The Precipitation Anomaly Classification: A Method for Monitoring Regional Precipitation Deficiency and Excess on a Global Scale

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ABSTRACT

An objective method to identify and track significant global precipitation anomalies on time scales of a month or longer is presented. The technique requires current observations of monthly precipitation amounts for each station and long term (20 or more years) monthly precipitation histories. Tests indicate that the technique compares favorably with the well-known Palmer Drought Severity Index (PDSI) and Crop Moisture Index (CMI) in the United States. Since monthly precipitation data are readily available in a near real-time framework, this method makes an automated, global precipitation anomaly monitoring system possible.

1. Introduction

Drought, from a meteorological point of view, can be defined as a persistent period, on the order of a month or more, during which precipitation is significantly below that which is expected. From the viewpoint of a hydrologist or agriculturist, this "definition" would likely include considerations of soil type, stage of crop development and so forth. Unfortunately, no universal definition exists—drought has different meanings to different people and disciplines. The system described below does not address the definition of drought but rather focuses on the more manageable problem of detecting one of the principal components of drought, i.e., precipitation anomalies.

Part of the mission of the Climate Analysis Center (CAC) of the National Weather Service (NWS) is to identify and describe, in near real-time, the initiation and evolution of significant precipitation anomalies over the land surfaces of the earth. Existing methods for such assessments, one being the Palmer Drought Severity Index (PDSI) (Palmer, 1965), for example, require estimates of soil moisture and type at or near the locations to be analyzed. These data, particularly soil moisture, are available neither globally nor in near real-time. In addition, both the CMI and PDSI are regional in scope, limited to the United States.

This paper describes the modification and implementation of a technique which was originally developed by the Australian Bureau of Meteorology (Lee, 1980). This technique requires only monthly accumulated precipitation observations, which are routinely available for most regions of the world in near real-time over the Global Telecommunications System (GTS). Assuming that precipitation is the most significant factor in determining whether an area is affected by drought, then this scheme can be implemented to create a global precipitation anomaly classification and monitoring system.

2. Methodology

The method, as originally developed by the Australian Bureau of Meteorology, classifies the recent precipitation regime into one of three categories: "severe deficiency," "serious deficiency" and "deficiency ended." The classification is determined solely on the comparison of three-monthly accumulated precipitation observations with a location's historical record for those three months. An area is considered to be "drought affected" when the precipitation for a period of three months or more falls within the lowest 10% of the historical distribution of precipitation observations for the same period of the year. Specifically, the "severe deficiency" category is selected when the precipitation for a three-month period at a location ranks in the lowest 5% of the historical observations for that period. The "serious deficiency" category is chosen when the three-month precipitation at a site ranks within the lowest 10% but above the lowest 5% of the site's historical record for that period. When either the "serious" or "severe" categories are selected, the location is considered to be "drought affected" until either of the following two conditions are satisfied:

1) the precipitation for the past month alone is sufficient to rank in the 30th percentile or greater of the historical record for the three-month period starting with that month, or

2) the precipitation for the past three months ranks in the 70th percentile or greater of the historical record for the corresponding three-month period.

The philosophy inherent in the scheme is that a spell of below-normal precipitation will, sooner or later, be followed by a period of above-average precipitation. Hence, the technique resembles a water budget scheme in that the "drought affected" locations retain that classification until the precipitation deficiency is made up, or until the recent precipitation regime has drastically changed. The property that the "drought affected" designations persist until specific criteria are satisfied demonstrates a memory mechanism inherent in the method.

Since the method was developed for Australia, and to our knowledge has been used there only, we examined its portability by applying it to the U.S. Climate Division dataset. This dataset, which was obtained from the National Climatic Data Center (NCDC), contains uninterrupted monthly precipitation amounts for 344 contiguous areas of the United States dating back to 1931. The monthly accumulated precipitation reported for each climate division is composed of the average of reports from many observers within each division. Figure 1 depicts the Climate Division boundaries.

The method was tested on data for the summer and autumn of 1983. The summer months of that year were abnormally dry in much of the southeast and midwest parts of the country. The autumn season was included so that the performance of the method in the aftermath of a dry episode could be evaluated. In order to assess the relative effectiveness of the technique, the results were subjectively compared to those of two "standard" drought assessment techniques used in the United States, namely the Palmer Drought Severity Index and the Crop Moisture Index (Palmer, 1968). These indices are routinely displayed during the growing season in the "Weekly Weather and Crop Bulletin," which is published by the joint NOAA/USDA agricultural weather facility, to assess climatic conditions in the U.S.

Figures 2a, b and c show the Precipitation Anomaly Classification (PAC), Palmer Drought Severity Index (PDSI) and Crop Moisture Index (CMI), respectively, for July 1983. Values of the PDSI that are less than −1 indicate areas which are experiencing some degree of drought. Values that are more negative indicate more extreme conditions. The CMI values have a similar meaning, but their interpretations are dependent on conditions which prevailed during the previous week to clearly define the episode; that is, the analyst needs to know whether the previous week was drier or wetter than the present one to precisely characterize the present conditions. In general, however, CMI values that are negative indicate drier than normal conditions—only the trend is in question without knowledge of the previous week's conditions.

All three methods indicate dry conditions in the middle and southeast Atlantic coastal states and in parts of Texas. The CMI indicates a much broader area of mild dryness extending westward to Kansas and Oklahoma that is not detected by the other techniques. The PAC shows serious to severe precipitation anomalies in parts of California and Nevada that are meaningless since little, if any, precipitation falls in these regions of the United States during the summer. A solution to this problem is discussed in the next section. Portions of eastern Montana and northern Wyoming are classified as "drought affected" by the PAC technique but not by the PDSI or CMI. However, this region is depicted as abnormally dry by all three methods in succeeding months.

By September (Figs. 3a, b and c), the drought has reached its greatest extent in both areal coverage and severity. The PAC depicts a broad, contiguous area

FIG. 1. Map of the 344 U.S. Climate Divisions.

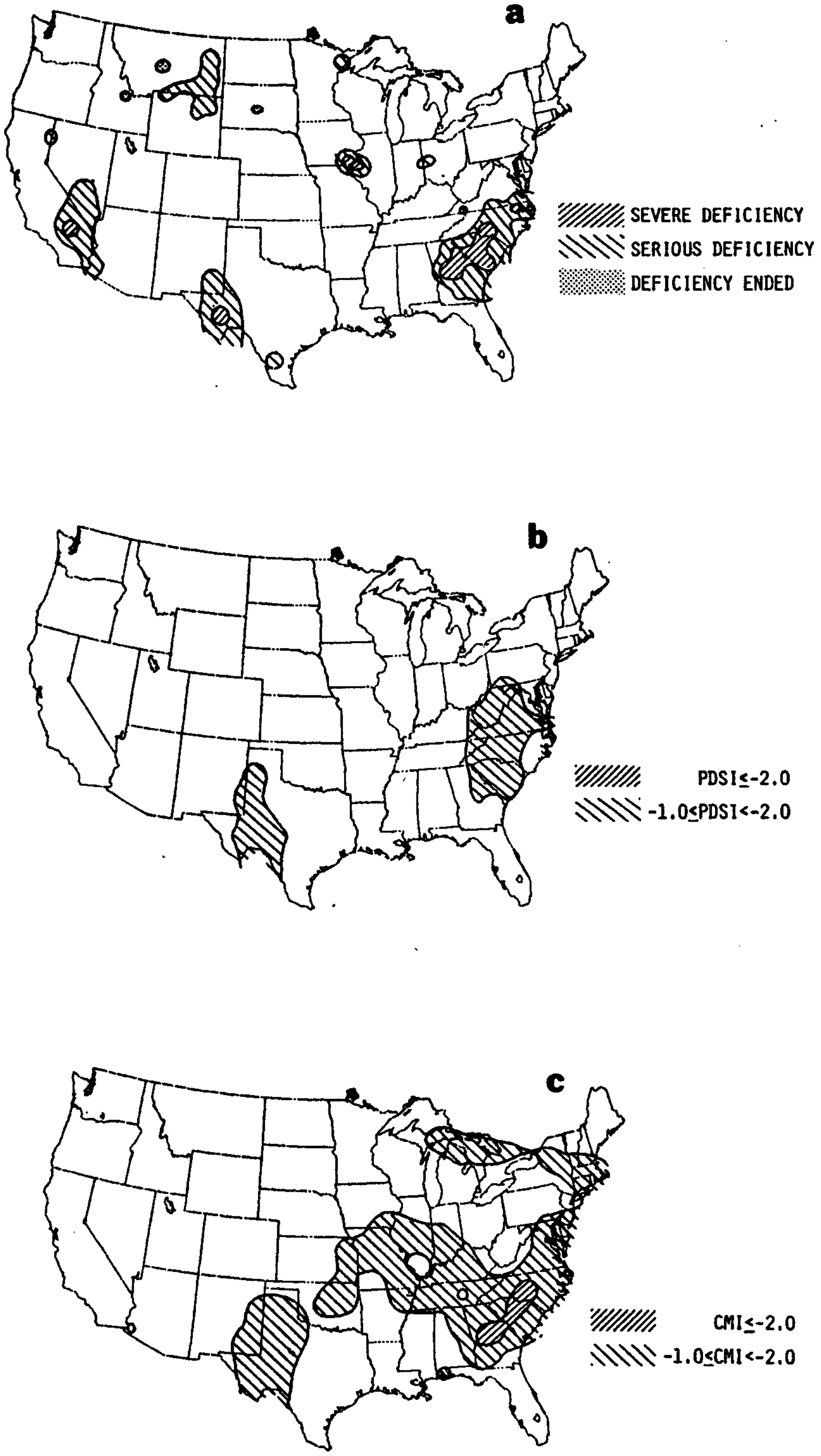

FIG. 2. (a) Precipitation Anomaly Classification (PAC), (b) Palmer Drought Severity Index (PDSI), and (c) Crop Moisture Index (CMI) for July 1983.

from the Atlantic to Kansas as "drought affected." The CMI agrees with the PAC west of the Ohio river valley, but does not indicate dry conditions in the Atlantic coastal states. The CMI is more responsive to short-term moisture supply fluctuations and is greatly affected by precipitation that fell in the southeast United

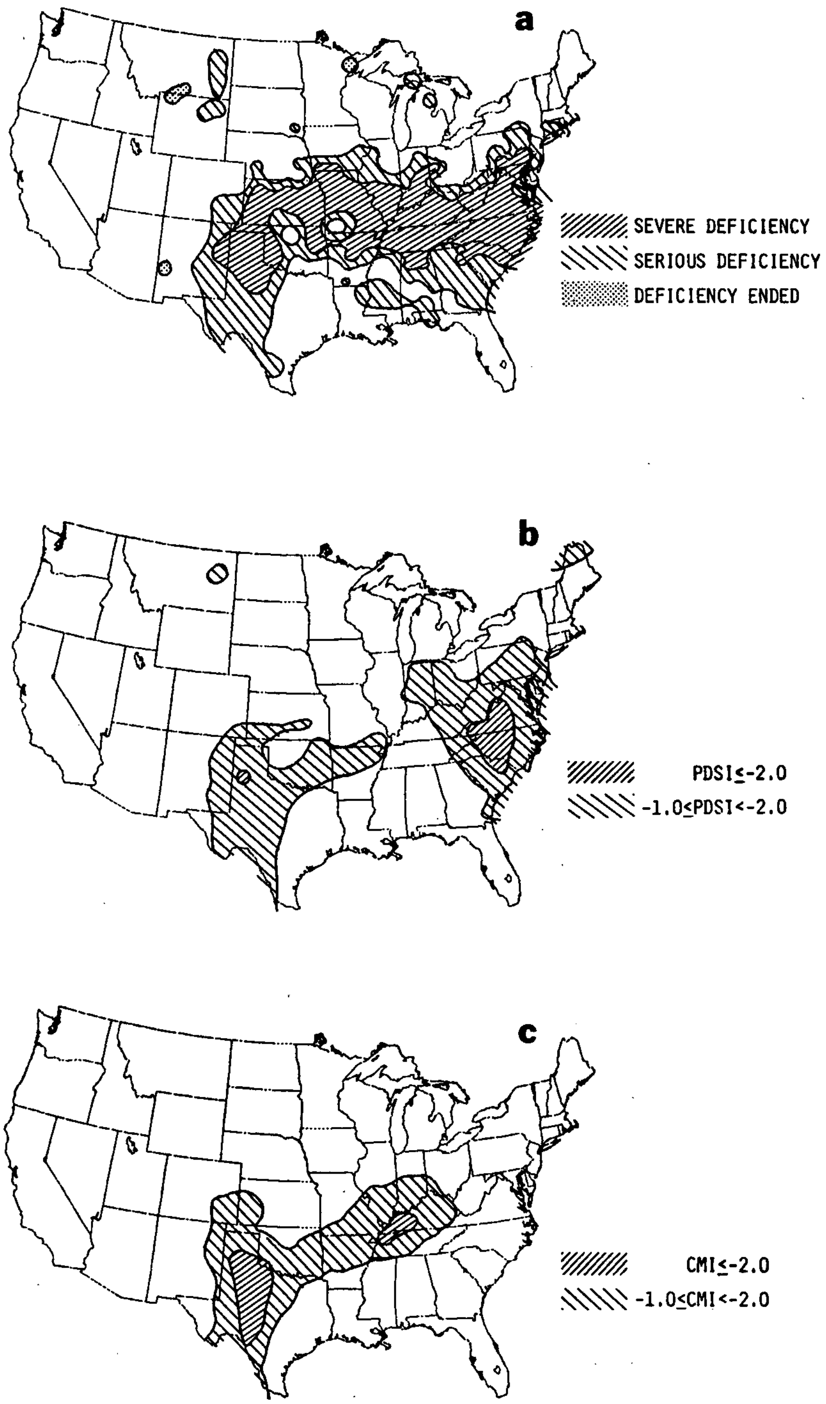

FIG. 3. (a) PAC, (b) PDSI, and (c) CMI for September 1983.

States during the last two weeks of September 1983. The PDSI agrees with the PAC in the mideast and southeast United States and in the southern plains states, but does not detect abnormally dry conditions in parts of the midwest. The fact that the PDSI does not indicate dryness in the lower midwest and eastern plains states is due to the rather wet spring and early summer in this part of the country, and the PDSI reflects long-term moisture availability.

Proceeding to November 1983 (Figs. 4a, b), one sees that the drought has subsided considerably. Large portions of the country have been classified as "drought ended" by the PAC. Both the PAC and PDSI indicate dry conditions persisting in southern Texas and eastern

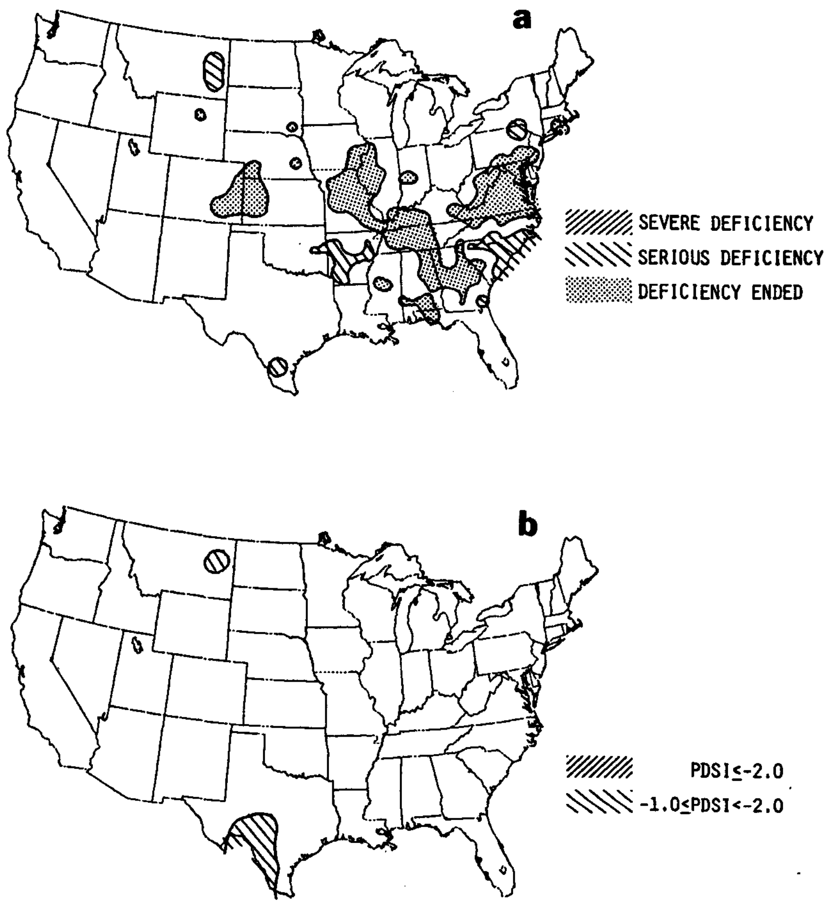

FIG. 4. (a) PAC and (b) PDSI for November 1983.

Montana. The PAC shows some lingering dryness in the Carolinas and central Arkansas. The CMI is computed during the growing season only, hence the figures for November are not available.

Although the comparisons of the PAC with the PDSI and the CMI are admittedly subjective, we feel that its performance on tracking the evolution and subsequent denouement of the drought of 1983 is as good as the PDSI and CMI. In general, it appears that the scheme reacts to dry episodes much more rapidly than the Palmer Drought Severity Index but not as rapidly (nor is it as volatile) as the Crop Moisture Index and hence, appears to be a compromise between these methods. Based on the results of this "case study," this method appears to be a promising tool for the assessment of precipitation anomalies on a global scale.

3. Modifications to the original method

The integrity of global, real-time station data cannot match that of the Climate Division data upon which the previous tests were performed. Hence, several modifications to the method were necessary before attempting to produce classifications on a global basis. Four significant changes were made to the original scheme.

First, instead of ranking the monthly and three-monthly precipitation observations against a station's historical record, a gamma distribution (Ropelewski et al., 1985a) was computed at each site, and the observations were compared to that distribution. We felt that this modification was necessary because precipitation observations do not generally adhere to a Gaussian distribution and are sometimes highly skewed. (This property is also true of the Climate Division data upon which the testing was performed.) In addition, the use of a probability distribution for comparisons, as opposed to ranking, alleviates problems encountered when comparing the results at locations which have unequal historical record lengths. Thus, one can, with proper caution, include stations which have gamma distribution parameters derived on different base periods so that spatial coverage in data sparse regions can be increased.

The second modification establishes a policy for handling missing real-time observations. Since the technique requires precipitation observations for the most recent three-months, some method for handling situations when one or more of the monthly observations is missing had to be devised. This problem led us to produce "pure" and "proxy" classifications. For the "pure" classification, zero precipitation is substituted for the missing observation at sites where the previous classification is "normal," and the 99th percentile (from the gamma distribution) is substituted at locations where the previous classification was "drought affected." If the classification remains the same as that of the previous month, after these substitutions, that classification is retained. If the chosen category changes from that of the previous month, a classification is not made for that month for that location and any preexisting drought conditions are terminated. These locations will not be classified for the next two months either, since observations for three consecutive months are required.

This policy for handling missing observations is very conservative in the sense that the missing observations will usually result in missing classifications since the precipitation values that are substituted are from the tails of the precipitation distribution and hence will likely have a profound effect on the ranking of the three-month accumulated precipitation. This conservative approach poses no problems for locations where the previous classifications are "normal." For "drought affected" sites, however, setting the new classification to missing effectively ends the dry spell, since the drought memory is erased. Classifications for such locations will resume after the next three-month period for which data are available for all three months; thus these locations are essentially removed "from the loop" for a three-month period.

Another approach is to substitute the median precipitation amount when missing observations are encountered. This "proxy" method is attractive when considering the paucity of data in some regions of the world. In addition, it is intended to prevent the artificial ending of dry classifications simply because the data for the present month is missing. Also, stations with a missing observation will not be classified for three months by the "pure" method and will be considered as "normal" prior to the next period for which sufficient data exists to classify the station. Therefore, the "pure" method may, in certain instances, be misleading. By replacing the missing value with the median, and thus allowing the dry spell to persist, more realistic classifications may result. For stations that were classified as "normal" prior to the month with missing data, the insertion of the median will perpetuate that status. Either method may be in error, but if both methods are employed and are judiciously used in tandem, the "proxy" method may prove useful in situations when the drought status in a particular region is not clear. Since data substitution is always risky, especially with precipitation data, it is probably wise to consult the results of the "pure" method as a quality control measure to ensure that the data substitution is reasonable.

Another reason for producing the "proxy" classification involves the fact that catastrophic real-time data losses are possible in an operational environment. The mechanisms of the "pure" PAC would prevent the classification for most of the locations for which the data were lost. This problem would propagate through the next two months as well, since the PAC requires monthly observations at each location for three consecutive months.

The third modification is intended to prevent "drought affected" classifications from being chosen in deserts and semiarid regions which "normally" receive no precipitation during parts of the year. This is achieved by defining the percentile of the gamma distribution for a given monthly or three-monthly period to be no less than the percent of the time that zero precipitation was observed for that period during a location's history. For example, if a location with a 100-year historical record received no precipitation during 20 of those 100 years for the period being examined, then the lowest percentile that location is allowed to assume during that period is the 20th percentile. Therefore, the location could not be placed into the "drought affected" categories during this season, since its precipitation must lie in the 10th percentile or less, by definition, to be classified that way. However, if the station had been classified as "drought affected" prior to the current assessment period, that classification is allowed to persist unless the drought-ending criteria have been satisfied.

Finally, we felt that it would be useful to provide an assessment of episodic wet spells, so a category was added for that purpose. This category is valid for the month being evaluated only, i.e., three-month accumulated precipitation observations are not used, and no memory of preexisting wet conditions is retained between analyses. This category is selected when the precipitation at a particular site is in the 90th percentile of the gamma distribution for the month being evaluated.

4. Application of the PAC to global data

The data used as input to the global classification scheme are from the Climate Anomaly Monitoring System (CAMS) data base (Ropelewski et al., 1985b) of the Climate Analysis Center. Data from this source were also used to compute monthly and three-monthly gamma distribution parameters for use in the PAC technique. Figure 5 shows the locations of stations in the data base which have 20 or 30 years of nearly continuous monthly precipitation observations between 1931 and 1980. The stations at the plotted locations also meet the criterion that their monthly precipitation observations are regularly received over the GTS each month. However, one must consider that when using this set of stations, some will have gamma-distribution parameters which were generated from the 1951–80

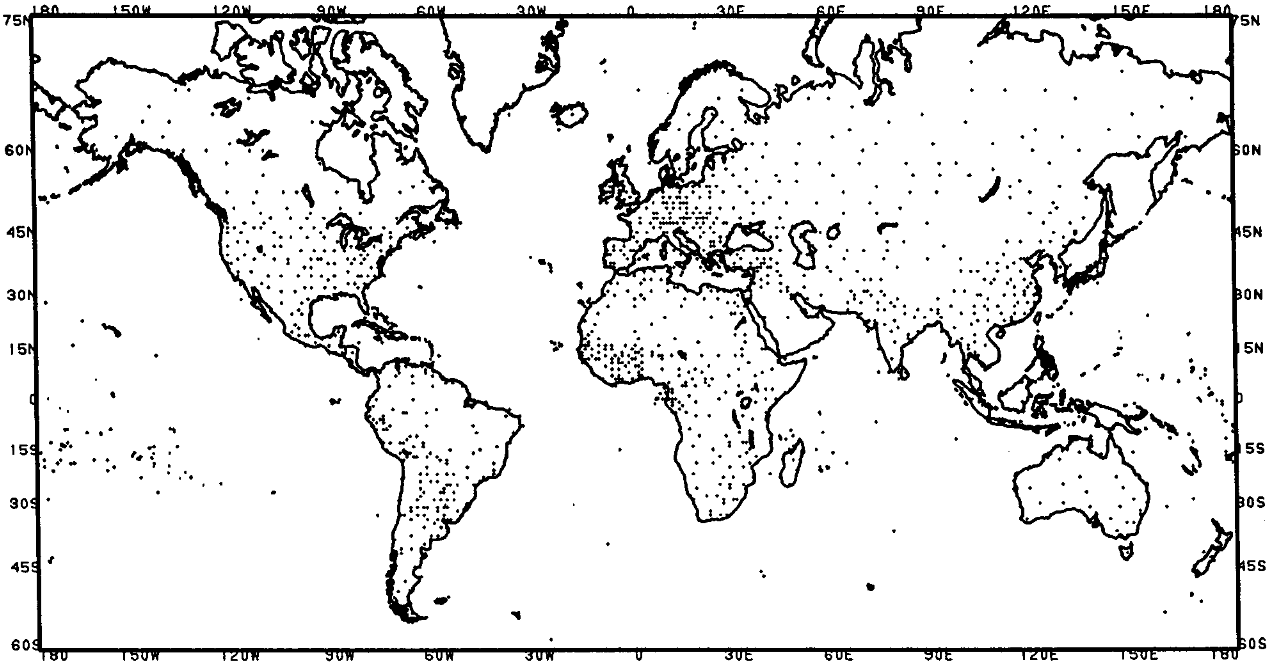

FIG. 5. Locations of stations in the Climate Anomaly Monitoring System (CAMS) data base with 20–30 years of historical data during 1931–80. (Locations with levels 1–7. See Table 1 for explanation of term "levels.")

base period, while others are based on data from 1941–60 or even 1931–50.

The data base design makes it simple to select stations based on their length, period of record and data quality. Therefore, we are able to generate maps of classifications for several categories of stations, with the ever present tradeoff of data quality versus data quantity. Table 1 depicts the various groupings of stations in the CAMS data base. Obviously, increased data coverage is desirable, but it is obtained at the cost of an analysis based on a nonhomogeneous dataset. The point here is that families of classifications can be produced, some of which use high quality data while others, in the interest of providing information in data sparse areas, use data of lesser quality.

Figure 5 reveals several areas, specifically in Africa, South America and Asia, for which historical data are lacking. The data problem is exacerbated when processing in an operational environment, since current observations must be received in a timely fashion in order for the historical data to be useful. The problem is even further compounded by the fact that three consecutive observations of monthly precipitation must be received from a location for it to be classified by the PAC method, unless provisions are made to substitute for missing data.

TABLE 1. List of periods of record for stations in the CAMS (Ropelewski, 1984) data base.

Level	Length	Period
1	30	1951–80
2	30	1941–70
3	30	1931–60
4	Not used	
5	20	1961–80
6	20	1951–70
7	20	1941–60

The results of the PAC for July 1984 are presented for various parts of the world in Fig. 6. Since sufficient data density for contouring does not exist in many areas, symbols (defined in Table 2) are used to denote the classifications. All maps in Fig. 6 were generated by the "pure" method, and only stations with levels 1 or 5 (Table 1) were used. Obvious data gaps are evident in large portions of Africa and South America. Europe is fairly well represented—note the relatively dry conditions in the United Kingdom and parts of south central Europe. These maps are contrasted with those in Fig. 7, which are also valid for July 1984, but the "proxy" method is applied, and all stations in levels 1 through 7 of the CAMS data base are used. Although large gaps remain in Africa and South America, the overall station density is 52% (154 stations) greater than in Fig. 6. Of course, this increased density is obtained at the cost of less reliability (since missing observations are replaced by the climatological median amount for one month of the three-month period) and decreased homogeneity of results since not all of the station statistics are derived on a common base period. However, the agreement between the two sets of maps implies,

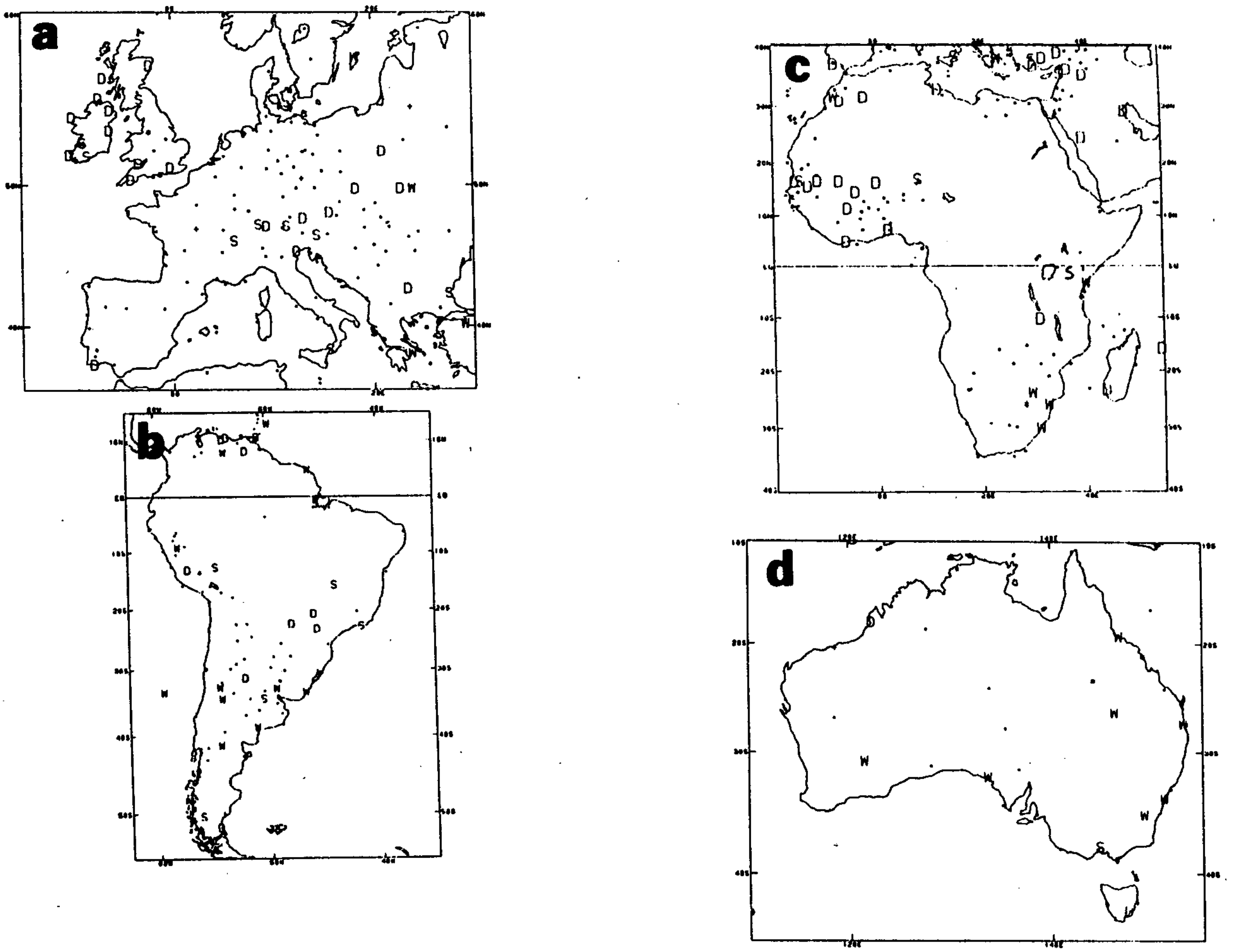

FIG. 6. Results of the PAC for (a) Europe, (b) South America, (c) Africa and (d) Australia during July 1984. The plotted symbols are defined in Table 2. These classifications were generated by the "pure" method.

for this particular case, that one can place a reasonable amount of confidence in the analysis, since conflicting results are not introduced when including stations for which median precipitation amounts have been substituted.

TABLE 2. Definitions for PAC symbols in Figs. 6 and 7.

Symbol	Definition
S	"Severe deficiency." Precipitation for the past three months in the lowest 5% of the historical record for that three-month period
D	"Serious deficiency." Similar to 'S' category but three-month precipitation between lowest 5 and 10% of historical record
●	"Normal"
+	"Drought ended." Criteria for ending discussed in Section II
W	"Wet month." Precipitation (for current month only) in the 90th percentile of historical record
*	Combination of + and W classifications

A possible shortcoming of the PAC technique involves areas of highly seasonal rainfall. Since the amount of precipitation that these regions receive varies greatly with time of year, the amount of rainfall necessary to end drought classifications is also highly variable. Hence, it is possible for locations which were classified as "drought affected" due to a poor rainy season, to be classified as "drought ended" during the following dry season even though the actual precipitation amounts were negligible, albeit above normal. Such circumstances could arise, for instance, in monsoon areas or portions of the west coast of the United States where most of the precipitation occurs during winter, and very little, if any, occurs during the summer months. Suppose that an abnormally dry winter season results in a "drought affected" classification for a location in the western United States and that a freak shower occurs during the ensuing summer months when the "normal" precipitation for this region is near zero. It is possible that such an event could end the "drought affected" condition since even a negligible

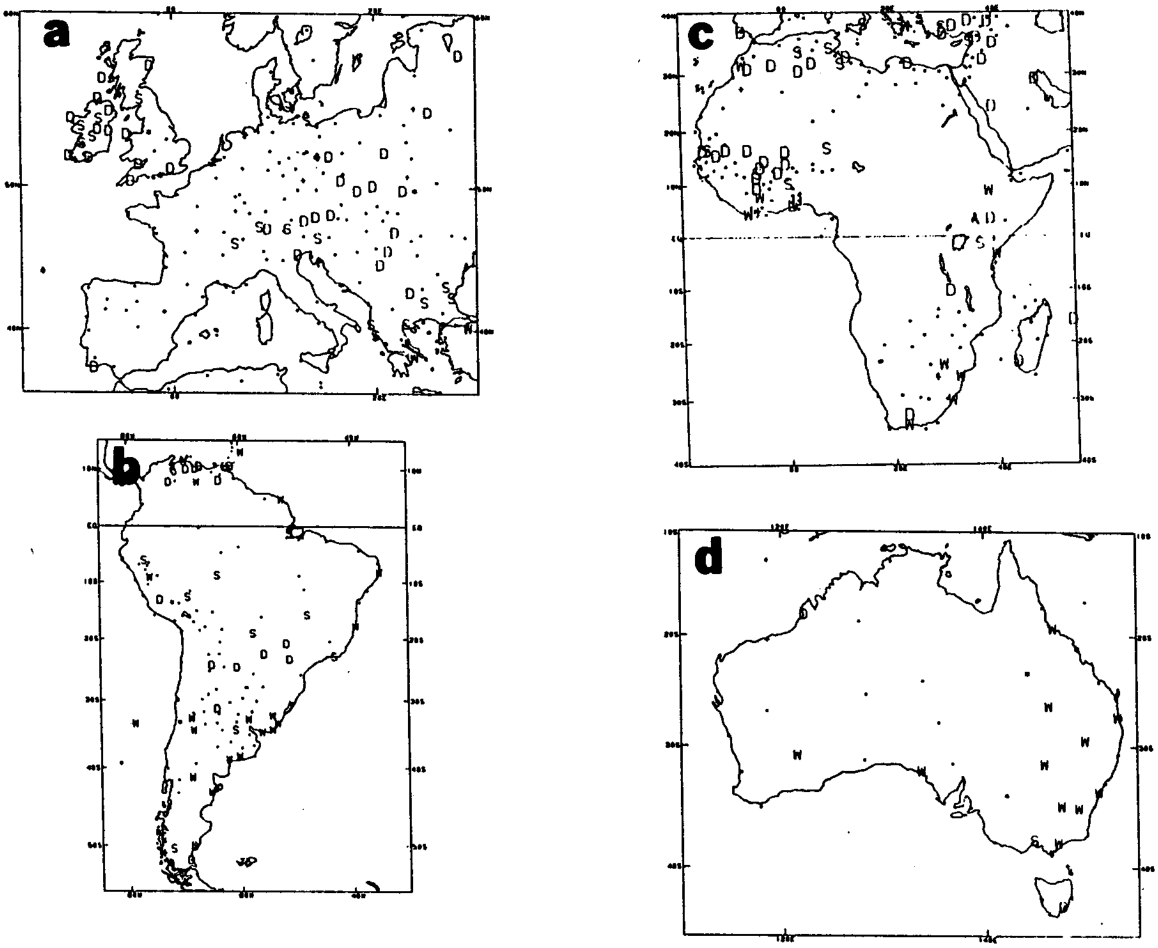

FIG. 7. Results of the PAC for (a) Europe, (b) South America, (c) Africa and (d) Australia during July 1984. The plotted symbols are defined in Table 2. These classifications were generated by the "proxy" method.

amount of precipitation will likely rank above the 30th percentile when little, if any, rainfall is usually observed during this time of year. A possible remedy for this situation is to require that some critical threshold amount be exceeded before the "drought affected" condition is allowed to end. The problem is a difficult one to solve, and solutions may potentially ruin one of the attractive features of this technique, namely, its simplicity.

5. Conclusions

Given precipitation data with adequate spatial resolution and sufficient historical data, we feel that this technique does a credible job of locating possible drought areas and monitoring the evolution and decay of these areas. The results of subjective comparisons of this method with other "standard" drought assessment techniques, namely the Palmer Drought Severity Index and the Crop Moisture Index, are favorable, and yet the PAC uses only monthly accumulated precipitation in conjunction with historical monthly amounts. This feature makes the method attractive for the global monitoring of precipitation anomalies. The technique also provides information about locations which are experiencing abnormally high monthly precipitation. However, current monthly precipitation observations, let alone locations with monthly observations for periods of twenty or more years, are sadly lacking in some important agricultural and political areas of the globe. Hence, the method ought to do a credible job in North America, Europe and parts of the other continents where the data density is comparatively high. But classifications in data sparse areas will be either nonexistent or must be inferred from surrounding locations that possess sufficient data to produce a classification.

It is possible that monthly precipitation estimates, as inferred from satellite outgoing longwave radiation measurements, will be available in the future. Such information could prove valuable, especially in data sparse regions. The lack of adequate historical data in data sparse regions will remain a problem, however, until further cooperative efforts are made to obtain this information.

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REFERENCES

Lee, D. M., 1980: On monitoring rainfall deficiencies in semidesert regions. *The Threatened Drylands—Regional and Systematic Studies of Desertification,* Mabbutt and Berkowicz, Eds., Fujinomiya. [Available from Australian Bureau of Meteorology, Melbourne, Australia.]

Palmer, W. C., 1965: Meteorological drought. Weather Bureau Res. Paper No. 45, 58 pp. [Available from the NOAA library, NESDIS, NOAA, Rockville, MD 20852.]

——, 1968: Keeping track of crop moisture conditions nationwide: The new crop moisture index. *Weatherwise,* **21,** 156–161.

Ropelewski, C. F., J. E. Janowiak and M. S. Halpert, 1985a: The analysis and display of real time surface climate data. *Mon. Wea. Rev.,* **113,** 1101–1106.

——, —— and ——, 1985b: The climate anomaly monitoring system "CAMS." Climate Analysis Center report, 38 pp. [Available from Climate Analysis Center, W/NMC52, Washington, DC 20233.]