Estimation of Rainfall in Burkina Faso Using the ESOC Precipitation Index

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ABSTRACT

Rainfall is estimated in Burkina Faso for a full year using the ESOC precipitation index (EPI), a statistical cloud indexing method based on satellite data from METEOSAT. The EPI is converted into rainfall with the linear regression calculated between the EPI and the observed rainfall from a dense network of rain gages. Only one regression line based on the largest possible sample is used. The purpose of the paper is to assess the accuracies of the yearly and seasonal rain estimates to find out whether a single EPI-rainfall relation can be applied.

The results show that the yearly precipitation can be estimated to a high degree of accuracy. On the other hand, the precision of the seasonal estimates exhibits large fluctuations. While the dry season estimates are reliable, the transition between the dry and rainy season is characterized by a considerable overestimation, caused by the abundance of cold, nonprecipitating cirrus on the northern side of the intertropical convergence zone. During the rainy season the method suffers from a slight underestimation.

To resolve the major problem, that of nonprecipitating cirrus, a lower temperature threshold of 220 K instead of 235 K is applied in the determination of the EPI. The rain estimates for the transition period do improve slightly, but the gain is offset by the deterioration of the rain estimates made for the whole year and the rainy season.

The results suggest that the rain estimates made with a single EPI-rainfall relation are useful, but that they could be improved with some type of seasonal adjustments.

1. Introduction

In recent years a number of attempts have been made to estimate convective precipitation using geostationary satellites. A comprehensive overview of different methods is given by Barrett and Martin (1981). The techniques in use vary substantially in their complexity. The most sophisticated ones, based on the continuous tracking of clouds throughout their lifetimes (e.g., Griffith et al. 1978; Stout et al. 1979), require considerable computer resources and manpower and can thus only be applied to restricted areas and limited times. If the interest lies in the climatological rainfall estimates, calculated for large areas and long periods, the approach has to be relatively simple. The statistical method based on the properties of IR cloud top temperature proposed by Arkin (1979) would be suitable for climatological precipitation mapping as shown by Arkin and Meisner (1987). In spite of the simplicity of their method, the 3-month large-scale rainfall estimates were in surprisingly close agreement with those obtained from other sources.

The ESOC (European Space Operations Centre) precipitation index (called hereafter EPI) constitutes another statistical method, applicable for climatological purposes. The EPI is also calculated by relating fractional cold cloud area to rainfall, but in addition, the data are segregated by the mean humidity in the upper troposphere. The formulation of the EPI is described in detail by Turpeinen et al. (1987) (called hereafter TEA). The first attempt to validate the EPI was carried out by comparing it with observed rainfall from five African countries: Kenya, Côte d'Ivoire, Senegal, Morocco, and Tunisia. The results indicated that a good multiple linear correlation existed between the precipitation and the EPI in the equatorial belt and that there the estimation of the accumulated precipitation was feasible with a reasonable level of accuracy. The mean difference between the observed and estimated monthly rainfall ranged from 10% to 43%. In the Sahel zone, the estimates turned out to be not as accurate, probably because cold nonprecipitating cirrus of frequent occurrence were misinterpreted as being precipitating (TEA).

The previous study suffered, however, from two major shortcomings. First, the time of validation was lim-

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ited to a 3-month period. Secondly, the number of rain gages used for validation was probably not fully sufficient considering the large local variability of convective precipitation. Therefore, it was felt that a follow-up study covering a full 12-month cycle needed to be undertaken. The ground truth data originate from Burkina Faso (formerly Upper Volta). Burkina Faso was selected since the country has a comprehensive network of rain gages, and it is situated in the tropical savannah belt, where clear-cut rainy and dry seasons can be distinguished.

The purpose of this paper is to test the rainfall estimation technique based on the EPI to study

(i) The seasonal and geographical variations of the accuracy of the precipitation estimates to determine whether the use of a single regression between the EPI and rainfall can be justified. This is a prerequisite of the reliance on statistical methods to estimate tropical rainfall in projects like the Tropical Ocean/Global Atmosphere Programme of the World Climate Research Programme (WCRP 1985).

(ii) The importance of the humidity information incorporated into the EPI. For this purpose, most of the calculations are carried out using both the EPI and the simple nonsegregated index.

(iii) The ways to eliminate cold nonprecipitating clouds, which cause frequent problems in the cloud indexing methods based on the IR radiances. This is done by slightly modifying the EPI and by lowering the temperature threshold to 220 K.

In previous studies only one season has been considered (e.g., Arkin (1979); TEA) or the ground truth data have been based on published rainfall climatologies subject to substantial uncertainties (e.g., Arkin and Meisner 1987). The original feature of the present study is the use of a dense tropical network of rain gages for a full year. This sample permits us to draw conclusions about the seasonal behavior of the relation between the EPI and rainfall.

The paper consists of three main sections: the description of data and methods used, the presentation of the results from the precipitation estimation, and the conclusions.

2. Data and methods used

Both satellite and ground truth data have been collected for the test period which ran from 3 October 1985 until 27 September 1986. The data originate from Burkina Faso, located in the Sahel region in West Africa. The climate of the country is tropical, characterized by two principal seasons: the dry and rainy ones, separated by a period of transition. The migrations of the intertropical convergence zone (ITCZ) determine the duration of the seasons, as the occurrence of the rain can be linked to the position of the ITCZ (Riehl 1979). In general, the rainy season lasts only 2 months in the northernmost parts of the country, whereas the southern areas have rain up to 6 months. Thus, the climate in the north is semiarid, but further south it increasingly resembles that of the equatorial regions. A large proportion of the yearly rainfall originates from the African squall lines, described in detail by Houze (1977).

a. Satellite data

The satellite data considered consist of the precipitation indices, EPI, originating from the European geostationary satellite METEOSAT. A general description of the METEOSAT Exploitation Project is given by de Waard (1987).

The EPI is a cloud coverage index, based on the IR and WV data and described in detail by TEA. The full description will not be repeated; only the main features will be briefly summarized. The following calculations are performed every 3 hours for every METEOSAT segment (about 150 × 150 km^2 at the subsatellite point)

(i) First, using an effective blackbody temperature colder than 235 K as a threshold, fractional cloud coverage is calculated. In the present study fractional cloud coverage also is calculated using a temperature threshold of 220 K.

(ii) Next, the upper tropospheric humidity is incorporated into the EPI. The humidity between 70 and 30 kPa is determined on the basis of the radiance in the METEOSAT 6.3 μm channel (Fischer et al 1981). The fractional cloud cover calculated in (i) is segregated into one of three classes corresponding to the humidity ranges of 75%–100%, 40%–75% and 0–40%.

The results are summed for 5 days and then archived. The period of study was composed of 72 5-day periods, but four of them had insufficient data in the archive. Thus, 68 5-day periods could be included. Only those segments fitting into the territory of Burkina Faso were considered (Fig. 1).

b. Ground truth data

Daily records from all regularly operating rain gages from Burkina Faso were collected, amounting to 101 rain gages. The gages were allocated among the segments according to their geographical coordinates. The gages located in the segments lying partially outside Burkina Faso were excluded.

The network of the rain stations is well suited for this study due to their fairly even distribution over the territory. The tropical precipitation is, however, characterized by an extremely irregular spatial distribution. Since the main interest of the present study lies in the mean rainfall calculated for each segment, it is essential to eliminate the highly local variations of the rainfall within each METEOSAT segment. Therefore, only the segments with seven rain gages or more are considered. The country is represented by seven segments (69 stations). The resulting network of rain gages distributed among the segments are illustrated in Fig. 1. The number of rain gages per segment is significantly larger than in the previous study, thus rendering the resulting statistics more meaningful.

The daily mean of observed precipitation is calculated for all the segments considered, and summed over 5 days to render the observed precipitation compatible with the EPI.

c. *Methods used*

Three slightly different methods to estimate rainfall are used in the present study. The first one (called hereafter EPI1) is simply based on the original (segregated) EPI, while the second one (EPI2) employs a nonsegregated version of the precipitation index. By comparing the first and second method, the importance of the segregation by the mean humidity can be inferred. The third method (EPI3) is based on a precipitation index in which the moist class (mean humidity of 75%–100%) is excluded. Results from TEA suggested that this modification might better filter out nonprecipitating cold cirriform clouds.

A number of calculations are carried out to compare the performances of the three methods. First, linear correlation coefficients are determined to study the relationship between the observed rainfall and precipitation indices EPI1, EPI2 and EPI3. The sample sizes are displayed in Table 1; parts (a) and (b) refer to the statistics of seasonal and regional variations, respectively. The former are studied considering all the segments and the latter considering the whole year to keep the samples as large as possible. In fact, the sample size always remains larger than 125, which is considerably larger than in the previous study, thus rendering the results statistically more significant.

TABLE 1. Sample sizes as a function of (a) the season: D, dry season (October–February); T, transition (March–May); R, rainy season (June–September); and Y, whole year (October–September). (b) The geographical area: South, the three southernmost segments; Center, the three central segments; North, the two nothernmost segments (see Fig. 1).

	(a) Season			
Description	D	T	R	Y
All segments	196	126	154	476

	(b) Region			
Description	South	Center	North	All
Whole year	136	204	136	476

Second, provided that the correlation coefficients are fair (>0.7), the three corresponding regression lines are determined (called hereafter ER1, ER2 and ER3). As the EPI1, EPI2, and EPI3 are cloud coverage indices, their conversion into rainfall is mandatory before they can be used for rain estimation. The methods had already been calibrated using the data from Kenya and Côte d'Ivoire by establishing lines of best fit between

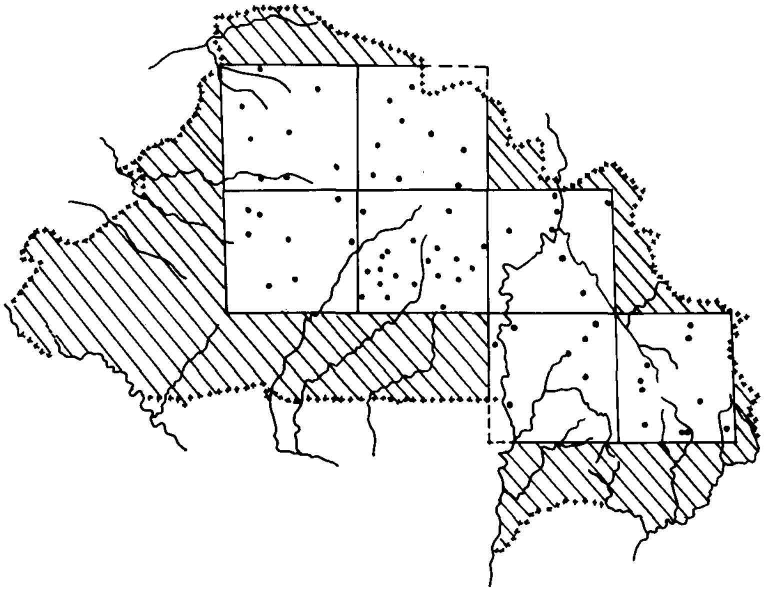

FIG. 1. The distribution of the 69 rain gages (black dots) among the seven segments retained (white squares) in Burkina Faso.

the indices and observed rainfall. The earlier values could have been used here, but it was felt that due to a considerably larger sample, it is more appropriate to rely on the data from Burkina. Thus, new regression lines between the observed precipitation and the EPIs were determined considering the whole 12-month period and all the segments. The three resulting regression lines are thus based on the largest possible samples.

Third, using the three regression lines, seasonal and regional precipitation estimates are determined. The accuracy of the estimates is assessed by comparing the estimated seasonal and yearly rainfall with the observed rainfall and by calculating the mean 5-day difference (MDIF) between the observed and estimated rainfall for the full year and various seasons.

The procedure described above is performed twice: first, for the precipitation indices with the temperature threshold of 235 K; then for the ones with the lower temperature threshold of 220 K.

3. Results

The results will be presented in three parts: first, the accuracy of the rain estimates depending on temporal factors will be discussed; secondly, the influence of the geographical location will be studied, and lastly, the effects of a lower temperature threshold of 220 K will be assessed.

a. Temporal variations

The variation of the observed rainfall (solid line) and the EPI2 (dashed line) as a function of time is displayed in Fig. 2. The curves represent fluctuations of the precipitation and EPI2 values, averaged over all the seven segments considered. The EPI2 values are multiplied by an arbitrary scaling factor (9), used exclusively for a better visualization. The solid line in Fig. 2 shows that three seasons can be distinguished:

(i) predominantly dry from October till the end of February;
(ii) a period of transition from the dry to rainy season from March till May;
(iii) rainy season from June until September.

The two curves in Fig. 2 bear a close resemblance and are well in phase. The similarity is especially striking during the rainy season. The magnitudes of the two curves, however, differ in a nonconsistent manner: during the transition, the EPI2 strongly exceeds the observed rainfall, whereas all through the rainy period the observed and estimated rainfall rather overlap. The qualitative results suggest that a single EPI2-rain relation would tend to overestimate rainfall during the transition season.

The relationship between the observed rainfall and precipitation indices is investigated more quantitatively by determining multiple and partial correlation coef-

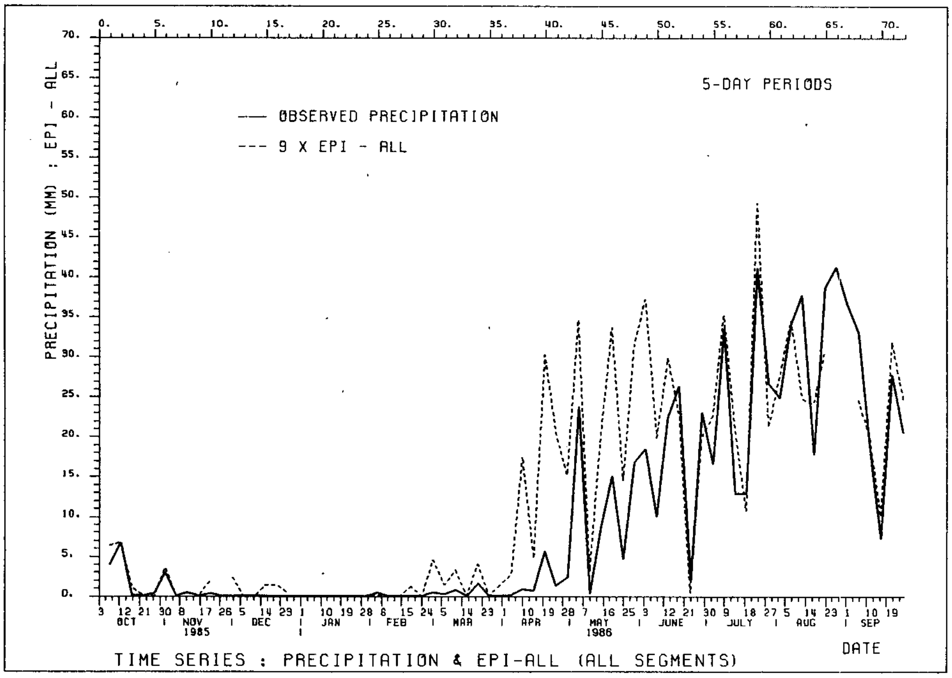

FIG. 2. The variation of the mean precipitation in millimeters (solid line) and EPI2 (dashed line), multiplied by a scaling factor of 9, in Burkina Faso during the 1-yr period. The temperature threshold of 235 K is used. Each time interval represents a 5-day period. All the segments are considered.

ficients both for the three seasons and the full year considering the EPI1, EPI2, and EPI3. The results are shown in Table 2. The correlation is generally high except for the rainy season. The differences between the various versions of EPI are small, the EPI1 tending to be superior and EPI3 to be inferior to the other methods. Most of the differences are, however, not statistically significant. Thus, based on the correlation figures, estimation of the precipitation seems to be plausible with a comparable skill using any of the three methods.

As the correlation coefficients did not clearly demonstrate the superiority of any of the three indices, all the corresponding regression lines are determined. The slopes of the lines of best fit are displayed in Table 3. In addition to the slopes based on the full year's data (Column Y), to be used in the rainfall estimation, the optimum slopes for each season are displayed (columns D, T, R) to demonstrate the fairly large seasonal variations of all the approaches. The values for the rainy season are often twice as large as those for the dry and transition seasons. This implies that the use of a single regression equation, with no seasonal adjustment, undoubtedly leads to rainfall estimates deviating from the observations. Notice (column KEN) the slopes of the regression lines determined for Kenya for a 3 month period consisting of a short rainy season followed by a dry spell (TEA), shown here for reference. The values are not identical, but still comparable to the ones obtained for Burkina Faso, hinting that the application of a single regression line may be plausible over equatorial Africa.

As the objective of this technique is to estimate rainfall with a single set of coefficients, only one set of three regression lines based on the full year's data will be used to estimate rainfall. The results of seasonal and annual rain estimation are shown in Table 4. The yearly rainfall can be estimated to a very high degree of accuracy, as the estimates never deviate more than 11% from the observed rainfall. The EPI1 and EPI2 yield equally precise estimates of accumulations, while the use of the EPI3 results in a slight underestimation.

In contrast to the annual estimation, the seasonally calculated rains experience larger deviations. During the dry season, all the three estimates are excellent. Little precipitation is estimated for the dry period, thus indicating no problems with nonprecipitating cirrus. In the previous study, the cirrus clouds constituted a serious problem in Senegal during the dry season. This was not the case in Burkina Faso. During the transition period the problem of nonprecipitating cold clouds did, however, reappear. Both the EPI1 and EPI2 led to a 100% overestimation of the precipitation. The results obtained with the EPI3 were slightly superior but the overestimation was still marked (about 70%). During the rainy season all the indices have a tendency to underestimate the rainfall by 20%–25%. The strongest deviation is experienced using the EPI3. As the overall performance of the EPI3 is worse than that of the other two indices and as it does not solve the problem of the

TABLE 2. Multiple (EPI1 and EPI3) and partial (EPI2) correlation coefficients between the observed precipitation and the three versions of EPI as a function of season for the temperature threshold of $T < 235$ K. All the segments are considered. If a correlation coefficient is significantly lower than the highest value for a season or year, one asterisk has been inserted for a 10%, and two asterisks for a 5% significance level. The symbols of the seasons are as in Table 1.

	Season			
Index	D	T	R	Y
EPI1	.77	.73	.52	.77
EPI2	.75	.70	.56	.76
EPI3	.77	.69	.45	.72*

TABLE 3. Slopes [$a(1)$, $a(2)$, $a(3)$, b, $c(1)$, and $c(2)$] of the following regression lines as a function of season:

$$ER1 = \sum_{i=1}^{3} a(i)I(i) \qquad (1)$$

$$ER2 = b \sum_{i=1}^{3} I(i) \qquad (2)$$

$$ER3 = \sum_{i=2}^{3} c(i-1)I(i) \qquad (3)$$

where $I(1)$, $I(2)$ and $I(3)$ correspond to the contributions to EPI from atmospheres with the upper tropospheric humidity of 75%–100%, 40%–75% and 0–40%, respectively, and where ER1, ER2 and ER3 are estimated rainfalls. All the segments have been considered. KEN is results for Kenya; the notations for the seasons are as in Table 1.

	Season				
	D	T	R	Y	KEN
*a*1	1.7	2.4	7.6	5.1	1.2
*a*2	7.8	5.8	9.8	8.9	8.5
*a*3	4.8	3.0	6.9	6.4	9.4
b	5.1	3.5	7.9	6.6	7.1
*c*1	8.0	6.7	12.6	10.8	8.8
*c*2	4.9	4.4	8.5	7.8	9.3

TABLE 4. Seasonal and annual rainfall (in millimeters) considering all the segments as a function of the regression line used, for the temperature threshold of $T < 235$ K. OR is observed rainfall; for the symbols of the seasons and regression lines, see Tables 1 and 3, respectively.

	Season			
Regression line	D	T	R	Y
OR	16	83	514	612
ER1	24	172	412	608
ER2	23	175	408	606
ER3	25	140	384	548

nonprecipitating clouds during the transition, it will not be considered in the following sections.

The reasons for the deviations, overestimation during the transition and a slight underestimation during the rainy season, were studied in greater detail. The strong overestimation could be partly attributed to the abundance of thick nonprecipitating cirrus at the leading edge of the ITCZ, dominating the skies during the transition. It is obvious that the nonsegregated index, EPI2, cannot distinguish a thick nonprecipitating cloud from a precipitating one. The results obtained here indicated that the segregation according to the humidity in the upper troposphere only marginally diminished the deviation. Another plausible explanation for the overestimation experienced could be that rain (from precipitating clouds) only partially reaches the ground due to the strong evaporation caused by particularly dry conditions in the lower layers of the atmosphere during the transition. To confirm this hypothesis, a mean relative humidity was determined for the months of April and July based on observations from all the nine synoptic stations of the country. In April, in the middle of the transition, the mean relative humidity was only 40%, whereas in the rainy season (July) it reached the value of 74%.

The deviation of the rainy season, only 20%–25% in contrast to the overestimation of 100% during the transition, could be explained by the nature of precipitation systems in Africa. Most of the rainfall can be attributed to the leading cumuliform edge of the African squall lines (Houze 1977). The cumuliform precipitation falls from thick cold clouds, well reflected by any cloud indexing method. But the trailing stratiform part, especially in its decaying stage, and unorganized convection may not be fully captured by the EPI, as the cloud tops tend to be warmer than the temperature threshold considered.

To judge the performance of the precipitation estimates of short duration, Table 5 was compiled, where the accuracy of the calculated 5-day rainfall is displayed as a function of season. The differences between the observed and estimated precipitation are typically 40%–60%, except for the transition season, where the deviations exceed 100%. The EPI1 and EPI2 result in a comparable accuracy. It can be concluded that the shorter the time scale, the larger the margin of the uncertainty of the rainfall estimates tends to be.

TABLE 5. Mean observed 5-day rainfall (MOR) and the mean differences (MDIF1, MDIF2) between the MOR and mean estimated 5-day rainfall according to the precipitation index used (1: EPI1, 2: EPI2), in 0.1 mm, as a function of the season for $T < 235$ K. For the symbols of the seasons, see Table 1.

Method	Season D	T	R	Y
MOR	10	50	230	90
MDIF1	6	57	101	51
MDIF2	6	60	101	51

b. *Geographical variations*

A similar approach to the one applied in the study of temporal variations is followed to examine the geographical variations. The same regression lines as in Section 3a are employed to determine the rainfall estimates.

Figures 3–5 illustrate the observed precipitation (solid line) and EPI2 (dashed line) as a function of time in the southern, central, and northern parts of the country, respectively. From the curves representing the observed precipitations, it can be inferred that the duration of the rainy season becomes drastically shorter as one moves from the south to the north, whereas the transition period seems to be longest in the north. Comparing the two curves in each figure it can be concluded that they are fairly well in phase, but that their magnitudes differ in a nonconsistent manner. In all of the regions the estimated precipitation tends to be higher than the observed one all through the transition period, while during the rainy season the inverse is true, thus confirming the results obtained for the whole country (Fig. 2).

The correlation coefficients between the observed rainfall and EPI1 and EPI2 were determined for the different parts of the country considering the whole 12-month period (not shown). They are fairly high (0.74–0.81) for all the regions. No statistically significant differences between the areas or two methods occur. These results imply that it should be plausible to use the linear regression to estimate precipitation in any of the regions.

Table 6, depicting the annual rain estimates against the observed rainfall, shows, however, that the use of a single regression line leads to some inaccuracies. In the north, where the transition period is particularly long, an overestimate of 20% results. On the contrary, in the south, where the rainy season has a long duration the annual precipitation is underestimated by about 10%. In the central parts of the country, corresponding to the average Burkina climate, the use of the single regression line results in very accurate estimates.

The dependence of the 5-day estimates of rainfall on the regional factors is shown in Table 7. The two methods based on the EPI1 and EPI2 possess almost identical error characteristics. The results are similar to those obtained for the whole country (Table 5). In the north, however, the differences are slightly larger: 70% instead of 55%, hinting that with an increasing distance from the equator, the estimates tend to deteriorate.

c. *Temperature threshold of 220 K*

As the results reported so far indicated that the overestimation of the precipitation during the transition

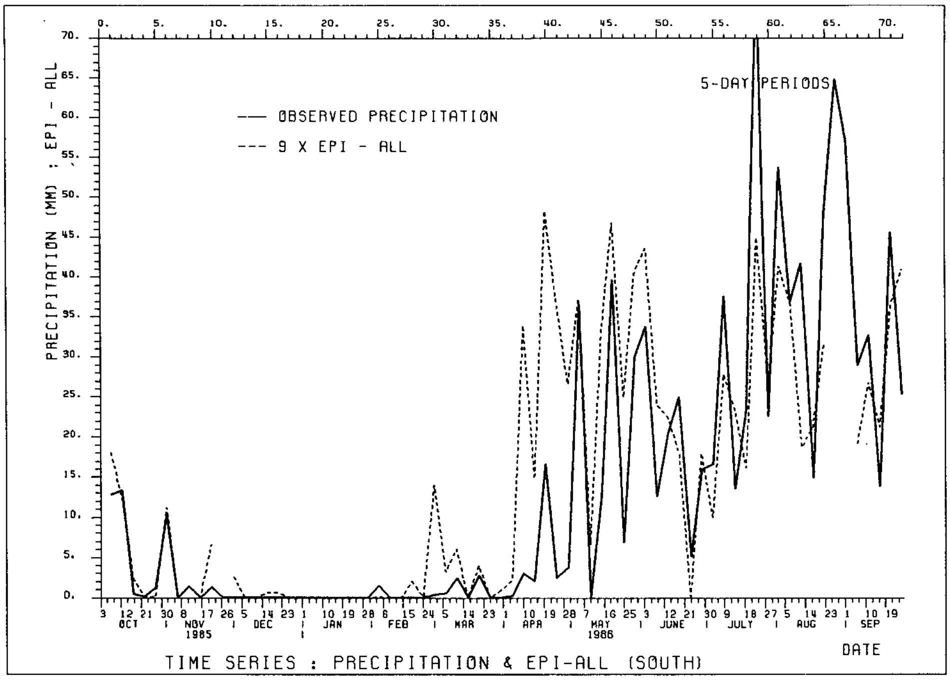

FIG. 3. As in Fig. 2, but for only the two segments in the south.

season, likely due to nonprecipitating cirrus, constituted a major problem, a lower temperature threshold was seen as a promising option to improve the estimates by filtering out some of these clouds. Richards and Arkin (1981) showed that the temperature threshold could be lowered down to 220 K without substantially changing the correlation between the cloud coverage index and observed rainfall. Therefore, this was selected as the temperature threshold.

The behavior of the EPI2 (multiplied by a scaling

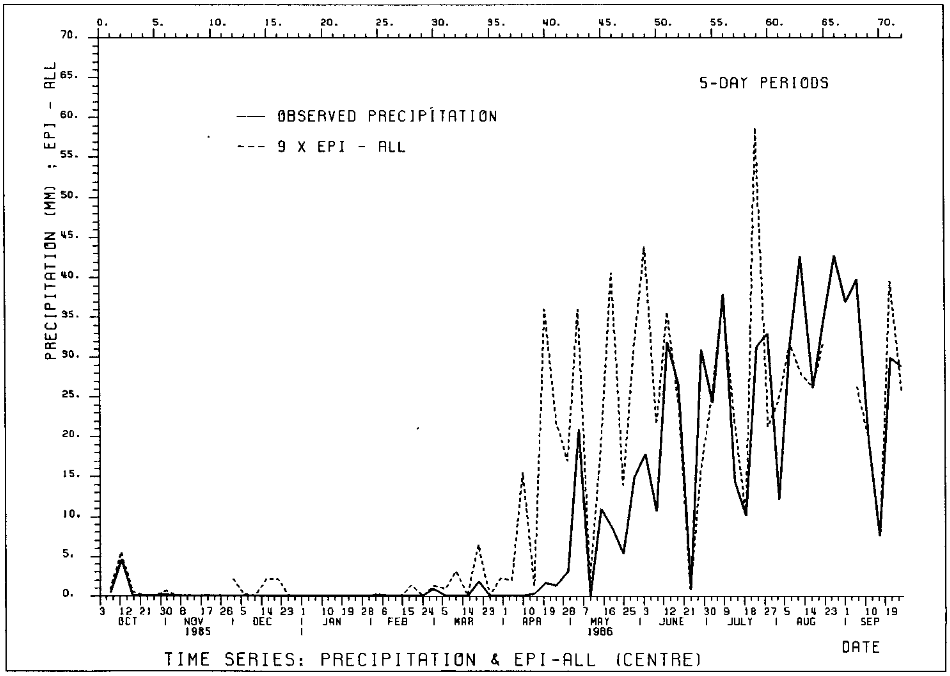

FIG. 4. As in Fig. 2, but for only the three central segments.

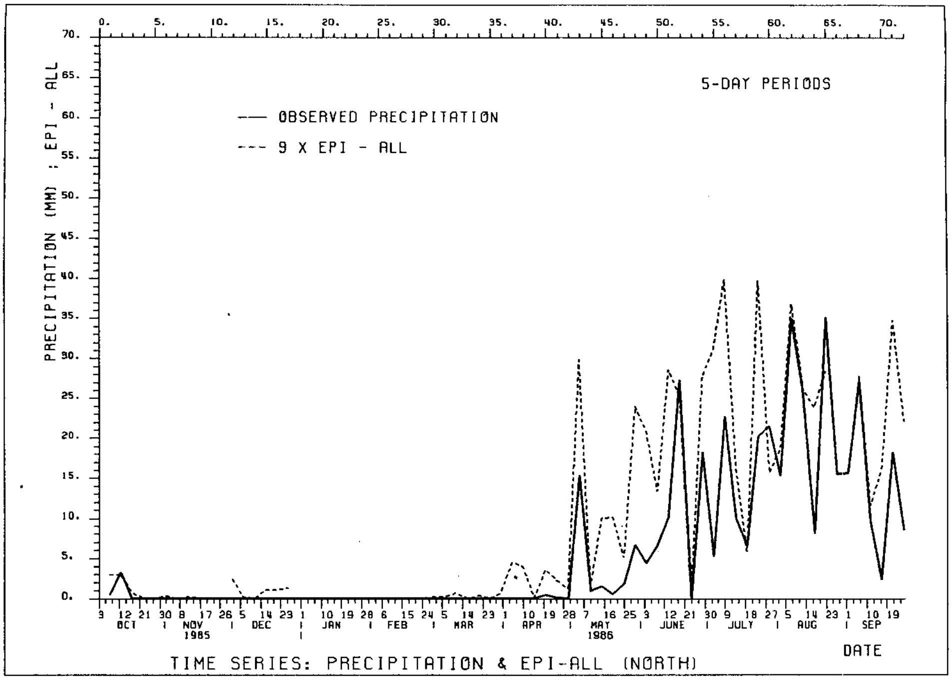

FIG. 5. As in Fig. 2, but for only the two segments in the north.

factor of 13) and the observed precipitation is illustrated in Fig. 6. The two curves are well in phase, like those calculated for 235 K. The magnitudes of the curves still differ in a nonconsistent way: the EPI2 tends to be larger than the observed precipitation during the transition period, whereas the inverse occurs during the rainy season. The qualitative results indicate that the problem of the overestimation of the rainfall during the transition may not be solved by the use of the lower temperature threshold of 220 K.

The correlation coefficients between the observed rainfall and the precipitation indices (EPI1 and EPI2) were determined and they are shown in Table 8. The two methods yield similar results, except during the dry season when the EPI1 has a significantly better performance. When compared to the values calculated for the temperature threshold of 235 K (Table 2), the coefficients are comparable; only the multiple correlation coefficient (EPI1) determined for the dry season is significantly higher (at a 5% level). These results are not surprising in the light of the findings by Richards and Arkin (1981), who showed that the correlation changed little as the temperature threshold decreased from 235 to 220 K.

The precipitation estimates are displayed in Table 9. Although the multiple correlation was systematically higher than the partial one, the calculated rainfalls are almost identical using the two methods. The results indicate that a decrease of the overestimation indeed occurred during the transition (from more than 100% to 65%). The results for the rainy season and the whole year, however, deteriorated, as some of the warmer rain clouds were no longer captured by the method. Thus, the introduction of the lower temperature threshold does not substantially improve the rain estimates; it does not fully solve the problem of the overestimation, while introducing an additional underestimation for the rainy period and the whole year.

TABLE 6. The annual rainfall (in millimeters) as a function of the geographical region and the line of regression for the temperature threshold of $T < 235$ K. The regression line OR is observed rainfall; the symbols for regression lines are as in Table 3.

	Geographical region		
Regression line	South	Center	North
OR	848	617	370
ER1	751	614	455
ER2	737	618	456

TABLE 7. Mean observed 5-day rainfall (MOR) and the mean difference (MDIF1, MDIF2) between the MOR and mean estimated 5-day rainfall according to the precipitation index used (1: EPI1, 2: EPI2), in 0.1 mm, as a function of the region for $T < 235$ K.

	Geographical region		
Method	South	Center	North
MOR	120	90	50
MDIF1	64	51	35
MDIF2	68	51	34

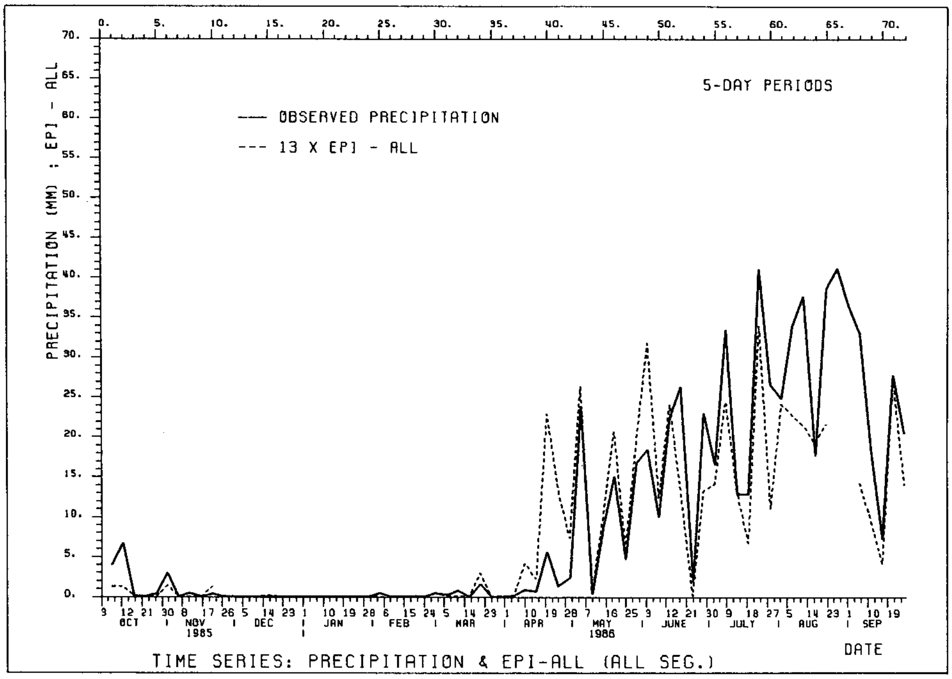

FIG. 6. As in Fig. 2 but the temperature threshold of 220 K and scaling factor of 13 are used.

4. Summary and conclusions

An attempt to estimate rainfall in Burkina Faso using the ESOC precipitation index (EPI) has been undertaken. The EPI, a cloud coverage index, was converted into rain estimates using a single line of regression determined between the full year's data of EPI and the corresponding observations from a high-density network of rain gages. The estimated and observed rainfalls were compared, with a particular emphasis on the temporal and regional variations of the accuracy of the estimates, to find out whether the use of the single regression line could be justified. In addition, the importance of the segregation of the EPI according to the humidity in the upper troposphere was assessed.

The accuracy of the estimates varied through the year. During the transition from the dry to rainy season, the estimates were particularly poor with a marked overestimation of the rainfall. The overestimation could be attributed to two factors: the abundance of thick nonprecipitating cirrus at the boundaries of the ITCZ, and the strong evaporation in the lower atmosphere caused by the low humidities, characteristic of the transition season. During the rainy season, the estimates were fairly accurate with a tendency to somewhat underestimate the rainfall. The estimates for both the whole year and the dry season were in excellent agreement with the observations.

In an attempt to solve the principal problem, the overestimation experienced during the transition, a lower temperature threshold of 220 K was applied in the calculation of the EPI. The overestimation did turn out to be weaker, but the gain was compromised by the increase of the underestimation both during the rainy season and the whole year.

The regional variations were less marked than the temporal ones. The northern parts of the country, exposed to a very long transition season, suffered from a slight overestimation of the rainfall. In the central and southern parts of the country the estimates were well in accord with the observations.

The segregation of the EPI into three classes accord-

TABLE 8. As in Table 2, but for the temperature threshold of 220 K.

Index	Season D	T	R	Y
EPI1	.84	.81	.55	.78
EPI2	.68**	.77	.53	.76

TABLE 9. As in Table 4, but for the temperature threshold of $T < 220$ K.

Regression line	Season D	T	R	Y
OR	16	83	514	612
ER1	7	138	391	536
ER2	6	138	391	535

ing to humidity constituted an improvement over the nonsegregated index, but in contrast to the results obtained by TEA, the differences were not generally statistically significant. Thus the inclusion of the upper tropospheric humidity does not seem to make any significant contribution to rainfall estimation in Burkina Faso.

The present study demonstrates the feasibility of estimating seasonal and annual rainfall in the central Sahel by means of a single regression line, linking the ESOC precipitation index to precipitation. The estimates providing a continuous spatial and temporal coverage will be particularly useful in climatological study programs, such as the WCRP, in complementing the observations from the sparse conventional rain gage network. The present approach is not, however, free of problems. Some adjustments may be mandatory to improve the accuracy of the seasonal rainfall estimates. In particular, the estimates made for the transition period between the dry and the rainy season, influenced by the leading edge of the ITCZ, should be subject to a correction to compensate for the nonprecipitating cirrus. To determine precisely the magnitude of the adjustments to be applied, studies for various regions are needed. The method should also be tested with an independent rainfall dataset.

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