P1.18 A REVISED U.S. CLIMATE EXTREMES INDEX

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1. INTRODUCTION

Nearly a decade has passed since the U.S. Climate Extremes Index (CEI) was first introduced (Karl et al. 1996). At that time, climatologists were struggling to find ways to determine if, and by how much, the climate was changing. In an effort to assist policy makers and inform the general public regarding our understanding of these changes, The Intergovernmental Panel on Climate Change (IPCC) published its initial findings in 1990 and subsequently has updated and revised these findings as new data and information became available in reports issued in 1995 (IPCC 1995) and in 2001 (IPCC 2001). In these reports, evidence was presented to detect climate change, attribute causes, project future climate change and offer suggestions for mitigation.

The CEI was first introduced in an effort to quantify observed changes in climate within the contiguous United States since the U.S. was not given extensive coverage in intergovernmental or national reports (IPCC 2001; NRC 1992; NRC 2001). The original index was generated from a composite of five indicators which investigated possible extremes in monthly mean temperature, daily precipitation and the Palmer Drought Severity Index (PDSI) on an annual basis. Recommendations were made in the seminal CEI paper regarding the addition of new climate extremes indicators as databases for a variety of elements improved. In addition, our ability to monitor extremes in near real-time (NRT) has also improved as electronic data ingest practices have become more common and advances in computing technology allow for timely reprocessing of large amounts of data.

In this article, our focus will be to present the fundamental changes and additions which have been made to the original CEI indicators. We will also report on how current extremes compare with historical extremes since the index was last calculated nearly ten years ago. The revised CEI is now calculated operationally for eight standard seasons: spring (Mar-May), summer (Jun-Aug), autumn (Sep-Nov), winter (Dec-Feb), annual (Jan-Dec), warm (Apr-Sep), cold (Oct-Mar) and hurricane (Jun-Nov). The index also incorporates a new sixth indicator utilizing land-falling tropical storm and hurricane wind intensity data. In addition, some modifications were made to how existing steps in the CEI were calculated and additional data have been incorporated including daily precipitation data from the TD-3206 dataset containing pre-1948 data.

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2. DATA USED

The revised CEI supplements quality-controlled historical data with near real-time data so that an operational CEI may be calculated. Time delays waiting for preliminary data to become final eliminate the possibility of operationally monitoring such an index in true real-time fashion.

The original CEI utilized over 600 continuous well-distributed maximum and minimum temperature observing sites across the United States: a subset of the U.S. Historical Climatology Network (HCN) (Karl et al. 1990). The revised CEI allows the entire HCN to be considered (1221 stations), but then utilize only those stations for which data are at least 65% complete for both period of record and within a given period (e.g. annual or seasonal). In Fig. 1, we see that this reduces the number of usable stations to nearly 1200, which translates into approximately 600 1° x 1° grid boxes. HCN data have been adjusted: a priori adjustments including observing time biases (Karl et al. 1986), urban heat island effects (Karl et al. 1988), and the bias introduced by the introduction of the maximum-minimum thermistor and its instrument shelter (Quayle et al. 1991); a posteriori adjustments included station and instrument changes (Karl and Williams 1987).

FIG. 1. Monthly USHCN temperature stations currently used with the revised CEI.

Extremes in daily precipitation were originally determined from a subset of 131 HCN stations and supplemented by non-HCN stations in the West where coverage was sparse. The revised CEI utilizes all TD3200/TD3206 daily precipitation stations which satisfy the 65% completeness threshold for both period of record and within a given seasonal period. Figure 2 shows that at the present time, approximately 2800 stations meet these criteria, which covers about 800 1° x 1° grid boxes.

FIG. 2. Daily Summary of the Day (TD3200 and TD3206) precipitation stations currently used with the revised CEI.

The National Climatic Data Center climate division precipitation and temperature database is used to calculate the PDSI (Karl 1986). The PDSI categorizes moisture conditions in increasing order of intensity as near normal, mild to moderate, severe, or extreme for both drought and wetness.

The newest dataset added to the index, the National Hurricane Center's North Atlantic Hurricane Database (HURDAT), was used as the source file for determining the wind speeds of tropical storms and hurricanes prior to landfall over the contiguous U.S. (http://www.nhc.noaa.gov/pastall.shtml). This database contains records for all Atlantic Basin tropical systems from 1851-2003 in six-hour intervals. Wind data for the most recent hurricane season are manually extracted in near real-time from the Unisys Weather website: http://www.weather.unisys.com/hurricane/index.html.

It was determined that since Pacific Basin tropical systems of tropical storm strength or greater essentially do not make landfall with the contiguous United States, only the Atlantic Basin storms would be considered for use in this index. If at some time it is determined that Pacific Basin systems make a significant impact on the U.S. mainland, wind speed data from these storms could easily be incorporated.

3. ANALYSIS

The original CEI was intended to be a baseline index which would evolve and grow as additional data become available, possible climate extreme indicator datasets become more easily attainable and as computers become better equipped to handle more sophisticated processing and computing techniques. Over the past few years, several modifications were made to the original index. Data used to calculate the index were also expanded and a new indicator was added.

3.1 *Additions to the CEI*

When the CEI was originally introduced, it was suggested that as data sources for other possible indicators of climate change improve, the CEI could evolve to include them. One such indicator which has now been added to the CEI is related to the land-falling wind speed of tropical storms and hurricanes. Tropical system data were assembled using the following criteria: Any Atlantic Basin tropical system of tropical storm strength or greater at landfall in which the center of the storm crossed over contiguous U.S. land was included. The value of the last observation before landfall was selected as the land-falling wind velocity since tropical system wind intensity can deteriorate quickly once over land. In addition, for any tropical system fitting the above description and making multiple landfalls the last wind speed before each landfall was used. The sum of squares of the land-falling wind speed was calculated for each period or season. The resulting distribution would then be scaled to the combined mean value of the other five indicators: an approximate value of 20 percent. In doing this, the resulting CEI mean value would remain the same with or without the sixth indicator, yet the year-to-year extreme percentages will reflect periods of increased and decreased tropical activity. This conversion was necessary since: the values were not spatially uniform over the entire contiguous U.S.; the resulting values were not percentages; and since the final percentages needed to be on a scale comparable to the remaining indicators within the index. This new indicator is calculated only for periods in which tropical storms and hurricanes are consistently active. Results for periods where tropical system activity is extremely infrequent (i.e. a few observations for the entire period of record) were difficult to work with and were subsequently left out of the index. Standard periods which include the new tropical system indicator are summer, fall, warm, annual and hurricane seasons.

The revised CEI utilizes additional data for which the original index did not have access. The TD3206 database consists of daily records for the pre-1948 period. Within the past several years, this dataset has been keyed from paper and film records and been made available digitally. In an effort to improve coverage across the U.S. with greater spatial resolution, the revised CEI utilizes the entire USHCN monthly temperature dataset as well as all of the TD3200 and TD3206 data for daily precipitation data. Records for each indicator are only used if they meet certain completeness criteria and therefore are not all included in the index.

3.2 *Changes to the CEI*

A couple of notable changes have been made in the calculation of the CEI. It was determined that the extreme threshold criteria for two of the five original indicators in the CEI were not true representations of the upper and lower tenth percentile. The fourth indicator in the CEI analyzes extremes in daily precipitation, but originally used a 2-inch threshold for the extreme criteria across the entire contiguous U.S. Looking at TD3200 and TD3206 daily precipitation ninetieth percentile values on an annual basis from 1910 to 2003 in Fig. 3, it becomes evident that the only region of the country capable of legitimately attaining this 2-inch threshold is in parts of the Deep South. Most of the country's daily extreme threshold value is at or below 1.5 inches. As a result of this finding, the CEI was revised to utilize the ninetieth percentile value as determined by the distribution of each 1° x 1° grid point. This ensures that each grid point has independently determined extremes and the results will reflect an overall average of ten percent at the extreme tail of the distribution.

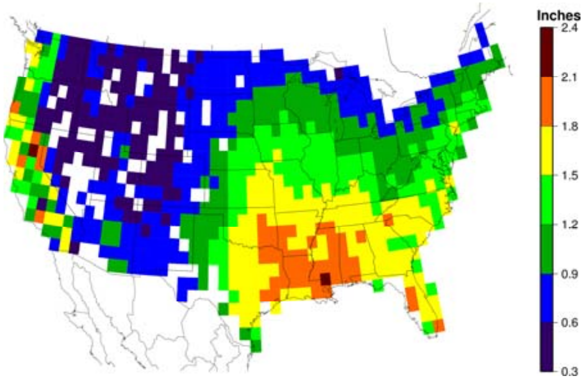

FIG. 3. Ninetieth percentile values of daily precipitation on an annual basis for each 1° x 1° grid box.

The third indicator in the CEI evaluates extremes in the PDSI as determined by the lowest and highest tenth percentile of the distribution. Theoretically speaking, this can be determined by finding values which exceed ± 3. In practice, this is not the case. The calibration period used to compute the long-term mean values for the various parameters utilized in the index is from 1931 to 1990. If you fit all the indices over the period of record to the distribution, the percentiles will not match. In addition, some of the constants involved in the calibration should be self-calibrated (Wells et al., 2004) for the location in which the Palmer indices are being computed. At the present time, the PDSI constants are the same across the country and were originally calculated for the Kansas/Iowa area. This difference does affect the statistical distribution of the index. Since the CEI is based on evaluating the upper and lower tenth percentile of the PDSI distribution, the resulting solution involved determining the lowest and highest tenth percentile for each climate division, rather than assuming values of ± 3. This is similar to what was done with the fourth indicator. The resulting severe drought values presently range from -1.7. to -3.9 and severe moisture surplus values range from 1.3 to 3.9.

Another difference with the fourth indicator is in the number of stations available for use to determine extremes in daily maximum precipitation. The original fourth indicator utilized 131 daily precipitation stations plus additional stations in the West, where coverage was sparse. The revised fourth indicator considers the inclusion of thousands of stations. As a result, multiple stations are located within the same 1° x 1° grid box across the contiguous U.S. Rather than averaging these data points together to create an extreme average value to represent a particular grid box, it was decided to take the largest daily precipitation value from among all stations within the grid box and have that one value represent the grid box for that particular day. It was discovered that in doing the former, the true daily extremes were in many instances being lessened due to an averaging of localized extreme events with neighboring values of little to no precipitation. By selecting the maximum daily precipitation value from within a grid box, we are evaluating and comparing true extremes in daily precipitation. Using one station per grid box is also more consistent with the original methodology for this indicator since so few stations were used with the original index.

3.3 *CEI Results*

Each indicator selected for use in the CEI was chosen based on its reliability, length of record, updateability, and its relevance to changes in climate extremes. The revised CEI is calculated with data for the conterminous U.S. and is defined as the arithmetic average of the following six indicators:

1) The sum of (a) percentage of the United States with maximum temperatures much below normal and (b) percentage of the United States with maximum temperature much above normal.
2) The sum of (a) percentage of the United States with minimum temperatures much below normal and (b) percentage of the United States with minimum temperatures much above normal.
3) The sum of (a) percentage of the United States in severe drought (equivalent to the lowest tenth percentile) based on the PDSI and (b) percentage of the United States with severe moisture surplus (equivalent to the highest tenth percentile) based on the PDSI.
4) Twice the value of the percentage of the United States with a much greater than normal proportion of precipitation derived from extreme 1-day precipitation events.
5) The sum of (a) percentage of the United States with a much greater than normal number of days with precipitation and (b) percentage of the United States with a much greater than normal number of days without precipitation.
6) The sum of squares of United States land-falling tropical storm and hurricane wind velocities scaled to the mean of the first five indicators.

Looking at the revised annual CEI in Fig. 4, we see a general increasing trend in extremes since the early to mid 1970s. This is about the time when the atmospheric circulation over North America and the Pacific underwent a significant change (Trenberth 1990; Trenberth and Hurrell 1994). Over the most recent ten year period, we notice considerable year-to-year variability in the percent of the U.S. influenced by extremes, yet the overall trend is increasing. Other shorter-lived extreme periods are evident during the 1930s and the 1950s, which are known periods of significant drought, as illustrated in Fig. 5.

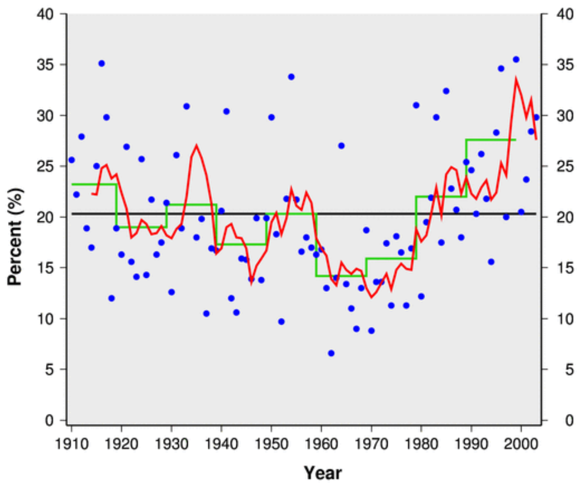

FIG. 4. U.S. Climate Extremes Index for annual period from 1910 to 2003. Dots represent annual values, the green bar-like curve depicts the decadal means and the red curve is a five-year moving average.

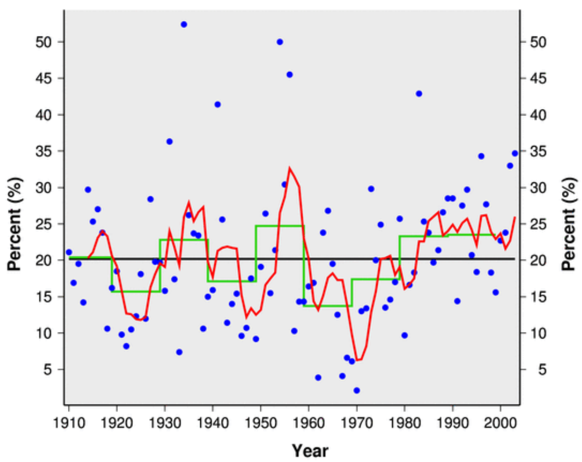

FIG. 5. Same as in Fig. 4, but for percentage of the conterminous U.S. area in severe drought and severe moisture surplus, combined.

It can be seen in Figs. 6-8 that over the past ten years, extremes in mean maximum and mean minimum temperatures, as well as extremes in 1-day precipitation events remain high or have continued to increase. It is also important to note that trends in annual precipitation across the country since 1910 have been on the rise with an average increase of about 0.32 inches per decade across the U.S. Similar results were noted in Groisman et al. (2004) using a 2.5° x 3.5° grid. This may lessen the overall proportion of extreme 1-day events to the total precipitation, assuming the magnitude of 1-day precipitation events remains constant. Looking at Fig. 8, we see that the percentage of the U.S. experiencing much above normal proportion of precipitation is steadily increasing with a more pronounced rise since the mid 1970s. These results would suggest that extremes in 1-day precipitation are certainly on the rise, which is also evidenced by findings in Groisman et al. (2001), and Karl and Knight (1998).

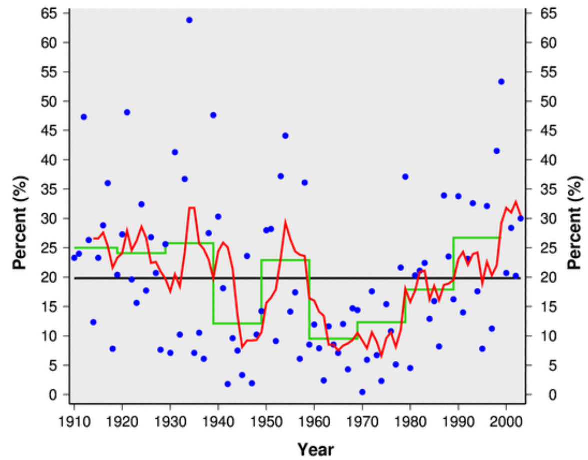

FIG. 6. Same as in Fig. 4, but for percentage of the conterminous U.S. area with much above normal and much below normal monthly mean maximum temperatures, combined.

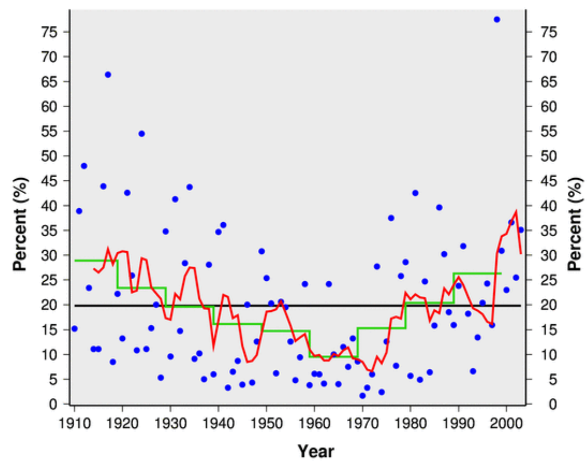

FIG. 7. Same as in Fig. 6, but for monthly mean minimum temperatures.

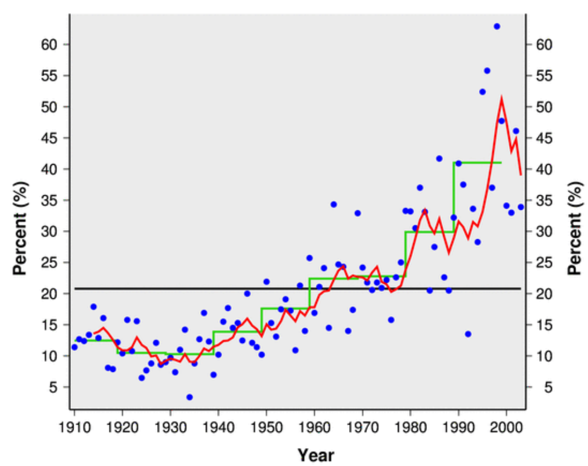

FIG. 8. Same as in Fig. 4, but for percentage of the conterminous U.S. area with a much above normal proportion of precipitation derived from extreme 1-day precipitation events.

In addition to the annual CEI, the warm and hurricane season CEI graphs in Figs. 9 and 10 also indicate increasing trends in extremes since the early 1970s. Notable extremes periods of shorter duration are evident for both the warm and hurricane seasons in the late 1910s, in the 1930s and also in the 1950s. This can be attributed in part to extremes in monthly mean maximum temperatures as well as periods of extreme PDSI drought.

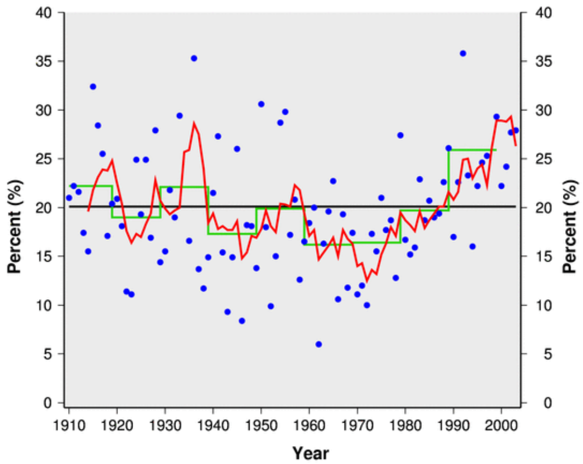

FIG. 9. Same as in Fig. 4, but for the warm season (Apr-Sep) from 1910 to 2004.

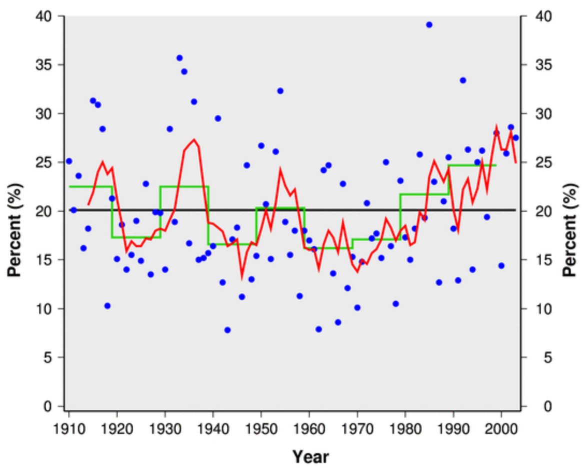

FIG. 10. Same as in Fig. 4, but for the hurricane season (Jun-Nov) from 1910 to 2003.

Incorporating U.S. land-falling tropical system data into the CEI was initially a challenge. Tropical system wind impacts only affect a fraction of the contiguous U.S. area and usually only along portions of the Gulf and East Coast. With this in mind, the goal for developing this new indicator was to find a way to compare extremes in the frequency and intensity of land-falling tropical systems to the extreme percentages calculated for the entire U.S., which the other five indicators inherently convey. As mentioned in section 3.1, it was determined that the computed sum of squares of land-falling tropical storm and hurricane wind speed values from the tropical system indicator would be scaled to the overall mean value of the other five indicators.

Results for the sixth indicator appear more erratic and percentages range widely when compared with the other five indicators due to the nature of tropical systems. Some years have very active and/or strong land-falling tropical system seasons. Other years have few to none. In the past ten years, both 1997 and 2000 had very little land-falling tropical storm and hurricane activity, which is indicated by extremely low annual values seen in Fig. 11. This annual graph also illustrates an increasing trend in land-falling tropical system activity from about the mid-1970s to the present. In 1998, 1999 and 2004, land-falling tropical systems were very active and intense. Figure 12 depicts the scaled land-falling tropical system extreme wind percentages for the warm seasons through 2004.

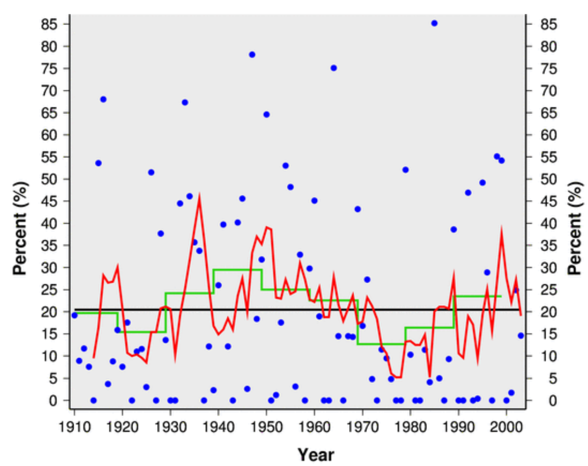

FIG. 11. Same as in Fig. 4, but for the sum of squares of U.S. land-falling tropical storm and hurricane wind velocities scaled to the mean of the first five indicators on an annual basis from 1910 to 2003.

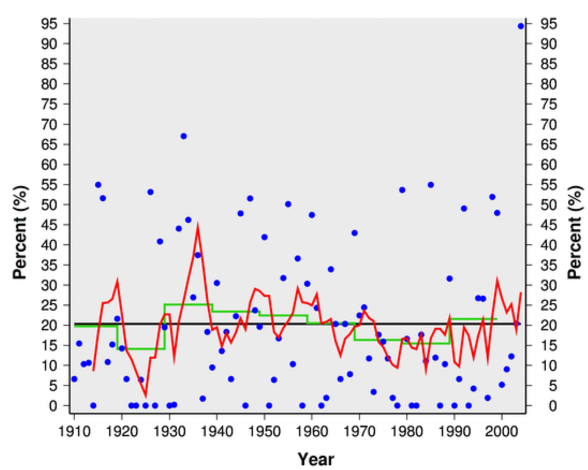

FIG. 12. Same as in Fig. 11, but for the warm season (Apr-Sep) from 1910 to 2004.

4. SUMMARY

The CEI was first presented in 1995 as a framework for quantifying observed changes in climate within the contiguous United States. The index is based on an aggregate set of conventional climate extreme indicators which now includes extremes in land-falling tropical storm and hurricane wind intensity. Originally, the CEI was calculated on an annual basis, and now the revised CEI is evaluated for eight standard seasons: spring, summer, autumn, winter, annual, cold season, warm season, and hurricane season. Additional temperature and precipitation stations have been added to the analysis to improve spatial coverage without compromising completeness of data. Near real-time data have also been incorporated into the index, which allow the CEI to be calculated operationally on a seasonal basis.

Revised CEI results indicate that for the annual, summer, warm and hurricane seasons, the percent of the contiguous United States experiencing extreme conditions has been generally increasing since the early 1970s. Graphs of the most current CEI and the individual indicators which comprise the CEI may be viewed at the NCDC CEI website via: http://www.ncdc.noaa.gov/oa/climate/research/cei/cei.html.

5. REFERENCES

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