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SECOND AUTUMN WORKSHOP ON
CLOUD PHYSICS AND CLIMATE

(23 November - 18 December 1987)

SEASONAL RAINFALL OVER INDIA AS A WHOLE
SOUTHERN OSCILLATION - EL'NINO

U.C. MOHANTY
IIT, Delhi
India

SEASONAL RAINFALL OVER INDIA AS A WHOLE: SOUTHERN OSCILLATION-EL'NINO

DATA SETS:

- DAILY HISTORICAL ANALYSES FROM THE SOUTH AFRICAN WEATHER BUREAU: (1951-58)
- DAILY OPERATIONAL NUMERICAL ANALYSES FROM THE AUSTRALIAN BUREAU OF METEOROLOGY: (1972-83)
- WORLD MONTHLY SURFACE STATION CLIMATOLOGY DATA RECORDS OF SLP.

METHOD:

- DIFFERENCE IN MEAN SH-SLP BETWEEN EXCESS AND DEFICIENT MONSOON RAINFALL YEARS.
- MEAN SH-SLP ANOMALIES IN $YEAR_D$ OF WARM EVENTS.
- COMPOSITE OF NORMALIZED SLP ANOMALIES OF A NUMBER OF INDIVIDUAL STATIONS IN SH FOR LARGE EXCESS AND DEFICIENT MONSOON RAINFALL YEARS.

INDIAN SUMMER MONSOON RAINFALL DA[illegible]

TO IDENTIFY YEARS OF LARGE EXCESS (FLO[illegible] AND DEFICIENT (DROUGHT) MONSOON RAINFALL OVER INDIA – A NUMBER OF PUBLISHED REPORTS/PUBLICA[illegible] WERE USED:

- BENERJEE AND RAMAN (1976)
  SCI. REP. NO. 76/6, IMD PUNE
- RASMUSSON AND CARPENTER (1983)
  MWR, V. 111
- BHALME AND JADHAV (1984)
  J. CLIMT., V. 4

IN THIS STUDY, WE DEFINED EXCESS AND DEFICIENT RAINFALL FOR ALL INDIA AS BEING 0.[illegible] STANDARD DEVIATION OR MORE ABOVE AND BELOW THE MEAN.

FOR INFORMATIONS ABOUT WARM EPISODE YEARS (ELNINO'S), WE USED PUBLICATIONS:

- RASMUSSON AND CARPENTER (1982)
  MWR, V. 110
- VANLOON AND SHEA (1985) MWR, V. 113

FLOOD	DROUGHT
1954	1951
1973	1953
1975	1957
1978	1972
	1976

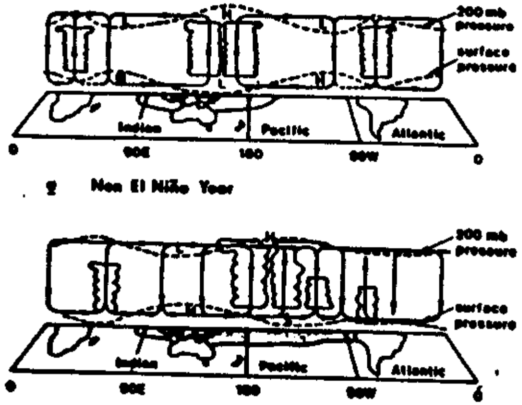
DATA: TWO TYPES OF DATA ARE USED FOR THIS STUDY

DAILY SH-SLP ANALYSES:

- DAILY HISTORICAL ANALYSES FROM THE SOUTH AFRICAN WEATHER BUREAU: 1951 - 1958
- DAILY OPERATIONAL NUMERICAL ANALYSES FROM THE AUSTRALIAN BUREAU OF METEOROLOGY: MAY 1972 - 1983

LONG RECORD OF MONTHLY MEAN SH SLP [illegible]

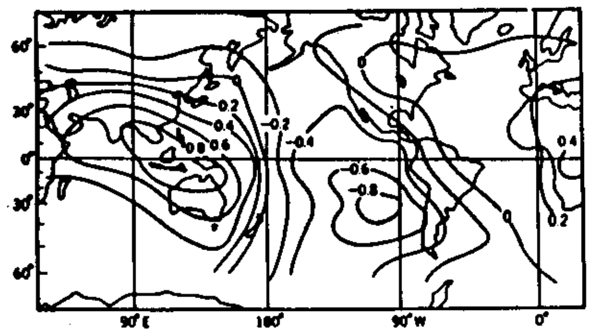
- WMSSC (WORLD MONTHLY SURFACE STATION CLIMATOLOGY) DATA RECORDS CONSISTS OF MONTHLY MEAN SLP, TEMPERATURE AND TOTAL MONTHLY PRECIPITATION FOR INDIVIDUAL STATIONS. THE PERIOD OF RECORD VARIES FROM STATION TO STATION. THE ORIGINAL WMSSC DATA SET WAS CONSIDERABLY UPDATED WITH DATA FROM SEVERAL METEOROLOGICAL AGENCIES IN THE SOUTH PACIFIC AND SOUTH AMERICA.
- THESE DATA SETS WERE OBTAINED FROM NCAR



a Non El Niño Year

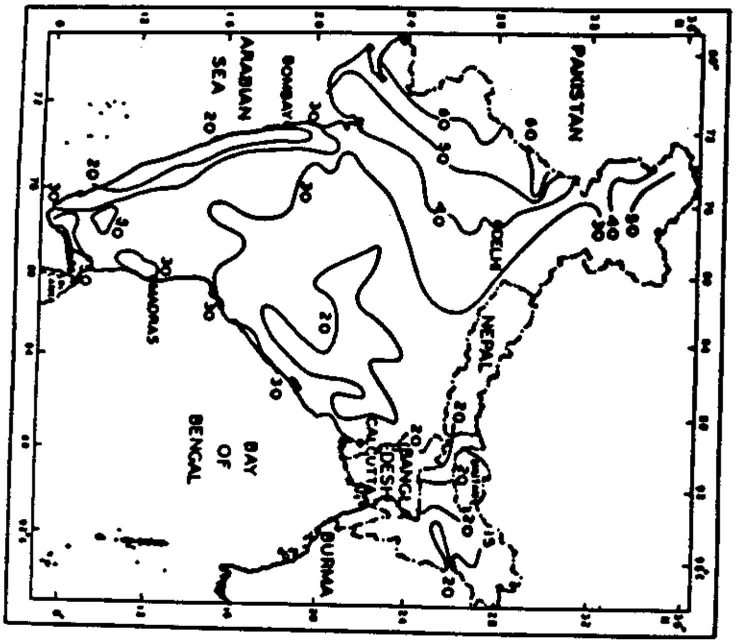
b El-Niño Year

Schematic view of the near-equatorial circulation or Walker Circulation described in the text for (a) the non-El Niño years when the sea surface temperature (SST) is maximum in the western Pacific and (b) for El Niño years when the SST maximum is much further east. Note the correspondence of the position of the convective cell to the SST maximum. Dashed lines represent pressure variations at the surface and in the upper troposphere, and the stippled regions represent areas where the SSTs are greater than 27°C (from J. Zillman, private communication).



Zero-Lag Southern Oscillation Index

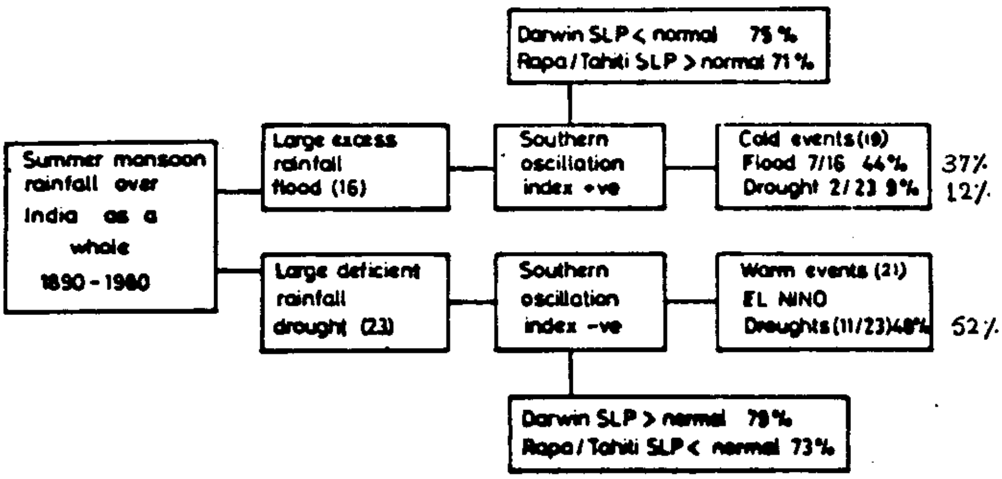
The correlation coefficient distribution of surface pressure variations relative to Darwin (from reference 8). Pattern indicates that when the pressure is anomalously high over Indonesia, it is low over the central and southeast Pacific Ocean, and vice versa. This seesaw of surface pressure defines the Southern Oscillation. It also shows why the Troup Index is a keen measure of the Southern Oscillation.



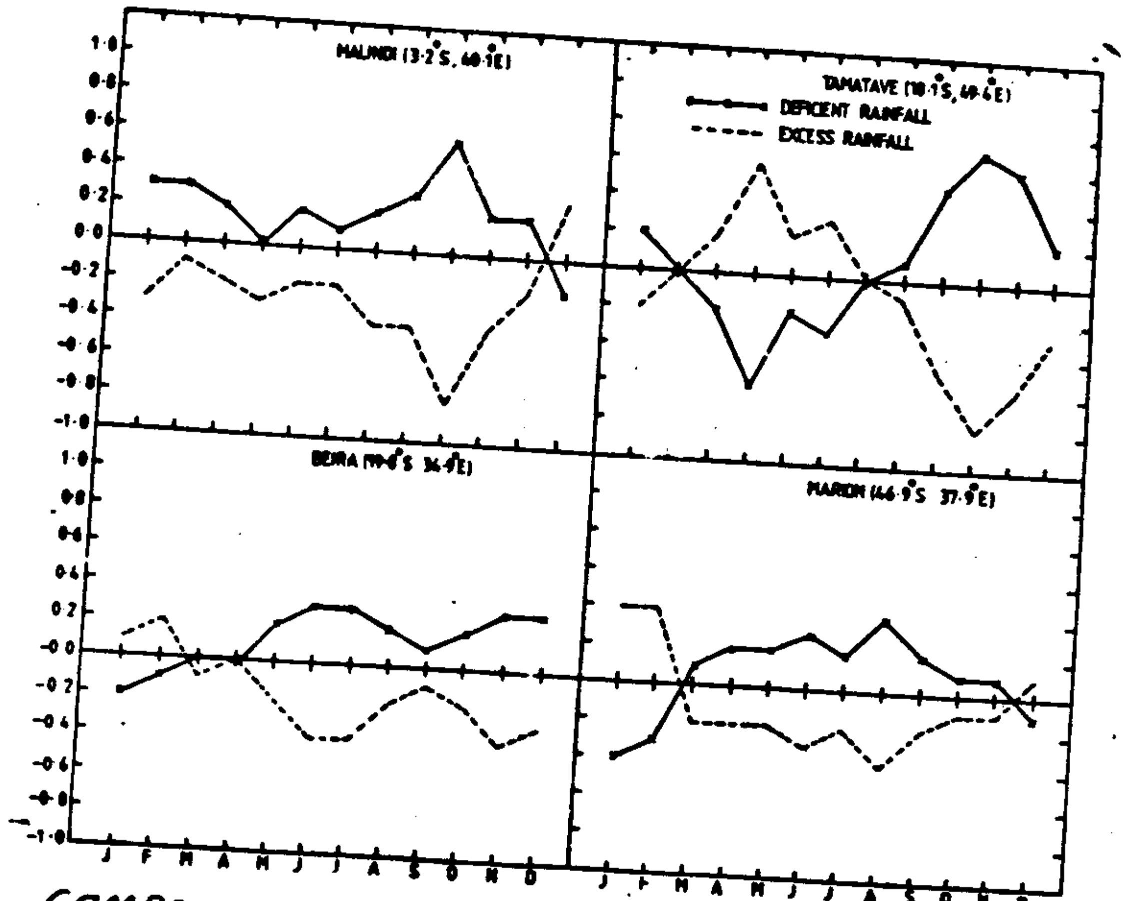
Coefficient of variation of rainfall for India

LARGE EXCESS MONSOON RAINFALL				
Rasmusson and Carpenter (1983)	Shukla and Paolino (1983)	Bhalme and Jadhav (1984)	Present work (1985)	Standard Deviation
-	-	-	1890	0·9
1892	-	1892	■1892	1·5
1893	-	1893	1893	1·4
1894	-	1894	1894	1·7
-	1908	-	-	0·7
1916	1916	1916	■ 1916	1·2
1917	1917	1917	1917	1·0
1933	1933	1933	1933	1·5
1942	1942	1942	■1942	1·3
1949	-	-	■1949	1·0
-	1953	-	-	0·5
-	-	-	1955	0·9
1956	1956	1956	1956	1·0
1959	1959	1959	1959	1·4
1961	1961	1961	1961	2·2
-	1970	-	■1970	0·9
-	1973	1973	■1973	0·9
1975	1975	1975	■1975	1·5

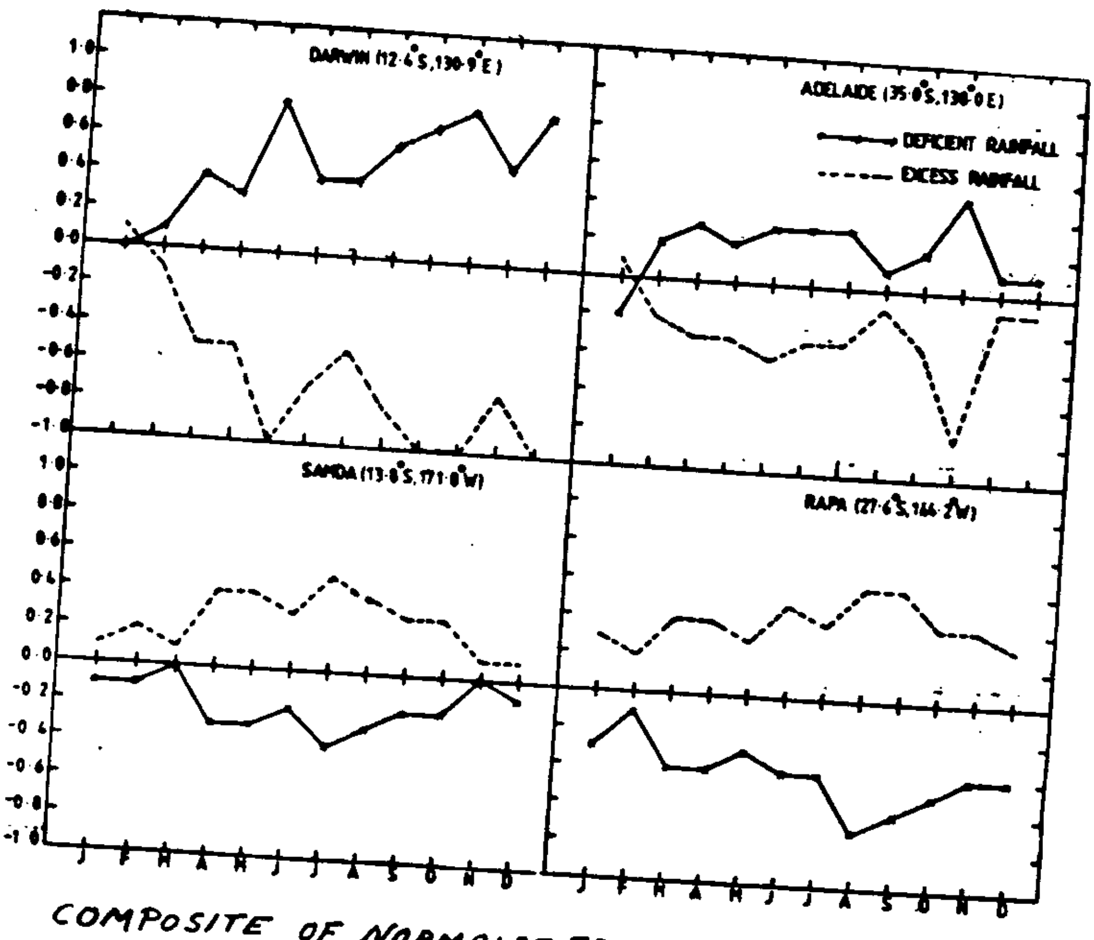
LARGE DEFFICIENT MONSOON RAINFALL				
Rasmusson and Carpenter (1983)	Shukla and Paolino (1983)	Bhalme and Jadhav (1984)	Present work (1985)	Standard Deviation
1891	-	-	+1891	−1·0
1899	-	1899	+ 1899	−2·6
1901	1901	1901	1901	−1·3
-	-	-	+1902	−0·9
-1904	1904	1904	*1904	− 1·2
1905	1905	1905	1905	−1·6
-	-	-	1907	−0·9
1911	1911	1911	+ 1911	−1·4
1913	-	1913	+ 1913	−1·1
1915	-	-	1915	−1·0
1918	1918	1918	+ 1918	−2·4
1920	1920	1920	■1920	−1·7
-	-	-	1928	− 0·9
1939	1939	-	+1939	−1·0
1941	1941	1941	1941	− 1·4
1951	1951	1951	+ 1951	−2·0
-	-	-	1952	−0·9
1965	1965	1965	+1965	−1·5
1966	-	1966	■ 1966	−1·1
1968	1968	-	1968	−1·1
1972	1972	1972	+ 1972	−2·3
1974	1974	-	1974	−0·9
1979	1979	1979	1979	−1·9



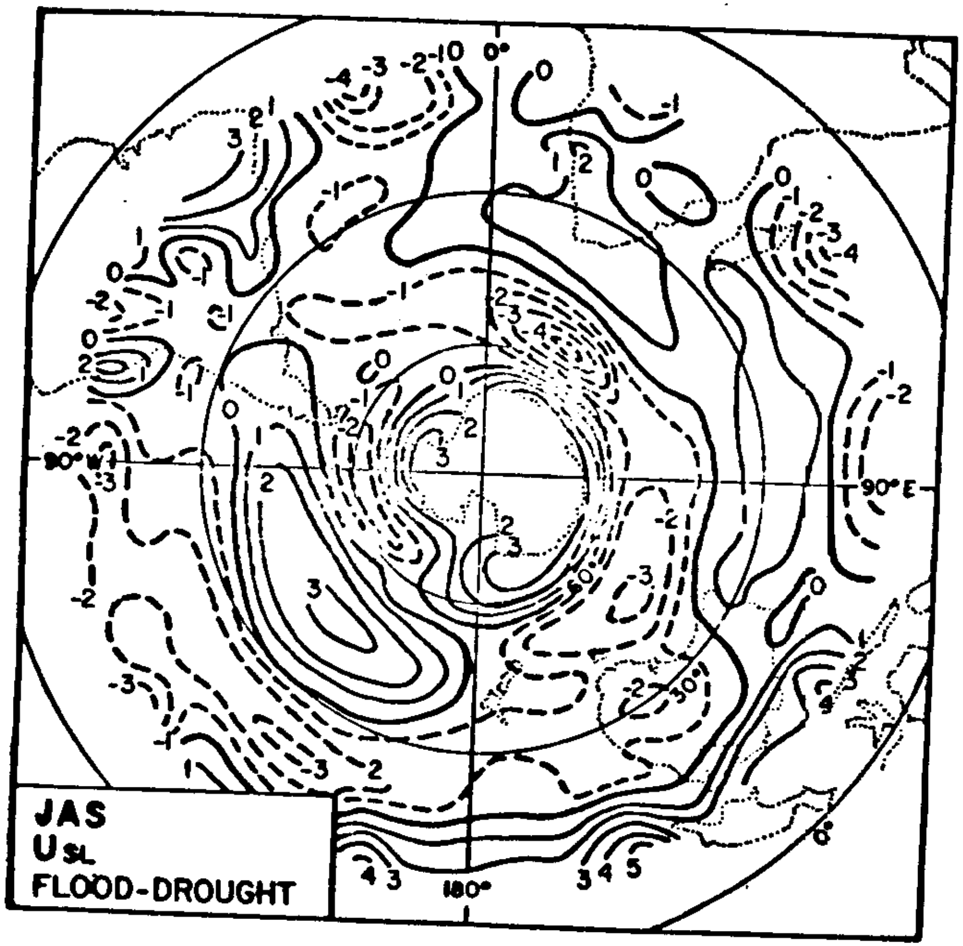
STATIONS	EVENTS (No. of cases)	Broad Characteristics from composite of MSLP	SUCCESSFUL OCCASIONS AGREEABLE WITH BROAD CHARACTERISTICS OF MSLP (IN PERCENTAGE)									
			MAR	APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC
DARWIN (12.4°S, 130.9°E)	Flood (16)	MSLP < Normal	73	69	81	75	56	75	93	93	87	94
	Drought (23)	MSLP > Normal	61	64	74	76	74	82	72	74	78	86
ADELAIDE ([illegible])	Flood (16)	MSLP < Normal	60	35	63	63	53	71	50	71	62	50
	Drought (23)	MSLP > Normal	57	59	65	62	61	54	50	65	67	43
SAMOA ([illegible])	Flood (16)	MSLP > Normal	50	53	64	64	56	63	56	50	53	53
	Drought (23)	MSLP < Normal	57	55	61	73	78	61	61	52	52	[illegible]
RAPA ([illegible])	Flood (7)	MSLP > Normal	86	57	50	71	80	80	71	57	71	[illegible]
	Drought ([illegible])	MSLP < Normal	71	57	50	57	67	83	83	83	83	67
[illegible] (32°S, 40.8°E)	Flood (6)	MSLP < Normal	50	80	60	33	50	75	100	67	60	33
	Drought (8)	MSLP > Normal	75	50	50	50	71	50	93	50	57	63
BEIRA (19.9°S, [illegible]°E)	Flood (12)	MSLP < Normal	59	45	67	58	78	55	67	60	73	93
	Drought (15)	MSLP > Normal	50	35	50	60	47	40	47	47	60	47
MARION (46.9°S, 37.9°E)	Flood (9)	MSLP < Normal	39	65	50	38	50	75	57	50	38	43
	Drought (8)	MSLP > Normal	39	50	62	43	62	62	83	50	71	38



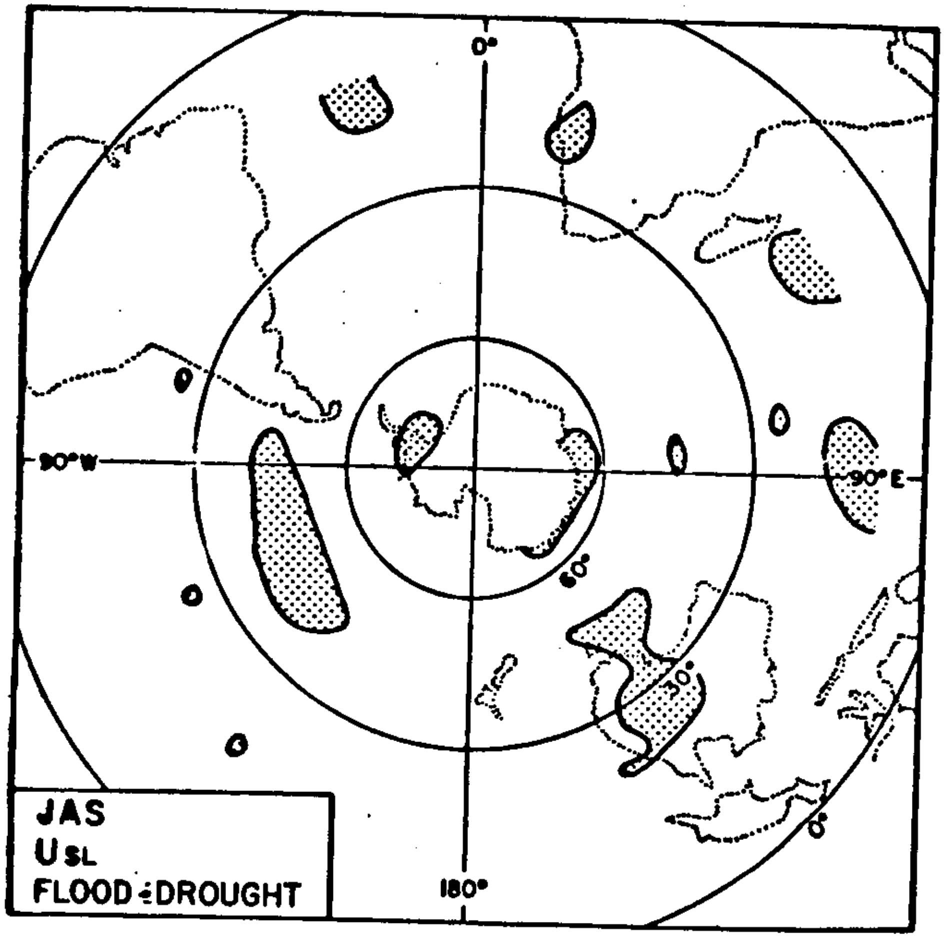
COMPOSITE OF NORMALIZED PRESSURE ANOMALY



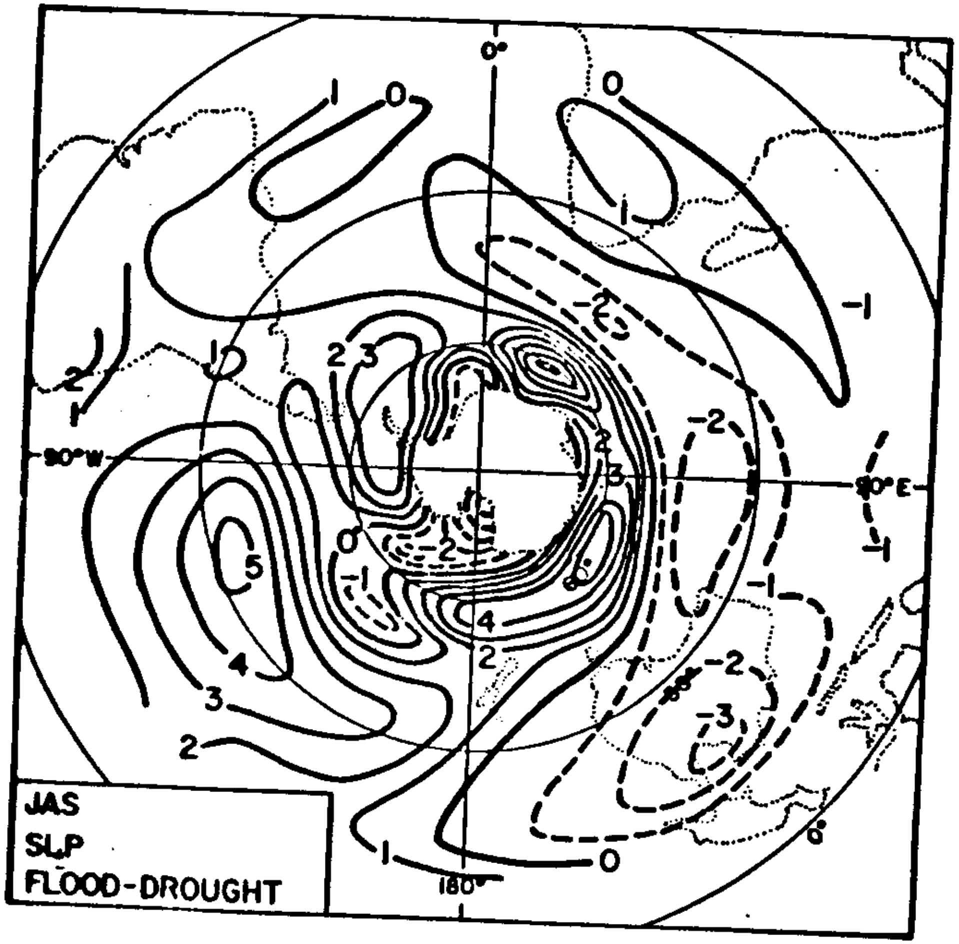
COMPOSITE OF NORMALIZED PRESSURE ANOMALY
DEFICIENT ----- EXCESS RAINFALL

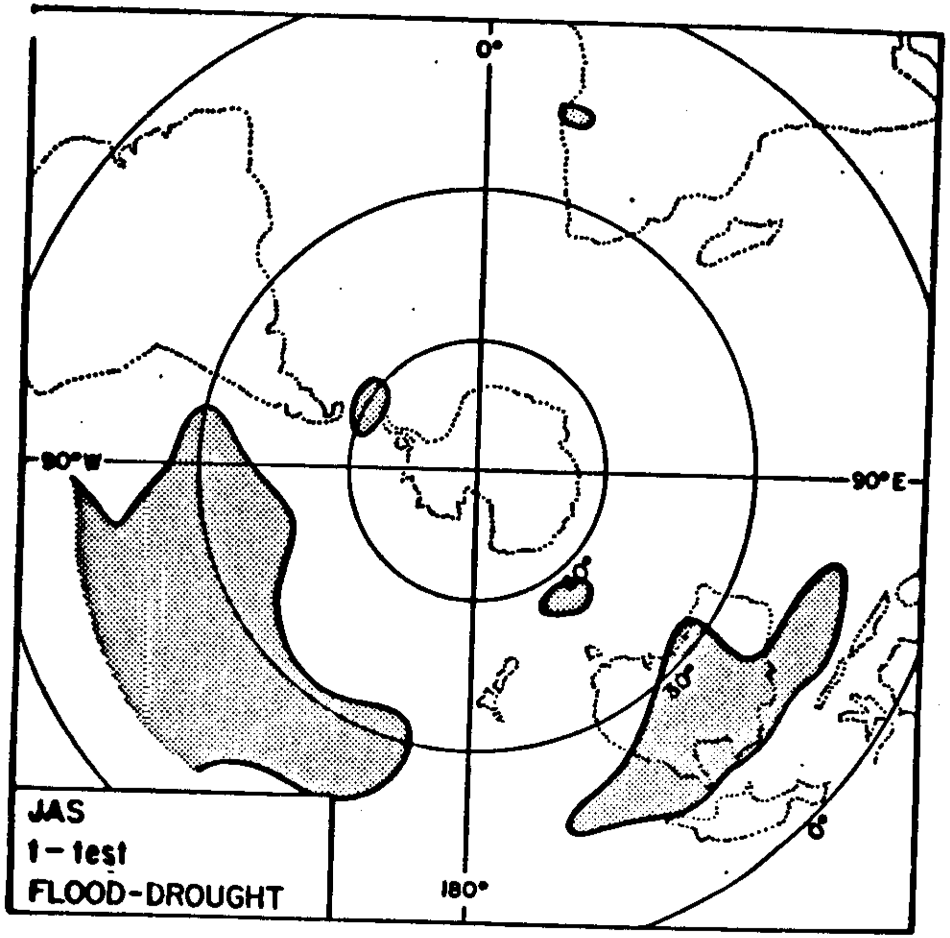

JAS
U SL
FLOOD-DROUGHT
0°
90°E
90°W
180°
30°
60°

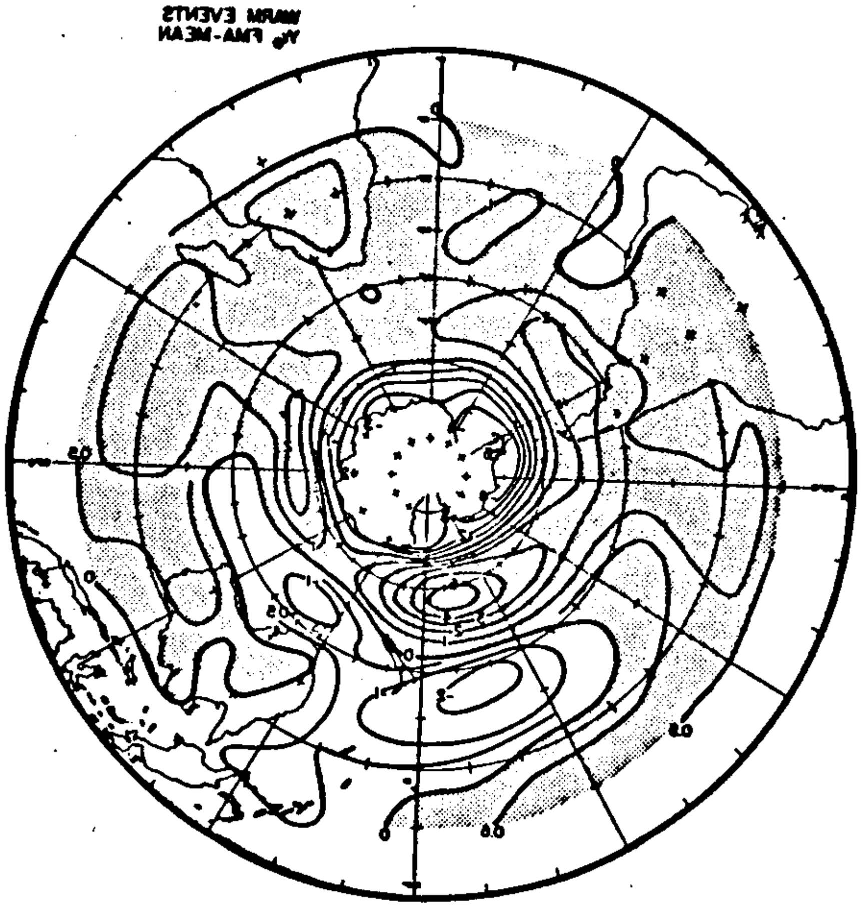
4

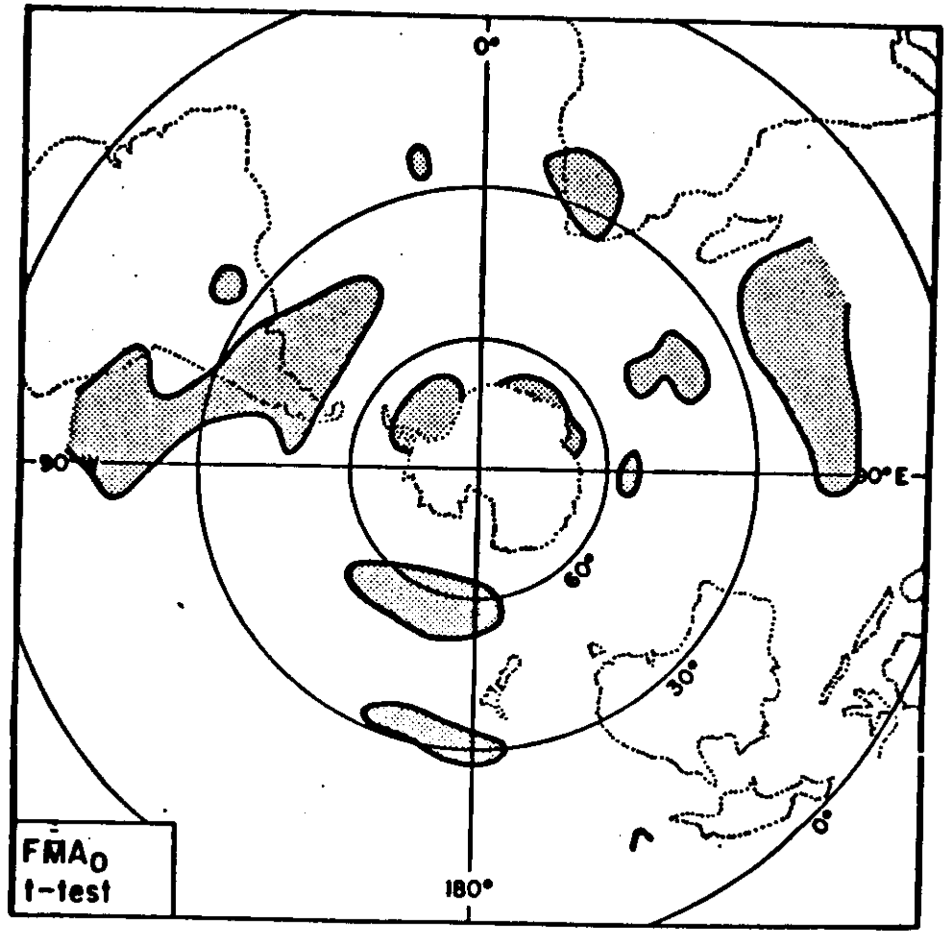

JAS
U SL
FLOOD-DROUGHT
0°
90°E
90°W
180°
30°
60°

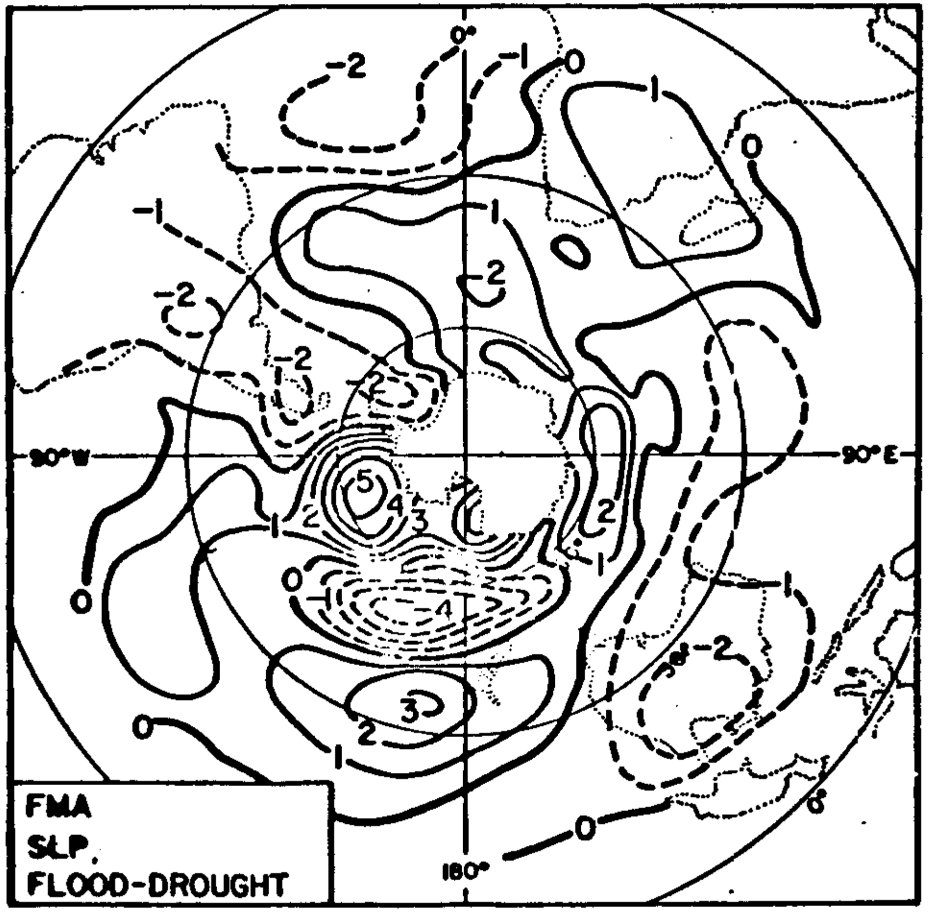
12

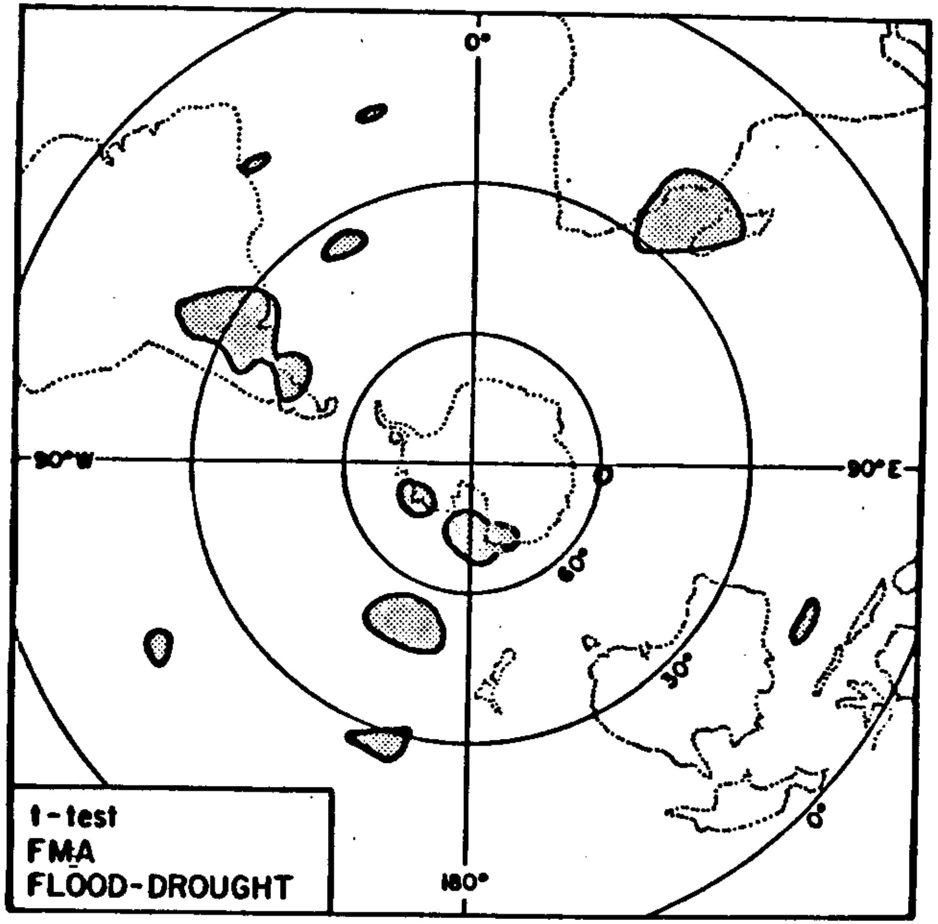

JAS
SLP
FLOOD-DROUGHT
0°
90°W
90°E
180°


JAS
t-test
FLOOD-DROUGHT
0°
90°W
90°E
180°



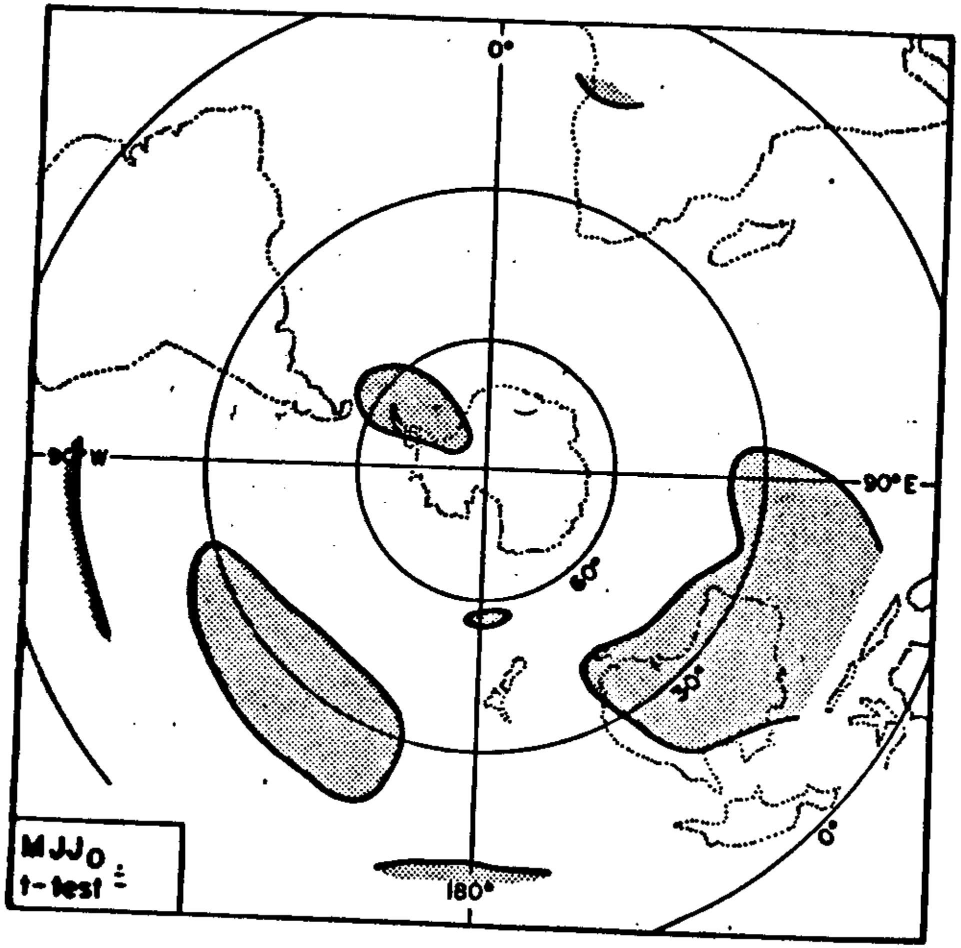

0°
90°W
90°E
60°
30°
0°
180°
FMA0
t-test

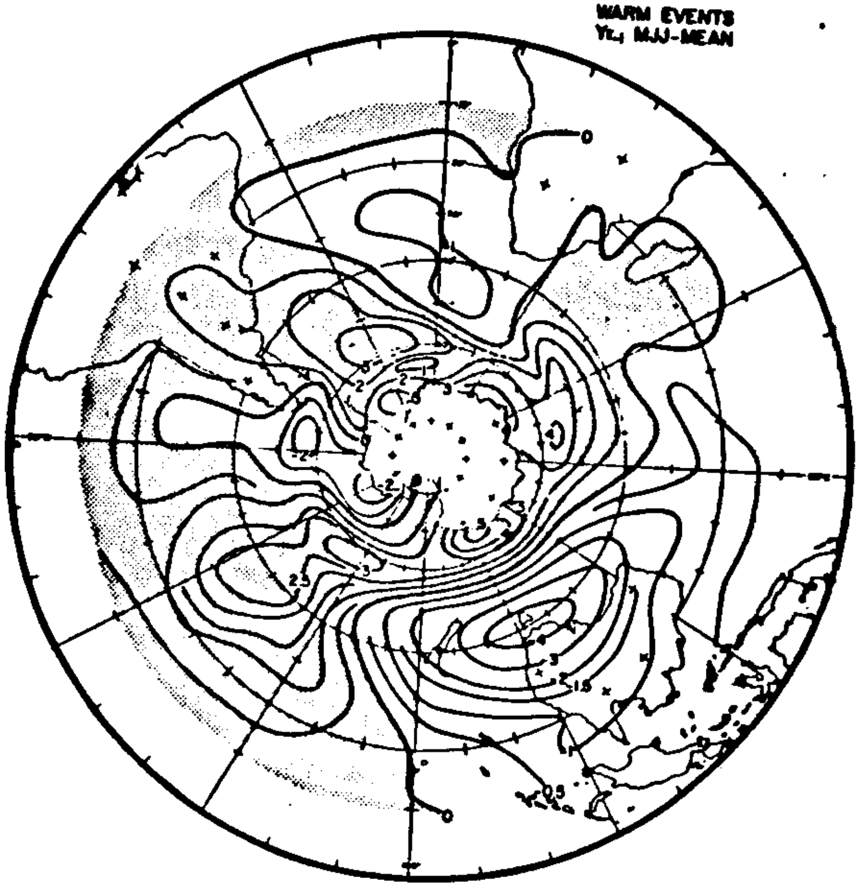

0°
90°W
90°E
180°
FMA
SLP.
FLOOD-DROUGHT

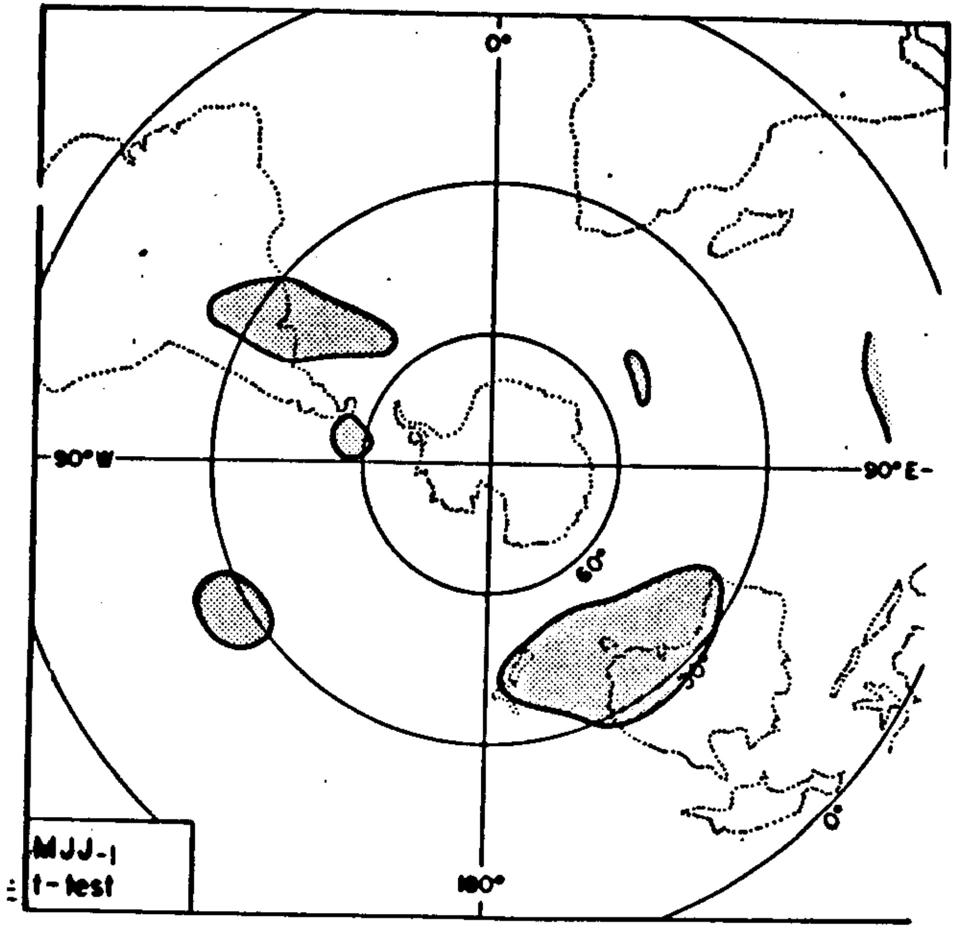

0°
90°W
90°E
180°
60°
30°
t-test
FMA
FLOOD-DROUGHT

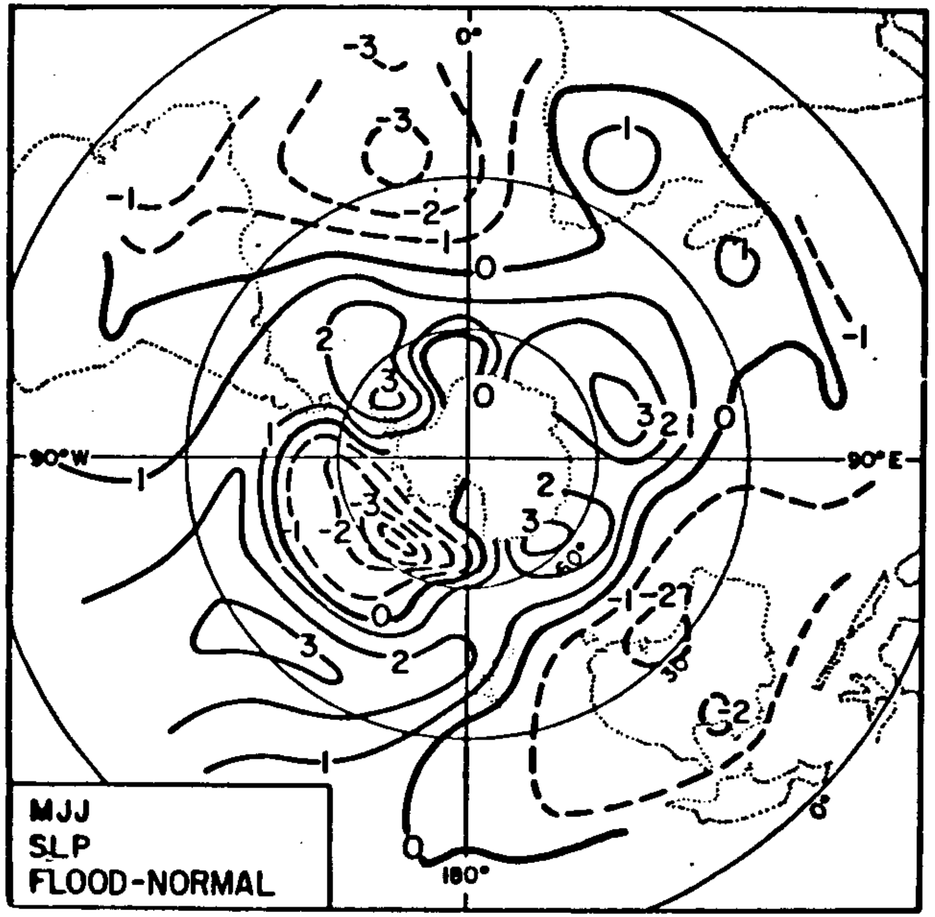
17

18

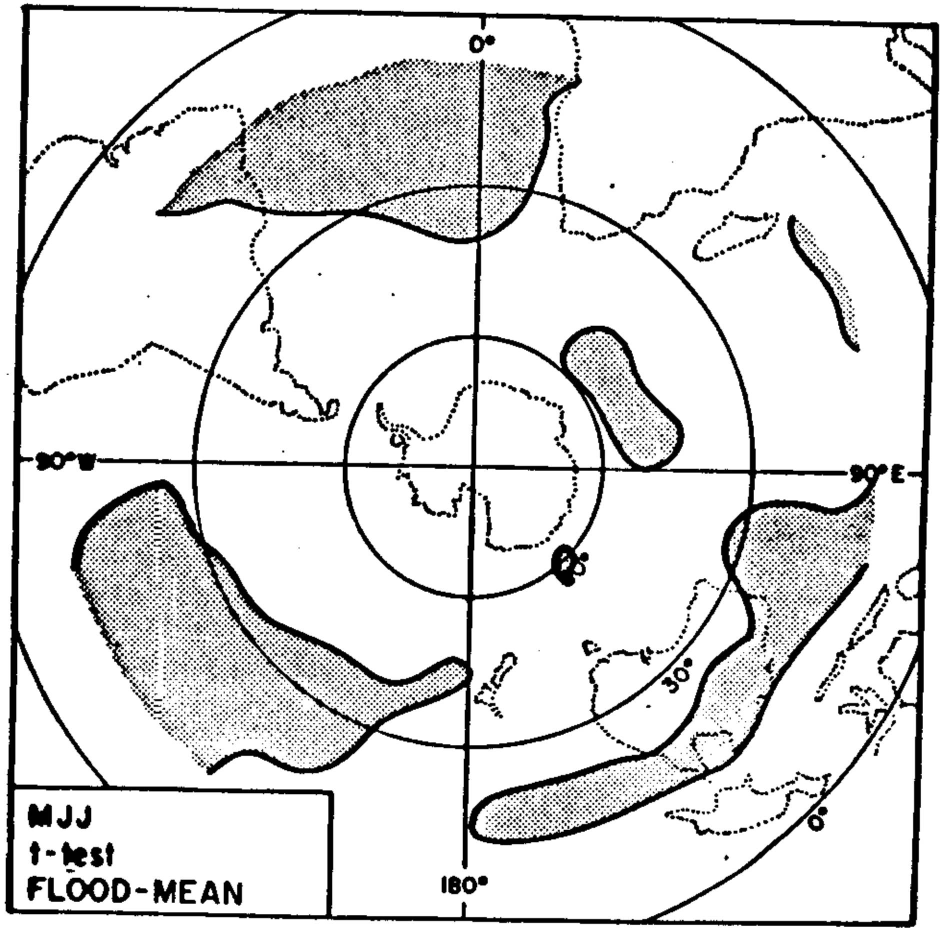

0°
90°W
90°E
60°
30°
180°
MJJ0
t-test


WARM EVENTS
Yr.; MJJ-MEAN

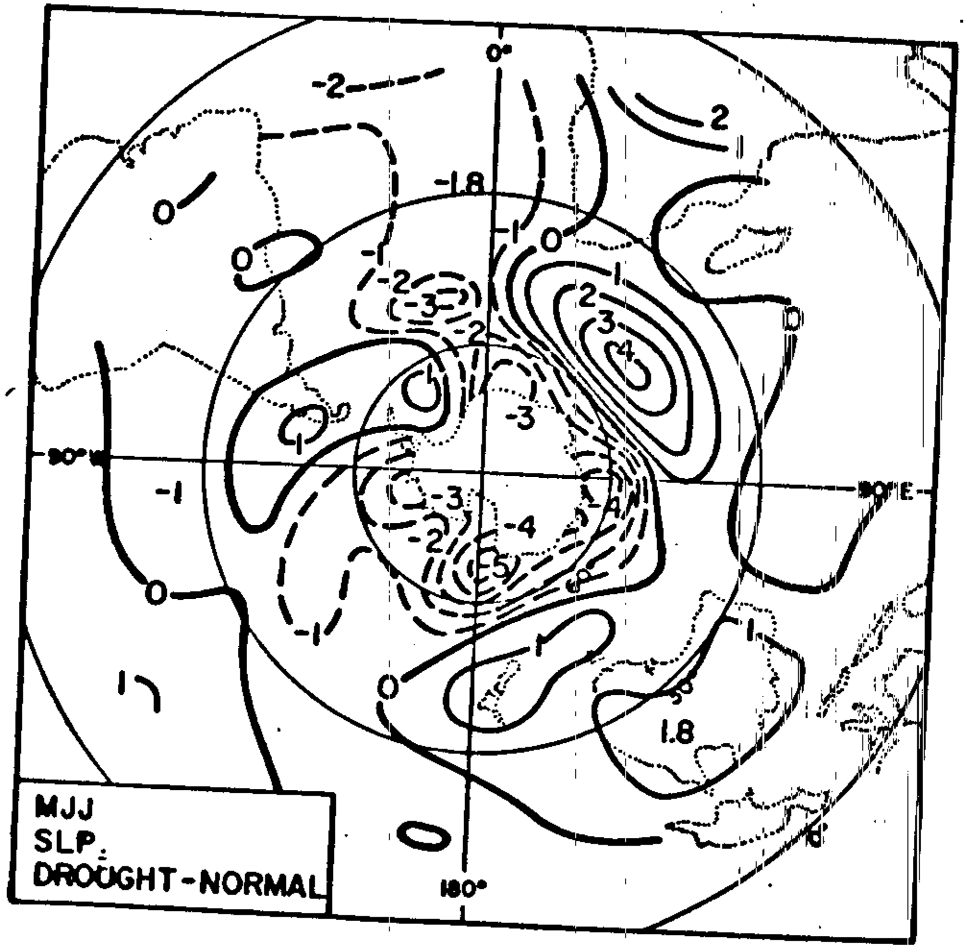

0°
90°W
90°E
60°
30°
180°
MJJ-1
t-test

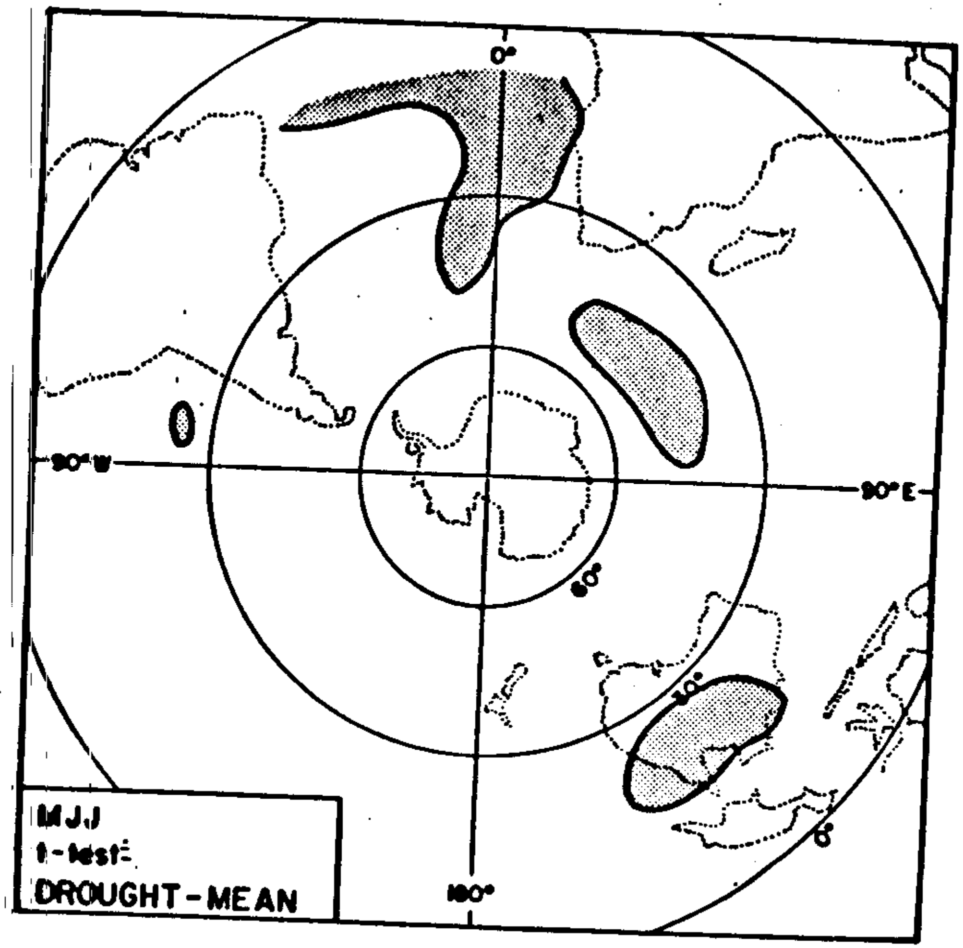

0°
90°W
90°E
180°
MJJ
SLP
FLOOD-NORMAL

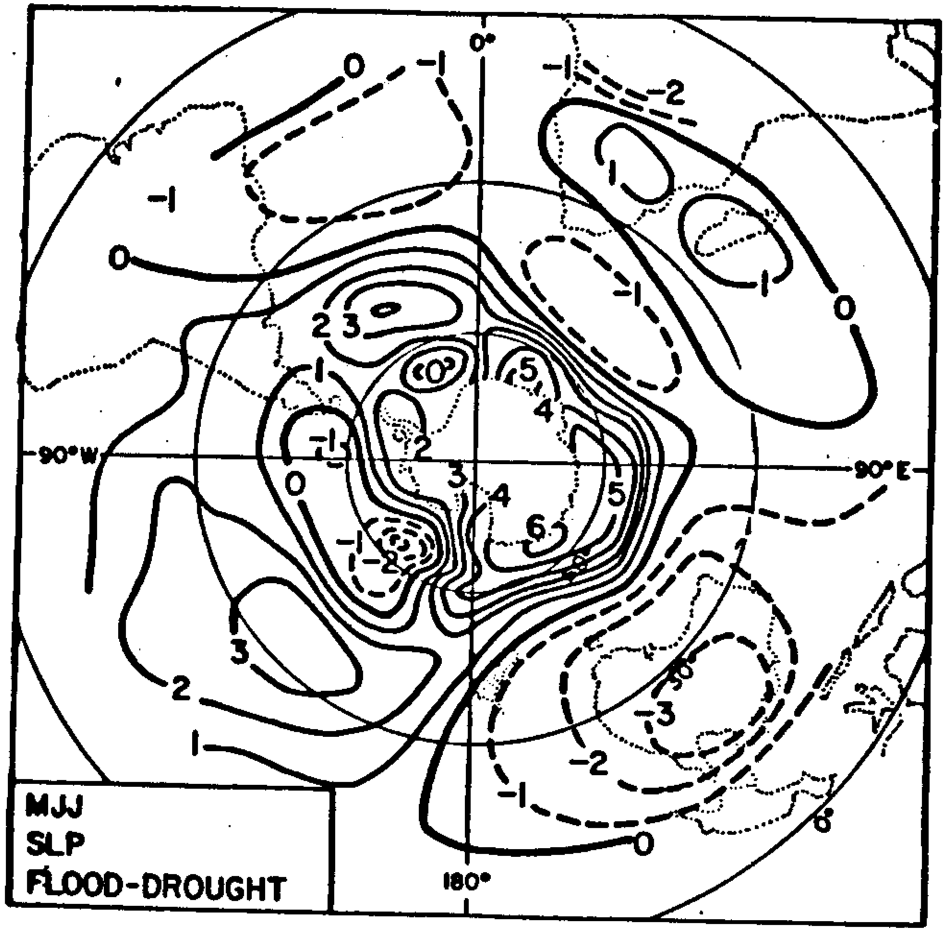
23

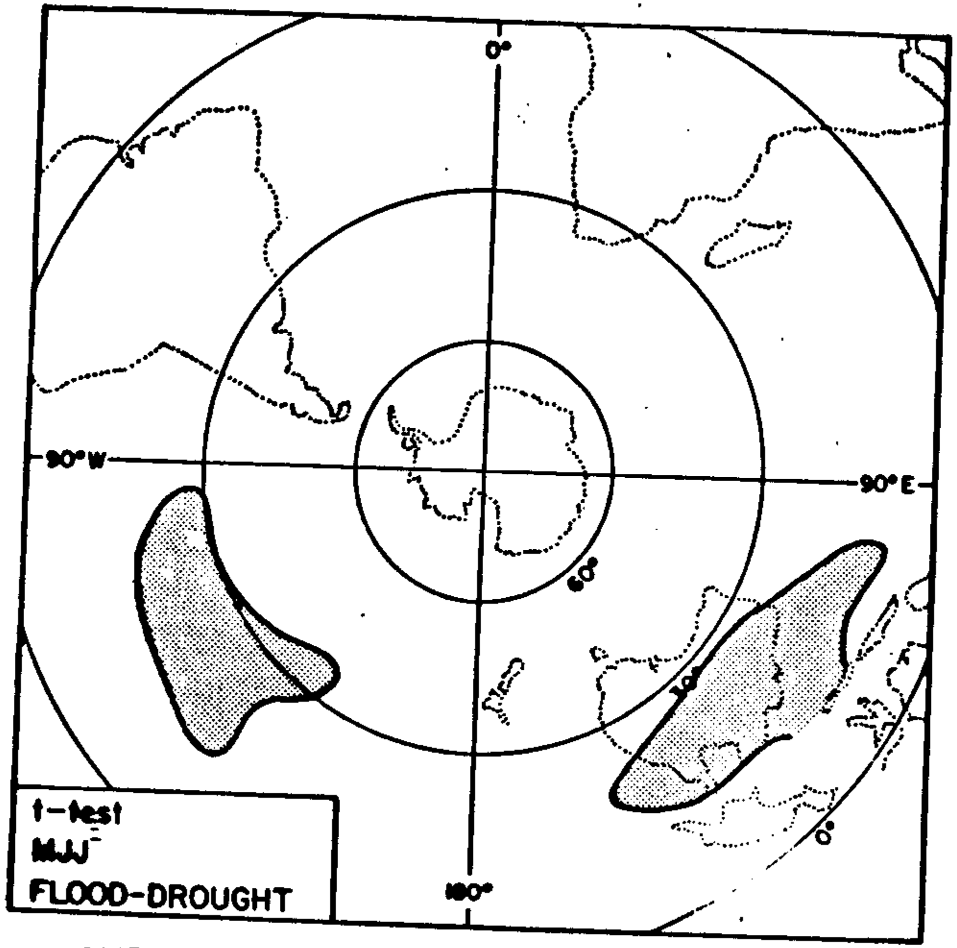

0°
90°W
90°E
180°
MJJ
t-test
FLOOD-MEAN

24

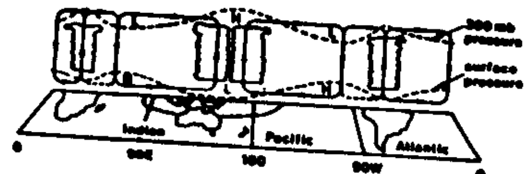

0°
90°W
90°E
180°
MJJ
SLP.
DROUGHT-NORMAL


0°
90°W
90°E
180°
60°
MJJ
t-test
DROUGHT-MEAN

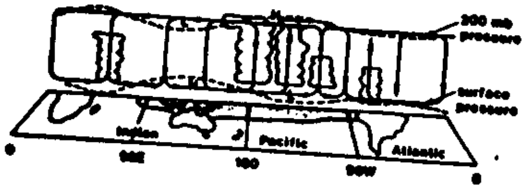




STUDENT T-TEST : THE SHADED AREA SHOW WHERE THE VALUES ARE ABOVE THE 95% CONFIDENCE LEVEL.

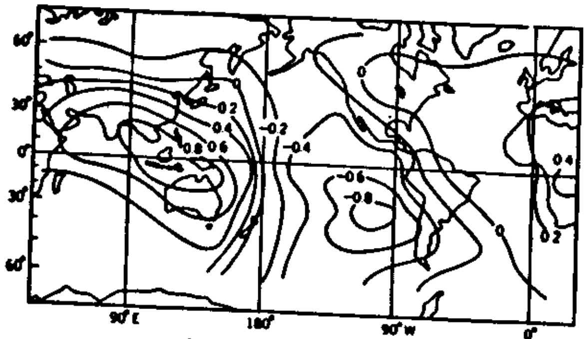


a Non El Niño Year



b El-Niño Year

Schematic view of the near-equatorial circulation or Walker Circulation described in the text for (a) the non-El Niño years when the sea surface temperature (SST) is maximum in the western Pacific and (b) for El Niño years when the SST maximum is much further east. Note the correspondence of the position of the convective cell to the SST maximum. Dashed lines represent pressure variations at the surface and in the upper troposphere, and the stippled regions represent areas where the SSTs are greater than 27°C (from J. Zillman, private communication).



Zero-Lag Southern Oscillation Index

The correlation coefficient distribution of surface pressure variations relative to Darwin (from reference 8). Pattern indicates that when the pressure is anomalously high over Indonesia, it is low over the central and southeast Pacific Ocean, and vice versa. This seesaw of surface pressure defines the Southern Oscillation. It also shows why the Troup Index is a keen measure of the Southern Oscillation.

CHARACTERISTICS OF SEA LEVEL PRESSURE ON THE SOUTHERN HEMISPHERE DURING YEARS OF EXCESSIVE AND DEFICIENT RAIN OVER INDIA AS A WHOLE

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H. van Loon

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Boulder, CO 80307 U.S.A.

1. INTRODUCTION

It is well established that the rainfall over India as a whole during the summer monsoon often is affected by the extremes of the Southern Oscillation (SO) in the sense that the rains tend to be below normal in a Warm Event and above normal in a Cold Event of the Southern Oscillation. Our purpose is not to establish this relationship yet another time, but to examine the characteristics of sea level pressure (SLP) on the Southern Hemisphere in years of excessive and deficient rains over *India as a whole*. We use SLP from the daily analyses made in the South African Weather Bureau and in the Australian Bureau of Meteorology. The sample is small: four years of excessive and five years of deficient rainfall (Table 1), but we have supplemented it with the mean pressure anomalies at key stations with fairly long records. We defined the years of extreme rains as being below or above 0.9 standard deviation for India as a whole, the deviations being conveniently obtained from the listing in Rasmusson and Carpenter (1983).

Table 1. Years of excessive and deficient rains (above or below 0.9σ) over India as a whole for which grid point values of SLP are available on the Southern Hemisphere (from Rasmusson and Carpenter, 1983).

FLOOD	DROUGHT
1955	1951
1956	1962
1973	1972
1975	1974
	1979

2. THE MEAN DEVIATIONS OF SEA LEVEL PRESSURE

Because of the small sample we show the mean difference of the anomalies in the two extremes as this presumably enhances the signal beyond that which can be obtained from the difference between the mean and an extreme. The use of three-month values is also meant to suppress noise.

The first example is the difference of SLP in May-June-July (MJJ) between the years of excessive and deficient rains in India (Fig. 1), which has the sign of the anomalies in the years of excessive rains. Quite clearly, the dominant signal in the SLP over much of the hemisphere is that of the SO (cf. Figs. 1b and f in van Loon and Shea, 1985. These figures appear also in the paper by H. van Loon in this volume). Only two of the five drought years are $Year_0$ in Warm Events (1951 and 1972 in Table 1), but all four of the flood years are either a $Year_0$ of a Cold Event (1973 and 1975) or part of the extended Cold Event which began in 1954 and ended in 1956. The strength of the SO signal in Fig. 1 is thus mainly due to the Cold Events. Figure 1 confirms the many correlations made over the years between indices of the Southern Oscillation and rain over India in summer, but it extends the association from spot values at stations to wide areas of the hemisphere. Note, however, that there are years when the monsoon rains were scarce (e.g., 1974 and 1979 in Table 1) which are not defined as Warm Events.

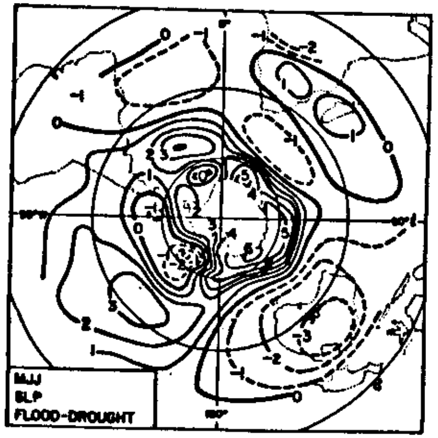

Fig. 1. The mean difference in sea level pressure in May-June-July between years of excessive and years of deficient summer monsoon rains over India as a whole.

The signal retains its strength till the end of the monsoon season and beyond (September-October-November in Fig. 2). One area where the signal of the SO in van Loon and Shea (1986) is not strong in the southern winter, the western Indian Ocean, also shows the weakest anomalies when the SLP is composited according to the extremes of Indian rainfall as in Figs. 1 and 2. We point out that the consistent positive differences from southern Africa across Malagasy in both figures are not substantiated by the longer records from Beira and Tamatave (Fig. 3).

We complement the scant evidence in Figs. 1 and 2 with the mean SLP anomalies at eight places (Fig. 3). Common to all of the mean anomalies in Fig. 3 is that they are of opposite sign in years of drought and years of flood. At Samoa and Rapa the anomalies are higher and at Darwin and Adelaide they are lower in the years of excessive rains. That part of the pattern in Figs. 1 and 2 thus appears to be a stable one. Table 2 states how frequently the anomaly of single events had the same sign as the mean anomaly at stations with comparatively long records. One must keep in mind that the percentages would have been higher if the difference between flood and drought and three-month means such as in Figs. 1 and 2 had been used instead of single months.

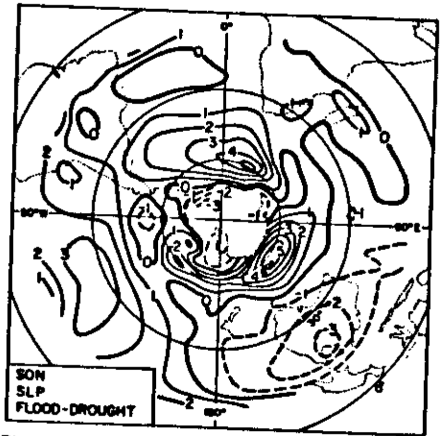

Fig. 2. The same as Fig. 1, but for September-October-November.

3. SUMMARY

If one composites the sea level pressure on the Southern Hemisphere according to the extremes of the summer rains over India as a whole, one obtains a pattern of anomalies which in the Pacific and Australia is similar to the one which one gets from compositing the pressure according to the extremes of the Southern Oscillation. This is despite the fact that not all of the rainfall extremes coincide with an extreme in the Southern Oscillation. The mean pressure anomalies at selected single stations from Africa to the Pacific show the opposite sign for excessive and deficient rains over India.

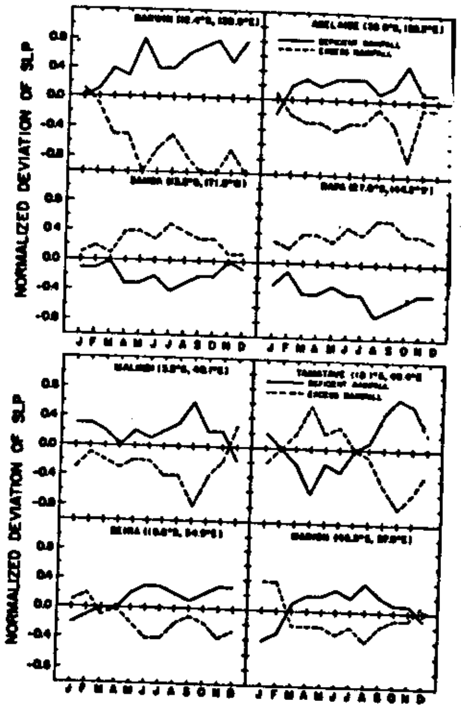

Fig. 3. Mean monthly sea level pressure anomalies, normalized, at stations on the Southern Hemisphere in years of excessive and deficient summer rains over India as a whole.

Acknowledgment. The National Center for Atmospheric Research is sponsored by the National Science Foundation.

References

Rasmusson, E. M., and T.H. Carpenter, 1983: The relationship between eastern equatorial sea surface temperatures and rainfall over India and Sri Lanka. *Mon. Wea. Rev.*, **111**, 517-528.

van Loon, H., and D. J. Shea, 1986: The Southern Oscillation. Part VI: Anomalies of sea level pressure on the Southern Hemisphere and of Pacific sea surface temperature during the development of a Warm Event. Submitted to *Mon. Wea. Rev.*. The maps referred to appear also in the paper by H. van Loon in this volume.

Table 2. Characteristics of sea level pressure at key stations on the Southern Hemisphere in years of excessive or deficient rains (above or below 0.9 σ) over India as a whole: the number of years in each extreme; the sign of the mean deviation of SLP; and the number of times when the SLP in a rainfall extreme had the same sign as the mean deviation.

		Mean deviation	Percentage of events which are of the same sign as the mean deviation						
			May	Jun	Jly	Aug	Sep	Oct	Nov
DARWIN	Flood (16)	MSLP<Normal	81	75	56	75	93	93	87
(12°S, 131°E)	Drought (23)	MSLP>Normal	74	78	74	82	82	74	78
ADELAIDE	Flood (16)	MSLP<Normal	63	63	53	71	50	71	62
(35°S, 138°E)	Drought (23)	MSLP>Normal	65	62	61	54	50	65	67
SAMOA	Flood (16)	MSLP>Normal	64	64	66	63	56	60	53
(14°S, 172°W)	Drought (23)	MSLP<Normal	61	73	78	61	61	52	52
RAPA	Flood (7)	MSLP>Normal	50	71	80	80	71	57	71
(28°S, 144°W)	Drought (7)	MSLP<Normal	50	57	67	83	83	83	83
MALINDI	Flood (6)	MSLP<Normal	60	33	50	75	100	67	60
(3°S, 41°E)	Drought(8)	MSLP>Normal	50	50	71	50	83	50	57
BEIRA	Flood (12)	MSLP<Normal	67	58	73	55	67	60	73
(20°S, 35°E)	Drought(15)	MSLP>Normal	50	60	47	40	47	47	60
MARION	Flood (8)	MSLP<Normal	50	38	50	75	57	50	38
(47°S, 38°E)	Drought(8)	MSLP>Normal	62	43	62	62	83	50	71