Objective Quantification of Drought Severity and Duration

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ABSTRACT

Common weaknesses of current drought indexes were analyzed. First, most of the current indexes are not precise enough in detecting the onset, end, and accumulated stress of drought. Second, they do not effectively take into account the aggravating effects of runoff and evapotranspiration, which build up with time. Third, they have a limited usefulness in monitoring ongoing drought because they are based on a monthly time step. Fourth, most of them fail to differentiate the effects of drought on surface and subsurface water supply.

A new series of indexes are proposed to solve these weaknesses and to improve drought monitoring. In the new indexes, daily, rather than monthly, time steps are used. A new concept, effective precipitation (EP), the summed value of daily precipitation with a time-dependent reduction function, is proposed as a basic tool.

Three additional indexes complement EP. The first index is each day's mean of EP (MEP). This index shows climatological characteristics of precipitation as a water resource for a station or area. The second index is the deviation of EP (DEP) from the MEP. The third index is the standardized value of DEP (SEP). By using these three indexes, consecutive days of negative SEP, which can show the onset, the ending date, and the duration of a water deficit period is categorized.

With the duration categorized, four additional indexes that can show drought severity are calculated: 1) accumulation of consecutive negative SEP, which shows the duration and severity of precipitation deficit together; 2) accumulated precipitation deficit, which shows precipitation departure from the normal during a defined period; 3) precipitation for the return to normal; and 4) effective drought index, a standardized index that can be used to assess drought severity worldwide. The merits and weaknesses of each index are compared. New quantified definitions on drought and its onset, end, and duration are proposed.

These indexes were tested in the High Plains region of the United States from 1960 to 1996. The results were compared to historical reports of drought. From this analysis, it was concluded that the new indexes not only advanced objectivity, but also offered a number of advantages in practical use. These are 1) a more precise determination of drought duration, 2) the usefulness in monitoring an ongoing drought, and 3) the variety of ways a drought's characteristics can be described.

1. Introduction

The study of drought can be classified into four categories. The first category deals with the causes of drought and seeks an improved understanding of atmospheric circulation associated with drought occurrences. The second category is directed at understanding the frequency and severity of drought in order to characterize the probability of occurrence of droughts of various magnitudes. The third category attempts to describe and understand the impacts of drought. This category focuses on the costs and losses associated with drought. These losses may be classified as economic, social, or environmental and may be either direct or indirect. The final category looks at responses, appropriate mitigation, and preparedness strategies and focuses on a reduction of the impacts associated with drought.

The first category evolved with the help of globally gridded meteorological data for the late twentieth century. Byun (1996), Byun et al. (1992a,b), Chu et al. (1993), Namias (1991), Trenberth and Branstator (1992), and a few more provide examples of research in this category. Most studies on the second category were conducted together with studies on the third category. Doornkamp et al. (1980), Landsberg (1982), Ratcliff (1978), Riebsame et al. (1991), Palmer (1965), and McKee et al. (1993, 1995) are examples of these studies. The fourth category has progressed in recent years and

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TABLE 1. Characteristics of current drought indices.

Name	Factors used	Timescale	Main concept	Source, year created
PDSI	r, t, et, sm, rf	m (2w)	Based on moisture input, output, and storage. Simplified soil moisture budget.	Palmer (1965)
RAI	r	m, yr	Compared r to arbitrary values of +3 and −3, which are assigned to the mean of 10 extreme + and − anomalies of r.	Rooy (1965)
Deciles	r	m	Dividing the distribution of the occurrences over a long-term r record into sections, each represents 10%.	Gibbs and Maher (1967)
CMI	r, t	w	Like the PDSI, except considering available moisture in top 5 ft of soil profile.	Palmer (1968)
BMDI	r	m, yr	Percent departure of r from the long-term mean.	Bhalme and Mooley (1980)
SWSI	P, sn	m	Weighted average of standardized anomalies of the main elements of the water budget.	Shafter and Dezman (1982)
SMDI	sm	yr	Summation of daily sm for a year.	Hollinger et al. (1993)
CSDI	et	s	Summation of the calculated et divided into possible et during the growth of specific crops.	Meyer et al. (1993)
SPI	r	3 m, 6 m, 12 m, 24 m, 48 m	Standardized anomaly for multiple timescales after mapping probability of exceedance from a skewed distribution.	McKee et al. (1993)
RI	r	yr, c	Patterns and abnormalities of r on a continental scale.	Gommes and Petrassi (1994)
RDI	r, t, sn, st, rs	m	Supply element–demand element.	Weghorst (1996)

Abbreviations: P—factors used in PDSI, r—precipitation, et—evapotranspiration, t—temperature, sm—soil moisture, rf—runoff, sn—snowpack, st—streamflow, rs—reservoir storage, w—week, m—month, s—season, yr—year, c—century, 3 m—3 months.

is evolving rapidly. The establishment of the National Drought Mitigation Center in Lincoln, Nebraska, is an example of proactive rather than reactive philosophy. Wilhite (1997a,b, 1996, 1993, 1991, and 1986), Wilhite et al. (1986), and Wilhite and Rhodes (1994) are examples of research in this category.

In spite of these studies, quantifying drought intensity and duration continues to be a problem. The present study focuses on the definition of drought and the quantification of its intensity and duration.

The general concepts that used today as meteorological definitions on dry periods are 1) consecutive days with no precipitation, 2) consecutive days with little precipitation, or 3) little precipitation during a specific period of time (Byun and Han 1994; Broccoli and Manabe 1992; Kim 1968; Steila 1986). The definitions of "consecutive days," "specific period," "no precipitation," and "little precipitation" are quantified by empirically or subjectively rather than objectively estimated values. Actually, in defining little precipitation, some meteorologists and climatologists generally regard it as "daily precipitation less than 2 mm," but others regard it as less than "5 mm." Also, on the definition

of no precipitation, some view it as daily precipitation less than a trace, while others view it as less than 2 mm because it has little impact on the ecosystem. On the definition of consecutive days, some use a period of more than 15 consecutive days (Huschke 1970), but others use a time frame of 25 days (Steila 1986). For the definition of "little precipitation during a specific period of time," some use a monthly unit, while others use seasons or other periods (Byun et al. 1992a,b; Byun and Han 1994).

Aside from these definition on dry period, general meteorological droughts are defined over a monthly or seasonal timescale as shown in Table 1. Drought may also be defined in hydrological, agricultural, and socioeconomic terms also. Factors in defining drought may include deforestation, land degradation, and construction of dams. They may also include precipitation shortages, pack snow, differences between actual and potential evapotranspiration, soil water deficits, reduced ground water, or reservoir level and reduction in power production. It is important to recognize that almost all of these factors are not independent but related to each other, and meteorological change (especially tempera-