FLOOD STUDIES:

TECHNICAL NOTE 1

AN INVESTIGATION INTO

TROPICAL CYCLONES IN THE SOUTH-WEST INDIAN OCEAN

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1. INTRODUCTION

Tropical cyclones, willy willy's, typhoons or hurricanes, the name depending on the geographical location of the observer, have accounted for some of the worst flood disasters in many parts of the world and in terms of damage to the environment have exceeded any other natural catostrophe.

It is fortunate that tropical cyclones have only a three percent efficiency in their conversion of heat energy to mechanical energy as they have the ability to 'squeeze' out 20 000 million tons of water in a period of 24 hours which is equivalent to the energy produced by 500 000 'Nagasaki' atomic bombs[1]

Two of the most disastrous tropical cyclones to have occurred so far anywhere in the world have been the 'killer' cyclone in Bangladesh, which in November 1970 caused the deaths of 300 000 people and cyclone 'Fifi' in Honduras during September 1974 which caused 9 000 deaths and damage equivalent to 60% of its gross national product.[2][3]

2. GENERAL DESCRIPTION

The World Meteorological Office classification for low pressure systems is as follows:

Tropical depression: is a system with low pressure enclosed within a few isobars and either lacks a marked circulation or has winds of less than 17 ms^{-1}

Tropical storm: is a system with several closed isobars and a wind circulation from 17-32 ms^{-1}

Tropical cyclone: is a storm of tropical origin with a small diameter and a minimum surface pressure of around 900 mb, having very violent winds, torrential rain and possibly thunderstorms. It usually contains an eye with light rain and fairly clear skies.

Tropical cyclones are circularly symmetrical low pressure systems comprising of cumulonimbus cloud enclosing a clear central area called the 'eye', see Fig. 1(a). The eye is calm, dry and hot relative to the surrounding atmosphere and pressure is very low. Moving away from the 'eye' one first encounters a 'wall' of cloud with a steep temperature gradient and high wind speed followed by a gradual decrease in temperature and wind speed but an increase in pressure. Fig. 1(b) shows a tropical cyclone as represented on a daily synoptic chart issued by the Weather Bureau, Pretoria.

Tropical cyclones are formed from pre-existing disturbances which have an anticyclonic upper tropospheric circulation. This results in high level divergence and low level convergence, which, if the former is the greater, causes an inflow of moist warm air to the disturbance and upon rising releases latent heat of condensation which intensifies the upper atmospheric anticyclone and in turn stimulates more low level influx of heat and moisture.

From Fig. 2 we can see that the tropical cyclone generating areas lie between 5° and 30° north and south of the equator where summer sea surface temperatures (above 26,5°C) and Coriolis force (caused by rotation of the earth) are favourable for cyclonic development. Their subsequent path is influenced by sea surface temperature and upper atmospheric pressure distribution.

Table 1 shows annual frequencies of tropical cyclones throughout the world. It can be seen that approximately 70% of tropical cyclones occur in the northern hemisphere.

TABLE 1: Annual cyclone frequency for the world

Ocean	Cyclones/year
North Atlantic	9,4
East North Pacific	15,2
West North Pacific	25,3
North Indian	5,7
South West Indian	11,2
South West Pacific and Australia	14,8

Source: Ref. 2

3. TROPICAL CYCLONES IN THE SOUTH WEST INDIAN OCEAN

Table 2 lists available data sources. These include reports by the Director of the Royal Alfred Observatory, Mauritius, which were compiled from ship's logs and presented in the form of frequency tables of observed cyclones and later as annual reports. The area covered is restricted to the major shipping routes between Madagascar and Mauritius. Wind direction and lowest recorded pressure are also noted. The SA Naval Forecasting Office produced daily synoptic charts during the second world war but these lacked detail and were confined to South African coastal areas. Daily synoptic charts are produced by the South African Weather Bureau and have improved over the years in terms of the area covered and detail included. The Madagascan Meteorological Service also produces daily synoptic charts which cover a much larger area than those of the South African Weather Bureau. The Reunion Meteorological Service produces a very useful annual summary of cyclone activity in the south west Indian Ocean. It includes details of the cyclone path, its pressure distribution and associated weather conditions.

Other useful sources of data were reports written by the Meteorological Services of France and Mozambique on tropical cyclone activity in the south west Indian Ocean and Mozambique Channel.[11][12] These comprise of a list of cyclones observed before 1961 and include information on their path and associated weather.

TABLE 2: Data sources

	Start of record	Length of record (Incomplete)
Royal Alfred Observatory Publ.: Mauritius	1814	(122)
SA Naval Forecasting Office Charts: Simonstown	1940	7
SA Weather Bureau Charts: Irrigation Dept.	1940	10
SA Weather Bureau Charts: Dept. of Transport	1950	34
SA Weather Bureau Newsletter: Dept. of Transport	1954	30
Madagascan Meteorological Service Charts	1960	10
Reunion Meteorological Service Reports	1965	19

From the abovementioned data sources it has been possible to compile a list of tropical cyclones occuring in the south west Indian Ocean since the 19th century. However, its degree of completeness is questionable for the period preceding 1927 when observations were scant. No attempt has been made to distinguish between tropical depressions and tropical cyclones and so all are referred to as tropical cyclones for convenience. The list from 1927 onwards has been summarised in Fig. 3 and shows that the annual frequency of tropical cyclones entering or originating in the south west Indian Ocean is usually between six and twelve with the most frequent annual total being ten. Low cyclone activity accurred in 1938, 1942 and 1957 with high activity in 1959, 1965, 1971 and 1978. The annual frequency of tropical cyclones entering or originating in the region to the west of Madagascar is between one and five with the most frequent annual total being two. Low activity occurred in 1980 and above normal activity occurred in 1956.

Table 3 shows the monthly frequency of tropical cyclones in the south west Indian Ocean. It appears that no significant change in the monthly distribution of tropical cyclones has occurred between the two periods (1848 - 1912 and 1912 - 1984) examined.

TABLE 3: Monthly frequency of cyclones in the south west Indian Ocean in % of total

Period	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	March	Apr.	May	Total number
1848 - 1912	0	1	2	13	29	26	17	7	3	345
1912 - 1984	1	2	4	13	30	26	17	6	1	589

Source Table 2 and Ref. (11) and (12).

Table 4 shows the monthly frequency of tropical cyclones travelling east and west of the west coast of Madagascar (Long 45°E). It can be seen that 27 percent of tropical cyclones, since 1927, passed through the area to the west of Madagascar and that the most favourable months for this to occur were January and February. Also, the similarity in the monthly distribution of cyclones travelling east and west of Madagascar seems to signify that no major change occurs in the aspect of tropical cyclone paths.

TABLE 4: Monthly frequency of cyclones travelling east and west of longitude 45°E for the period 1912 - 1984 in % of total

Path	Oct.	Nov.	Dec.	Jan.	Feb.	March	Apr.	May.	Total %	(number)
West of Long 45°	0	0	4	10	7	4	1	0	27	(159)
East of long 45°	2	3	11	22	18	13	4	1	73	(430)

Source Table 2 and Ref. (11) and (12)

It should be noted that in the south west Indian Ocean the resident anticyclone off the east coast of Southern Africa moves south during the summer resulting in the appearance of an inter tropical convergence zone (ITCZ) which has the necessary thermal and mechanical properties for cyclone development. In the winter the anticyclone moves northwards, the ITCZ is no longer present and so tropical cyclones do not develop.

4. TROPICAL CYCLONES AFFECTING SOUTH AFRICA

Fig. 4 shows the distribution of tropical cyclone tracks west of Madagascar since 1927 and as would be expected most cyclones pass through the Mozambique Channel with very few penetrating the mainland or south of 30° latitude.

From the above distribution, Fig. 5 shows the path of cyclones causing significant rainfall over the Transvaal and Natal since 1950. Their progress is shown in greater detail in Figs 6 to 15. Of the 10 tropical cyclones shown in Fig. 5 only one tropical cyclone has traversed South Africa (Domoina 1984). Six other tropical cyclones had a slight effect on weather conditions over South Africa and their paths are shown in Fig. 16. In the northern hemisphere it was found that the number of hurricanes making landfall was not related to the frequency of hurricane occurence.[4] This seems to hold true for the south west Indian Ocean where the tropical cyclones shown in Figs 6 to 15 occurred in years of 'normal' cyclone activity (with the exception of tropical cyclone 'A' in 1956).

It should also be noted that tropical cyclones travelling through the Mozambique Channel can have a negative effect on the chance of rainfall over South Africa, (e.g. Jan. 1953). Warm, moist air rises near the 'eye', giving rainfall, after which it spreads out as dry air in the upper troposphere before subsiding some distance away producing warm and dry weather conditions.

Isohyetal maps (Figs 17 to 26) were drawn for each of 10 tropical cyclones causing significant rainfall (defined as rain in excess of 100 mm over the storm period). Unfortunately daily rainfall for the required periods was not available from Mozambique or Zimbabwe and so storm rainfall and rainfall volumes are relevant to South Africa only. Table 5 is a summary of the isohyetal maps and shows Domoina to be by far the largest storm, followed by Astrid and Eugenie. Records of past floods were studied and positions of relevant flood events indicated on isohyetal maps. The listed flood peaks were the largest observed at the given site.

TABLE 5: Summary of isohyetal maps of 10 tropical cyclones

Date	Tropical cyclone	Storm days	Storm rainfall* (p>100 mm)		
			Area (km^2)	Mean depth (mm)	Volume (x 10^6 m^3)
Feb. 1956	'A'	5	65 000	155	10 000
Dec'57/Jan. 1958	Astrid	6	82 000	230	19 000
Jan/Feb. 1960	Brigette	4	49 000	155	7 600
Dec'65/Jan. 1966	Claude	7	24 000	175	4 200
Feb. 1972	Caroline	7	10 200	170	1 700
Feb. 1972	Eugenie	7	101 000	150	15 000
Jan. 1976	Danae	5	66 000	175	12 000
Feb. 1977	Emilie	5	53 000	180	9 500
Jan. 1984	Domoina	5	107 000	370	40 000
Feb. 1984	Imboa	5	26 000	155	4 000

* Data refer only to South Africa.

5. SUMMARY AND CONCLUSIONS

The average annual frequency of tropical cyclones in the south west Indian Ocean was found to be 9 (based on records after 1927).

Out of the total number of cyclones observed in the south west Indian Ocean since 1950, 33% have entered the Mozambique Channel and 4% (10) have caused heavy rainfall and flooding in South Africa. (Events before 1950 need further investigation to determine their effect if any on South Africa.)

The eventual destination of these cyclones on entering the Mozambique Channel cannot be predicted. However, most cyclones making land fall entered the continent north of South Africa where the combined effect of rainfall and cloud cover deprive the tropical cyclone of its heat source, curtailing its thermo convective driving mechanism and resulting in its expiration. Other tropical cyclones veer south east and peter out due to passing over areas of low sea surface temprature or due to changes in its internal circulation.

Since 1950 only one cyclone-centre (Domoina) has penetrated South Africa, although several have moved inland close to our borders and caused exceptional rainfall over considerable areas of Natal and the Transvaal. Domoina covered parts of South Africa, Mozambique and the whole of Swaziland for three days, resulting in the highest ever recorded rainfall and flooding over large areas of Natal.

Nothing certain can be said about the risk of a similar occurence. However, the observed cyclone tracks (since 1927) suggest that there exists a real possibility that the same event (in terms of penetration and residence) could happen again within a matter of decades. The greatest chance for this to happen is in the Eastern Transvaal Lowveld and Northern Transvaal.

It appears that the eastern escarpment is an efficient barrier against the heavy rains, caused by tropical cyclones, penetrating the highveld.

Until now no heavy rain has been caused by tropical cyclones in Natal, south of latitude 30°.

6. ACKNOWLEDGEMENTS

My thanks are due to Mr Z. Kovacs (Department of Water Affairs) for his guidance in presenting this report. To Mr K. Estié (Weather Bureau) for his appraisal of the report and to Mrs B.M. Rowlands and Mrs G. Swart (Weather Bureau) for their help in obtaining the necessary data and information used herein.

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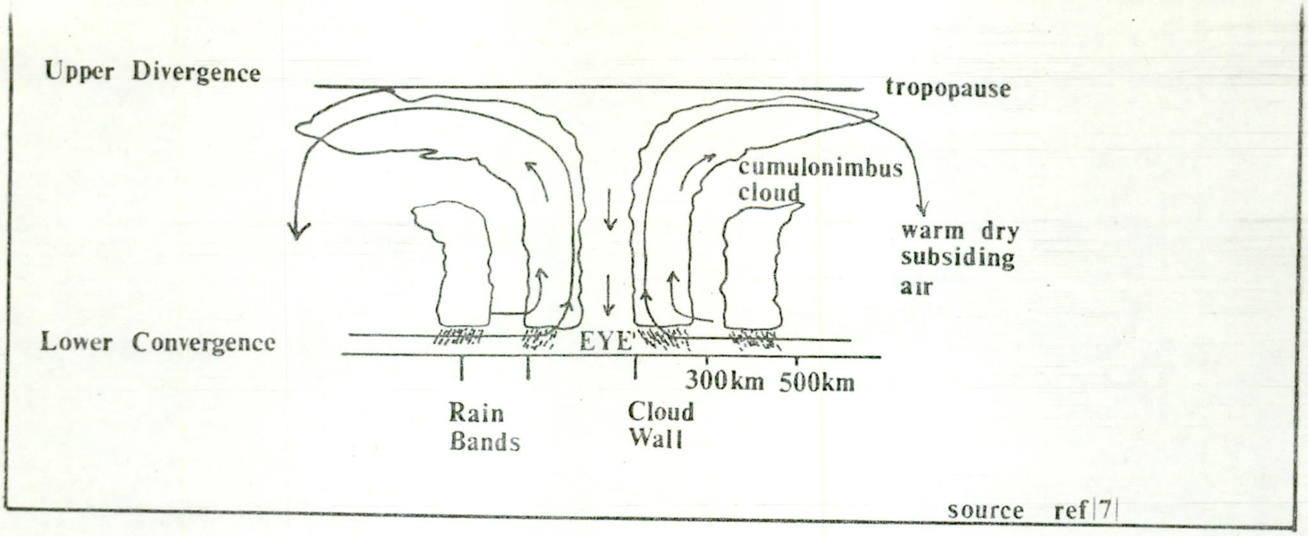


FIG 1a SCHEMATIC CROSS SECTION OF A TROPICAL CYCLONE

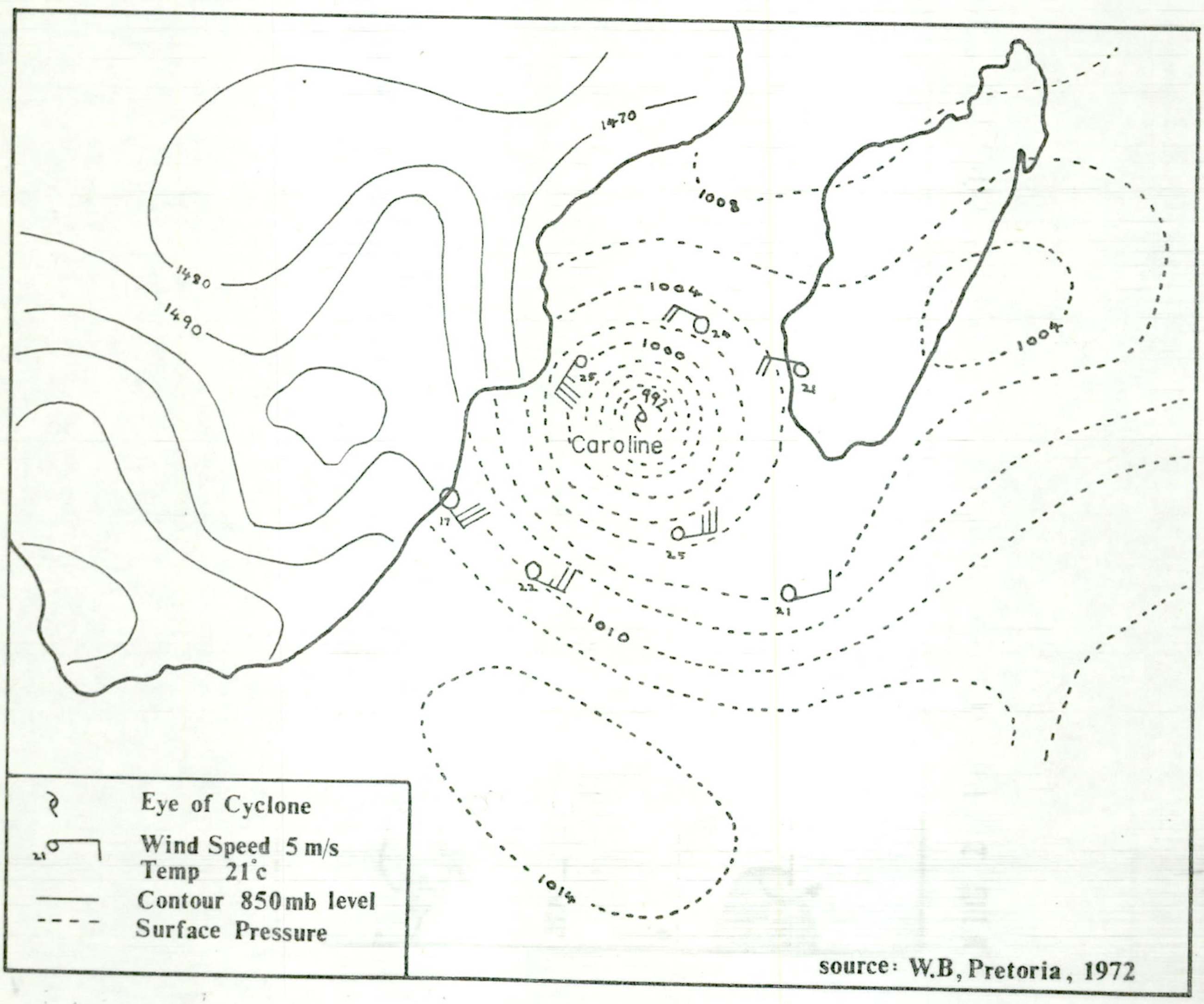


FIG 1b: EXAMPLE OF A SYNOPTIC WEATHER MAP

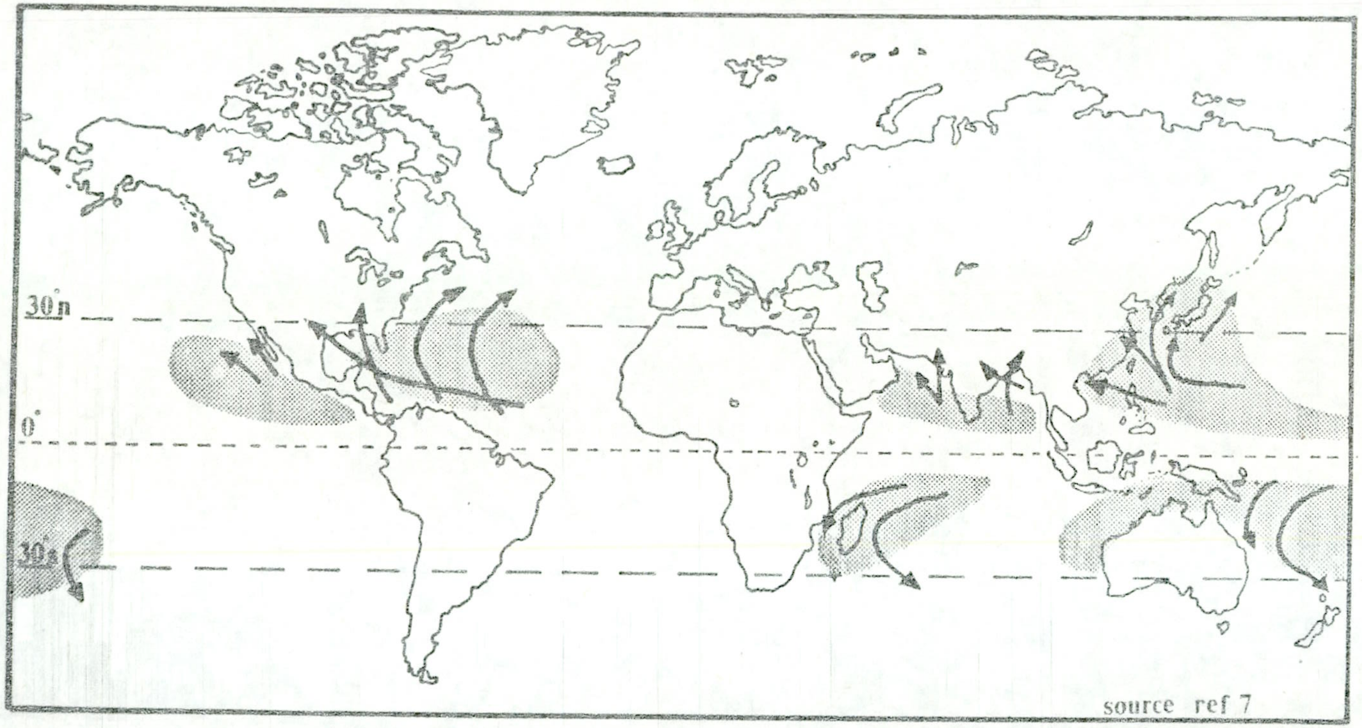


FIG 2 PRINCIPAL PATHS AND DEVELOPMENT ZONES OF TROPICAL CYCLONES

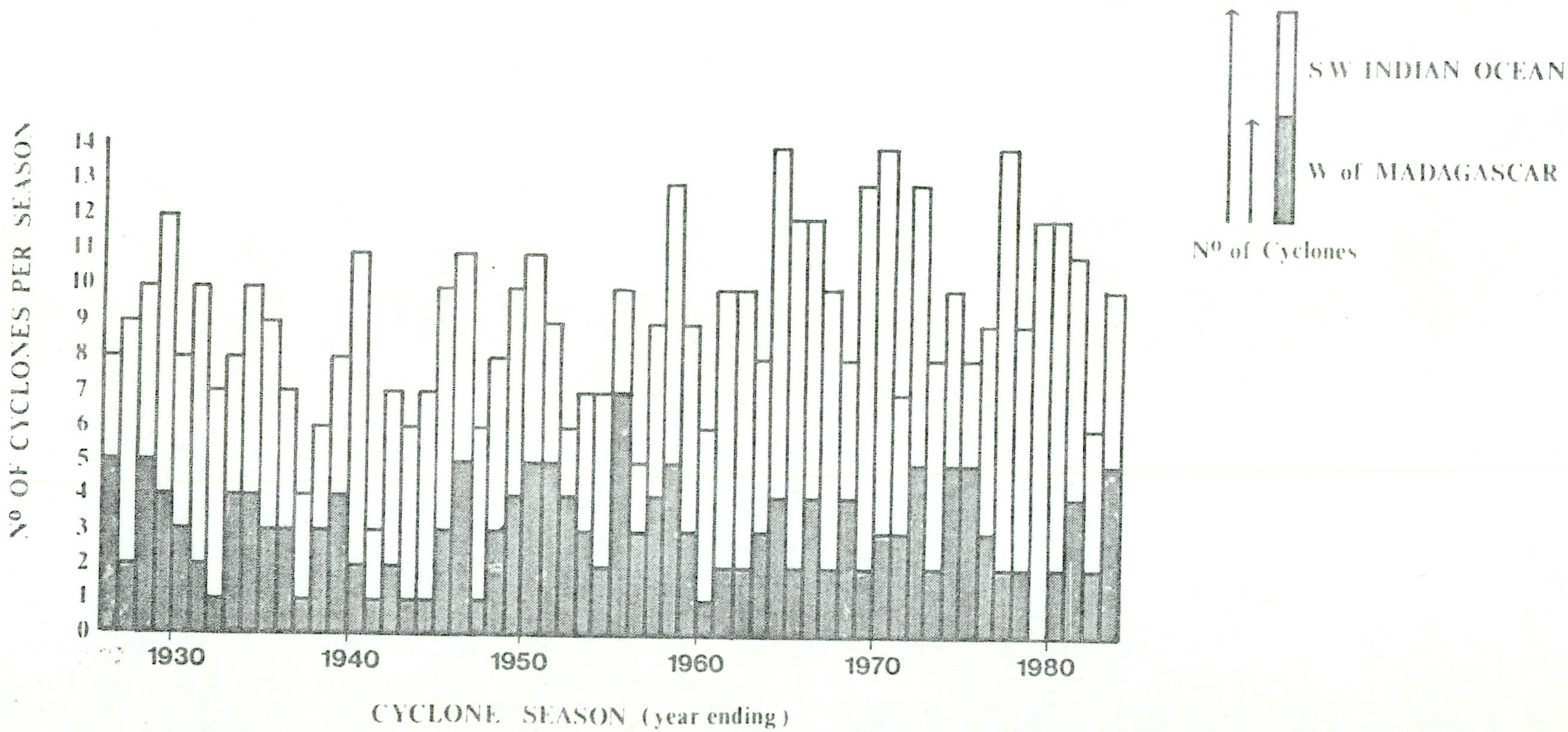


FIG 3 ANNUAL FREQUENCY OF TROPICAL CYCLONES

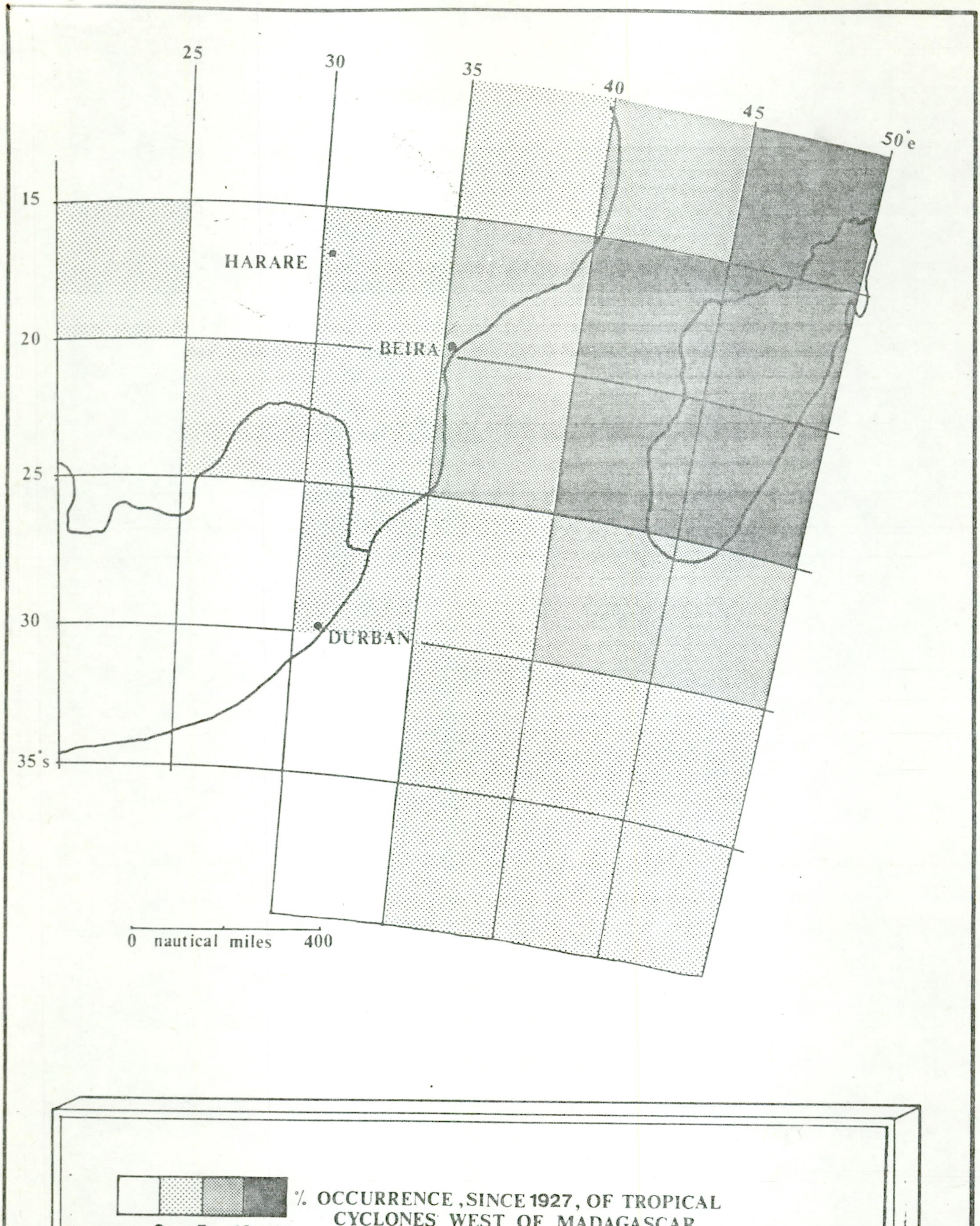


FIG 4 THE DISTRIBUTION OF TROPICAL CYCLONES SINCE 1927

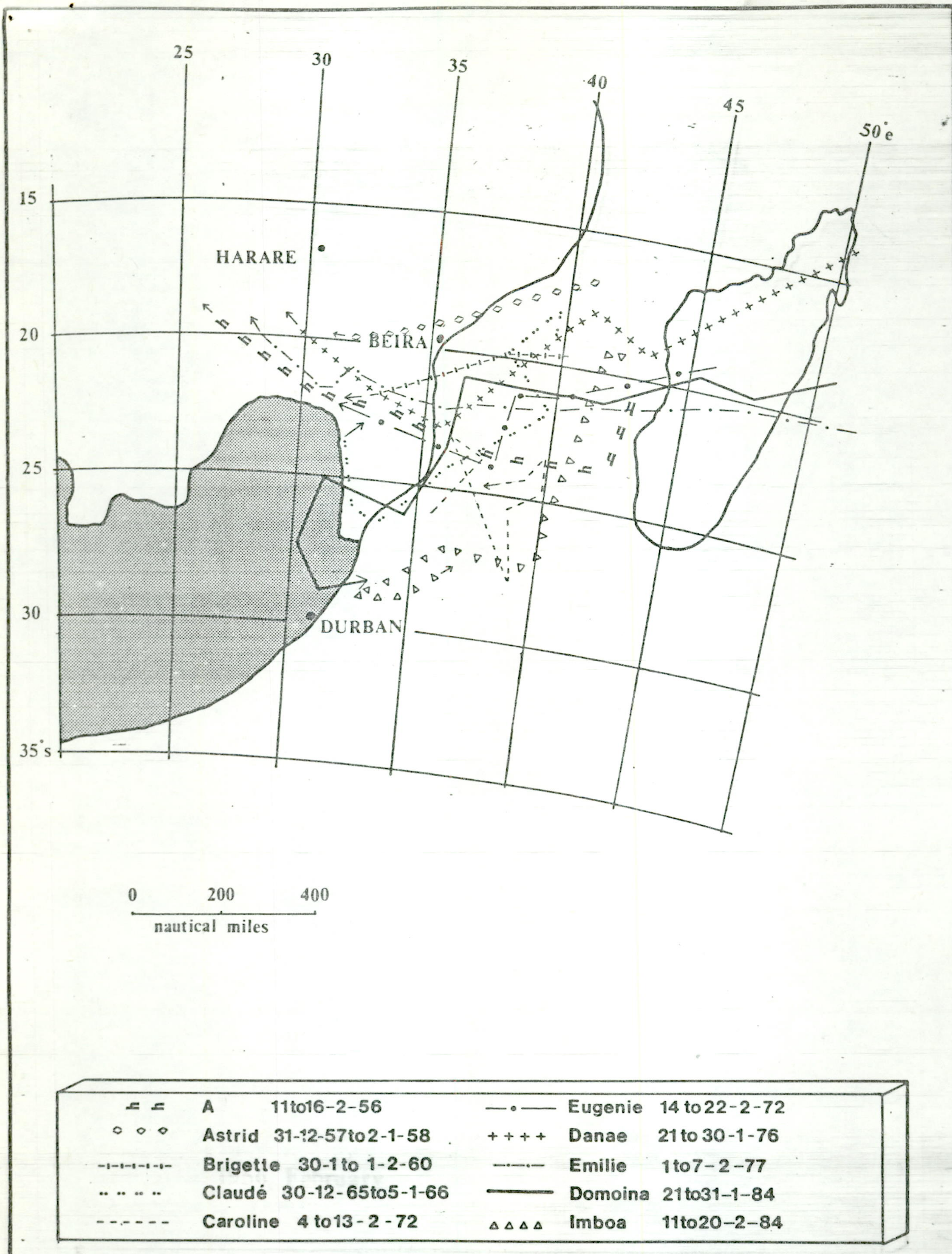


FIG 5 PATHS OF TROPICAL CYCLONES CAUSING SIGNIFICANT RAINFALL OVER SOUTH AFRICA SINCE 1950

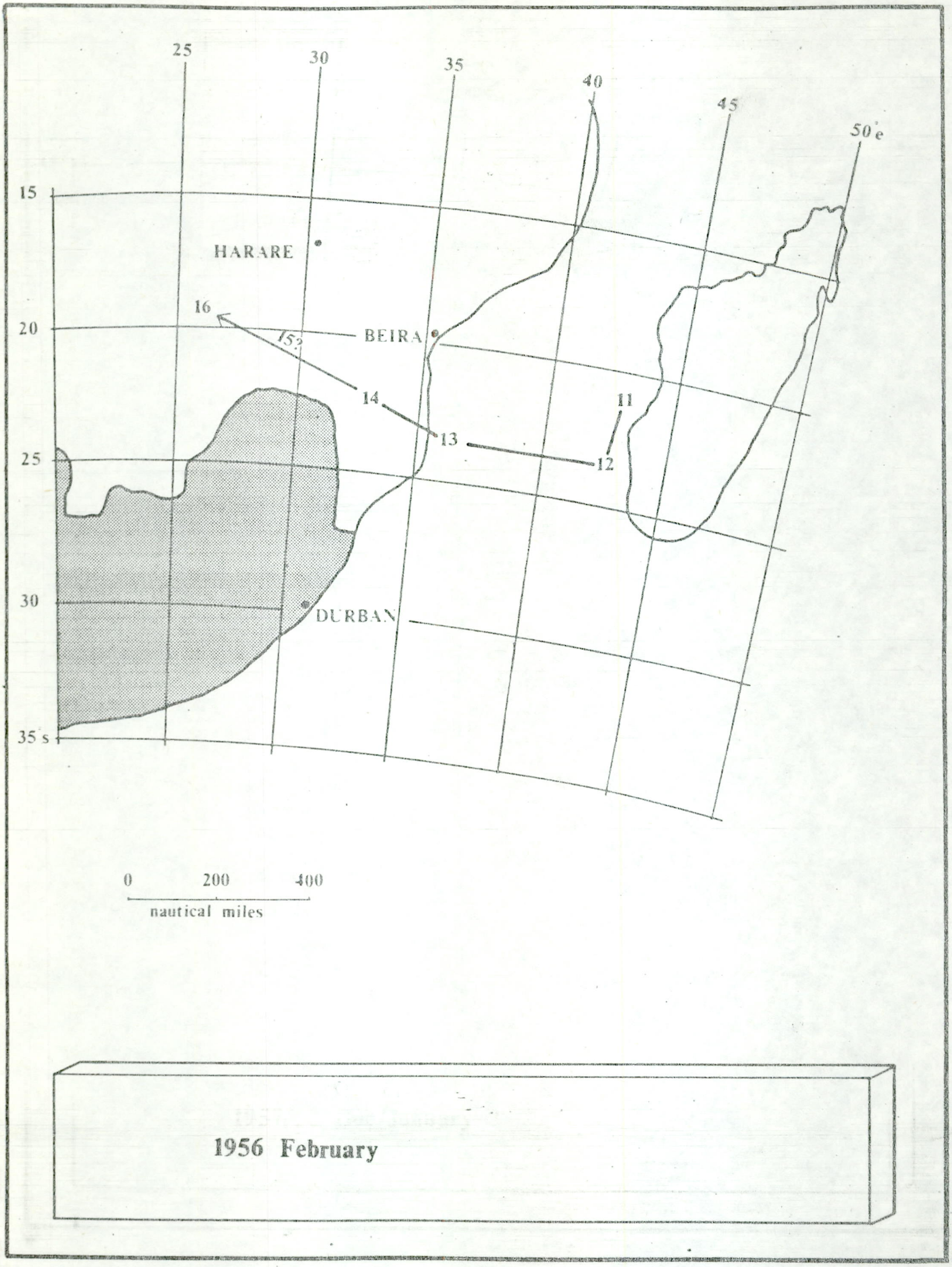
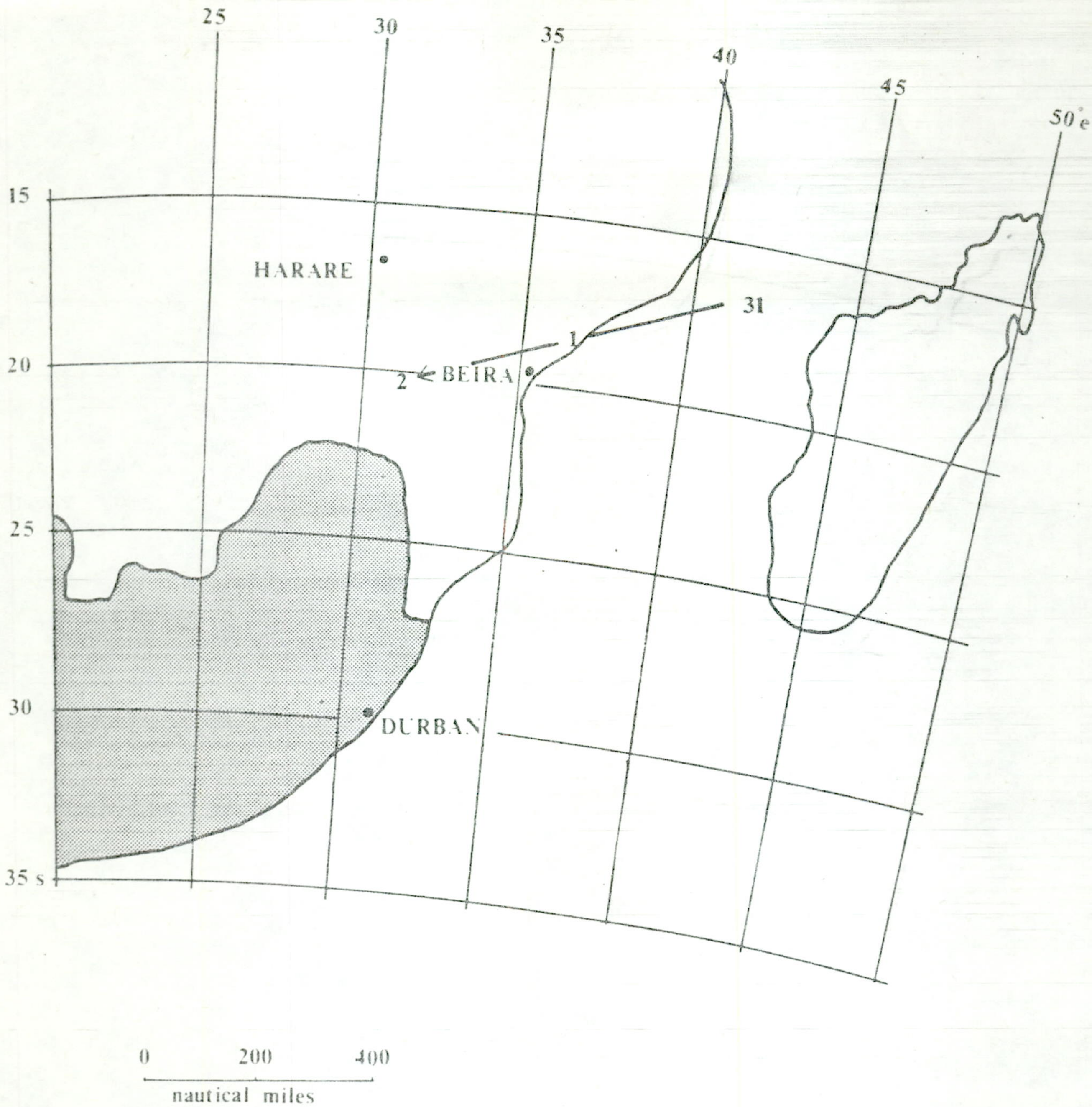


FIG 6 PATH OF TROPICAL CYCLONE 'A'



1957/58 Dec/January

FIG 7 PATH OF TROPICAL CYCLONE 'ASTRID'

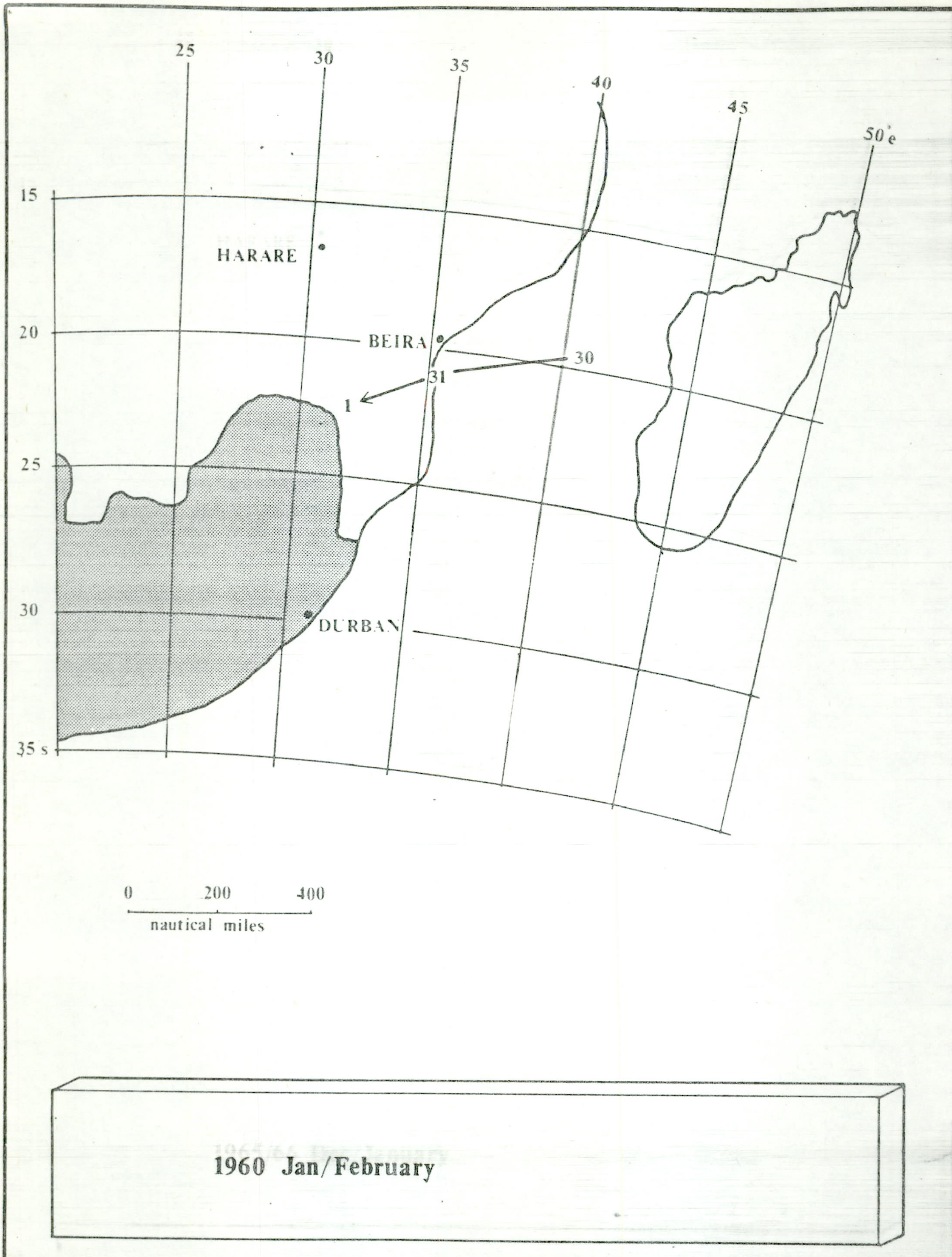


FIG 8 PATH OF TROPICAL CYCLONE 'BRIGETTE'

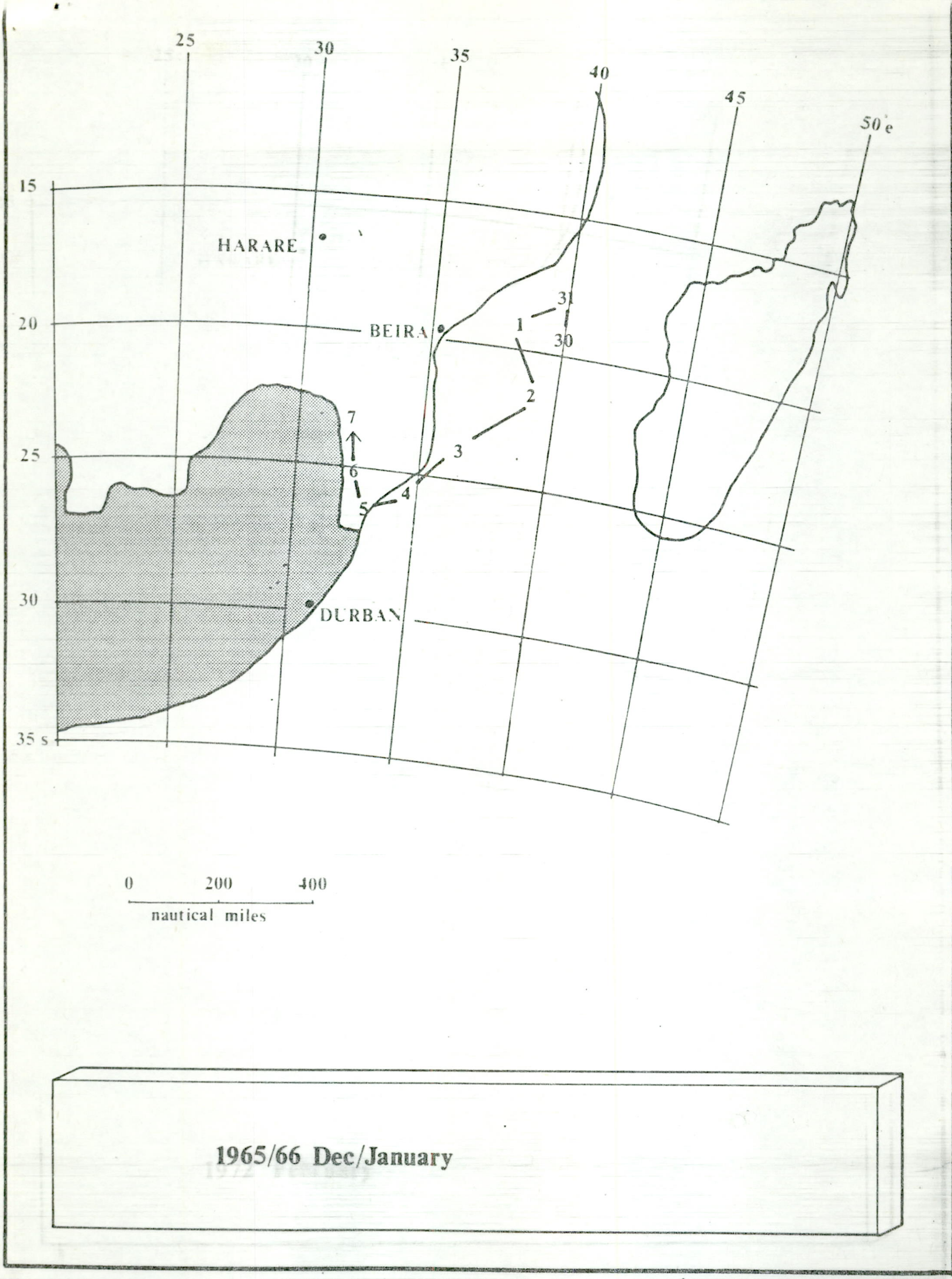


FIG 9 PATH OF TROPICAL CYCLONE 'CLAUDÉ'

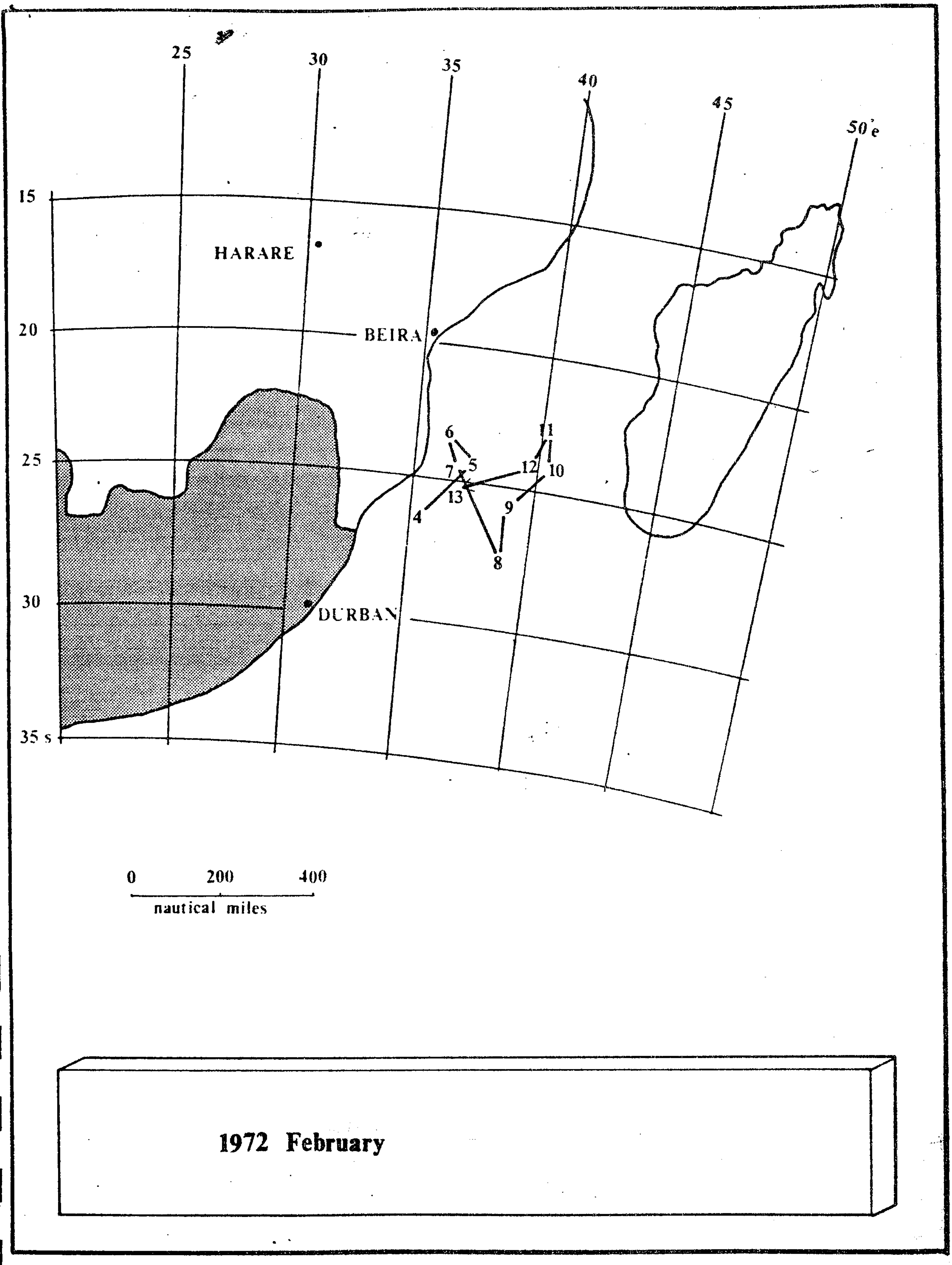


FIG 10 PATH OF TROPICAL CYCLONE 'CAROLINE'

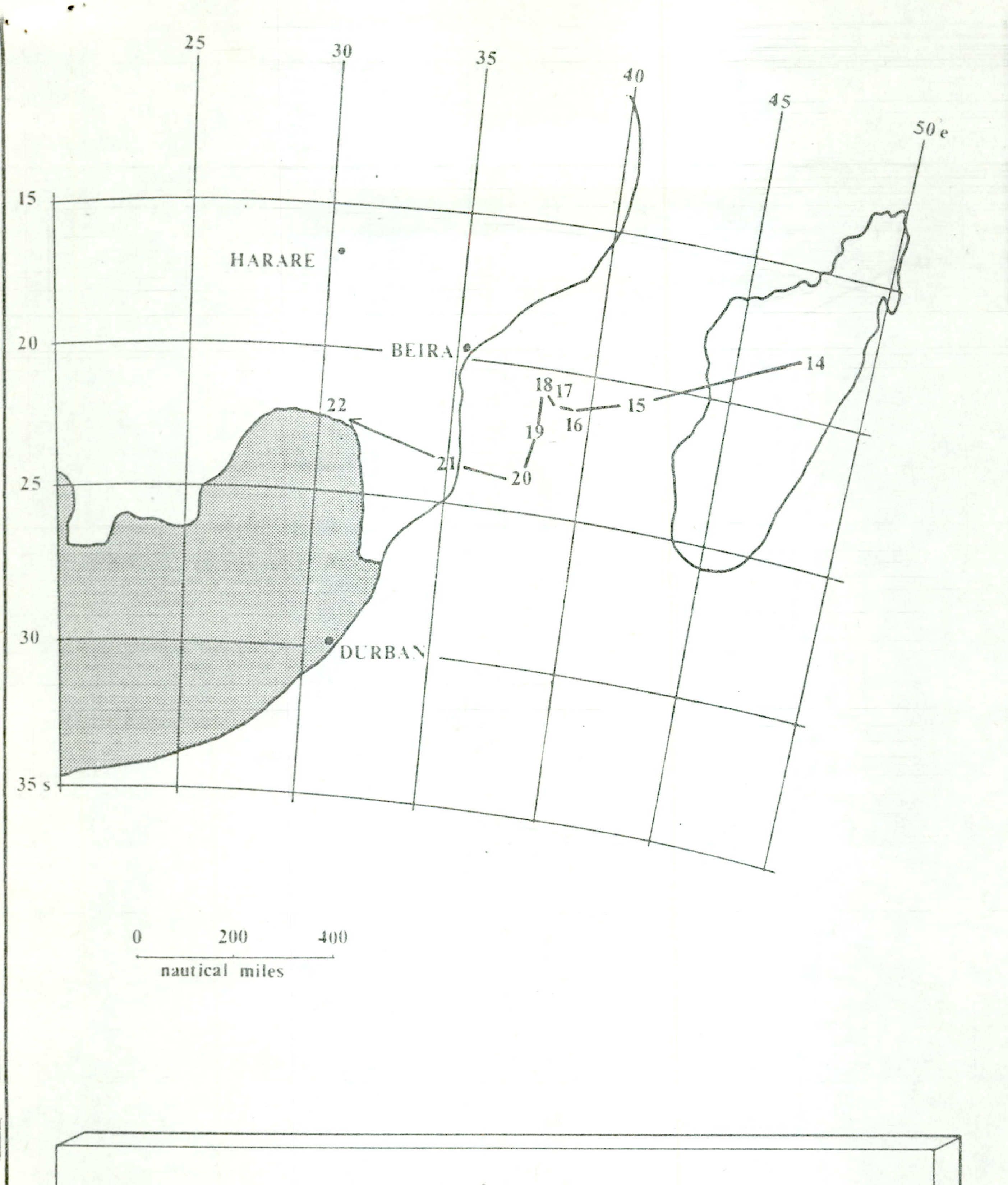
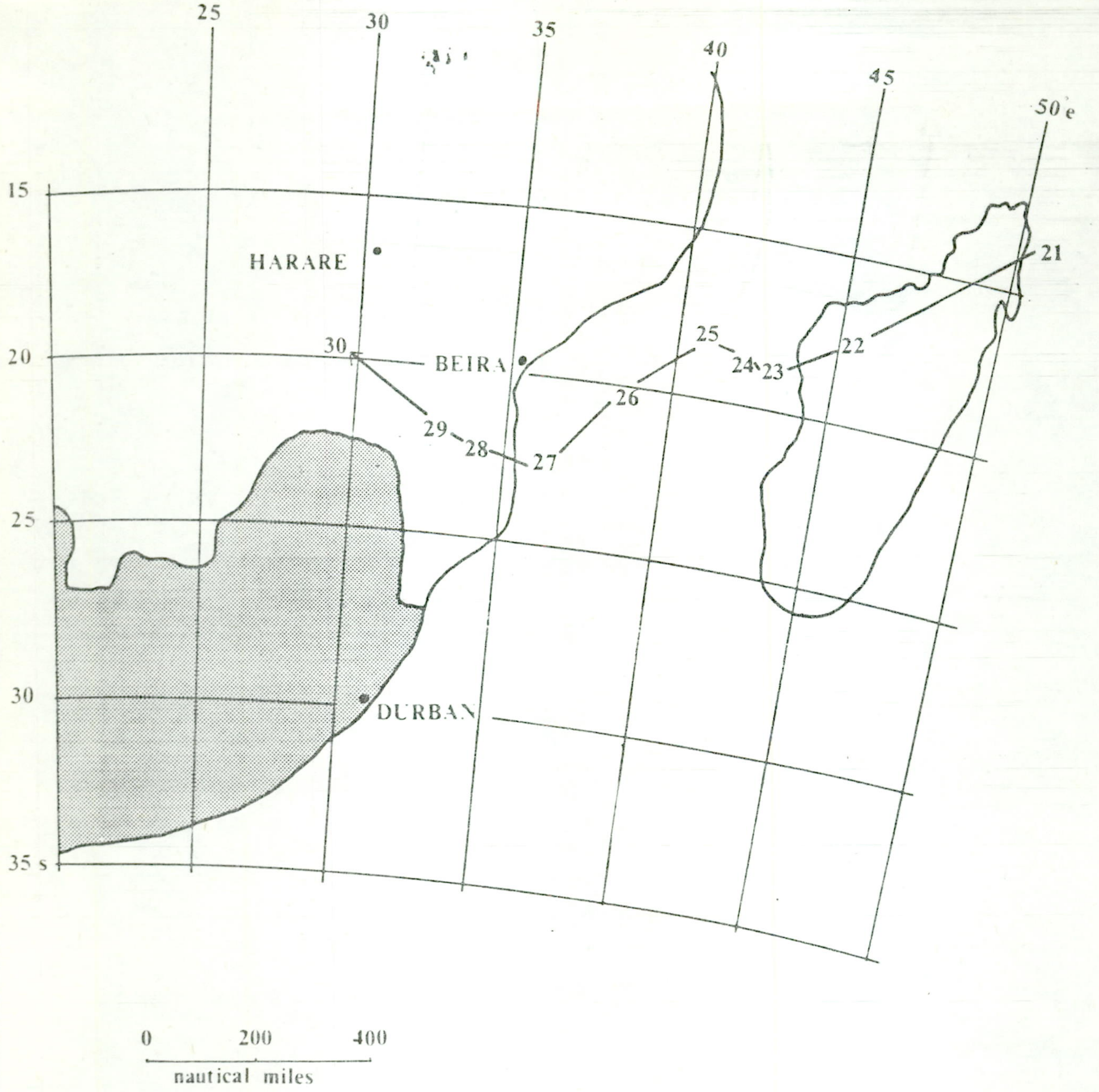
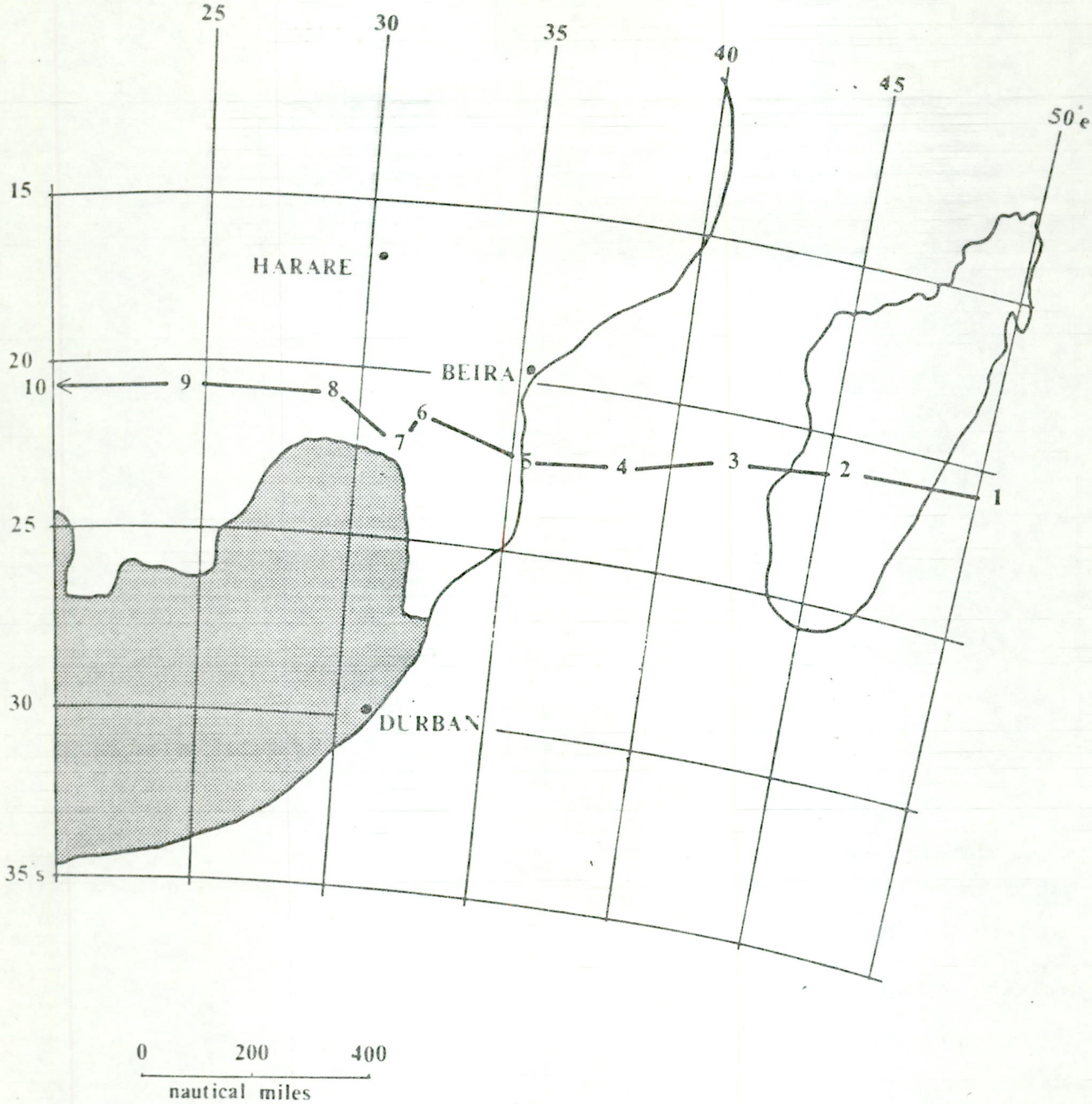


FIG 11 PATH OF TROPICAL CYCLONE 'EUGENIE'



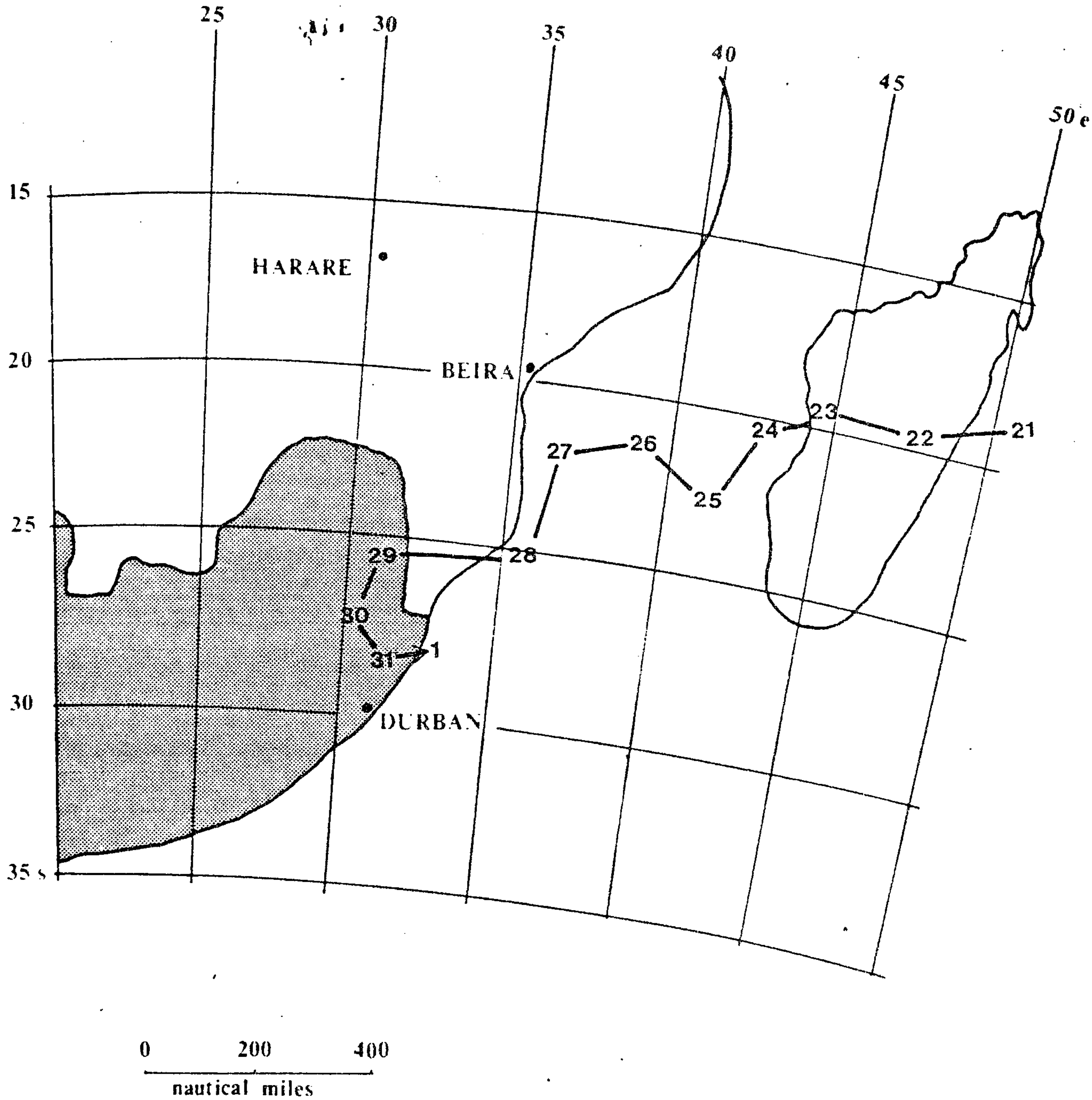
1976 January

FIG 12 PATH OF TROPICAL CYCLONE 'DANAE'



1977 February

FIG 13 PATH OF TROPICAL CYCLONE 'EMILIE'



1984 January

FIG 14 PATH OF TROPICAL CYCLONE 'DOMOINA'

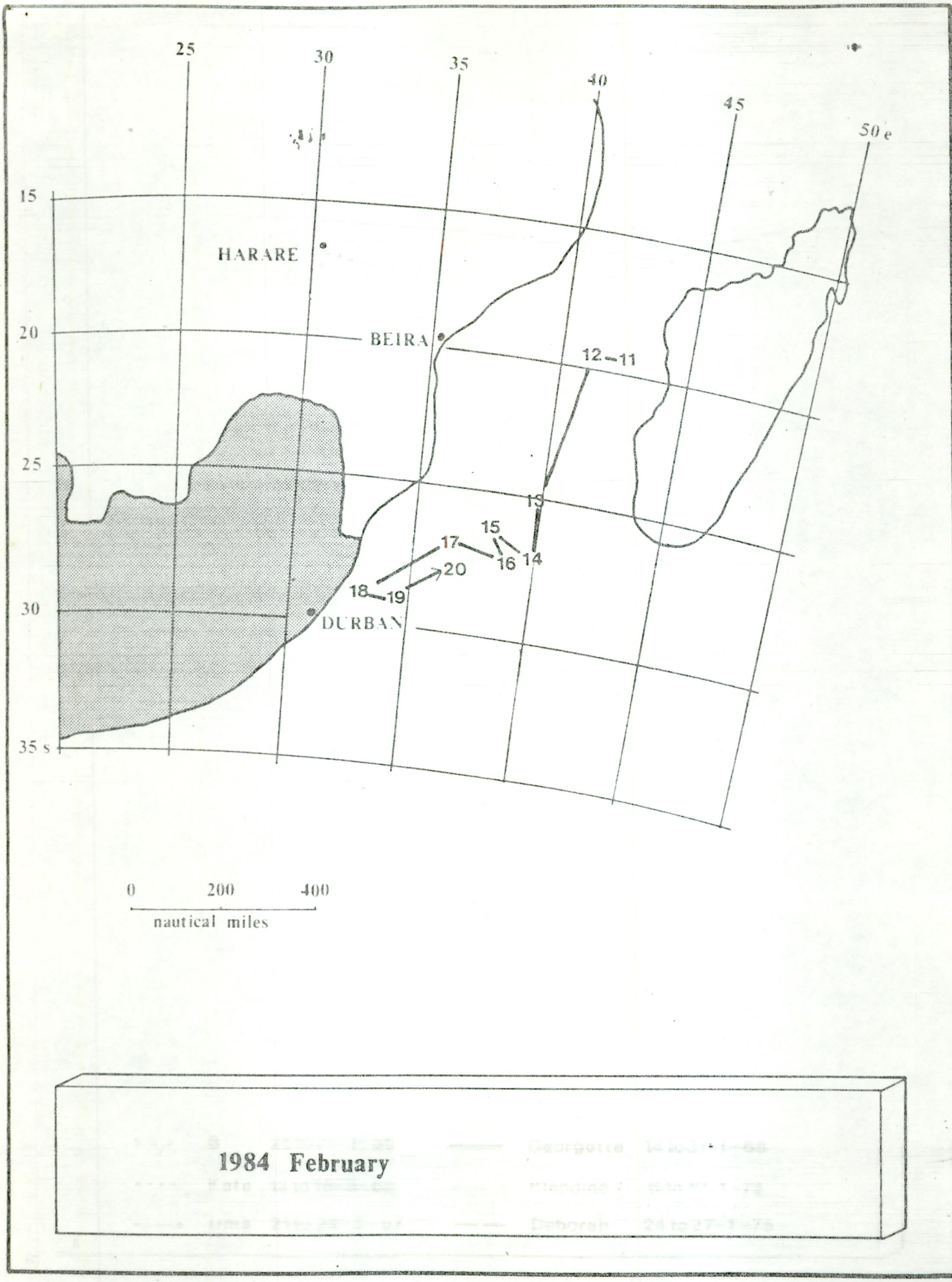


FIG 15 PATH OF TROPICAL CYCLONE 'IMBOA'

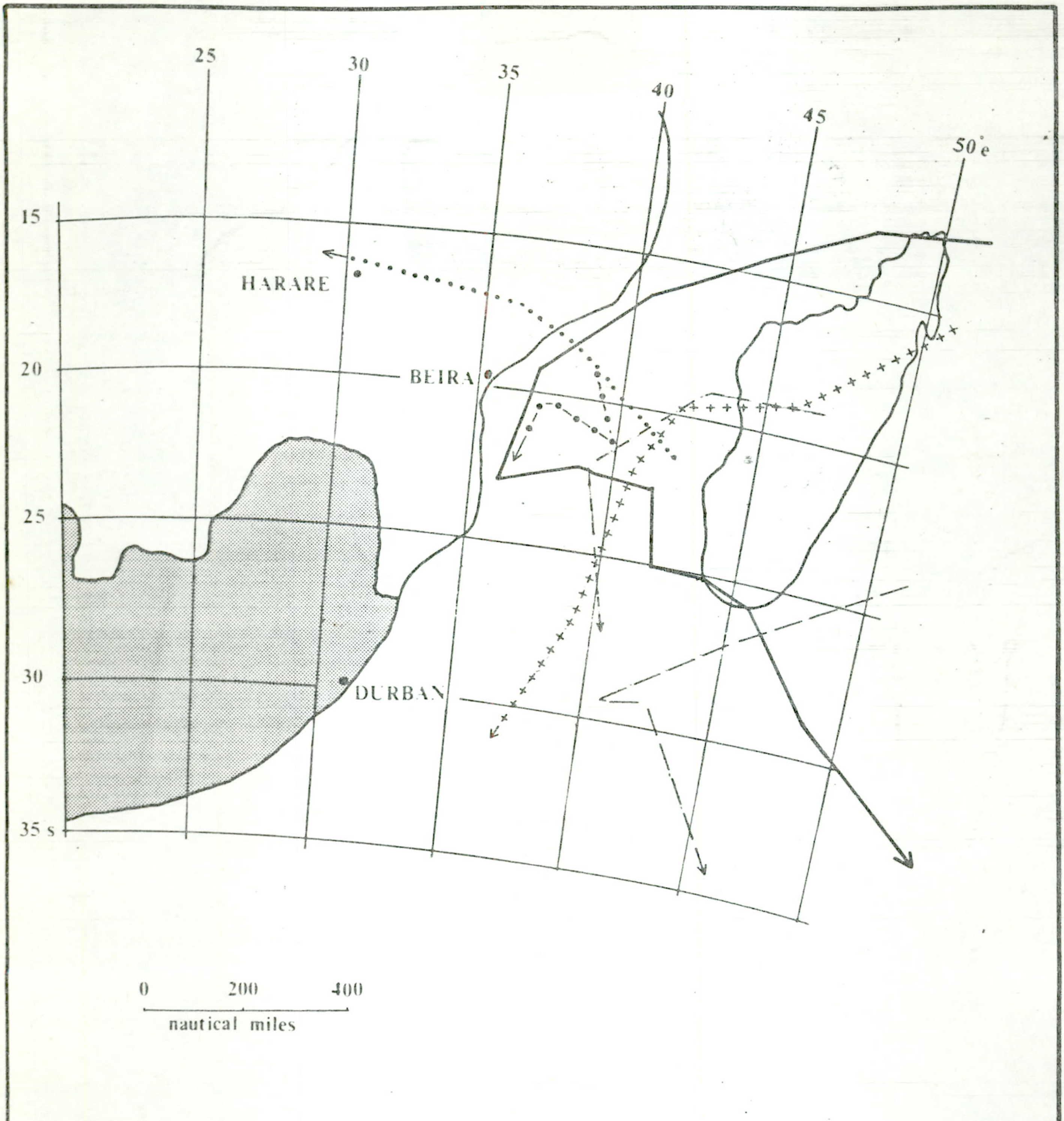
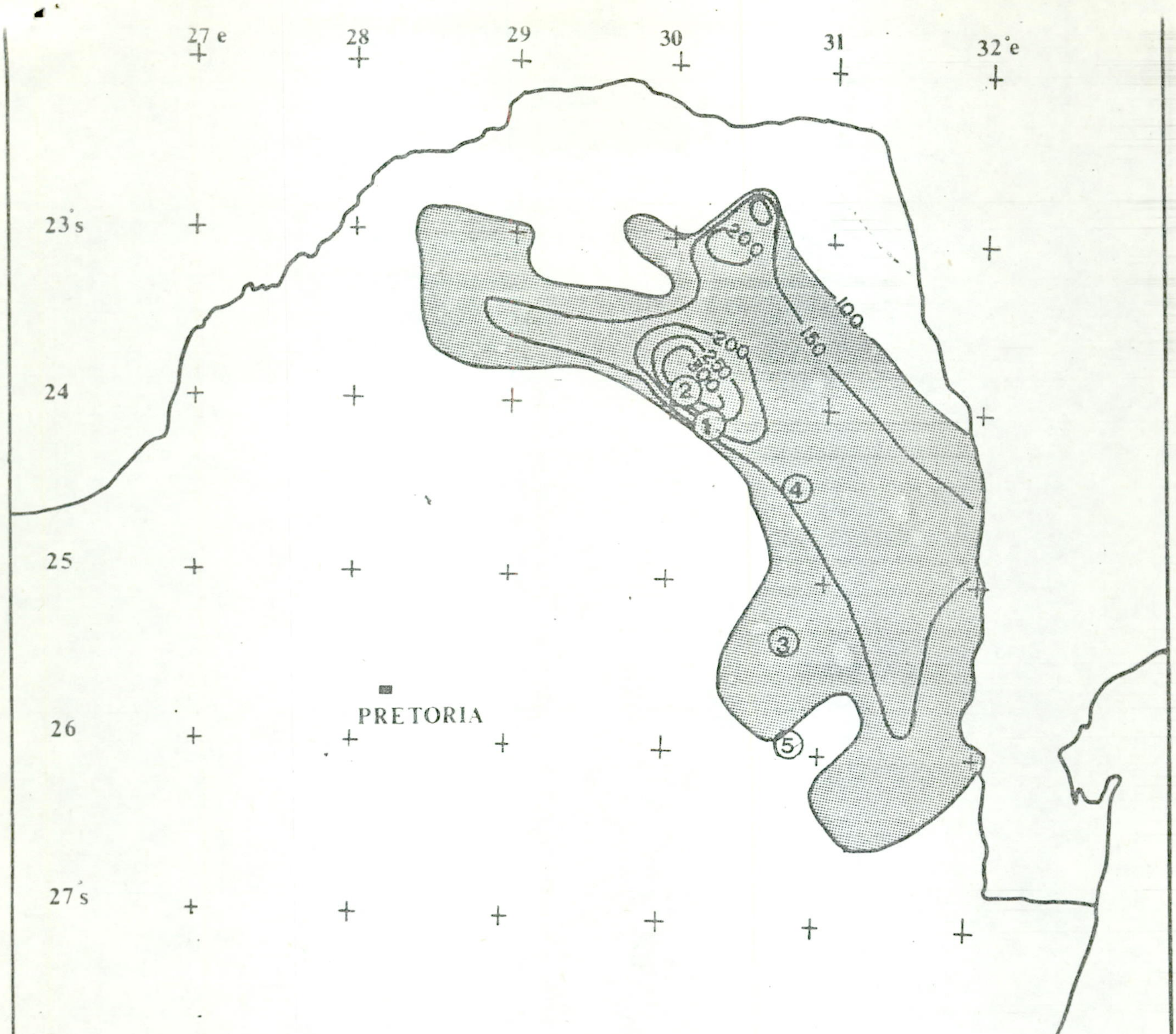


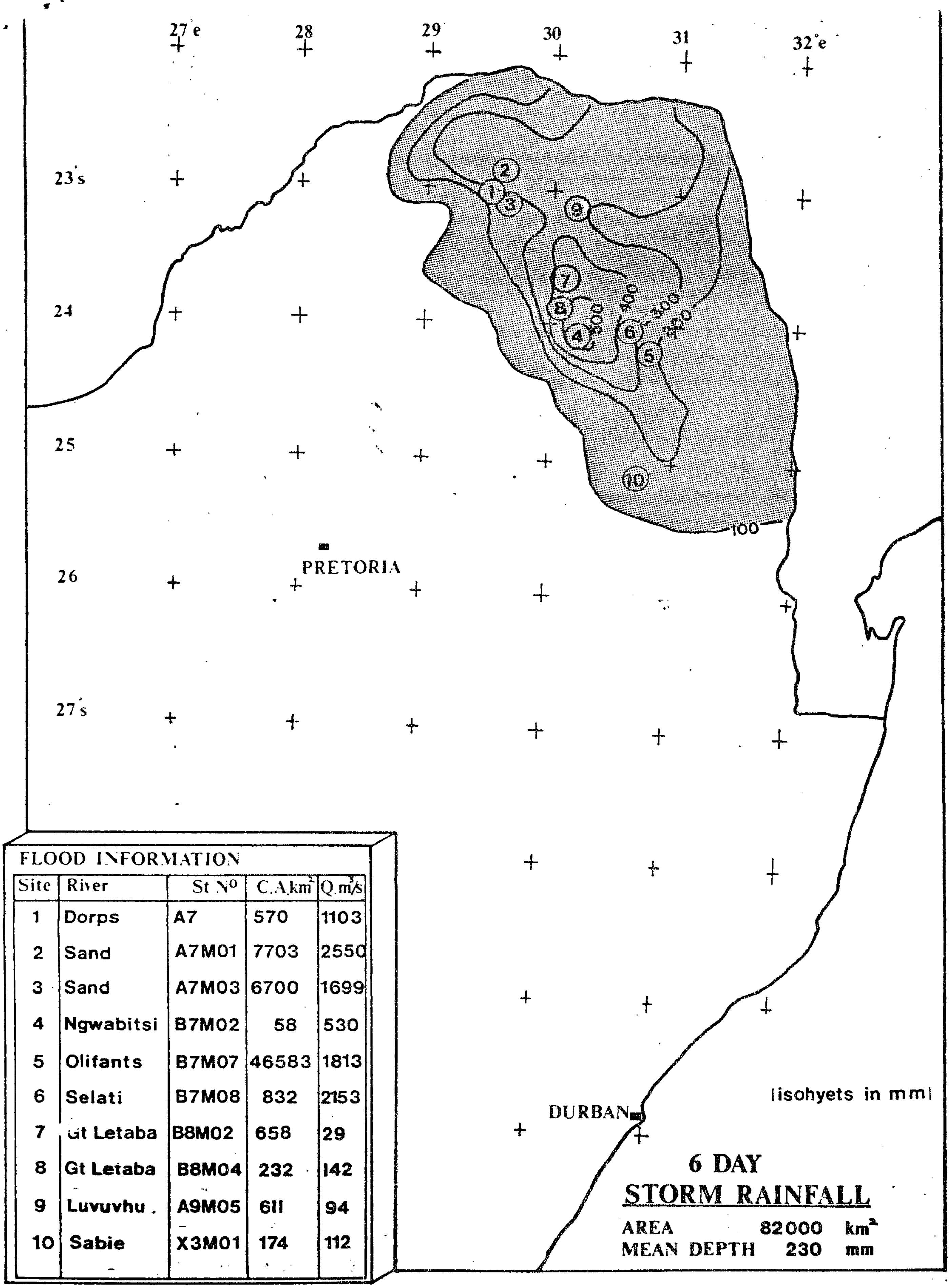
FIG 16 PATHS OF TROPICAL CYCLONES CAUSING INSIGNIFICANT RAINFALL OVER SOUTH AFRICA SINCE 1950



FLOOD INFORMATION

Site	River	St N⁰	C.A km²	Q m³/s
1	Ngwabitsi	B7M02	58	530
2	Gt Letaba	B8M04	232	107
3	Sabie	X3M0I	174	23
4	Blyde	B6M04	2241	58
5	Suidkaap	X2M09	280	63

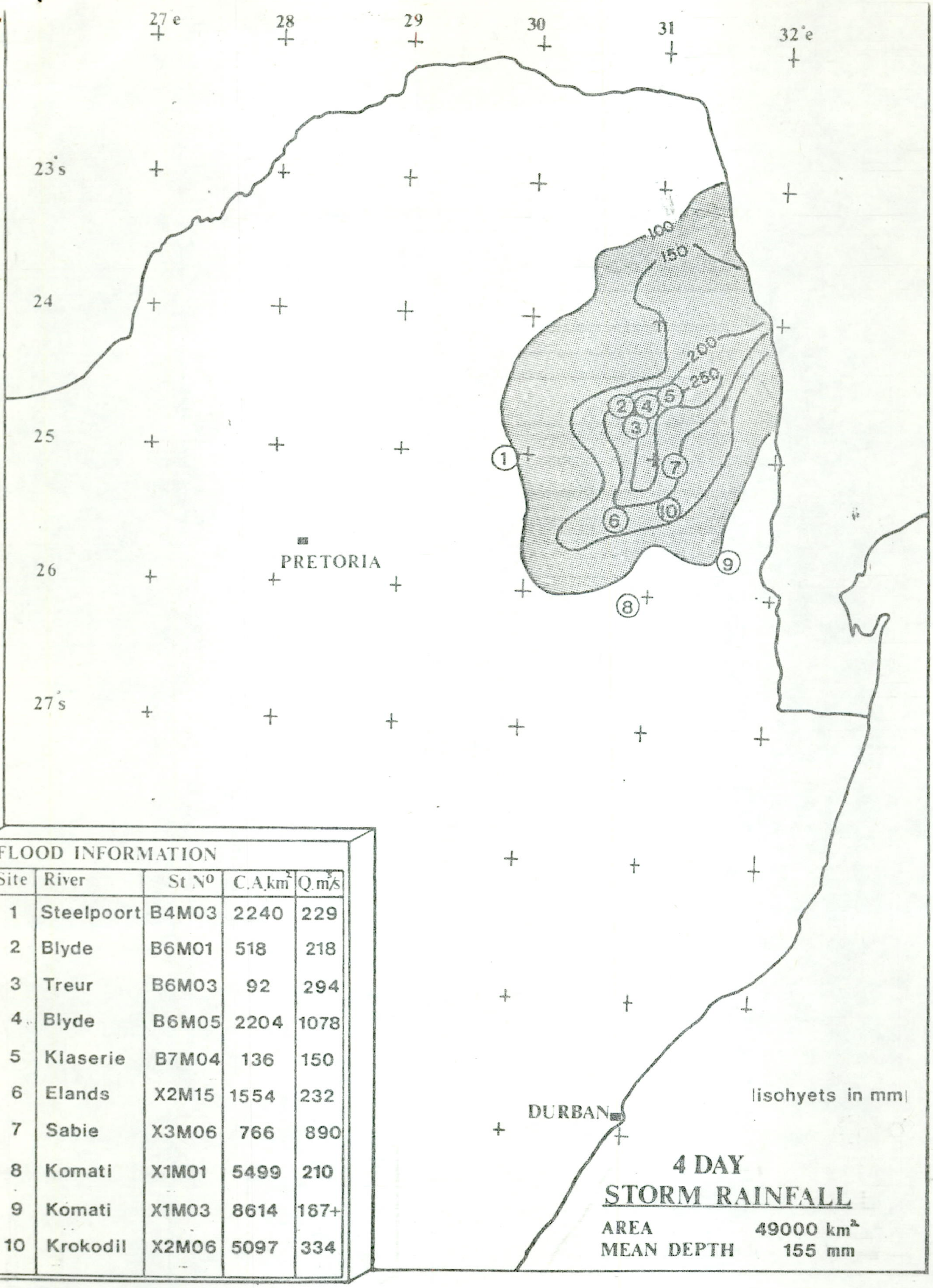
FIG 17. ISOHYETAL MAP OF TROPICAL CYCLONE 'A', 1956.



FLOOD INFORMATION

Site	River	St Nº	C.A km²	Q m³/s
1	Dorps	A7	570	1103
2	Sand	A7M01	7703	2550
3	Sand	A7M03	6700	1699
4	Ngwabitsi	B7M02	58	530
5	Olifants	B7M07	46583	1813
6	Selati	B7M08	832	2153
7	Gt Letaba	B8M02	658	29
8	Gt Letaba	B8M04	232	142
9	Luvuvhu	A9M05	611	94
10	Sabie	X3M01	174	112

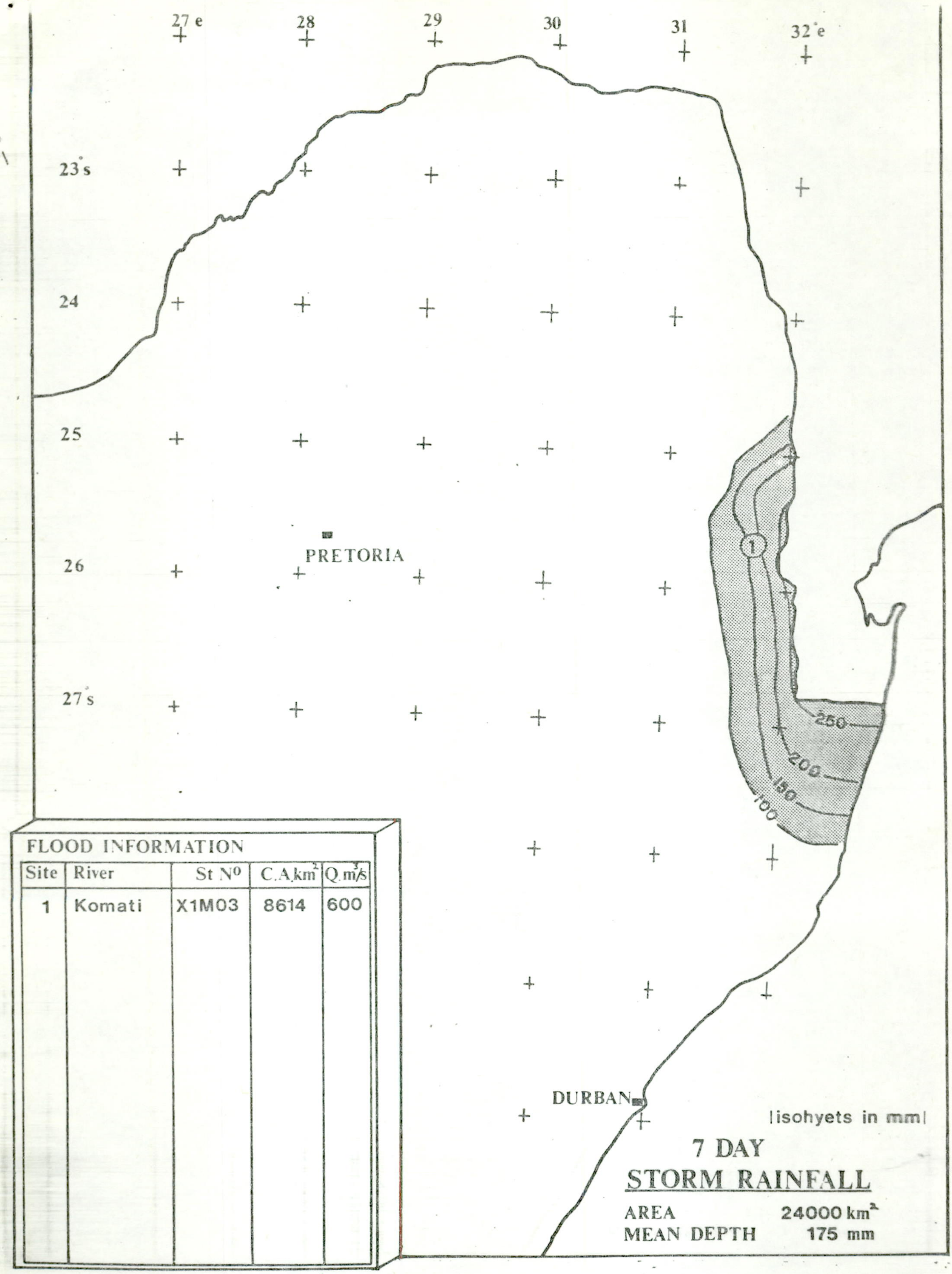
FIG 18 ISOHYETAL MAP OF TROPICAL CYCLONE 'ASTRID', 1958.



FLOOD INFORMATION

Site	River	St Nº	C.A.km²	Q.m³/s
1	Steelpoort	B4M03	2240	229
2	Blyde	B6M01	518	218
3	Treur	B6M03	92	294
4	Blyde	B6M05	2204	1078
5	Klaserie	B7M04	136	150
6	Elands	X2M15	1554	232
7	Sabie	X3M06	766	890
8	Komati	X1M01	5499	210
9	Komati	X1M03	8614	167+
10	Krokodil	X2M06	5097	334

FIG 19. ISOHYETAL MAP OF TROPICAL CYCLONE 'BRIGETTE', 1960.



FLOOD INFORMATION

Site	River	St Nº	C.A km²	Q m³/s
1	Komati	X1M03	8614	600

FIG 20. ISOHYETAL MAP OF TROPICAL CYCLONE 'CLAUDE', 1966.

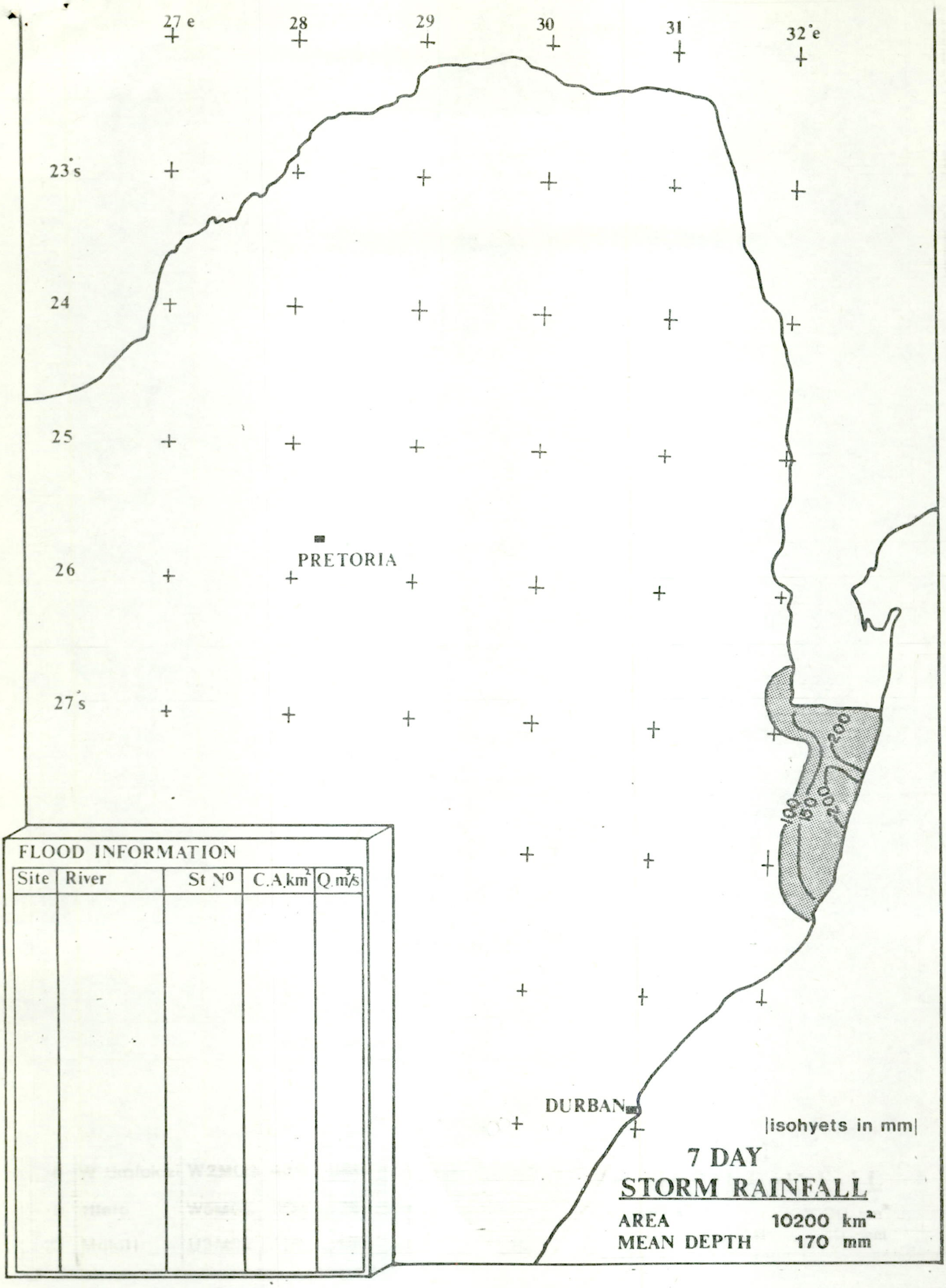
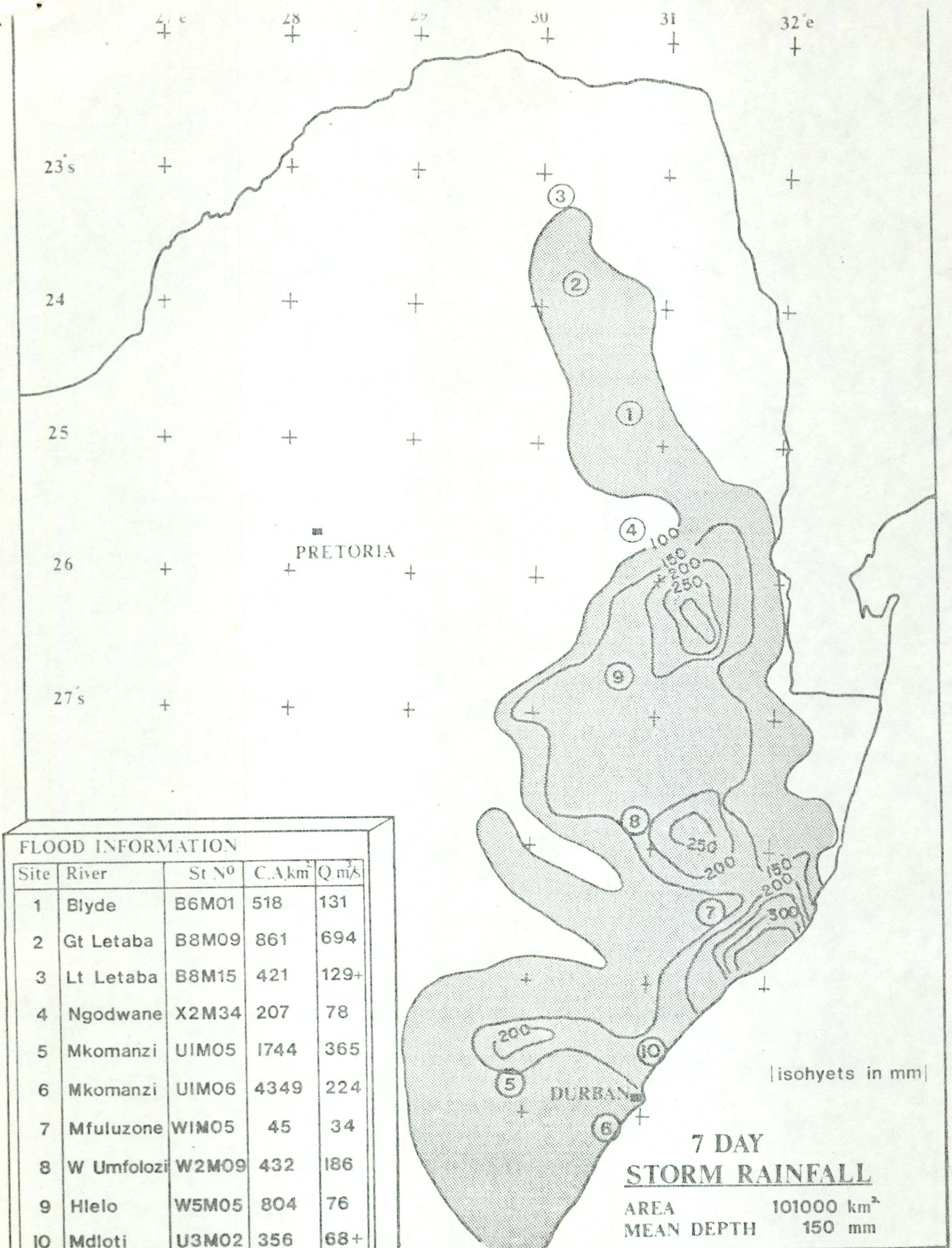


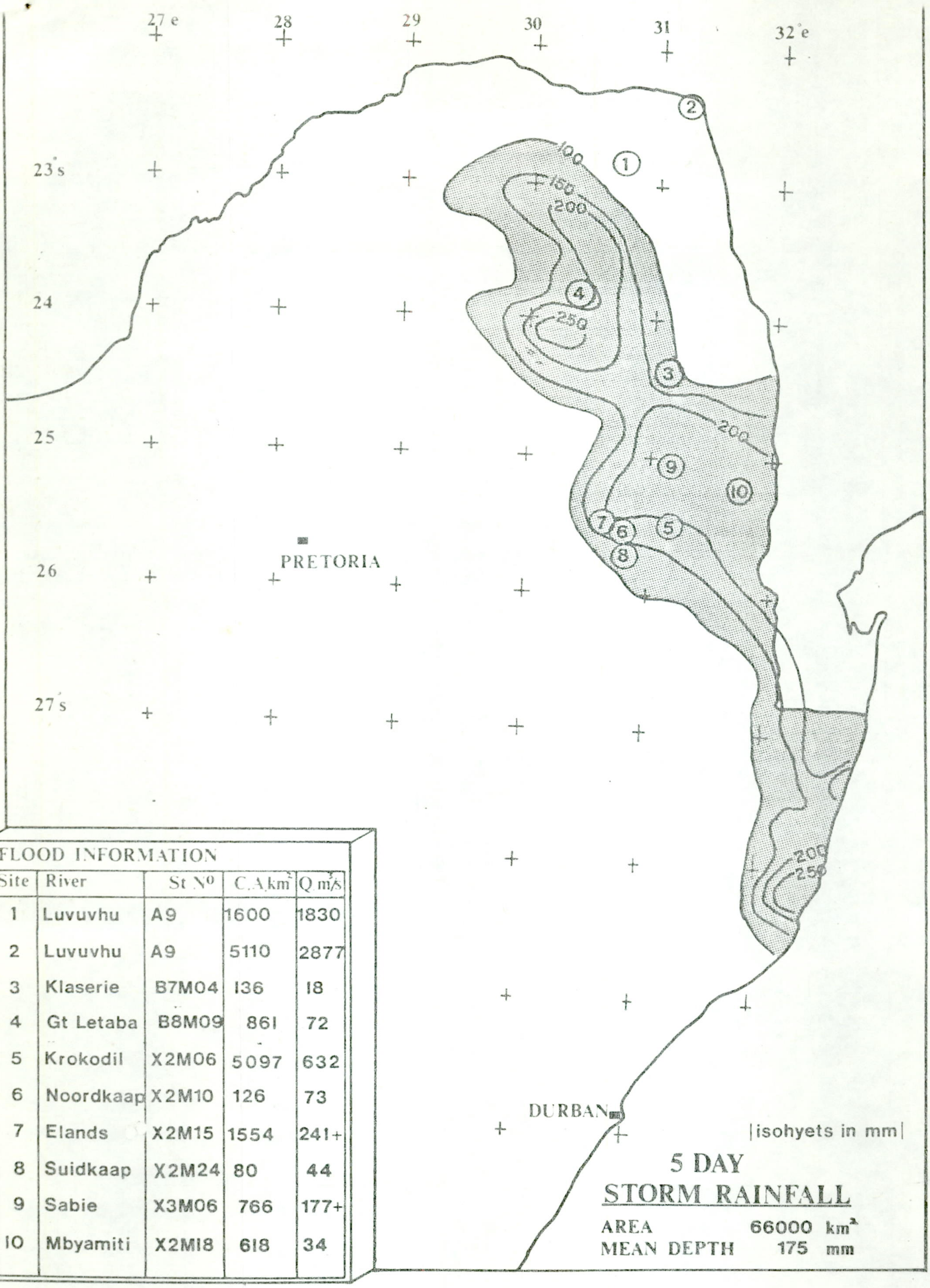
FIG 21. ISOHYETAL MAP OF TROPICAL CYCLONE 'CAROLINE', 1972.



FLOOD INFORMATION

Site	River	St Nº	C.A km²	Q m³/s
1	Blyde	B6M01	518	131
2	Gt Letaba	B8M09	861	694
3	Lt Letaba	B8M15	421	129+
4	Ngodwane	X2M34	207	78
5	Mkomanzi	UIM05	1744	365
6	Mkomanzi	UIM06	4349	224
7	Mfuluzone	WIM05	45	34
8	W Umfolozi	W2M09	432	186
9	Hlelo	W5M05	804	76
10	Mdloti	U3M02	356	68+

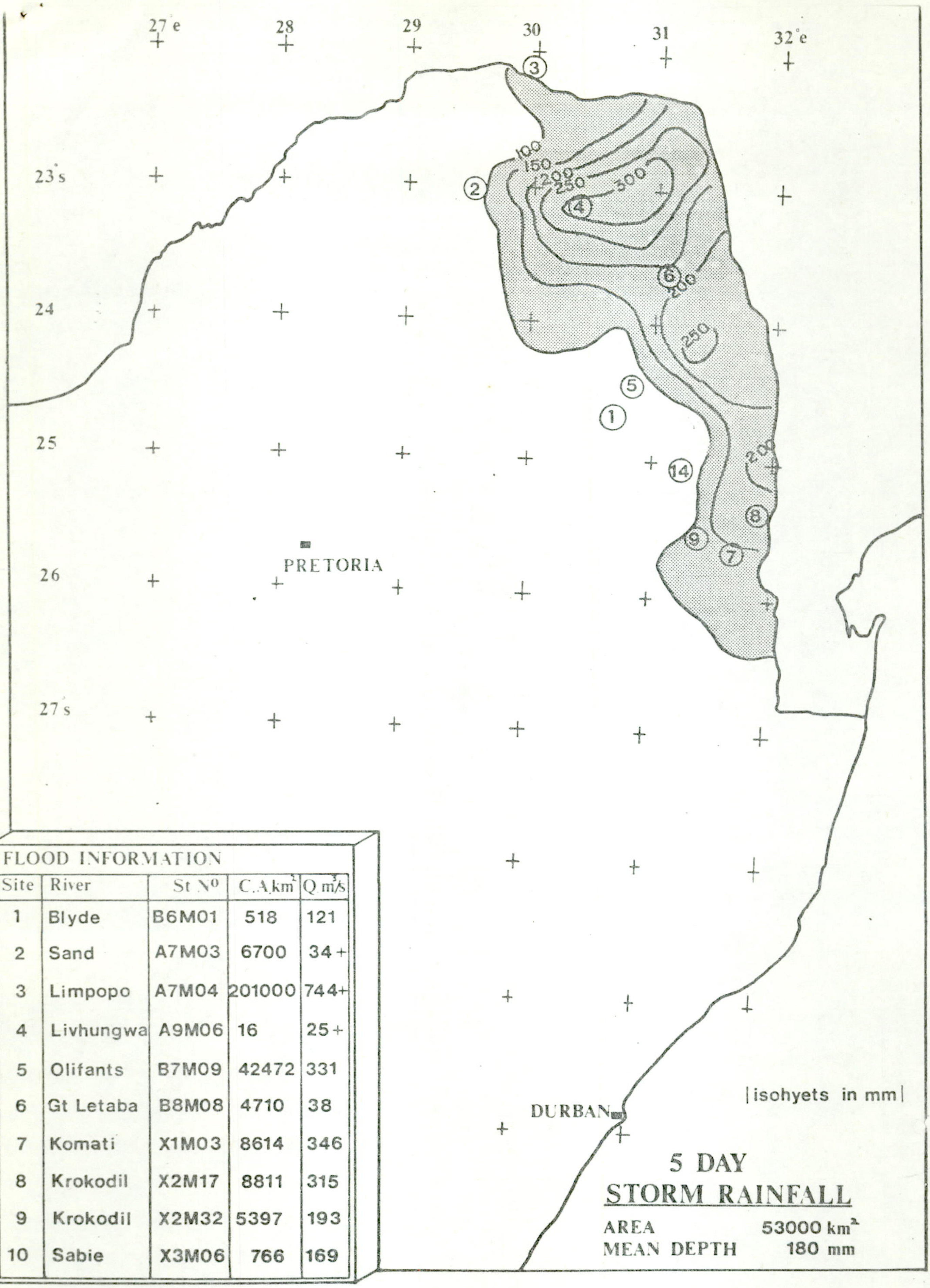
FIG 22. ISOHYETAL MAP OF TROPICAL CYCLONE 'EUGENIE', 1972.



FLOOD INFORMATION

Site	River	St N°	C.A km²	Q m³/s
1	Luvuvhu	A9	1600	1830
2	Luvuvhu	A9	5110	2877
3	Klaserie	B7M04	136	18
4	Gt Letaba	B8M09	861	72
5	Krokodil	X2M06	5097	632
6	Noordkaap	X2M10	126	73
7	Elands	X2M15	1554	241+
8	Suidkaap	X2M24	80	44
9	Sabie	X3M06	766	177+
10	Mbyamiti	X2M18	618	34

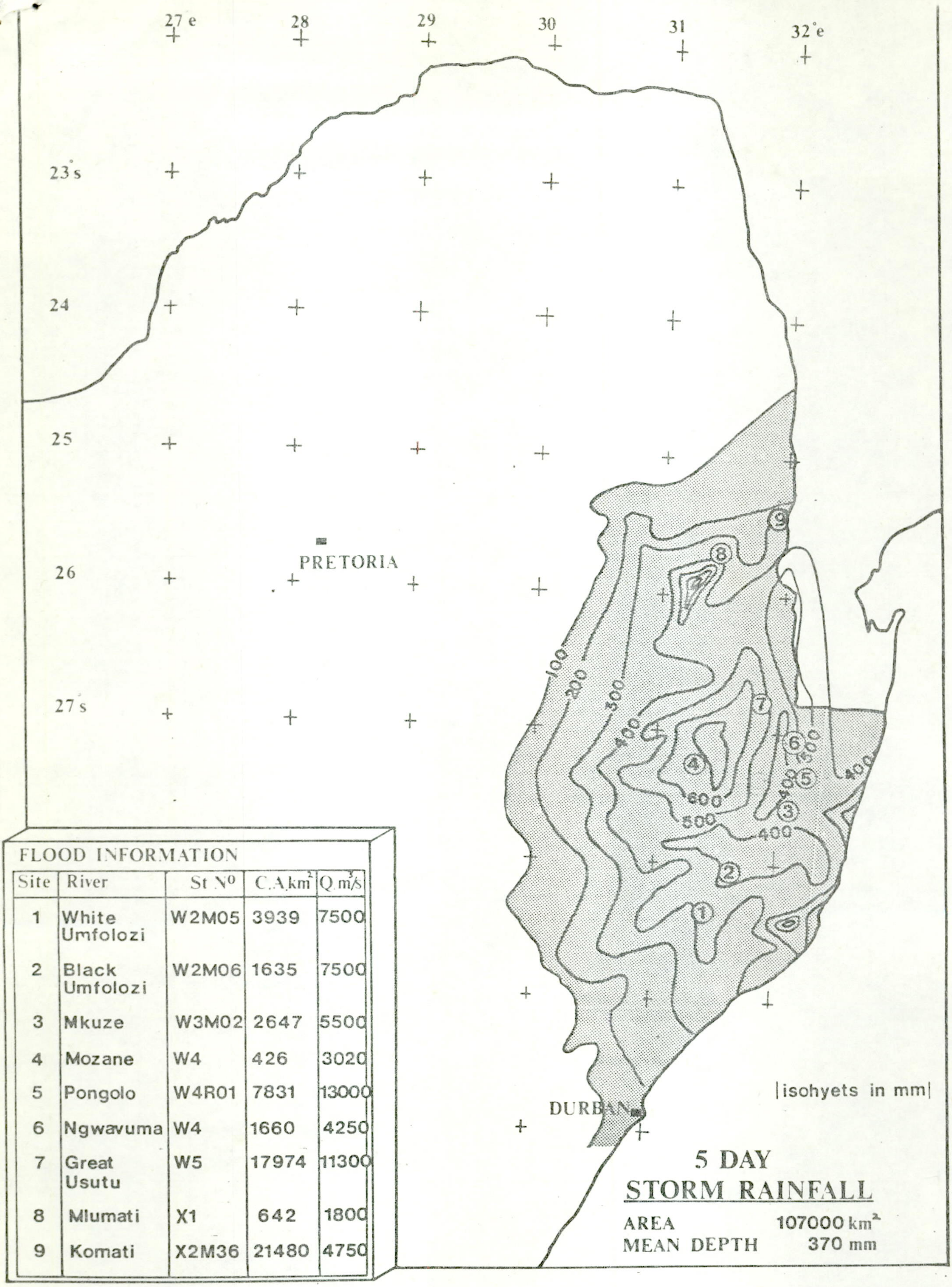
FIG 23. ISOHYETAL MAP OF TROPICAL CYCLONE 'DANAE', 1976.



FLOOD INFORMATION

Site	River	St Nº	C.A.km²	Q m³/s
1	Blyde	B6M01	518	121
2	Sand	A7M03	6700	34+
3	Limpopo	A7M04	201000	744+
4	Livhungwa	A9M06	16	25+
5	Olifants	B7M09	42472	331
6	Gt Letaba	B8M08	4710	38
7	Komati	X1M03	8614	346
8	Krokodil	X2M17	8811	315
9	Krokodil	X2M32	5397	193
10	Sabie	X3M06	766	169

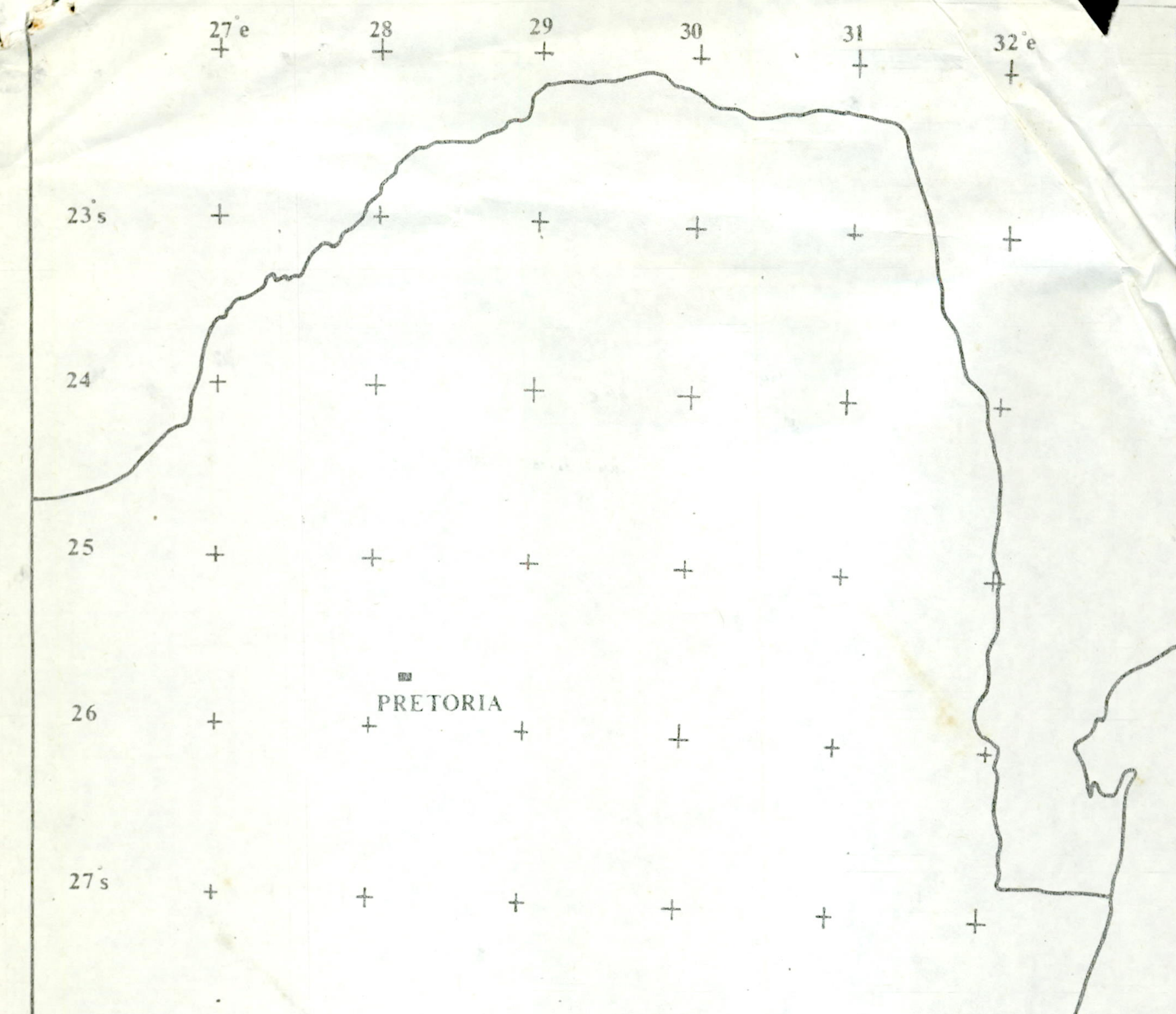
FIG 24. ISOHYETAL MAP OF TROPICAL CYCLONE 'EMILIE', 1977.



FLOOD INFORMATION

Site	River	St N⁰	C.A.km²	Q m³/s
1	White Umfolozi	W2M05	3939	7500
2	Black Umfolozi	W2M06	1635	7500
3	Mkuze	W3M02	2647	5500
4	Mozane	W4	426	3020
5	Pongolo	W4R01	7831	13000
6	Ngwavuma	W4	1660	4250
7	Great Usutu	W5	17974	11300
8	Mlumati	X1	642	1800
9	Komati	X2M36	21480	4750

FIG 25 ISOHYETAL MAP OF TROPICAL CYCLONE 'DOMOINA', 1984.



FLOOD INFORMATION

Site	River	St Nº	C.A.km²	Q.m³/s
1	Mhlatuze	W1R01	1273	1290
2	Mfuluzone	W1M05	45	99

FIG 26. ISOHYETAL MAP OF TROPICAL CYCLONE 'IMBOA', 1984.