El Niño–Southern Oscillation and Rainfall Variability

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ABSTRACT

The relationship between mean rainfall and the relative variability of annual rainfall is shown to be different for stations that have consistent relationships with ENSO compared with stations not affected by ENSO. Variability is typically one-third to one-half higher for ENSO-affected stations. It appears that ENSO causes a more variable climate in the areas it affects.

1. Introduction

The El Niño–Southern Oscillation (ENSO) phenomenon influences rainfall in many parts of the globe. Ropelewski and Halpert (1987) have identified areas with a consistent relationship between ENSO and the interannual variations in rainfall, thereby consolidating the results of many earlier studies. The present study examines the relationship between ENSO and rainfall *variability,* as distinct from rainfall *variations.*

Conrad (1941) defined the relative variability of annual rainfall (v), as 100 times the mean of the absolute deviations of annual rainfalls from the long-term mean, divided by the long-term mean:

$$v_r = 100|\bar{p} - p|/(n\bar{p})$$

where p is the precipitation in millimeters in year i, n is the number of years, and $\bar{p}$ is the long-term mean. Conrad reported that variability decreased, in general, as the mean precipitation increased. He found that the function

$$v_r = 13 + 3600/(\bar{p} + 60)$$

fit his data, from 384 stations from across the globe, quite well. Conrad then calculated anomalies ($v_r - \hat{v}_r$) at each station and found that large "regions of the earth's surface show anomalies of the same sign. The distribution of positive and negative anomalies is therefore not to be ascribed to chance or accidental local conditions, but represents a significant climatological element."

Conrad believed that some of the regions of positive anomalies (i.e., "excess" variability) were due to the El Niño phenomenon, viz., the large positive anomalies at Malden Island and in Peru and Chile. His data have been reexamined to determine whether the El Niño–Southern Oscillation (ENSO) causes "excess" variability outside the immediate El Niño area of the equatorial east Pacific and the Pacific coast of South America. This reexamination was motivated by a comparison of Conrad's map of excess and deficient variability (his Fig. 1) with a map of areas where rainfall is consistently related to the ENSO (Fig. 21 in Ropelewski and Halpert, 1987). The areas with excess variability mainly seemed to be areas with consistent teleconnections to ENSO. The possibility that rainfall was more variable in areas where the interannual variations are related to ENSO was tested by examining the relationship between mean rainfall and relative variability for two groups of stations; those which show consistent correlations with ENSO, and those which do not.

2. Data and method

The data tabulated in Conrad (1941) were used in this study because they are readily available (in his Table 5), and because use of all his data lessened the possibility that the selection of stations might bias the results. Conrad lists the mean annual rainfall and the relative variability for 384 stations.

Conrad's stations were divided into three groups:

(I) Stations in the immediate El Niño area, i.e., Malden Island, stations in Peru and Chile (north of 40°S), and Apia in West Samoa (13 stations).

(II) Stations outside this immediate El Niño area but located in areas where Ropelewski and Halpert (1987) report a consistent teleconnection to ENSO (their Fig. 21). These stations with their latitudes and longitudes are listed in Table 1 (80 stations).

(III) All other stations (291 stations).

Nonlinear regression was used to fit relative variability to mean rainfall for all the stations together, and then separately for group II and then group III stations. Both of these values for each station were

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TABLE 1. Stations in group II (those with consistent teleconnections with ENSO), taken from Conrad (1941). Some stations have had name changes since 1941.

Station	Lat	Long	Station	Lat	Long
Salt Lake City	40.8°N	111.9°W	Yuma	32.8°N	114.6°W
Modena	37.8°N	114.6°W	Phoenix	33.5°N	112.0°W
Abilene	32.4°N	99.7°W	Mobile	30.7°N	88.0°W
Charleston	32.8°N	79.9°W	Hatteras	35.2°N	75.7°W
Lahore	31.6°N	74.4°E	Simla	31.1°N	77.2°E
Honolulu	21.3°N	157.9°W	Chihuahua	28.6°N	106.1°W
Monterrey	25.7°N	100.3°W	Corpus Christi	27.8°N	97.4°W
Galveston	29.3°N	94.8°W	New Orleans	30.0°N	90.1°W
Key West	24.6°N	81.8°W	Nassau	25.1°N	77.4°W
Karachi	24.8°N	67.1°E	Haiderabad	25.4°N	68.4°E
Ahmadabad	23.0°N	72.6°E	Jaipur	26.9°N	75.9°E
Nagpur	21.2°N	79.2°E	Allahabad	25.5°N	81.9°E
Patna	20.7°N	83.2°E	Port-au-Prince	18.6°N	72.4°W
Caracas	10.5°N	67.0°W	S. Juan	18.5°N	66.1°W
Christiansted	17.8°N	64.7°W	Richmond Hill	12.1°N	61.8°W
Trinidad	10.7°N	61.5°W	Barbados	13.1°N	59.6°W
Bombay	18.9°N	72.9°E	S. Jose	9.9°N	84.1°W
Colon	9.4°N	79.4°W	Georgetown	6.8°N	58.2°W
Entebbe	0.1°N	32.5°E	Cochin	9.9°N	76.3°E
Colombo	6.9°N	79.8°E	Nuwara Eliha	7.0°N	80.8°E
Trincomalee	8.6°N	81.2°E	Sandakan	5.8°N	118.2°E
Menado	1.5°N	124.8°E	Quixeramobin	5.3°S	39.2°W
Fortaleza	3.7°S	38.5°W	Batavia	6.2°S	106.8°E
Ponianak	0.0°	109.3°E	Pasuran	7.6°S	112.9°E
Kajoemas	7.9°S	114.2°E	Amboina	3.7°S	128.2°E
Manokwari	0.9°S	134.3°E	Pt. Moresby	9.5°S	147.2°E
Salisbury	17.8°S	31.1°E	Antanarivo	18.9°S	47.5°E
Kupang	10.2°S	123.6°E	Darwin	12.5°S	130.8°E
Goya	29.2°S	59.2°W	Corrientes	27.4°S	58.8°W
Asuncion	25.3°S	57.7°W	Posadas	27.4°S	55.8°W
Kimberley	28.7°S	24.8°E	Johannesburg	26.2°S	28.1°E
Bulawayo	20.2°S	28.7°E	Durban	29.8°S	31.0°E
Alice Springs	23.6°S	133.6°E	Cordoba	31.4°S	64.2°W
General Acha	37.1°S	64.1°W	Bahia Blanca	38.7°S	62.2°W
Buenos Aires	34.6°S	58.4°W	Concordia	31.4°S	58.0°W
Mar del Plata	38.0°S	57.1°W	Ajo-G. Lavalle	36.5°S	56.8°W
Montevideo	34.9°S	56.2°W	Aliwal	30.7°S	26.7°E
Adelaide	34.9°S	138.6°E	Puerto Madryn	42.8°S	64.9°W

taken from Conrad's Table 5. The data were fitted to the function suggested by Conrad:

$$\hat{v}_r = A + B/(\bar{p} + C).$$

The method of false position (Ralston and Jennrich, 1979) was used to fit the model to the data. The method is available in the SAS statistical analysis system and is described in SAS (1985).

3. Results

The values of the parameters A, B, and C estimated by the nonlinear regression are listed in Table 2. Conrad's model is also included for comparison. The four models are plotted in Fig. 1 for mean rainfalls between 100 and 3000 mm. Conrad's model and the nonlinear regression using all 384 stations are very similar throughout the range.

The other two models differ substantially. In the range 100–1000 mm the model fitted to group II stations (those teleconnected to ENSO) produces relative variabilities one-third to one-half higher than the model for group III stations (those not strongly affected by ENSO). The fit of the model between v_r and $\bar{p}$ is also better if the relationship with ENSO is taken into account. Residuals between observed v_r and $\hat{v}_r$ estimated from the appropriate group II or group III model were calculated for the 371 stations in groups I and II. The mean absolute residual was 4.2%. Data from these 371 stations were then fitted to a single model and residuals again calculated. In this case the mean absolute residual was 4.6%. Thus, taking account of whether a station is in an area teleconnected to ENSO reduces the mean absolute error of the model by about 10%. There is little doubt that the difference between the models is significant since the difference is large and the models were fitted to large numbers of observations (80 for group II; 291 for group III).

There seems to be no obvious reason, apart from the relationship with ENSO, for the substantial differences in variability. Stations in both groups II and III range from arid to very moist environments, from locations in the middle of continents to coastal areas, and from the midlatitudes to the equator. The group

TABLE 2. Results of nonlinear regression between relative variability and mean rainfall. The model parameters estimated by the nonlinear regression are *A*, *B*, and *C*.

	Conrad (1941)	This study		
		All stations	Group II	Group III
		Global data		
A	13	12.49	12.19	12.03
B	3600	4568.59	9915.44	3638.47
C	60	77.27	195.57	59.36
No. stations	384	384	80	291
		Northern Hemisphere		
A		12.17	10.13	11.99
B		4001.86	12 092.12	3498.86
C		58.98	215.11	48.15
No. stations		304	49	255
		Southern Hemisphere		
A		13.98	14.81	13.65
B		6843.04	9548.42	2881.77
C		147.65	398.35	54.43
No. stations		80	31	36
		Tropics (latitude < 30)		
A		9.99	14.18	12.31
B		13 192.67	5761.32	6316.90
C		272.49	−47.62	126.52
No. stations		149	60	85

II stations have a slightly higher group mean rainfall (1283 mm vs 1051 mm) but this difference between the two groups does not seem large enough to cause the substantial differences in the models shown in Fig. 1. The only substantial geographical difference between the two groups is that a higher proportion of group II stations comes from the tropics and the Southern Hemisphere.

The possibility that the differences between the models are due to interhemispheric differences was checked by fitting the nonlinear regression models separately for the two hemispheres. The results are shown in Fig. 2 and Table 2. The group III models for the two hemispheres are very similar. The group II models are rather different, but for mean rainfalls between 125 mm and 2500 mm both group II models produce expected variabilities well in excess of those from the two group III models. The differences between the group II and group III models in Fig. 1 (i.e., with data from both hemispheres) are not, it is concluded, due to interhemispheric differences.

There are proportionally more tropical stations in group II than in group III. To check whether this was the cause of the differences between the group II and group III models, data from the tropics only (within 30 deg latitude of the equator) were fitted to the model. The results are shown in Table 2 and Fig. 3. At low rainfalls, the group II and group III models both produce higher expected variabilities than their counterparts in Fig. 1 (which uses the global data). However, once again the group II model produces substantially higher expected variabilities than the group III model. The group II model produces very high variabilities for mean rainfalls below 250 mm. Figures 2 and 3 indicate that differences in latitude between group II and group III stations are not the cause of the substantial differences between the models.

The difference in variability between ENSO-affected stations and other stations may actually be an underestimate for two reasons. First, the stations in the immediate area of the El Niño (group I stations) were excluded because the amplification effect of El Niño on rainfall variability had already been noted by Conrad for these stations. If, however, these stations were included in group II (stations affected by ENSO), the difference between the group II and group III models widens. Second, only stations from areas Ropelewski and Halpert (1987) found that had consistent relationships with ENSO were included in group II. Conrad found an area of high variability in the Middle East. Ropelewski and Halpert found that rainfall in this area was related to ENSO but that the relationship exhibited secular shifts in sign, casting doubt on the reality of the relationship. These stations were *not* included in

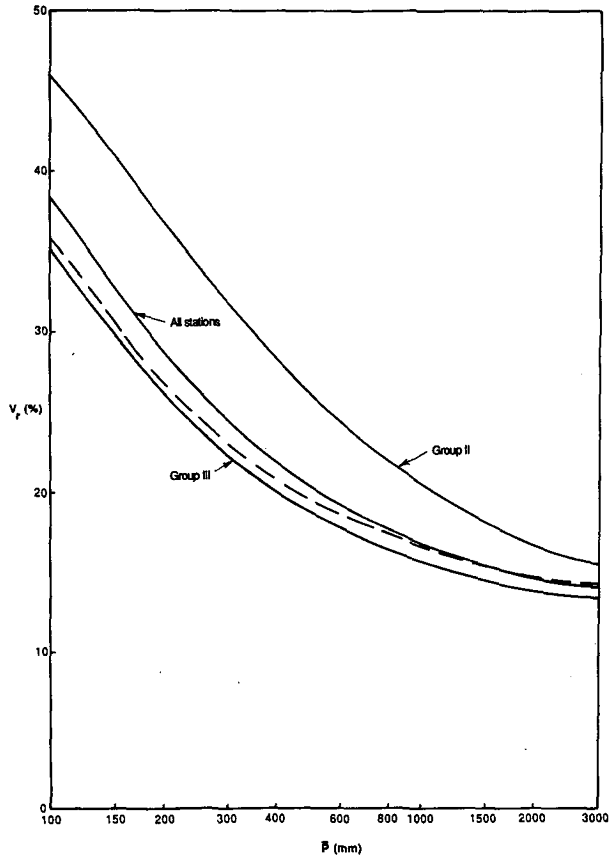

FIG. 1. Relationship between relative variability (v_r) and mean rainfall ($\bar{p}$) for four models: Conrad's model (broken line), from this study with all stations, from just group II stations, and from just group III stations.

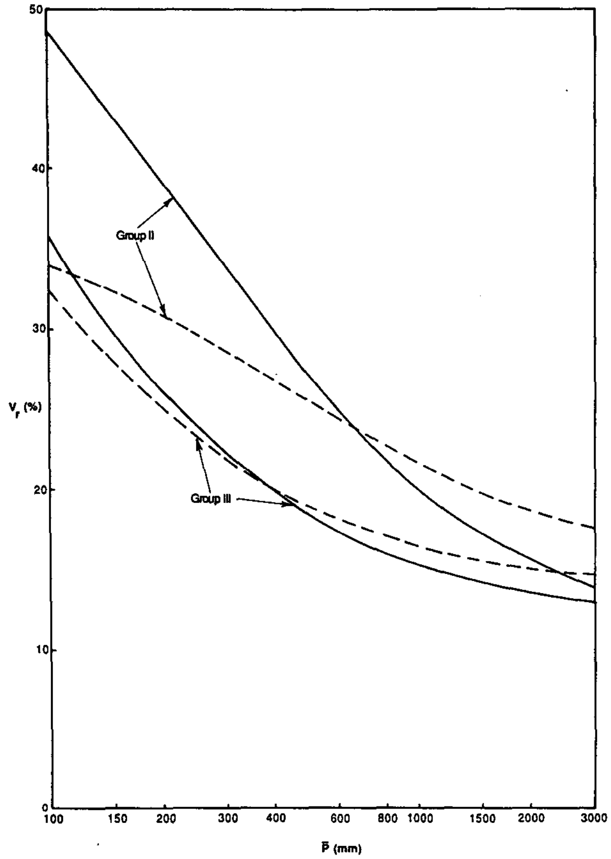

FIG. 2. Relationship between relative variability (v_r) and mean rainfall ($\bar{p}$) for group II and group III stations, using data separately for the Northern Hemisphere (full lines) and the Southern Hemisphere (broken lines).

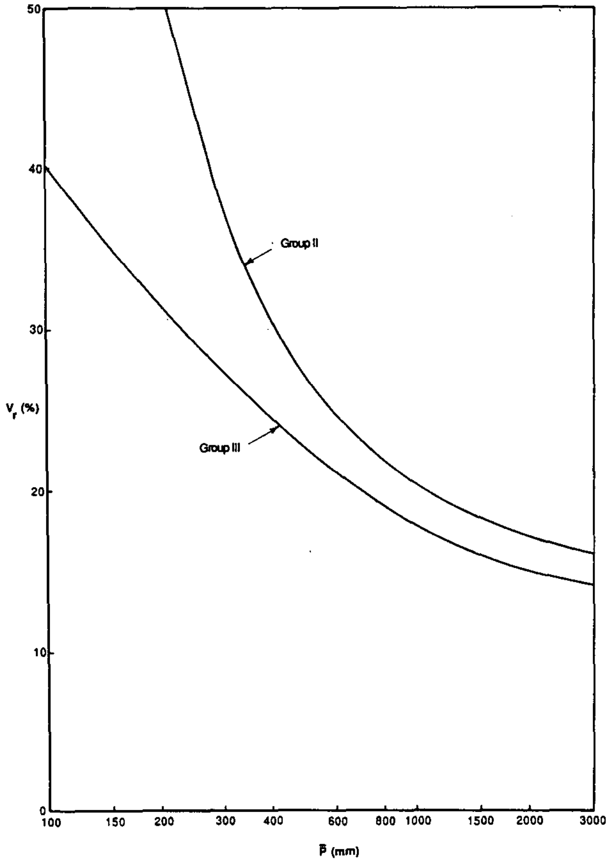

FIG. 3. Relationship between relative variability (v_r) and mean rainfall ($\bar{p}$) for group II and group III stations, using only tropical data.

group II (stations related to ENSO). If they had been, the differences between the group II and group III models would have widened again.

4. Concluding remarks

The variability in annual rainfall tends to be substantially higher in areas affected by ENSO, even outside the immediate area of influence of the El Niño. It seems reasonable to conclude that this higher variability is due to ENSO. Not only are fluctuations in ENSO related to rainfall fluctuations over large areas of the globe, but ENSO also amplifies, typically by one-third to one-half for most stations, the magnitude of the interannual rainfall fluctuations in these areas. Areas affected by ENSO are truly lands "of droughts and flooding rains."[1]

Conrad used data only from before 1930. Data since then could be used to confirm the differences in variability between ENSO-affected regions and other areas. Such data could also be used to examine the functional form of the effect of ENSO on variability in more detail, e.g., whether it is a multiplicative or additive effect. It would also be worth repeating this study using the coefficient of variation (standard deviation divided by the mean) as a measure of variability, instead of Conrad's relative variability.

A more substantial concern deserving further study is the possible impact of this "excess," ENSO-related variability. If the ENSO phenomenon has operated for a long period, e.g., thousands of years, the higher rainfall variability in ENSO-affected areas must have influenced the evolution of physiography, fauna, and flora. If wildlife which adapted to higher rainfall variability tends to be concentrated in areas now affected by ENSO, this might suggest that the ENSO phenomenon has indeed existed for a very long time.

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[1] "My Country" (1911), by Australian poet Dorothea Mackellar.

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