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An overview of weather and climate extremes – Products and trends

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ABSTRACT

This paper provides an overview of trends in weather and climate extremes as presented at a recent WMO Symposium on global food security and biodiversity. Analyses and conclusions about weather and climate extremes are best based on daily data, and an internationally agreed-upon set of daily extremes indices has been devised for this purpose. Characteristics of climate data sets which are necessary for an adequate analysis of changes or trends in extremes are identified. Analyses summarized in the Intergovernmental Panel on Climate Change Fifth Assessment Report indicate that, since the 1950s, there has been a trend toward fewer cold days and nights and more warm days and nights globally, increasing heavy precipitation events in many parts of the world, and regional trends (both increasing and decreasing) in drought and dryness extremes. A more detailed discussion of indices for the USA illustrates features of some of these trends, including a significant change in trends of extremes which occurred in the 1970s. There is considerable decadal variability in drought area in the contiguous USA, and the long-term trend depends on the beginning and ending years chosen, but there has generally been an increasing trend in drought area over the 20th to 21st centuries and over the last four decades. The annual percent area of the USA experiencing greater-than-normal number of days with (without) precipitation has increased (decreased) over the 20th to 21st centuries, but both indices have increased over the last four decades. There has been an increase in the occurrence of extreme 1-day precipitation events over the last hundred years, with the rate of increase accelerating in recent decades. Extremely warm maximum and minimum temperatures have shown an increasing trend over the 20th to 21st centuries and over the last four decades, while the occurrence of extremely cold maximum and minimum temperatures has decreased over these periods. The U.S. Climate Extremes Index, which integrates several extremes indices, indicates that the 1940s and 1960s were the decades of most stable (smallest occurrence of extremes) climate in the last 104 years, and that recent decades have become as unstable (variable) as, or more unstable than, the early decades of the 20th century but for different reasons.

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1. Introduction

Climate variability and climate change have impacted civilization throughout history. Droughts, floods, heat waves, cold waves,

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and other extreme events touch every economic and social sector, including the foundation of civilization – agriculture. The very survival of some early civilizations came into question when the climate varied (Bryson and Murray, 1977; Fagan, 2004). In the last two centuries, scientific and technological advancement have been accompanied by a rapid increase in population and a more interconnected world. The transfer of resources and relief from unaffected regions to a region affected by a natural disaster can help lessen the impact of the disaster. But the opposite is also true: in the present global economy, a weather or climate disaster in one country can affect the economies of other countries.

Climate change has accelerated in recent decades (Sheffield and Wood, 2011). This is evident in a number of climate variables (Hartmann et al., 2013). The number of weather-related natural catastrophes has risen on all continents since 1980, most notably for North America, and this has had a dramatic impact on the insurance industry (Munich Re, 2012). Developed countries today are better able to manage the impacts of a variable climate, but in developing countries the increasing frequency and magnitude of extreme weather events pose potentially disastrous consequences for agriculture and food security (Field, 2000; Wilhite, 2005; Sheffield and Wood, 2011; Sivakumar et al., 2011a). Knowledge of how and where the climate has varied and is changing is crucial to developing successful coping strategies for agriculture and ecosystems in general.

Many aspects of climate are well represented by monthly means, and some extremes (such as drought) are analyzed using indices based on monthly data (e.g., Palmer Drought Severity Index, Standardized Precipitation Index), but information about extremes is best obtained from daily data. Consequently, an internationally agreed-upon set of daily extremes indices (ETCCDI, from Expert Team on Climate Change Detection and Indices) has been devised (Frich et al., 2002; Zhang et al., 2011; Hartmann et al., 2013). Zhang et al. (2011) suggested that multi-parameter indices, such as the Climate Extremes Index (Gleason et al., 2008) which combines daily- and monthly-based indices, might someday be added to the ETCCDI suite of extremes indices. Indices based on daily data provide insight into local conditions, but few physically-based thresholds have relevance in all parts of the world. Consequently, the daily-based indices now often focus on relative thresholds that describe features in the tails of the distributions of meteorological variables. This paper surveys trends in several climate extremes (drought, heavy precipitation/flooding, and maximum and minimum temperatures) over the last several decades to the last century across the globe, with special emphasis on those areas having adequate climate data. The importance of defining the analysis period is illustrated by a more detailed discussion of trends in extremes in the USA.

2. Characteristics of indices of weather and climate extremes

It is important that the measures of climate extremes be rigorous and clearly defined. Klein Tank et al. (2009), Zhang et al. (2011), and the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) (Hartmann et al., 2013) have summarized various characteristics of climate data sets which are necessary for an adequate analysis of changes or trends in extremes. These include:

- Data availability, quality, and consistency are important as they can affect the statistics of extremes. Measurement practices (observation practices and instrumentation) should be consistent and unchanging over time.
- For statistical studies, counts of threshold exceedance (frequency, duration) and departures from high percentiles/return periods (intensity, severity, magnitude) are highly sensitive to changes in the shape and scale parameters of the statistical distribution and geographic location.
- Consistent methodologies should be used to create the datasets. Different data sets using different gridding methods (or reanalysis methodologies) and/or different input data and varying levels of quality control could affect results comparing region to region.
- The period of record (p.o.r.) should be consistent. A different p.o.r. between regions and between stations could affect spatial comparisons of trends (the importance of p.o.r. is illustrated in Figs. 1, 2, 5 and 6 later in this paper). A long p.o.r. is needed to obtain meaningful trends and statistics, and the same (or comparable) p.o.r. should be used amongst regions.
- A universal and consistent definition of extremes indices is needed, and the reference period which they are based on needs to be consistent. This fundamental characteristic is basic for not only comparison of indices between regions, but it also affects the resulting statistics. For example, for precipitation extremes, analysis and framing of questions regarding sub-daily precipitation extremes is becoming more critical; variations in the spatial pattern of trends for daily precipitation depend on event formulation and duration. The IPCC AR5 Working Group 1 identified extreme indices that have been chosen for their robust statistical properties, their applicability across climates, and their available data (Hartmann et al., 2013, Box 2.4, p. 221).
- The spatial density of surface weather stations needs to be sufficient to adequately represent the spatial variability of extremes, and the data need to be homogeneous so that false trends and variability are excluded. Hartmann et al. (2013) pointed out that non-climatic factors can affect data homogeneity and noted, as an example, that changes in flood frequency can depend on changes in river management practices.

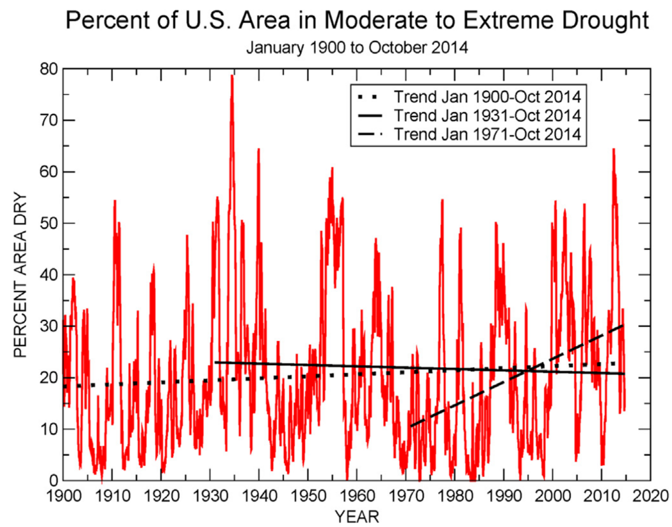

Fig. 1. The percent area of the contiguous USA (CONUS) experiencing moderate to extreme drought (Palmer Drought Severity Index (PDSI) ≤ -2.0) from January 1900 to October 2014 (red curve). The dotted line is a linear regression over the period of record (linear trend $= +0.40\%$ decade^{-1}), the solid line is for January 1931–October 2014 (-0.26% decade^{-1}), and the dashed line is for January 1971–October 2014 ($+4.49\%$ decade^{-1}). (After Fig. 4 in Peterson et al. (2013), but updated through October 2014 and based on the improved climate division dataset, nClimDiv (Vose et al., 2014).) (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Other issues relevant to climate extremes indices were identified by speakers at the October 2014 International Symposium on Weather and Climate Extremes, Food Security and Biodiversity in Fairfax, Virginia, USA. These include:

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