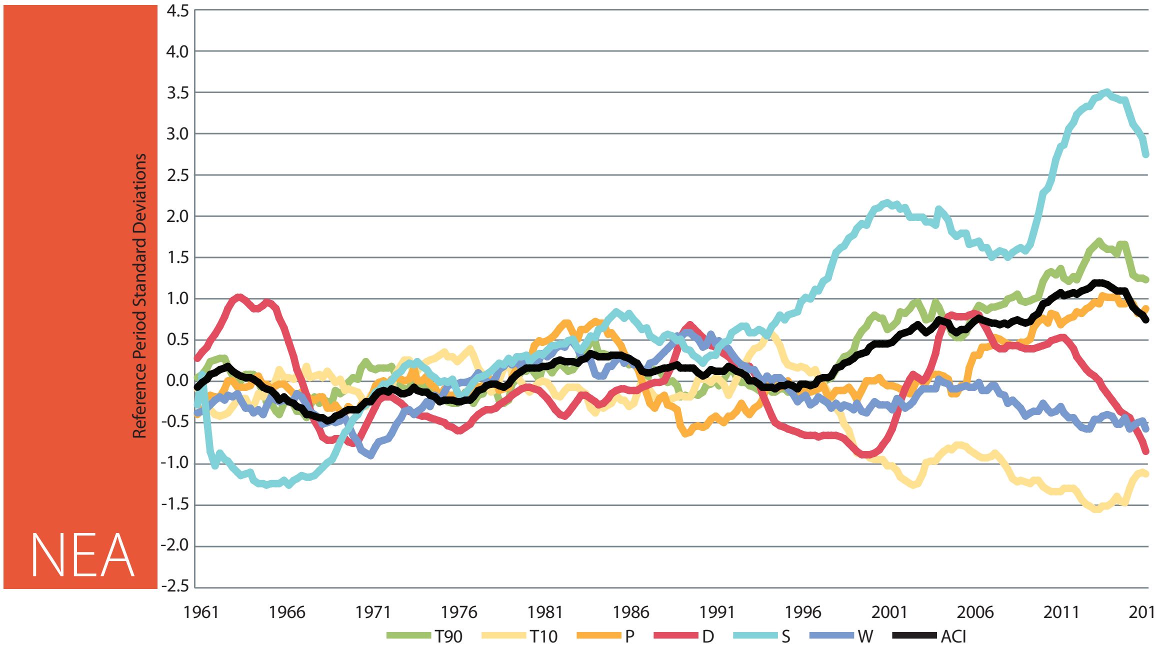
Appendix 2a. Actuaries Climate Index–United States by Component.



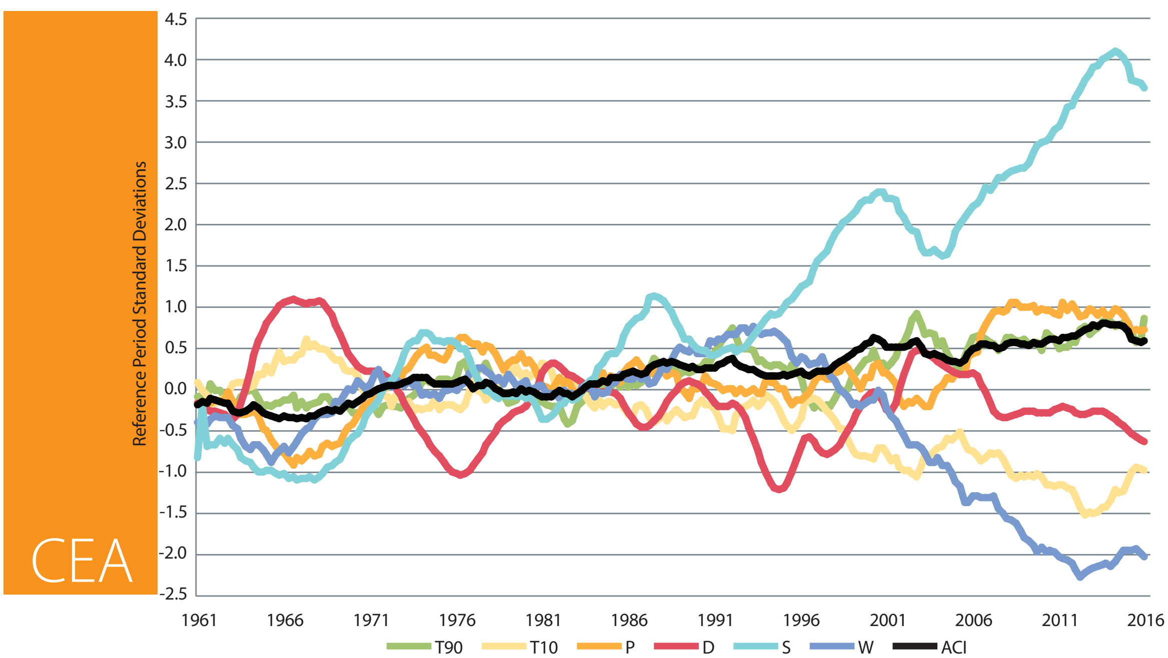
Appendix 2b. Actuaries Climate Index–Canada by Component.



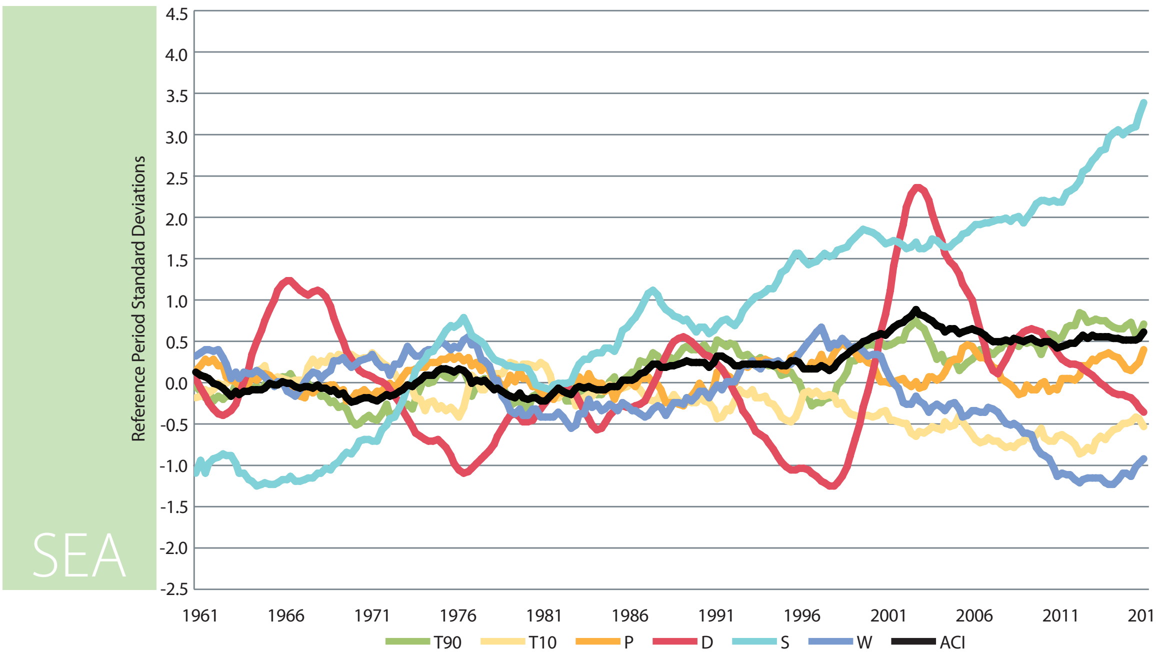
Appendix 2c. Actuaries Climate Index–Northeast Atlantic by Component.



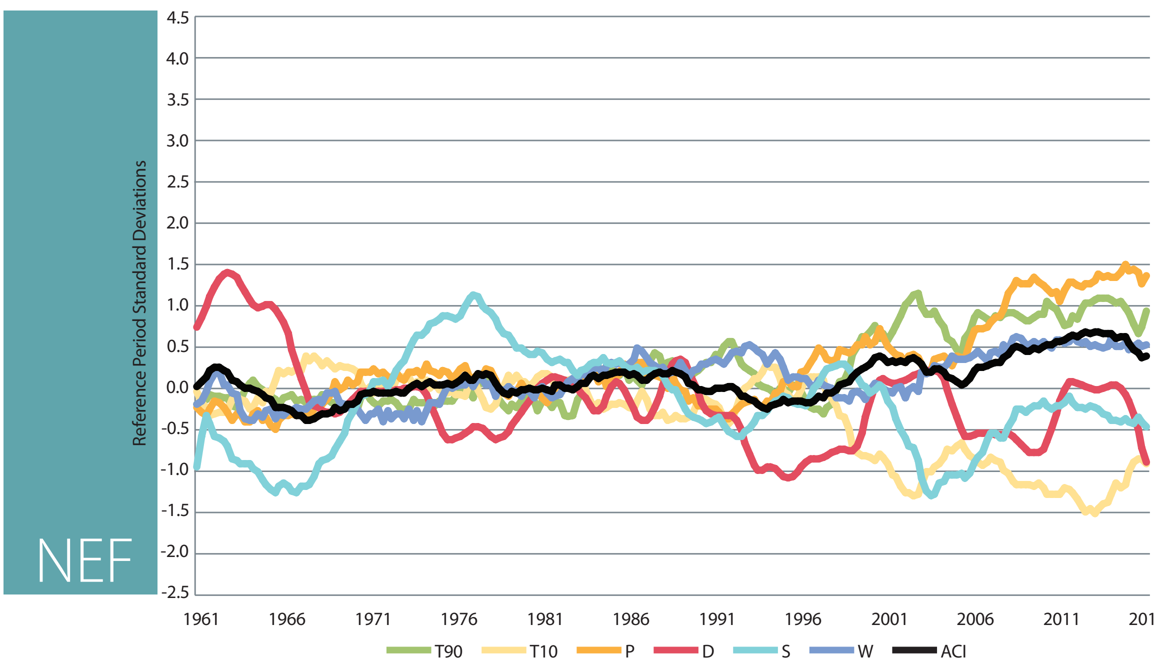
Appendix 2d. Actuaries Climate Index–Central East Atlantic by Component.



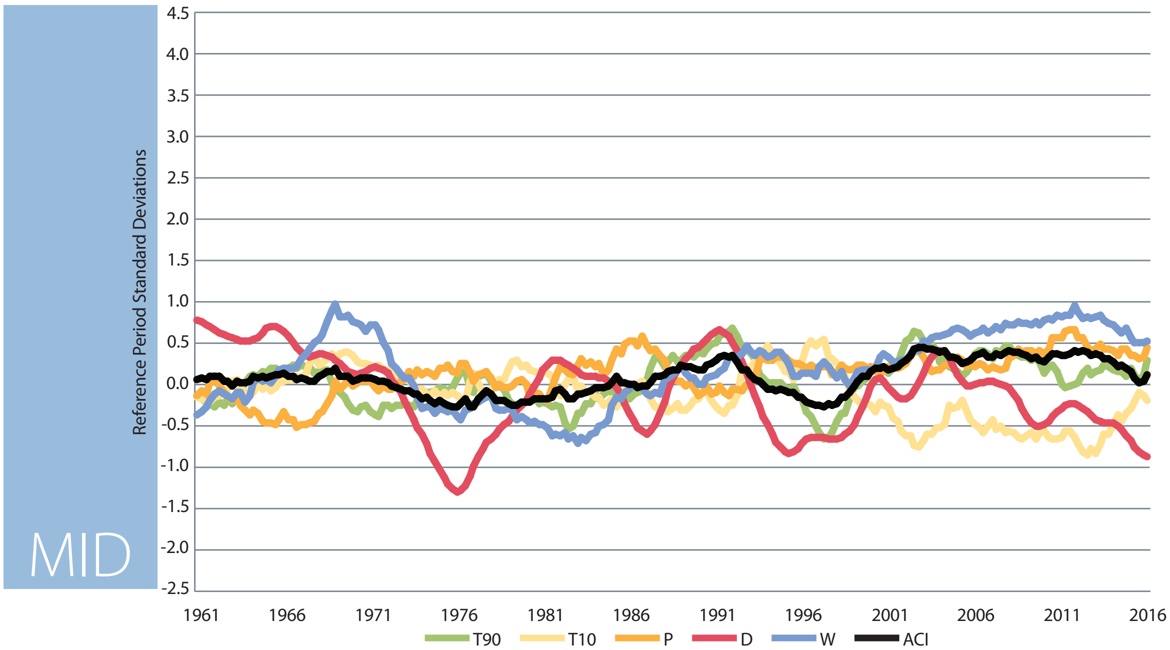
Appendix 2e. Actuaries Climate Index–Southeast Atlantic by Component.



Appendix 2f. Actuaries Climate Index–Northeast Forest by Component.

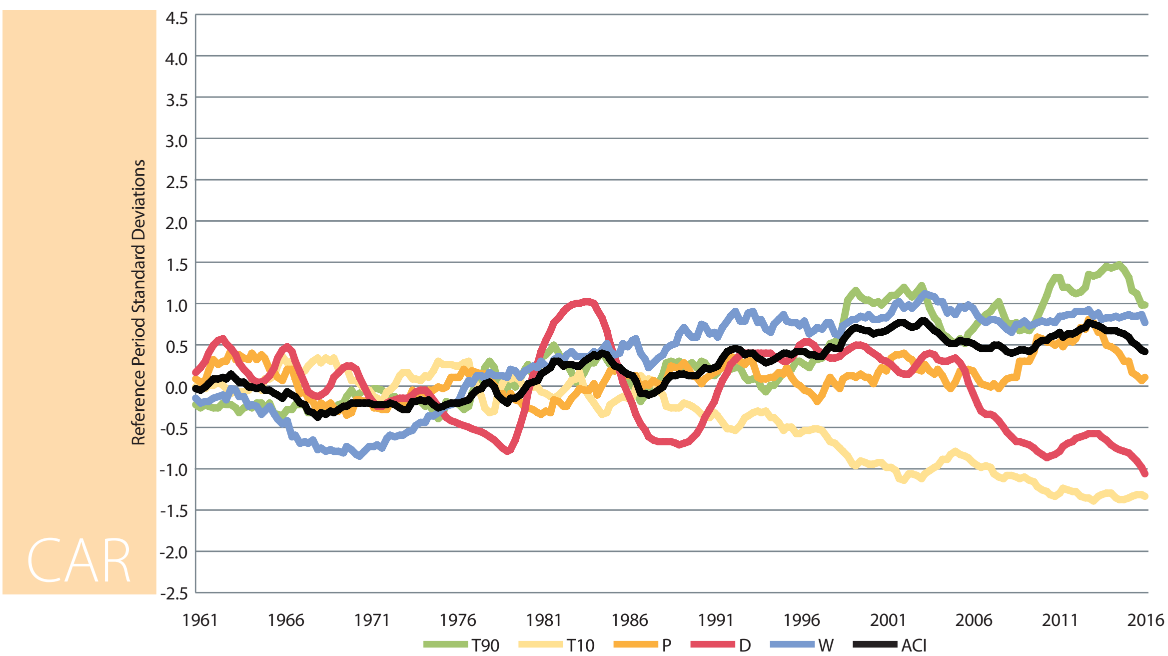


Appendix 2g. Actuaries Climate Index–Midwest by Component.



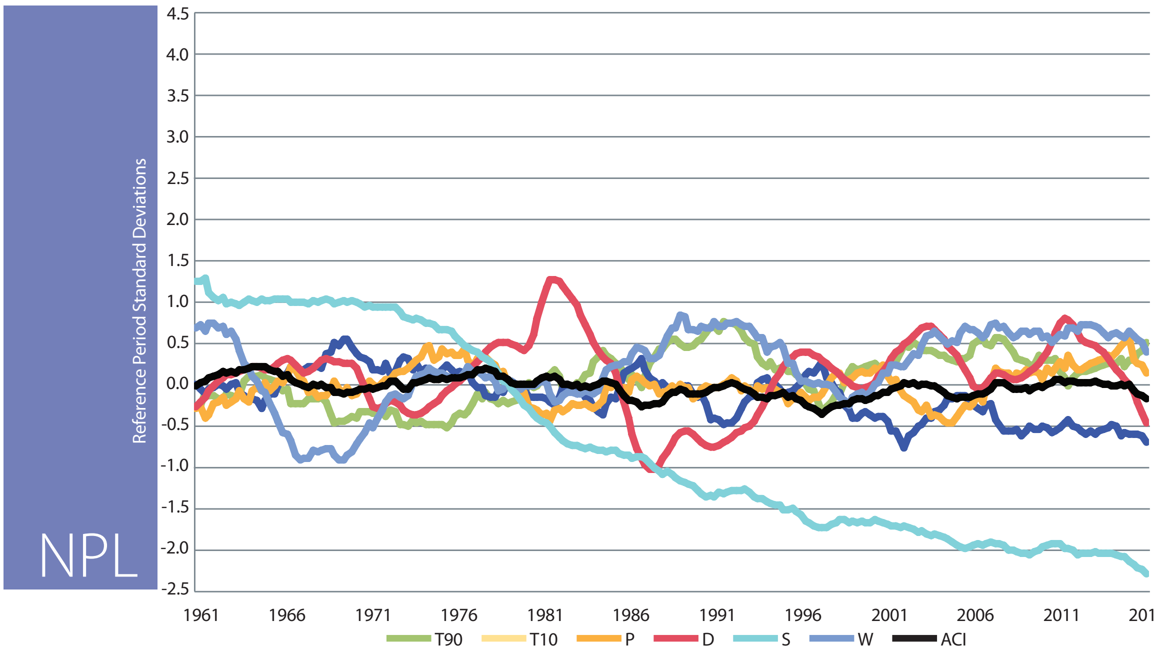
No Sea Level Component for MID

Appendix 2h. Actuaries Climate Index–Central Arctic by Component.

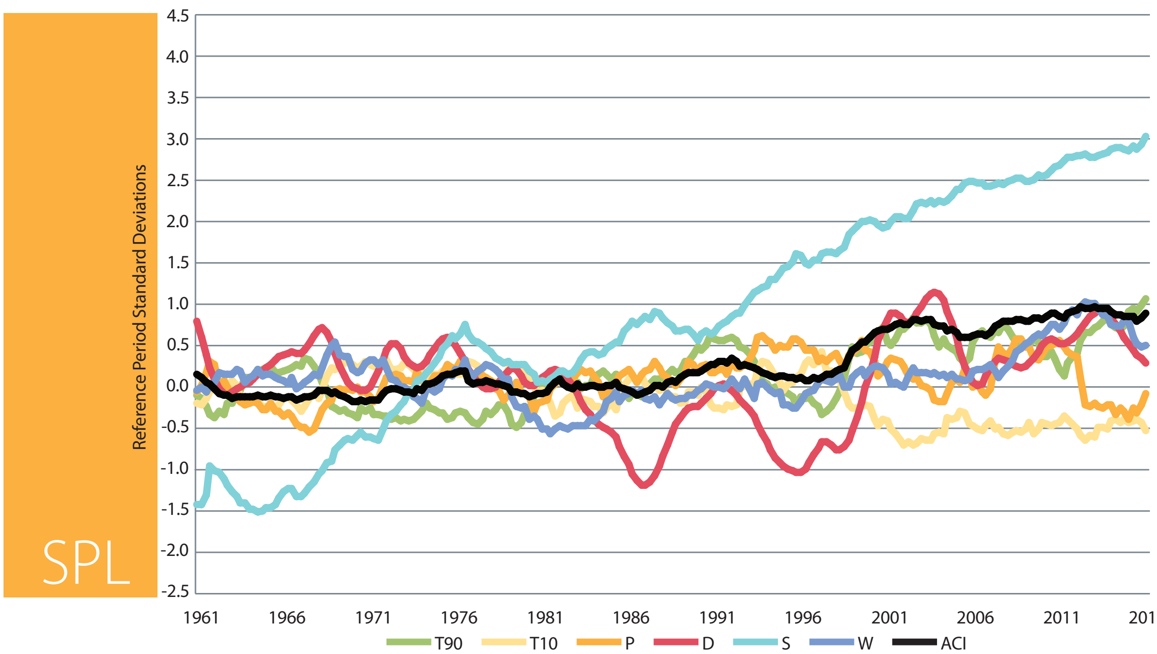


No Sea Level Component for CAR

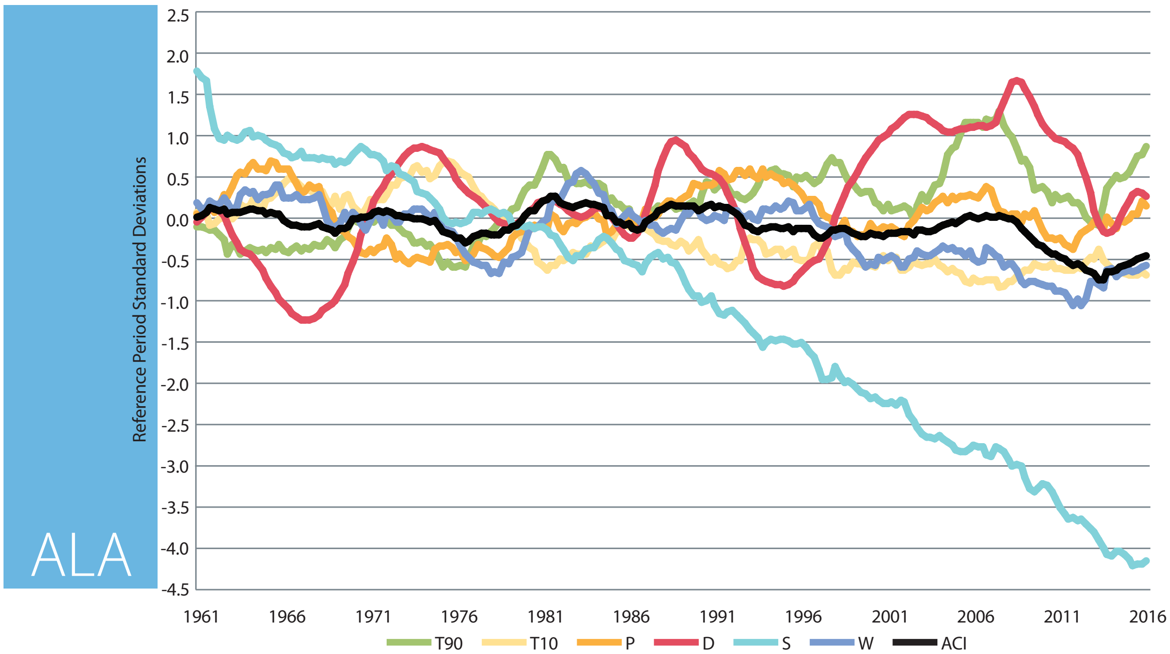
Appendix 2i. Actuaries Climate Index–Northern Plains by Component.



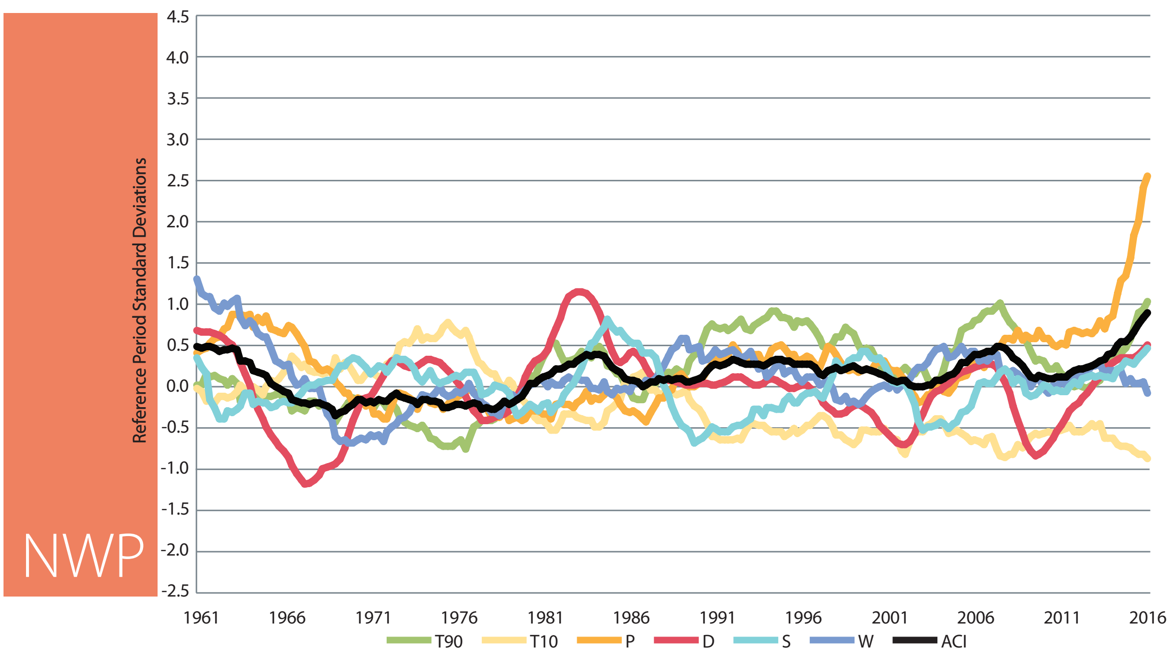
Appendix 2j. Actuaries Climate Index–Southern Plains by Component.



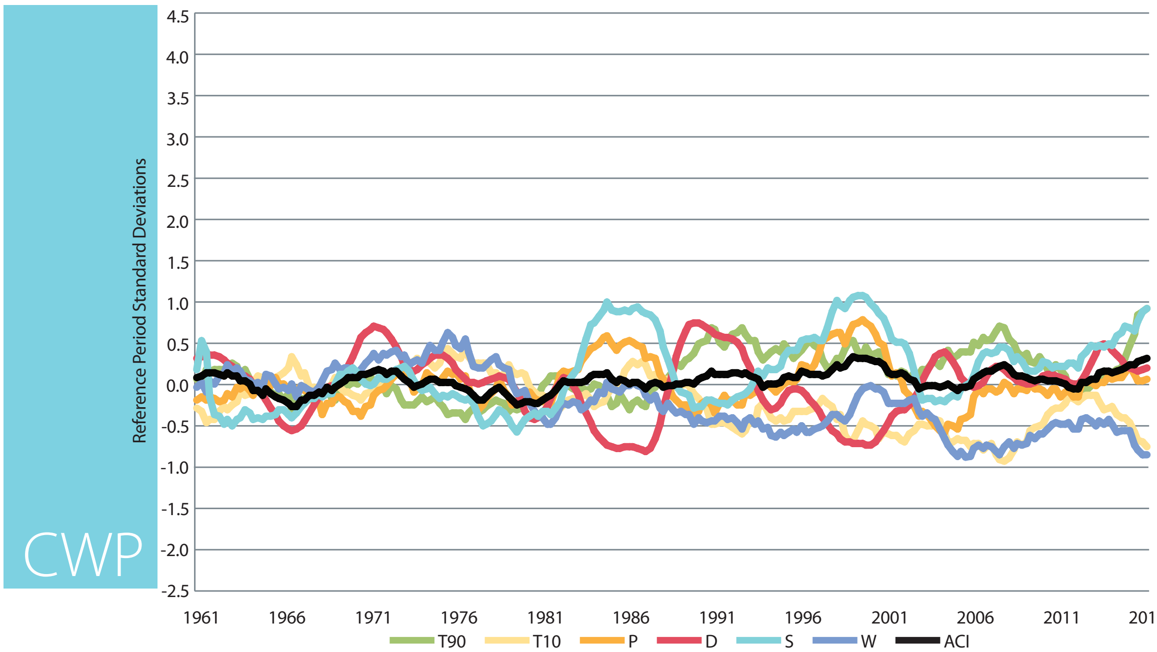
Appendix 2k. Actuaries Climate Index–Alaska by Component.



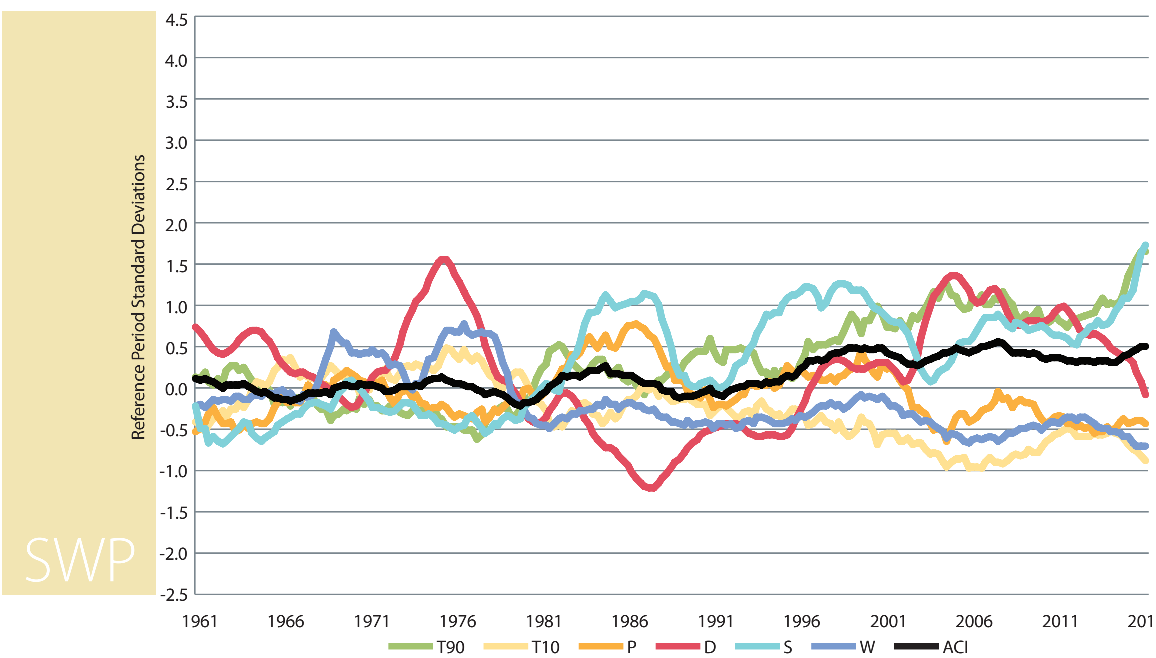
Appendix 2l. Actuaries Climate Index–Northwest Pacific by Component.



Appendix 2m. Actuaries Climate Index–Central West Pacific by Component.



Appendix 2n. Actuaries Climate Index–Southwest Pacific by Component.



Appendix 3—Region Definitions

REGION	DESCRIPTION	STATES/PROVINCES
UNITED STATES		
ALA	Alaska	AK
CEA	Central East Atlantic	CT, DC, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VT, WV
CWP	Central West Pacific	ID, OR, WA
MID	Midwest	IA, IL, IN, MI, MN, MO, OH, WI
SEA	Southeast Atlantic	AL, AR, FL, GA, KY, LA, MS, NC, SC, TN, VA
SPL	Southern Plains	KS, MT, ND, NE, OK, SD, TX, WY
SWP	Southwest Pacific	AZ, CA, CO, NM, NV, UT
CANADA		
CAR	Central Arctic	NT, NU
NEA	Northeast Atlantic	NB, NL, NS, PE
NEF	Northeast Forest	ON, QC
NPL	Northern Plains	AB, MB, SK
NWP	Northwest Pacific	BC, YT

Regions are those used in the U.S. National Climate Assessment, with names changed to be internally consistent here, and based on similar criteria in Canada.

Values for each region are based on grid level data, where each grid is 2.5 degrees latitude by 2.5 degrees longitude (within the land and coastal area of the U.S. and Canada from 25 to 75 degrees North latitude and 50 to 170 degrees West 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.

Appendix 4—ACI Development Considerations

In the course of developing the ACI methodology, there were a number of considerations that warranted extended deliberations. The purpose of this appendix is to summarize those considerations and to explain the decisions around them.

The need for the actuarial community to add a climate index to those that already exist

Section 5 of the Phase I report (see footnote 1, page 9) lists a number of climate indices that already exist, including one that focuses on climate extremes, the U.S. Climate Extremes Index (CEI).[12] Despite some similar data sources, it was decided that the ACI should have a significantly different formulation than the CEI. A secondary consideration was the desire to create an index with the flexibility to extend its reach beyond the United States and Canada.

The focus on United States and Canada

Initially, there was interest in creating a global set of indices. The strategy that emerged was to focus on the home countries of the sponsoring organizations, but in such a way that other international actuarial organizations could easily create an ACI for their region of interest, where similar data exists. The necessary historical data exists in many other parts of the world, though quality and time scales covered vary by location.

Creating indices at the country and total level independently of the indices by region

Rather than taking averages or weighted averages of the regional ACIs, the broader indices are calculated directly using standardized anomalies for all the grids in these larger regions. As noted on page 16, this calculation can result in index values (standardized anomalies) that are higher for the combined regions than for any sub-region. While this feature may require additional explanation to users, it is consistent with the way the regional indices are calculated.

12 For an overview, go to the U.S. Climate Extremes Index's website.

Subtracting *T10* in the calculation of the ACI

There was discussion about eliminating *T10* from the formula or including it with a positive rather than negative sign. Because cold temperatures have been declining by about the same magnitude as warm temperatures have been increasing, adding them together would have nearly eliminated the effect of temperature on the Index, whereas both the reduction in *T10* (left tail) and the increase in *T90* (right tail) indicate a rightward shift of the whole temperature distribution. There are some significant negative impacts resulting from the decline in cold temperatures, such as less insect dieback and more thawing of permafrost, and the reduced cold also strengthens the impact of the increase in warm temperatures. There are also some beneficial aspects of the decrease in cold temperatures, but on balance it was concluded that a decline in cold temperatures should increase the Index, consistent with the other five components, which all tend to produce a higher Index when the negative impacts are increasing.

Excluding soil moisture

Versions of the ACI were produced during developmental stages that included a seventh component, soil moisture. This component is now excluded because the data was quite variable, and not always in directions consistent with temperature and precipitation movements. The inclusion of consecutive dry days was considered to adequately cover the risk of drought.

Defining the wind component

Hurricanes and tornados represent some of the most damaging events to society, yet a definition of extreme winds was chosen that includes much less damaging winds. The main reason for not specifically including some measure of the frequency of these most damaging winds is that they are short-lived and localized events relative to the seasonal time scale and large regions that are used in the ACI. Consideration was also given to selecting a higher percentile such as the 95^{th}, rather than the 90^{th}, but this would have added to the variability of the wind component. In any case, because the wind component looks at the frequency of winds that are above the 90^{th} percentile in the reference period, those frequencies will increase if there are more extreme wind events.

The use of standardized anomalies, which increased the complexity of the ACI and made it more difficult for a non-technical audience to understand

The standardized anomaly was used because the scales of the six components were quite different (high and low temperatures, heavy precipitation, consecutive dry days, wind power, and sea level); comparing each anomaly to its standard deviation produced measures by component that could reasonably be averaged together. The standardized anomaly is a common statistical technique in such situations.

The schedule of quarterly updates by season

The source data for the indices is updated on varying schedules, which means that complete source data through the end of the latest season for each component will not always be available. For example, the index for consecutive dry days is only updated once per year, and the other data sources are not all updated on the same schedule. The ACI update process will use the latest available update as a constant value to fill in any missing seasons, and will correct prior data points when actual data becomes available.

Appendix 5—Participants in the Index Development Process

Solterra Solutions:

Charles Curry, Ph.D.

Andrew Weaver, Ph.D.

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Actuaries Climate Index Working Group:

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Frank Grossman, FCIA, FSA

Yves Guérard, FCIA, FSA

Steve Kolk, ACAS, MAAA

Neil Leibowitz, FCAS, MAAA

Caterina Lindman, FCIA, FSA (Chair)

Karen Lockridge, FCIA, FSA

Vijay Manghnani, FCAS, MAAA

Stuart Mathewson, FCAS, MAAA

Tom Strickland, FCIA, FSA

Tom Taylor, EA, FSA, MAAA

Sponsoring Organization Liaisons:

American Academy of Actuaries: David J. Nolan; Bill Rapp

Canadian Institute of Actuaries: Les Dandridge

Casualty Actuarial Society: Cheri Widowski

Society of Actuaries: Dale Hall FSA, MAAA; Ronora Stryker ASA, MAAA

Note:
ACAS = Associate, Casualty Actuarial Society
ASA = Associate, Society of Actuaries
EA = Enrolled Actuary
FCAS = Fellow, Casualty Actuarial Society
FCIA = Fellow, Canadian Institute of Actuaries
FSA = Fellow, Society of Actuaries
MAAA = Member, American Academy of Actuaries

Appendix 6—Review of the Actuaries Climate Index by the National Oceanic and Atmospheric Administration

A team of scientists[13] at NOAA's National Centers for Environmental Information was asked to review an earlier version of this document. The agreed focus of their review was to evaluate the datasets and methods used to create the Index. The document summarizing their review follows this introduction.

We greatly appreciate the time and expertise provided by the review team, and their many helpful suggestions for improvement.

In response to the NOAA review, the following changes in methodology have been made or are under consideration:

- The Sea Level component in the version reviewed by NOAA included an adjustment to remove land movements from the tide gauge data. That adjustment has been removed.
- The use of the NOAA dataset as the source of sea level data is being considered.
- Alternative data sources for the Drought component are being considered.

13 The review was led by Karin Gleason, co-author of the U.S. Climate Extremes Index, which has some similarities to the Actuaries Climate Index.

A Data and Methods Review of the Actuaries Climate Index Development and Design Document

by Karin L. Gleason, Monitoring Branch Meteorologist; Derek S. Arndt, Monitoring Branch Chief; Michael A. Palecki, U.S. Climate Reference Network Science Project Manager; and David R. Easterling, Observations and Data Records Branch Chief

NOAA's National Centers for Environmental Information (NCEI)
Submitted April 2016
Final May 2016

I. SCOPE & TERMS

Scientists at NOAA's National Centers for Environmental Information (NCEI) were asked to evaluate the *Actuaries Climate Index - Development and Design* document which describes the motivation behind developing such an index, data and methods used to create each component as well as the rationale and method behind constructing a composite index. This review team was asked to evaluate the datasets used to construct the components of this index to ensure they are appropriate for this type of analysis as well as the methods used to construct the index, itself. The review team was not asked to evaluate the effectiveness of the index nor endorse it in any way. Nevertheless, the review team has proposed several recommendations for future improvements to the ACI and/or any successor index. The version of the document describing this index provided to the team for review was dated "February 2016". Subsequent revisions of the document were not considered as part of this review.

In this document, "development team" refers to the group that constructed the proposed "Actuaries Climate Index". They are affiliated with the Canadian Institute of Actuaries, the Society of Actuaries, the Casualty Actuarial Society, and the American Academy of Actuaries, with climate expertise and research provided by Solterra Solutions. "Review team" refers to the NCEI scientists listed as authors on this document. This review in no way represents an endorsement of the effectiveness, usefulness or value of the Index, and should not be perceived or advertised as such.

I. FINDINGS

The ACI is designed to track a set of potentially important changes in a variety of climate variables over time. The development team has indicated that the Actuaries Climate Risk Index (ACRI) will address the relationship between climate change and its associated perils.

A. Data Sources

Six climate components comprise the Actuaries Climate Index (ACI). The GHCNDEX dataset[14] is used to compute four of the six components, namely, the two temperature, extreme rainfall and consecutive dry days components. Each variable contained within this dataset is applied to a 2.5° longitude by 2.5° latitude grid. The temperature component, which takes a look at both maximum and minimum temperature, is based upon NOAA's GHCN-Daily (GHCN-D) station-based data set. Specifically, these components identify the frequency of daily maximum and minimum temperatures, which occur below the 10th and above the 90th percentiles of the probability distribution function (PDF). Temperature data derived from this dataset show good spatial coherence and allow for complete coverage over the domain for this index.

The GHCNDEX maximum 5-day rainfall is used to represent large precipitation events. This dataset may be a reasonable detector for flood potential, but may not capture actual flood events from heavy precipitation over a relatively short period of time that causes infrastructure damage and other losses. This variable will also not necessarily capture the multi-week heavy rain periods responsible for the largest spatial scales of flooding.

GHCNDEX consecutive dry days (CDD) are used to determine changes in meteorological drought. Creating monthly values of the consecutive dry days component by interpolating between annual values is of concern. The propensity of dry days and their impacts vary with season. For instance, 30 consecutive dry days in June in southern California is perfectly normal, while the same in December would be very unusual and harmful to everything from water supplies to natural vegetation and agriculture. In the Midwest, dry days in spring are beneficial to a certain point for agriculture to prepare the ground for planting; they become important after a certain threshold is reached where the ground is too dry to plant seeds.

14 Donat, M.G., et al., "Global Land-Based Datasets for Monitoring Climatic Extremes," *Bulletin of the American Meteorological Society*, July 2013.

The wind power component input data appear to be reasonable if observing changes in wind measurements alone. Daily wind speed measurements are obtained from NOAA's Earth System Research Laboratory (ESRL) and are converted to wind power, since impacts from high winds have been shown to be proportional to wind power. However, wind is not measured everywhere that wind damage occurs. One could create a "severe weather" component based on area counts of severe thunderstorms, hail storms, tornadoes and areas impacted by hurricane landfall. It is widely known that the frequency and magnitude of storms which generate large insurance claims have been increasing in recent decades and a component based on the mean state of the wind alone does not reflect this.

Data from the Permanent Service for Mean Sea Level are used to determine sea level measurements at 76 permanent coastal stations along the Canadian and U.S. coastlines which demonstrate a reliable and lengthy record. These data are not updated with the desired frequency to provide seasonal analyses of the ACI. An alternative dataset for consideration is available via NOAA[15] and is updated more frequently (latency of about a month), accounts for the mean seasonal cycle, which is desirable, and presents local relative data, which does include local land movement. These data are available only for the U.S. coasts.

B. Methodological Execution

For each component, a historical mean value is computed (in this case, from 1961-1990). Values for each time frame are compared with this historical average and a difference value, or delta, is computed. Positive delta values correspond to an observed increase in that component, whereas negative values indicate a decrease in the observed component. The delta values are then compared to its reference period standard deviation and a dimensionless standardized anomaly is computed for the entire period of record.

It is important when combining results from multiple indicators that the individual components are able to be combined easily and have comparable terms. Standardizing results from each component before combining into the ACI composite allows for a meaningful apples-to-apples comparison and contrast between components. In addition, the ACI is defined as the mean of the indicator standardized anomalies, which also makes the results easy to compute. An ACI value exceeding 1 implies that observed extremes are 'unusual' and values greater than 2 are 'highly unusual'. For users not familiar with

15 NOAA, Sea Level Trends from "Tides and Currents," accessed Nov. 11, 2016.

statistics, these definitions can be easily explained and results become accessible for all users. Although the review team has identified some concerns with the representativeness of individual elements (see below), the components of ACI do combine into the composite index in a way that seems consistent with the development team's intent, with one exception: the low temperature extremes component.

The manner in which a decrease in frequency of low temperature extremes is assumed to result in an increase in perils across the U.S. and Canada is not consistent with many studies. We acknowledge that this change can create an increase in perils for some regions, but also recognize that many regions may benefit by experiencing fewer periods of extreme cold conditions, especially with regards to human mortality/morbidity from disease and accidents during winter. In addition, the seasonal cycle matters when identifying perils resulting from extreme temperatures. Perils resulting from extremes in maximum/minimum temperature vary with season, especially between summer and winter. For example, a 90^{th} percentile temperature event during summer is much more perilous than a 90^{th} percentile temperature event during winter. This component would be more useful if seasonal variants were considered rather than a blanket approach for all months in all regions.

The precipitation component, which takes into consideration the changes in the maximum 5-day precipitation each month, is somewhat inadequate for gauging heavy precipitation caused by hydrologic events that damage infrastructure and cause other losses. Perhaps this dataset would work as a general signal of flood potential. However, quiescent periods and dry periods are included in the running average, suppressing the signal of heavy precipitation events. Metrics like the frequency of heavy precipitation events or the percentage of total precipitation occurring within heavy precipitation events may be better associated with crop and infrastructure damage, and human morbidity (transportation accidents caused by heavy precipitation events and flash flooding).

Looking more closely at the meteorological drought component, we see that there is only one value of CDD per year listed within GHCNDEX. From those values, monthly values are obtained by applying a linear interpolation to the annual values. As already stated, this is of concern due to the seasonality of dry days in some regions. Converting CDD to a percentage anomaly and then standardizing appears reasonable and is consistent with the other components. For a more clear measure of drought and changes in drought over time, use of the North American Drought Monitor (NADM) is recommended. While the U.S. Drought Monitor has a time series of only 15 years, and the North American Drought Monitor even less, these products are based on a blend of objective components that have much longer time scales, and human intelligence of experts with decades of experience with drought in their country/region. The NADM is by far the best drought monitoring product available for North America. Indicators such as the NADM which combine more comprehensive climate information provide insights into the type of approach used in the applied climatology community. The review team recognizes that the limited period of record presents some challenges for this analysis and recommends investigating other drought-measuring alternatives.

The wind power component appears to characterize the base state of the wind and the change in it over time rather than winds which might be observed during an extreme event. An increase in the mean state of the wind is not necessarily perilous. In fact, there are many benefits to an increased base flow. If the purpose of this index is to categorize climate components which may relate to perils, a different dataset should be considered; perhaps one which relates to extreme events such as tornado intensity/frequency, thunderstorm winds, landfalling tropical storms, hurricanes and the like.

Sea level does not change rapidly so it appears fairly constant over time. By standardizing this component, it effectively accounts for even small changes in sea level, which is desirable for this index. The review team questions the rationale behind giving equal weight to this component when merging with the other components, especially because coastal perils have little to no impacts on interior regions of the continent. Effects from land subsidence are intentionally removed from this component. The review team would expect that land subsidence be considered because the intent of this component appears to provide a measure for coastal flooding, to which downward land movements, like those observed in delta regions in Louisiana and along the Mid-Atlantic coast, contribute.

III. RECOMMENDATIONS

The ACI development team should consider producing a gridded version of the index. This would allow modifications to the index such that higher (lower) impact variables could be included (excluded) in different areas. For example, currently sea level weighting is done by distance of coastline, instead of how much population and economic activity is impacted for each region. Also, a decrease in the frequency of cold extreme temperatures across parts of Canada leads to an increased risk of perils due to melting permafrost. This is not the case across the U.S., where a decreased risk of perils may be attributed by these same conditions. These suggestions may exceed the original intent, but a more useful index could be obtained.

The review team strongly recommends calibrating extreme components to the overall index by season, as several extremes are beneficial in one season and harmful in another. It would be beneficial to consult with experts in applied climatology, human health, infrastructure, agriculture, business and any industry connected with perils resulting from a change in climate. This would go a long way in optimizing the combination of components, weights, seasonal variations and magnitude of impacts.

Much of the ACI is based on data contained within GHCNDEX. Although convenient, we believe the ACI would be of greater value if the individual components were generated from raw data which better represent a relationship between climate and an increase in perils resulting from a change in climate.

Each of the six components which comprise the ACI is weighted equally when combined to create the ACI. Two of the six components relate to changes in temperatures and two components (sea level and wind power) show little to no trend over time. In the future, the development team should consider varying weights by season depending on the expected impacts of changes in temperature, precipitation and other extremes. For now, the only weight that the review team considers inadvisable is subtracting cold extremes from the other components. Throughout the contiguous United States (CONUS), fewer cold waves lead to less impact. Negative change in cold waves should be additive, reducing the total index. As time permits, the development team should consider regional (Arctic vs. CONUS) and seasonal (cold waves mainly good during the summer months) variations.

Replacing the sea level component with a coastal (nuisance) flooding component or something similar which captures regional and local flooding events may be a better measure of the impacts of long term climate change. Work in this area is still emerging, yet nuisance flooding is directly connected with many coastal perils. This is a recommendation for future action. However the http://tidesandcurrents.noaa.gov/sltrends/sltrends.html data for the U.S. and a few spots in Canada provide sea level data through the nearest month that includes both oceanic and land level change effects on the coastal water level, which is a truer measure of impacts than global ocean level alone.

This review team believes the North American Drought Monitor (NADM) is the best tool to directly measure changes in meteorological and hydrologic drought.[16] Unfortunately, the NADM is a relatively new tool with a limited time series. The review team maintains its position that the consecutive dry days annual dataset is not well-suited for a monthly analysis and other alternatives should be investigated.

The mathematics of the ACI assumes that a reduction in extreme cold events is of equal and equally perilous magnitude as an increase in extreme warmth. Although this may be out of the scope of a methodological review, this seems is not congruent with the relevant research. Care should be taken to ensure that this is an appropriate representation of increased peril, rather than a simple measure of climate change.

IV. ADDENDUM

For any index or product created from data which do not come from internal sources, care should be taken to ensure the data are acquired from the source provider rather than through a third-party provider. Even if not deliberate, values may be altered and the results from any index using such data would be degraded.

16 For an overview, go to the North American Drought Portal.

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