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THE SEVERE RAINFALL OCCASION, 16-18 JUNE 1972

BY

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PREFACE

The purpose of this report is to place on record for easy reference some of the more important hydrological and meteorological aspects of the 1972 rainstorm which caused many landslips and the loss of 148 lives.

The information reproduced here is condensed from more detailed manuscripts which have been available in the Royal Observatory library for some years. These manuscripts will continue to be maintained in the library for reference by those who require more detail than is included in this Technical Note.

The large amount of information on which this report is based has been collected and processed by many officers in the Royal Observatory. However, the main authors were Messrs. T.T. Cheng and W.P. Kwong who collected and prepared the rainfall information, some of which was given in evidence to the Commission of Enquiry, and Dr. M. Yerg and Mr. W.C. Poon who were responsible for the preparation of the meteorological assessment.

The most significant features of these reports were extracted by Messrs. P. Peterson, H.C. Leong and T.S. Li who prepared the information and diagrams for publication.

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1. INTRODUCTION

A distinct, four-day period of rainfall occurred in Hong Kong from 15 to 18 June, 1972 with very heavy rain (over 200 mm per day as recorded at the Royal Observatory) falling on each of the last three days (see Figure 1). By the end of the period, considerable damage to property as well as the loss of about 150 lives had taken place in landslips or floods caused by the heavy rains. Two areas had major disasters : Sau Mau Ping (in the eastern district of Kowloon) and Po Shan Road (in mid-levels near Hong Kong University on Hong Kong Island). Detailed information on the landslips and other incidents which happened during that time can be found in the Interim and Final Reports of the Commission of Inquiry into the Rainfall Disasters, 1972 (Ref. 11 and 12). A summary of the effect of these rainstorms in Hong Kong is presented at the end of the next section.

The primary period being considered is from 16-18 June, 1972 (hereafter also referred to as Day 1, Day 2 and Day 3). This report is divided into two parts : the first one dealing with the hydrometeorological aspects of these days and the second part identifying the synoptic conditions which were associated with this period.

Most of the hydrometeorological information is chosen to provide historical perspective on heavy rain situations in Hong Kong. This particular occasion in June 1972 will be directly compared with the June 1966 heavy rain which was documented by Chen (1969). Table 5 contains data on the maximum average depth of rainfall for 16 - 18 June 1972. Values tabulated in the table are in mm/squar mile. 'Square miles' which are not part of the SI System are used in Table 5 in order that direct comparison can be made with historical figures given in Tables 6-7.

The synoptic analysis concentrates on reviewing the basic weather patterns which gave rise to the very heavy rains. In this regard, the days are divided between one type of synoptic pattern for Day 1 and Day 2 and a second, distinct synoptic pattern for Day 3.

2. HYDROMETEOROLOGICAL ANALYSIS

(a) Historical perspective

The Royal Observatory, Hong Kong together with the Water Works Office of the Public Works Department maintains about 140 raingauges at 117 locations throughout the area (see Figure 2). The lack or overabundance of rainfall has often had critical effects on Hong Kong either in the form of acute water rationing (such as in 1963 and 1967) or as a cause of disastrous landslips and flooding (as in 1966).

The official measurement of rainfall is taken hourly at the Observatory's headquarters using an 8-inch ordinary raingauge (a 5-inch and an 8-inch autographic gauge as well as a Jardi rate-of-rainfall recorder are also in operation). Other rainfall measurements are made in Hong Kong at outstations, manned mainly by voluntary observers, which provide a 24-hour accumulated rainfall total taken either at 9:00 a.m. or at 3:00 p.m. H.K. ST. T. (and usually acknowledged as the rainfall for that day) or an autographic record from which hourly readings are possible. The 24-hour rainfall for stations over south China are available at 0000 GMT (8:00 a.m. H.K. ST. T.) each day. Because of these variations in the times of measurement, the figures and tables in this section will differ depending on whether they apply to south China, to the local raingauge network or just to the autographic gauges. A day during the months of May or June in which 200 mm or more of rain falls in Hong Kong is not exceptional. During the 25-year period (1947 to 1971) there were three such days in May (1957, 1964, 1970) and four in June (1959, 1960, 1966, 1968). Basically, there are two usual causes for very heavy rain in Hong Kong : (1) a slow-moving trough of low pressure along the coast of south China or (2) a tropical cyclone near Hong Kong. (The southwest monsoon, by itself, is not usually enough to cause very heavy rain). The return period for rainfall in Hong Kong in excess of 200 mm per calendar day is 2½ years; for 400 mm or more in two days is 8 years; for 600 mm or more in three days is 25 years. The theoretical return periods for the actual amounts which fell in June 1972 are given in Table 1.

The rainstorms of June 1972 took place on the three consecutive days of the 16th, 17th and 18th. The total amount of rainfall during those three days was 652.3 mm at the Royal Observatory and 988.8 mm, up to 3.00 p.m. on June 18, at Aberdeen Upper Reservoir. It was the first occasion on record when over 200 mm were recorded on each of three consecutive days (205.9 mm, 213.8 mm and 232.6 mm respectively). The average depth of rain over the land area of Hong Kong was estimated to be about 480 mm during these three days. This is equivalent to some 500 million cubic metres of water which would have been sufficient to provide Hong Kong with water for more than a year.

June is normally the wettest month of the year with about 20.4 % of the mean annual rainfall (457.5 mm out of 2246.4 mm based on the period 1947-1976). In fact, the rainfall total for some Junes (1868, 1959 and 1966) has actually exceeded the annual rainfall total for 1963 (which is the driest year on record). Table 2 shows that the month of June normally experiences more rainy days than other months and that the chance of heavy rainfall is also greatest. Other comparisons of probable maximum rainfall can be found in Chin (1965).

June 1972 was not climatologically unusual with respect to most meteorological parameters except rainfall (see June 1972 Meteorological Extract, Table 3). During that month, almost twice the average amount of rain was recorded (799.8 mm) making it the fifth wettest June on record. June 1972's rainfall was about 28.5 % of that year's total rainfall. A comparison of the January-to-June rainfall in 1972 with other years on time scales from six months down to one hour are made in Table 4.

(b) Areal rainfall analysis

A mean rainfall chart for June of south China has been compiled using records of varying length and not necessarily consecutive years. For many reasons, complete rainfall data for stations in China are not available since 1937 in long periods. However, the values plotted in Figure 3(a) do contain, in general, about 20 years of data. This mean rainfall chart is accompanied by the chart for June 1972, one for the 96-hour period ending at 0000 GMT 19 June 1972 and a topographical chart, Figures 3(b,c,d) respectively.

The mean rainfall map of south China for June includes the rain-producing weather patterns of slow-moving surface troughs, the southwest monsoon and tropical cyclones. In general, variations in topography and availability of precipitable water account for the resulting pattern (with part of the unevenness attributable to data record length). The rainfall map for June 1972 shows a somewhat different pattern with the area of maximum rainfall confined mostly to the coast. This result was caused by (1) a trough which remained near the coast of south China in mid-month and (2) two tropical cyclones which affected the northern part of the South China Sea and the coastal areas of south China. The rainfall pattern for 15-18 June 1972 (inclusive) is similar to the monthly one. On the 96-hour rainfall chart, the secondary maximum which lies over the eastern portion of China was caused by a low pressure area which developed during the period. The topographical chart illustrates the relationship between geographical configuration and rainfall.

The rainfall charts in Figure 3 all show that Hong Kong usually receives most precipitation. This is considered to be partly the result of topography as Hong Kong rises abruptly from the sea and 78 % of its area is above 50 metres and partly its shape which protrudes into the South China Sea and therefore lacks protection from most rain-producing weather systems. The Royal Observatory rainfall figure used as the official reading has already been shown by Starbuck (1950) to be a very good approximation to the areal rainfall.

Figures 4(a,b,c,d) show the rainfall in individual 24-hour periods ending at 0000 GMT on 16, 17, 18 and 19 June. The rainfall over south China areally decreased over the first three charts as the trough which helped produce the rain weakened. On the final day, the rainfall was generally confined to a small area of south China (including Hong Kong, of course). The rain mechanism was different on this last day from the other days.

Figures 5(a,b) show the monthly mean rainfall over Hong Kong for June and the actual rainfall for June 1972. Both charts show maxima over higher elevations. The maximum over Lantau Island for June 1972 is slightly displaced from its normal position because of two tropical cyclones to the south of Hong Kong on 11-12 and 27 June 1972.

Areal analyses of rainfall at half-hourly and hourly intervals have been carried out for the two periods, 0400-1100 hours on Day 1 and 0930-1300 hours on Day 3 when the heaviest rainfall occurred. Results of these analyses have not been included in this report but are available in the departmental Library together with the original manuscript and other working charts.

On Day 1, the main area of rain existed in the southern portion of Hong Kong with an apparent west-southwest to east-northeast movement of storm cells with the maximum over higher elevations on Hong Kong Island. On Day 2, a large area of high rainfall covered Lantau Island, Hong Kong Island and the New Territories. The larger coverage of the rainstorms was a result of the proximity of the surface trough and the maxima over higher elevations were quite typical. Day 3 was characterized by the rapid movement and isolated nature of the individual rain echoes. The heaviest rainfall lay along the path from the Chi Ma Wan peninsula on Lantau Island into the western part of the harbour and then from Hong Kong Island towards Kwun Tong. The rapid movement of the storms is evident in Figure 6(c) in that the maximum and minimum areas are both thin and parallel (running roughly southwest to northeast). The composite rainfall map for the three days in Figure 6(d) shows the expected maxima over Hong Kong Island and the mountainous areas in the New Territories. Lantau Island did not receive a substantial maximum on Day 1 and then, on Day 3, appeared to have been missed by the main storm paths. This resulted in a rather mixed 3-day pattern for this area.

Of particular note is that the minimum rainfall recorded (74.5 mm) in the northwest part of the New Territories was only about 7.5 % of the maximum (988.8 mm) over Hong Kong Island. This is a ratio of about 1 to 13 over a distance of around 30 km. Figure 7 shows the spatial variation in accumulated rainfall from four selected stations with recording raingauges during the four-day period starting at midnight on 15 June 1972. These four mass curves show the cellular nature of the rainfall especially in the morning of Day 1, afternoon of Day 2 and around midday of Day 3.

Another way of viewing the accumulated rainfall is to show the length of time it took for various locations to reach specified depths. Figures 8(a,b,c) show the isopleths in hours for accumulated rainfall after midnight on 15 June 1972 for (a) 50 mm, (b) 200 mm and (c) 400 mm. Parts of the New Territories never reached the second and third depths and the figures show how the minimum time required to attain each level gradually progressed southwards. This type of analysis helps explain, for instance, why damage to property and live stock in the New Territories was not particularly serious during these rainstorms while at the same time disastrous landslips were occurring over Kowloon and Hong Kong Island.

(c) Depth-area-duration and intensity analysis

Two depth-area-duration analyses have been made for rainstorms on 16-18 June 1972 following the procedure recommended by the World Meteorological Organization (1969). Figure 9(a) shows the maximum depth-area curves for durations of 15 minutes to 6 hours and Figure 9(b) shows the same for durations of 12 to 72 hours. These curves are drawn for the land area of Hong Kong using the maximum amount of rainfall which occurred during specified time periods. Figure 9(a) shows again the short time period of the rainfall (of the order of two hours) and a maximum decrease in average depth of rainfall of about 80 mm as the area increases from 5 to 50 km^2 (one order of magnitude). Figure 9(b) shows that there was a 36-hour period when rainfall occurred fairly regularly but that a lull of about half a day took place before a 12-hour period of rainfall again occurred. For the entire period, an increase in area from 5 to 50 km^2 shows a decrease in the depth of rainfall by about 100 mm while an increase from 5 to 500 km^2 shows a decrease of about 275 mm. Table 5 shows the maximum average depth of rainfall for certain selected area sizes for the time intervals used in Figures 9(a and b). Comparing this table with those for the probable maximum rainfall for Hong Kong (reproduced here from Bell and Chin, 1968 as Table 6) and for the rainstorm in June 1966 (reproduced here from Chen, 1969 as Table 7), the intensities of the 1972 rainstorms can be seen to be much less than the other cases.

The intensities of the rainfall during the three days have been compiled for time periods up to one day from the autographic raingauge network and compared with the record maximum for similar time periods. Figure 10 and Figure 11 respectively show the comparison of extreme rainfall for all stations in Hong Kong and for the Royal Observatory in particular. Because Figure 10 shows that both Tai Mo Shan Farm (elevation 640 m) and Tai Tam Reservoir (elevation 155 m on Hong Kong Island) recorded the maximum rainfall amounts during June 1972 for the time periods analysed, Table 8 is prepared to show rainfall intensities at those locations for durations up to 12 hours. As with the depth-area-duration analysis, the rainfall intensities during 16 to 18 June 1972 are again not particularly significant in comparison with either the record amounts or the probable maximum.

The maximum rainfall for the three days at 15-minute, 30-minute and 60-minute intervals are shown in Figures 12(a-c), 13(a-c) and 14(a-c) respectively. Both Day 1 and Day 3 show maxima over Hong Kong Island where a number of landslips occurred on those days. Day 3 also shows how the maximum area over Hong Kong Island extended through Sau Mau Ping to the south of Tate's Cairn. On Day 2, the areas of short-period maximum rainfall were quite isolated although the actual values of the amounts are comparable with the other two days.

Four Jardi rate-of-rainfall recorders are installed in Hong Kong at the Royal Observatory, King's Park, Kai Tak and Tate's Cairn. The maximum rates measured over a 15-second period are listed in Table 9 for each of the three days. The extreme maximum instantaneous rate-of-rainfall during this three-day period was 301 mm/h recorded at the Royal Observatory. This figure has a return period of just over 5 years (see Table 7.3 in Bell and Chin, 1968) and is well below the record maximum of 513 mm/h which was recorded at Tate's Cairn Weather Radar Station on 17 August 1971 during the passage of typhoon Rose. Maximum instantaneous rainfall can also be estimated from the radar display. Plate 1(a) is the radar display at 8.25 p.m. on 18 June. Plate 1(b) shows the same display attenuated 45.7 db which, using the standard relationship $Z = 200\ R^{1.6}$, is equivalent to 250 mm/hr. This agrees with the rates recorded by the Jardi listed in Table 9.

(d) Comparison with June 1966 rainstorm

A comparison of the severe rainstorm of 12 June 1966 and the very heavy rains which occurred from 16 to 18 June 1972 is made in section 3(e) using synoptic reasoning. Here, a brief comparison is made on a hydrometeorological and engineering basis.

The two severe rainstorm events differ in the fact that the June 1966 occasion lasted about 18 hours and included some record amounts of rainfall while the June 1972 occasion took place over a three-day period and no shorter period records were broken. The two events were similar primarily in their result, i.e., they both produced extensive landslips, flooding, destruction of property and loss of life.

A brief digression into the probable cause of these landslips from the view point of rainfall might illustrate further the similarities of these two occasions. The rate of infiltration of water through soil is governed by a number of factors such as the voids ratio, the degree of saturation, the drainage, the soil type and the integrity of the underlying rocks. In general it takes several days or even weeks for the soil to become saturated to a significant depth. Once it has become saturated a violent rainstorm over a comparatively short period can cause a sudden build up of pressure behind a slope and may trigger a lansdslip. In both 1966 and in 1972 this mechanism seems to have applied as the soil must have been almost saturated before the major rainstorm.

During the two-week period before 12 June 1966 there was rain everyday and a total of 383.4 mm. The 382.6 mm additional rainfall on the 12th was enough to cause extensive landslides. Although the two-week period before 16 June 1972 had less rainfall on fewer days (141.6 mm over 8 days) than in 1966, the very heavy rainfall over the three days reached a total of 652.3 mm with the major landslips occurring on the third day. In addition, the rainfall in May 1972 was more than twice the normal amount (654.5 mm compared with 289.3 mm normal) thereby increasing the possibility of fairly rapid soil saturation.

More details of other factors contributing to the various landslides in 1972 can be found in references 11, 12 and 15.

In the more general sense, the rainfall maps for south China show that Hong Kong had the greatest amounts of rain during both occasions but that the rainfall was generally heavy all along the coast with the maximum areas running parallel to it. Locally, Hong Kong Island received the highest amounts with the values higher for 1966 than 1972. Table 10 shows that the maximum rainfall intensities at the Royal Observatory for durations less than three days were all higher in 1966 than in 1972.

(e) Effects of heavy rainfall in Hong Kong

The topography of Hong Kong is fairly mountainous with many high-rise buildings as well as the make-shift huts of squatters located on the mountain sides. The developed areas have numerous places where the mountain slopes have been restrained or reinforced. Occasions of heavy rain in Hong Kong usually cause some landslips to occur and, because the area is densely populated, the damage to property and loss of life can be considerable.

During the rainstorms of 16-18 June 1972, 148 people were killed and 56 were injured. Altogether forty buildings collapsed and 2750 wooden huts or stone cottages were destroyed or damaged. There were reports of flooding at 53 low-lying areas and residents were evacuated from many of them. The rainstorms also caused widespread damage to market garden crops. Damage to public works included washouts and collapsed road surfaces with repair costs of about HK$48 232 800.

Loss of life was reported at the following locations with the collapse of an embankment at Sau Mau Ping claiming 71 lives and a landslide and multiple house collapse at Po Shan Road claiming 55 lives :

(a) Sam Ka Tsuen (Kwun Tong, Kowloon)

(b) Kam Mun New Village (Sham Shui Po, Kowloon)

(c) To Yuen Tung (Tai Po, New Territories)

(d) Waterfront near Wong Shiu Chi Middle School (Tai Po, New Territories)

(e) Waterfront between Yuen Chau Tsai and Tai Po Kau (Tai Po, New Territories)

(f) Fung Yuen (Tai Po, New Territories)

(g) Belcher's Street (Western District, Hong Kong)

(h) Bullock Lane (Wan Chai, Hong Kong)

(i) Chai Wan (Hong Kong)

(j) Shau Kei Wan (Hong Kong)

(k) Shiu Fai Terrace (Wanchai, Hong Kong)

(l) Ap Lei Chau (Aberdeen, Hong Kong)

(m) Po Shan Road (Hong Kong)

(n) Sau Mau Ping (Kwun Tong, Kowloon)

As mentioned previously, the disasters at Sau Mau Ping (KV 143709 on the Universal Transverse Mercator Grid) and Po Shan Road (KV 052668 on the U.T.M. Grid) have been investigated in considerable detail by the Commission of Enquiry. The first occurred around 1.00 p.m. on 18 June 1972 during a particularly heavy downpour (see Figure 1). The latter happened around 9:00 p.m. the same evening although minor landslips took place in the area at times during the day.

No rainfall stations were located at these two disaster sites and, although a non-recording gauge was located at the Kwun Tong District Branch Office (quite near to Sau Mau Ping), observations there were made only once a day at 4:00 p.m. No meaningful analysis of short-term rainfall intensities can be computed from such records. However, hourly rainfall values over these two disaster sites have been estimated by interpolation from several selected rainfall stations' mass curves and the resultant figures compared with the isohyetal maps for all of Hong Kong. The movement of rain echoes was calculated from radar pictures and has also been taken into account. Figures 15 and 16 show the results. Table 11(a and b) contains the hourly rainfall amounts as obtained from the estimated mass curves. Basically the heavy rainfall around the time of the landslip at Sau Mau Ping is evident in Table 11(a) while the same maximum hourly rainfall for the day is shown at Po Shan Road. The rainfall around the time of the major landslip at Po Shan Road was relatively light, but, after complete soil saturation, a large amount of additional rainfall is not necessary to trigger a landslip.

Two photographs illustrate the effects of heavy rainfall in Hong Kong. Plate 2 shows the Sau Mau Ping landslip. The main cause of the loss of life at Sau Mau Ping was the mud avalanche which suddenly came down to completely bury all the squatter huts over an area of 11,000 square metres. Plate 3 shows some of the damage at Po Shan Road. Other photos are available in the Interim and Final Reports of the Commission of Inquiry.

3. SYNOPTIC ANALYSIS

(a) Climatology of June

In Hong Kong, summer conditions are normally well-established by June with no further outbreaks of the northerly or northeasterly monsoon. During June and early July the sun passes north of Hong Kong coincident with the northward passage of the upper-tropospheric sub-tropical ridge and the activation of the Mei-yu (or Baiu) front over south China. The displacement of the mean 200-mbar ridge from May to July can best be seen in Chin and Lai (1974). The predominant surface synoptic patterns, as described by Heywood (1953) and Bell (1969), which produce rainfall in Hong Kong during June are the "S" (southwest monsoon), "T" (trough near Hong Kong), "E" (easterly flow) and "C" (tropical cyclone). The "E" type reaches a minimum percentage frequency of occurrence during the June (Bell, 1969) and is usually a transitional pattern between the "S", "T" or "C" patterns. The "C" pattern occurs on the average between 2-3 times during June (Chin, 1973) and does not often cause daily rainfall above 50 mm.

The "S" and "T" types together account for about 77 % of the synoptic situations in June with the "T" being the more persistent and wetter. The "T" pattern is most frequent in June (as compared with other months) while the "S" pattern shows comparatively low occurrence and persistence (Bell, 1969). Around 78 % of the "S" and "T" days have precipitation with about 18 % of these having heavy rain 0.30" or 7.6 mm per day as defined by Heywood (1953). On his definition, heavy rain occurs on an average on about 10 days in June. Upon examining a 12-year record (1965 to 1976) the average number of days with rainfall of 50 mm or more was found to be about 3 days. The terminology in this paper will therefore be that a moderate rain day occurs when between 20.0 and 49.9 mm of rainfall is recorded at the Royal Observatory with heavy rain defined as 50.0 to 99.9 mm and very heavy rain as 100 mm or more. A 12-year (again 1965 to 1976) analysis of rainfall figures show that from April to September, the month of June has the most moderate, heavy and very heavy rain days. Also, the analysis shows that thunderstorms occurred on over 85 % (30 out of 35) of the days when heavy or very heavy rain fell during the month of June. The analysis of thunderstorms over this period shows that, on average, about 8 to 9 days in June have thunderstorms with about one-third of these being accompanied by either heavy or very heavy rain (which corresponds well with the previous figures). Thus, it can be said that a situation which favours thunderstorm development in Hong Kong is a necessary condition for heavy rain.

As shown in Figures 14 and 15 of the paper by Bell (1969), there is a distinct morning maximum of radar echoes in the vicinity of Hong Kong during southwest monsoon conditions. This corresponds well with Figure 17 here which shows a statistically significant (at 95 % signficance level) morning maximum (and evening minimum) of hourly rainfall amounts during the period 1965 to 1976 for the month of June under all synoptic conditions.

Very heavy rainfall in June is normally associated with surface troughs of low pressure in the vicinity of Hong Kong which have been activated by upper-air disturbances. These upper-air disturbances are usually in the form of vortices moving along a trough with a distinct low-level (usually 700 mbar) jet which often extends several hundred kilometres behind the moving vortices. These upper-air disturbances are not evident in the mean charts which are discussed in this section, but they are shown in analyses of other very heavy rain occasions (Chen, 1969 and Lam, 1975) and will be discussed later.

The upper-air circulation changes abruptly during late May and early June. The monthly mean upper wind circulations for the year over Southeast Asia can be found in Chin and Lai (1974). Basically, the winter to summer transition is illustrated in the mean patterns for May, June and July. The sub-tropical ridge at 200 and 300-mbar level moves from below 20°N in May to around 30°N in July. During the same period, the jet at 500-mbar level to the south of the Himalayas can no longer be thermally sustained. As it suddently collapses (Dao, et al. 1958), the southwest monsoon circulation over India develops and the sub-tropical Pacific ridge moves northward and westward and eventually stretches across central China in July. At 700 mbar, the westerly flow near the southeastern edge of the Himalayas in May weakens after the jet at 500 mbar disappears and because of the topography, a vortex appears along the trough line which can be seen at both the 500-mbar and 700-mbar levels. The interplay between the Pacific ridge and the lee side trough at 500 mbar during June results in activating this vortex at times and its subsequent movement across south China.

At the surface, polar fronts begin to lose their frontal characteristics as they move southwards across China during May. Their southward penetration is usually limited to the area of the coast of south China during June when they linger for days or sometimes weeks (Bell, 1969) as troughs commonly referred in the literature as Mei-Yu troughs (Dao, et al, 1958; Zou, et al 1964; Hsu, 1965; Ramage, 1971) or Baiu troughs (Matsumoto, et al, 1970 and 1971).

The northward advancement of the Mei-Yu troughs and upper subtropical ridge is not smooth over the three-month period, but occurs in a series (of about three) distinct moves separated by relatively long periods of stagnation. The duration of the Mei-Yu over south China (Nanling Ranges), central China (Yangtse valley) or north China (Shantung Province area) often determines whether these areas experience floods or droughts (Hsu, 1965). During the Mei-Yu period in south China, the weather conditions, particularly rainfall, are closely related to developments at higher latitudes.

Chin conducted a study in 1973 showing the association of rain with surface troughs (as analyzed on the 1800 GMT daily weather charts of the Royal Observatory) covering the month of June from 1963 to 1972. Table 12 shows that on the average, about four troughs per year are near Hong Kong with three troughs passing through Hong Kong during June: two of which move from north to south, the other from south to north with the former having about 10 % chance of being part of a double passage while the latter has about 50 % chance (note the small sample size). For these ten years of study, the total number of rain days was 210 and on only 49 of those days was there no trough near Hong Kong and of those 49 days 86 % had less than 10 mm of rain. Therefore, it can be concluded that apart from tropical cyclones, heavy rain or very heavy rain is unlikely without a surface trough near Hong Kong.

(b) Synoptic Patterns of 16 and 17 June 1972

The synoptic pattern on 16 June 1972 can be seen in Figures 18-22 for the surface, 850-mbar, 700-mbar, 500-mbar and 200-mbar levels. The hourly rainfall figures for 16, 17 and 18 June (Day 1 to Day 3) show that most of the rainfall on each of the three days occurred within four to five hours of 0000 GMT and very little occurred around 1200 GMT. It is neteworthy that sequences or combinations of synoptic situations which individually cause unusual weather, may together break meteorological records and cause severe consequences.

On 15 June 1972, the weather in Hong Kong was already marked by rain-showers and thunderstorms, but the accumulated rainfall during the day was only 24.9 mm at the Royal Observatory. The surface trough was around 25°N and the heavier rain showers associated with it were still well north of Hong Kong. The surface low over China was around 24°N, 109.5°E at 0000 GMT and as a double low with the moving portion at 24°N, 112°E at 1200 GMT. The area of associated thunderstorms and heavy rain-showers moved eastward towards Hong Kong along with the moving vortex (approximate speed: 12 knots). The 850-mbar, 700-mbar and 500-mbar levels all showed the vortex at the same longitude with a slight tilt in the vertical towards the north. The low-level jet associated with this vortex at 700 mbar and 850 mbar was south to southeast of the vortex centre, but still to the west of Hong Kong. At 200 mbar, the sub-tropical ridge was fairly broad just to the immediate south of Hong Kong. The positive vorticity advection with the moving vortex along with the presence of outflow at 200 mbar provided the mechanism for some rain showers and thunderstorms on 15 June. Of interest both at 500-mbar and 200-mbar levels was a vortex located in the Pacific to the east of the southern Philippines. This vortex which moved westwards caused a narrowing of the sub-tropical ridge at both these levels although at different latitudes.

On June 16 the moving low pressure area continued its steady progression to the east and then east-northeast with the area of severe weather continuing to advance along with it. Conditions on 16/1200 GMT fitted the criteria (Bell, 1969) for very heavy rainfall in Hong Kong over the next 24 to 36 hours (i.e. a low near Liuchow and a trough within 60 nautical miles of Hong Kong) and were used successfully for forecasting the rainfall on Day 2.

Figures 19 to 22 show the 850-mbar, 700-mbar, 500-mbar, and 200-mbar charts at this time. The moving vortex had lost most of its northward tilt and had reached its maximum intensity as shown by the 500-mbar vorticity pattern (Figure 23). The low-level outflow areas north of 30°N over China helped to keep the moving low from moving northward and acted to increase the cyclonic curvature in the streamlines. Also, the low-level jet (core of maximum winds) increased in strength and extent as the vortex increased in intensity and the gradient tightened between the advancing vortex and the sub-tropical ridge (which was also being affected by the vortex in the Pacific as it continued its westward movement). At 200-mbar, the outflow area had narrowed between the mid-latitude long-wave (and almost stationary) trough and tropical vortex. The narrowing of the upper-ridge resulted in increased ventilation over the area as strong winds (above 15 to 20 kn) with almost opposite directions occurred within a small area. The presence of all these factors contributed to producing the area of moderate to heavy thunderstorm activity over the coastal areas of southeast China including Hong Kong on 16 June. The heavy thunderstorms in Hong Kong occurred around 0000 GMT when the vorticity maximum was just to the north. The satellite photo for the morning of Day 1 showed not only the area of weather near the vortex, but also another developing area near Liuchow in China.

Figure 24 shows the 500-mbar vorticity pattern at 0000 GMT on day 2. The moving low continued to move east-northeastwards across China and into the East China Sea. The vortex lost some of its vertical extent and was difficult to identify at the 500-mbar level. Similarly, the area of cloud cover associated with the vortex was less widespread.

A trough could still be clearly seen on the satellite photograph and identified on the surface, 850-mbar, 700-mbar and 500-mbar charts, sloping towards the north from south China. However, the trough now lacked distinct thermal support (becoming non-frontal in character) although earlier there had been some frontal characteristics. The strong directional shear across the trough was maintained by the low-level jet which stretched behind the moving vortex in the East China Sea. The jet parallelled the coast of south China long enough following the passage of vortex to cause thunderstorms over Hong Kong especially around 0000 GMT.

Many studies have been made showing the effect of the low-level jets under favourable conditions in the vertical, especially with moderate to strong outflow in the upper troposphere. For Hong Kong, these include the studies of Chen (1966),and Lam (1975). Browning and Pardoe (1973) studied the line convection associated with mid-latitude jets at low levels in advance of cold fronts over Great Britain. Their model for the vertical flow in the vicinity of this jet (up to 30 ms^{-1}) is reproduced in Fig. 26. Of special significance is the strong but relatively narrow area of ascending motion within 50 km of the jet core on the cyclonic side. Matsumoto et al (1970, 1971) noted the extremely dry areas to the right and below the low level jet which Browning and Pardoe's model also describes. The primary differences suggested in studies by Matsumoto et al (1970 and 1971) of the low-level jet associated with the Baiu front near Japan is that conditions in Asia occur where the low-level flow is rather deep and strongly convective with a jet core as high as 3 km. Situations where Hong Kong lay on the cyclonic side of the jet have produced heavy rains before (Chen 1966 and Lam 1975) when either the jet developed along the coast or moved into the vicinity of Hong Kong in association with a moving disturbance.

The jet over the coast of south China on Day 2 seemed to be maintained by the convergence of flow from China, Indochina and the South China Sea into this one area. The existence of the jet at such a distance behind the moving vortex could only be sustained for about 24 hours before weakening.

Other factors should be noted on Day 2. A separate area of positive vorticity developed behind the one with the moving vortex (shown near Hong Kong on Day 2 in Fig. 24). This area has continuity from Day 1 as the satellite photographs illustrated. It is likely that this moving vorticity area was sustained by the presence of the low level jet and the cyclonic shear zone.

The tropical vortex over the southern Philippines kept the 200-mbar ridge narrow in the vicinity of Hong Kong and helped to push the subtropical ridge at 500-mbar towards the north in the South China Sea area.

(c) Synoptic Pattern for 18 June 1972

The moving vortex and the associated low-level jet (now both much less intense) were affecting the weather in Japan on the morning of Day 3. Over south China, a surface trough was still identifiable just to the north of Hong Kong on the 0000 GMT analysis. Not so easily identified on the surface charts was a developing trough over the South China Sea to the south of Hong Kong near Pratas Island (Dongshadao, 20.7°N 116.8°E). The primary indicator was the wind at Pratas Island which was southeasterly at 0000 GMT but shifted to southerly as early as 0600 GMT. Both the 0600 GMT and the 1200 GMT analyses began to show a surface trough over the northern part of the South China Sea just off the coast of south China moving northwards. Even though the analyzed surface trough did not move through Hong Kong until about 1400 GMT, the heaviest rainfall occurred around 0400 GMT. This is consistent with Bell's findings in 1969 that the heaviest rainfall in Hong Kong during May and June often occurs when the surface trough is about 1° latitude south of the coast.

The upper-air charts for 0000 GMT on Day 3 showed that at 850-mbar, the main trough lies from southwest China to the East China Sea. With a tilt towards the north, this same trough can be seen at 700-mbar and then only faintly at 500-mbar in the vicinity of the low pressure area around 27°N 103°E. An area of showers and thunderstorms began to develop in the vicinity of this vortex over southwest China although these were too far west to affect Hong Kong. The cause of the very heavy rainfall in Hong Kong (and elsewhere along the south China coast and inland as it moved northward) was the developing trough at 500-mbar which could later be identified on the surface charts. Identification of this trough required careful analysis of the winds at 500-mbar along the coast of south China at 0000 GMT. At 500-mbar, a shortwave trough formed in association with the developing vortex over Indochina and was advected northwards by the strong southwesterly flow at lower levels in the atmosphere as shown on the 850-mbar and 700-mbar charts. After the trough moved northwards (19 June), the 500-mbar sub-tropical ridge became reestablished over the coast of south China. At 200-mbar, the outflow in the vicinity of Hong Kong continued with the axis of the ridge about 2 degrees south of the coast. Interestingly, later charts showed the 200-mbar ridge advancing northwards together with the active weather area.

It is not an uncommon event for a mid-tropospheric triggering mechanism to activate an area of weather in the presence of positive vorticity and adequate moisture supply (in this case from the two previous days of convective activity). Nor is it unusual that the triggering mechanism (in the form of a shortwave trough) be evident only in the mid-troposphere and at the surface but not at levels in between. The surface trough is often phenomenologically induced (i.e. caused by the particular weather phenomena produced by the triggering mechanism) and thus, in a sense, it follows the movement of the triggering mechanism. On 18 June, this involved an increased amount of organized, near-ground convergence in the vicinity of the main area of thunderstorm activity and changes in surface pressure associated with vertical motions and precipitation.

The 500-mbar vorticity pattern (Figure 25) shows the main area of activity was located near the low pressure area around southern Japan but, with a continued broad area of vorticity maximum over south to southwest China and Indochina. This area had the potential for some thunderstorm development which was begun by the 500-mbar triggering mechanism producing heavy rain.

The satellite photograph for 18 June showed widespread development of cumulonimbus activity both over extreme southwest China and over the coast of south China near Hong Kong. The sequence of satellite photographs from 15 to 18 June showed the changes which occurred as the rapidly moving vortex moved across south China towards the East China Sea and Japan leaving a clearly defined line of activity on the 17th which then weakened in the East China Sea but remained active near southwest China where other vortices and a shortwave trough were forming.

(d) Upper-air Statistics

The analyses presented in this section give a vertical or time cross-section of the basic data already shown in the upper-air (horizontal) charts of the preceding sections. Most of the features illustrated here have been discussed previously but become clearer when viewed from the different perspective. Thunderstorm occurrences have already been shown to be a necessary condition for heavy or very heavy rain in Hong Kong. Several factors associated with severe storm development in the USA (Miller, 1967) will be investigated here including the low-level jet, low-level moisture, instability or convective instability, strong vertical motion, direction or velocity cyclonic shear and a triggering mechanism.

(i) Royal Observatory time cross-section

Figure 27 is the Royal Observatory time cross-section for 0000 GMT 15 June 1972 to 0000 GMT 19 June 1972. Among the many features displayed on the time cross-section, the most significant are the upper winds over Hong Kong. From 0600 GMT on 15 June to 0600 GMT on 17 June, a low-level core of strong winds (above 30 kn) persists with the maximum (above 40 kn) occurring around 700 mbar at 0600 GMT on 16 June. This area of strong winds gradually diminishes in strength and extent as well as altitude after reaching its maximum. The low-level core of strong winds again is evident around 850 mbar at 0600 GMT on 18 June 1972. A quick temporal correlation between wind speed and precipitation might suggest that the presence of precipitation enhances low-level wind strengths. However, Figure 26 shows and Matsumoto and others (1970) have suggested that the actual low-level jet core and the area of maximum precipitation do not coincide. Therefore, by adding the knowledge of a northward moving jet core (at least on 18 June), it would be logical for upper-wind speeds to show an increase following heavy precipitation. One must be careful when making "one-dimensional" correlation studies. It is clear, however, that both visually and physically (as explained earlier) a strong relationship exists between the low-level jet and heavy or very heavy rainfall.

The aforementioned passage through Hong Kong of a perturbation (analyzed as a northward-moving trough on the 500-mbar chart) becomes clearer when examining the wind directions between 4 to 7 km from 0600 GMT on 17 June to 1800 GMT on 18 June. Interestingly, the period during which the winds were northeast to southeasterly (perturbation to south of Hong Kong) was the time when the weather as shown on the plotted station circles improved substantially during the three-day rainfall occasion. The apparent southward movement of a 500-mbar minor vortex through Hong Kong no doubt helped to cause the formation of a trough at that level which returned through Hong Kong and the rest of south China the following day causing widespread showers and thunderstorms. The veering of the 500-mbar winds was reflected in the similar movement of the thermal winds.

Also of interest is the variability in speed and direction of the 9 to 12 km winds. This will be seen again in an analysis of the 200-mbar wind speeds during June 1972.

The surface winds were generally southwesterly during 15 to 17 June with variations attributable to the presence of thunderstorms in the area (i.e. mesoscale variations in winds usually caused by thunderstorm gust fronts). However, although generally not above 5 km, the winds on 18 June were persistantly from the east to southeast. They veered between 1500 GMT and 2100 GMT which was the time a surface trough was analyzed to have passed from south to north through Hong Kong.

No significant change in surface pressure (corrected for diurnal variation) was observed during the trough passage around 1800 GMT on the 18th. In fact, throughout the period from 15 to 19 June, the surface pressure showed a slow, but steady rise. Obviously other factors (including perhaps global-scale pressure changes) were affecting the surface pressure in the area of Hong Kong during this period.

(ii) Upper-winds over Hong Kong

Figure 28 shows the temporal variation in the low-level winds over Hong Kong from 0600 GMT 16 June to 0600 GMT 18 June. (The 0600 GMT winds were selected because the 0000 GMT upper-winds on 18 June were lost due to instrument failure). The winds were plotted for absolute velocity only and not given as u and v components of the wind for two reasons : (1) the low-level winds were all predominantly southwesterly and (2) the absolute intensity of the low-level wind maximum is the important factor in its influence on vertical motion and not its orientation. The changes in the height, depth and intensity of the low-level wind maxima from day to day is worthy of further study in other very heavy rain occasions. One would suspect that any height or depth of the jet core would still give the strong vertical motion on its cyclonic side with the strength the lift proportional to the intensity of the jet and the horizontal directional or velocity shear.

Figure 29 shows the westerly wind component at 200 mbar over Hong Kong for June 1972. Bell (1969) and Chin (1973) proposed that the changeover period from westerly to easterly winds in the upper-troposphere over Hong Kong was significant for heavy rain occasions as it is indicative of the nearness of the upper-tropospheric ridge. Although other factors may be overriding, heavy rain can be expected in Hong Kong during those periods when the preceding 5-day mean westerly wind component at 200-mbar is between 0 to 20 kn. When the winds begin to show an easterly component, there is little chance of heavy rain other than rain from tropical cyclones). This concept is supported by the June 1972 very heavy rainfall occasion.

(iii) Temperature and pressure height over Hong Kong

The variations in upper-air temperatures over Hong Kong at 0000 GMT from 10 to 25 June 1972 are shown in Figure 30. Tephigrams showed the lowering of 850 and 700 mbar temperatures from 15 to 17 June increased low-level instability and although the 500-mbar temperature was increasing at same time, the effect of the increase was not enough to stop free convection. The tephigrams also showed that moisture was well-distributed throughout the troposphere either from ongoing or recent deep convection.

Pressure heights at 0000 GMT for the standard pressure levels for the period 10 to 25 June 1972 are shown in Figure 31. A major trough near Hong Kong can be seen throughout the atmosphere from around 15 June to 17 June. The re-establishing ridge in the lower troposphere followed the trough over Hong Kong with only a slight perturbation in the rise of the 500-mbar surface between 18 and 19 June which was an indication of the presence of the short wave trough at that level over Hong Kong.

(iv) Dewpoint depressions and water vapour flux

The variation of the dewpoint depression over Hong Kong from 10 to 25 June is seen in Figure 32. The rainy period from 10 to 12 June and the very heavy rainfall occasion from 16 to 18 June show good moisture distribution in the lower- and mid-troposphere. The latter occasion had considerable moisture even into the upper-troposphere, indicating the extent of deep convection. The dry area around 700 mbar at 1200 GMT on 17 June coincided nicely with the breaking up of lower-level clouds in Hong Kong and also can be viewed as an indication of the difference in the synoptic situations between Days 1 and 2 and Day 3.

Table 13 presents values of mean water vapour flux at four standard levels of the atmosphere for Day 1 to Day 3. On all three days, the primary level of water vapour flux was at 850 mbar. The unavailability of wind data for the 0000 GMT sounding on 18 June makes the calculation for that day not quite as representative as for the other two days.

(v) Upper-air diveregence in the vicinity of Hong Kong

Table 14 shows the results of estimating the degree of diveregence over south China for Day 1 to Day 3. The stations used were 45004, 57993, 58847 and 59431. Besides the usual inaccuracies involved with such calculations (i.e. using orders of magnitude of larger wind components containing errors to calculate divergences), additional variations in the calculations occurred because of the large area of coverage, in this case most of south China. Nevertheless, the results show low-level convergence and high-level divergence as would be expected.

(vi) Other calculations

It is felt that air trajectory calculations have little value in the presence of such strong vertical motions. Therefore, these trajectories were not computed.

The Royal Observatory does not presently use any method for calculating stability indices because past experience has shown that the available ones have little forecasting value in the tropics. However, both the Showalter and Wang instability indices were calculated for the 0000 GMT sounding for several days in June 1972 and are presented in Table 15. A visual check of both indices with daily rainfall values shows the variability and general unreliability of these indices although Wang's index is generally better. For Showalter's index, severe thunderstorms are said to be likely at values less than -3.0; for Wang's index, the values should be greater than -100.

(e) Comparison with June 1966 Rainstorms

In section 2, comments concerning the rainfall statistics were made relating the 3-day, very heavy rainfall occasion of June 1972 to the one in June 1966. Comparisons in this subsection will deal with the synoptic conditions and thermodynamic calculations.

The upper-air pattern for 0000 GMT on 12 June 1966 was similar to that at 0000 GMT on 16 June 1972. In the lower levels, an active, moving vortex was embedded in a trough stretching across south China with an outflow area located above 30°N over China and the Yellow Sea. In the upper-troposphere, a narrow ridge was less than 2 degrees south of Hong Kong. The vortex in the 1966 case did not have quite the same depth and organization as on Day 1 of 1972. Just the same, the presence of cyclonic curvature over Hong Kong and the low-level jet just to the south of Hong Kong gives each case increased similarity. The synoptic patterns of Day 2 and Day 3 have different features from Day 1 and are therefore not comparable except in general terms with 12 June 1966.

A few additional points of similarity are worth noting :

1) The day of very heavy rain in June 1966 shows similar temperature changes at 850, 700 and 500 mbars from day to day as the 17 June 1972 case (Figure 30).

2) The mean water vapour flux over Hong Kong is primarily around 850 mbar. For the June 1966 study, the mean values were calculated over a one-month period and thus are, in general, smaller in absolute value.

3) The upper-air sounding taken at 0000 GMT on 11 June 1966 is very similar to the one taken at 0000 GMT on 18 June 1972 while that at 0000 GMT on 12 June 1966 resembles the one at 0000 GMT on 16 June 1972.

4) The Showalter and Wang instability indices show roughly the same result, i.e., lower values for Showalter's index and higher (positive) values for Wang's index during heavy or very heavy rain situations.

5) The 200-mbar westerly wind component for June 1966 is plotted in Figure 33 for comparison with Figure 29. It becomes more evident here that a period of a few days with the 200-mbar westerly wind component less than 20 kn is a more conducive factor in producing a heavy or very heavy rainfall occasion than just a brief period of low wind values (less than 24 hours) just before the wind component becomes easterly (as on 28 June 1966). However, the lessening of rainfall amount in Hong Kong after the 200-mbar winds become easterly (and in the absence of tropical cyclones) is evident.

4. CONCLUSION

(a) Major factors contributing to the 3-day rainfall occasion

The very heavy rainfall occasion spanning 3 days from 16 to 18 June 1972 was caused by a sequence of synoptic patterns, each of which could individually produce very heavy rainfall in Hong Kong if similar conditions recur in isolation. The primary factors for each day were :

<u>Day 1</u> A well-developed vortex moving along the trough from southwest to east China, passing just to the north of Hong Kong. A narrow ridge in the upper troposphere. This situation is very similar to the 12 June 1966 very heavy rainfall occasion (Chen 1969).

<u>Day 2</u> Strong low-level convergence in the vicinity of south China with a distinct low-level jet just south of Hong Kong. Upper troposphere divergence. Day 2 is similar to August 1969 and 1972 rainstorms (Lam 1975).

<u>Day 3</u> Favourable conditions in Hong Kong and across south China for showers and thunderstorms (i.e. low level moisture, low-level jet, conditionally unstable upper-air, outflow aloft, positive vorticity area) with a developing mid-tropospheric trough to act as a triggering mechanism as it passes from south to north through Hong Kong. Ridge to south of Hong Kong at 200 mbar which moved northward with an area of showers and thunderstorms.

During all three days, a surface trough was continuously analyzed around Hong Kong, but this is not considered a primary cause of the very heavy rainfall. The general lack of continuity in the positions of the trough and the sparse data over the northern part of the South China Sea for placing a trough to the south of Hong Kong suggest that the surface trough was difficult to identify and/or broad so that actual weather events determined its position, thus making the surface trough a manifestation of the upper-level synoptic conditions and not a prime cause of the severe weather of the three days.

An upper-level disturbance (seen at 500 and 200 mbar) moved from the Pacific into the central part of the South China Sea and narrowed the ridge at both 500 and 200 mbars. This, coupled with the troughing over China at both levels, helped virtually to eliminate the subsiding effect of the 500 mbar ridge over south China while also narrowing the ridge at 200 mbar over the northern part of the South China Sea and gave increased outflow in the upper-troposphere. The ridge at 500 mbar returned after both the mid-latitude trough and the perturbation over the South China Sea had weakened. It is felt that an overall strengthening of the sub-tropical ridge in the area of the South China Sea is not identificable without knowledge of the dynamics of the atmosphere on the macroscale (at least the eastern part of the northern hemisphere).

Forecasting for Day 1 was aided by knowledge of the June 1966 occasion and by continued close watch on the movement of the synoptic pattern over south China. The weather on Day 2 fitted a pattern suggested by Bell (1969), for rainfall in Hong Kong of more than 200 mm. On day 3 forecasting proved difficult because of the lack of data to the south of Hong Kong and the fact that rapid development was taking place. A list of the thunderstorms and heavy rain warnings issued by the Royal Observatory is given in Table 12.

The individual days did not produce record rainfall intensities in Hong Kong. However, the 3-day cumulative effect produced record amounts of rain. It was also this cumulative effect which caused the landslide disasters in Hong Kong.

(b) Forecasting concepts for heavy rain

The tropical atmosphere almost daily has certain of the necessary conditions for thunderstorm development such as adequate supply of low-level moisture and a conditionally unstable atmosphere aloft. With the addition of surface convergence, some form of vertical motion and weak outflow in the upper troposphere (such as a slightly convergent sea breeze along a hilly coastline), showers and thunderstorms can (and often do) develop daily in the tropics. To produce heavy rainfall from these storms, additional factors must be occurring and these factors provide increased intensity to the basic conditions already mentioned.

For the case of 16 to 18 June 1972, strong positive vorticity advection occurred over south China causing widespread heavy thunderstorm activity during Day 1. Day 2 had strong convergence in the vicinity of Hong Kong coupled with vigorous vertical motion on the cyclonic side of the low level jet. Day 3 had a mid-tropospheric triggering mechanism which produced heavier than normal thunderstorms. All three days experienced a continuous supply of low-level moisture in the southwesterly airstream and moderate to strong outflow around 200 mbar.

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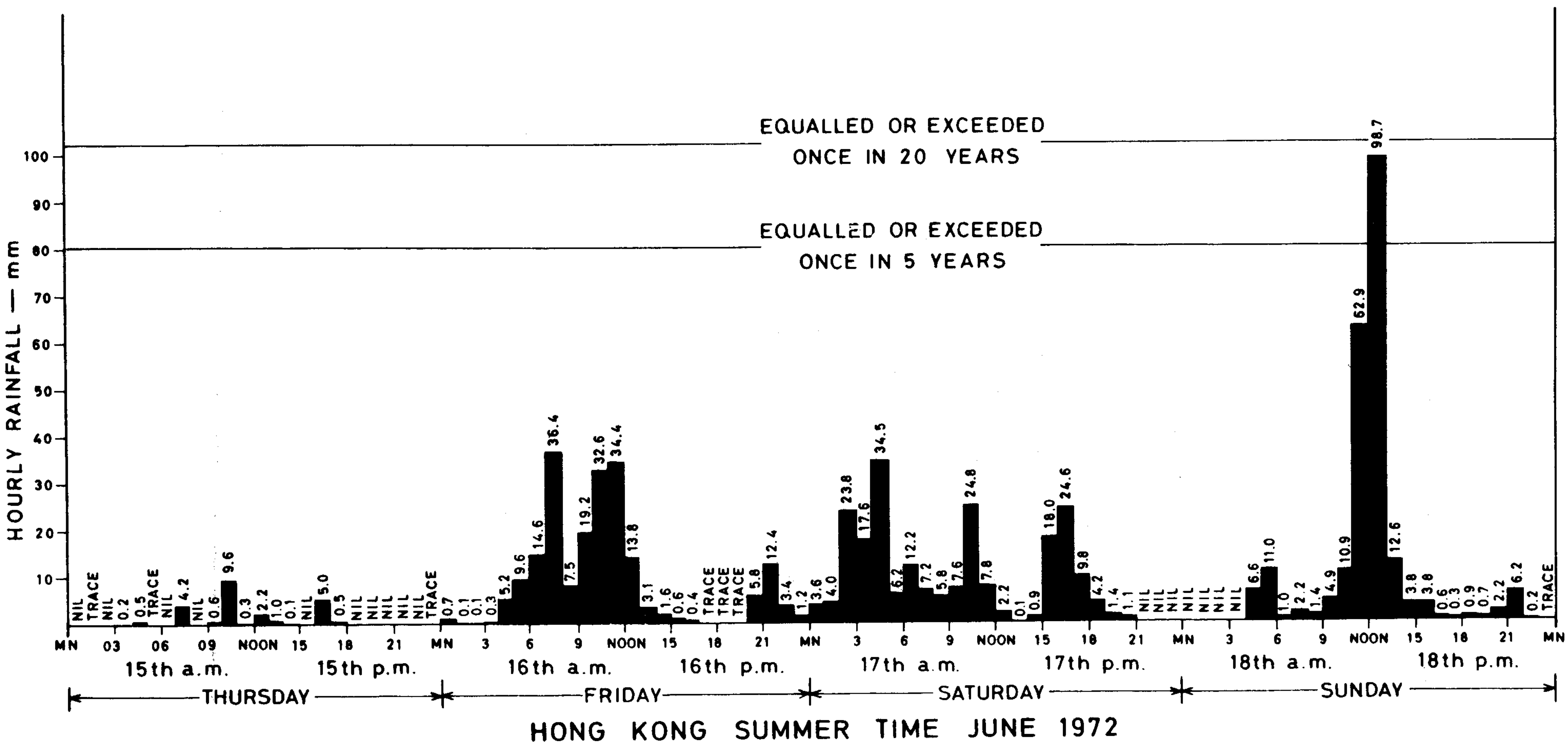


Figure 1 Hourly rainfall amounts from 15 to 18 June 1972 as recorded at at the Royal Observatory, Hong Kong

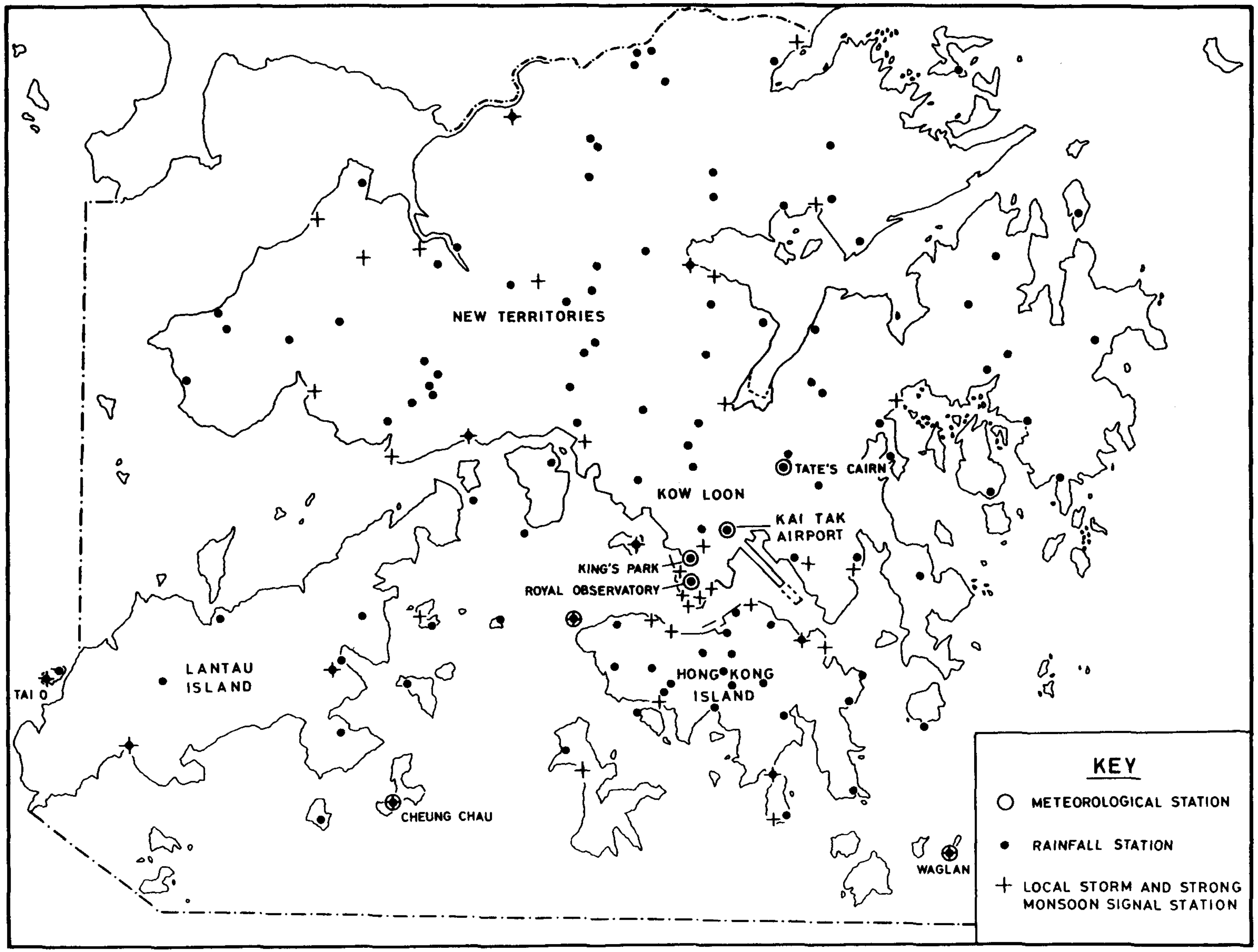


Figure 2 Hydrometeorological rainguage network in Hong Kong

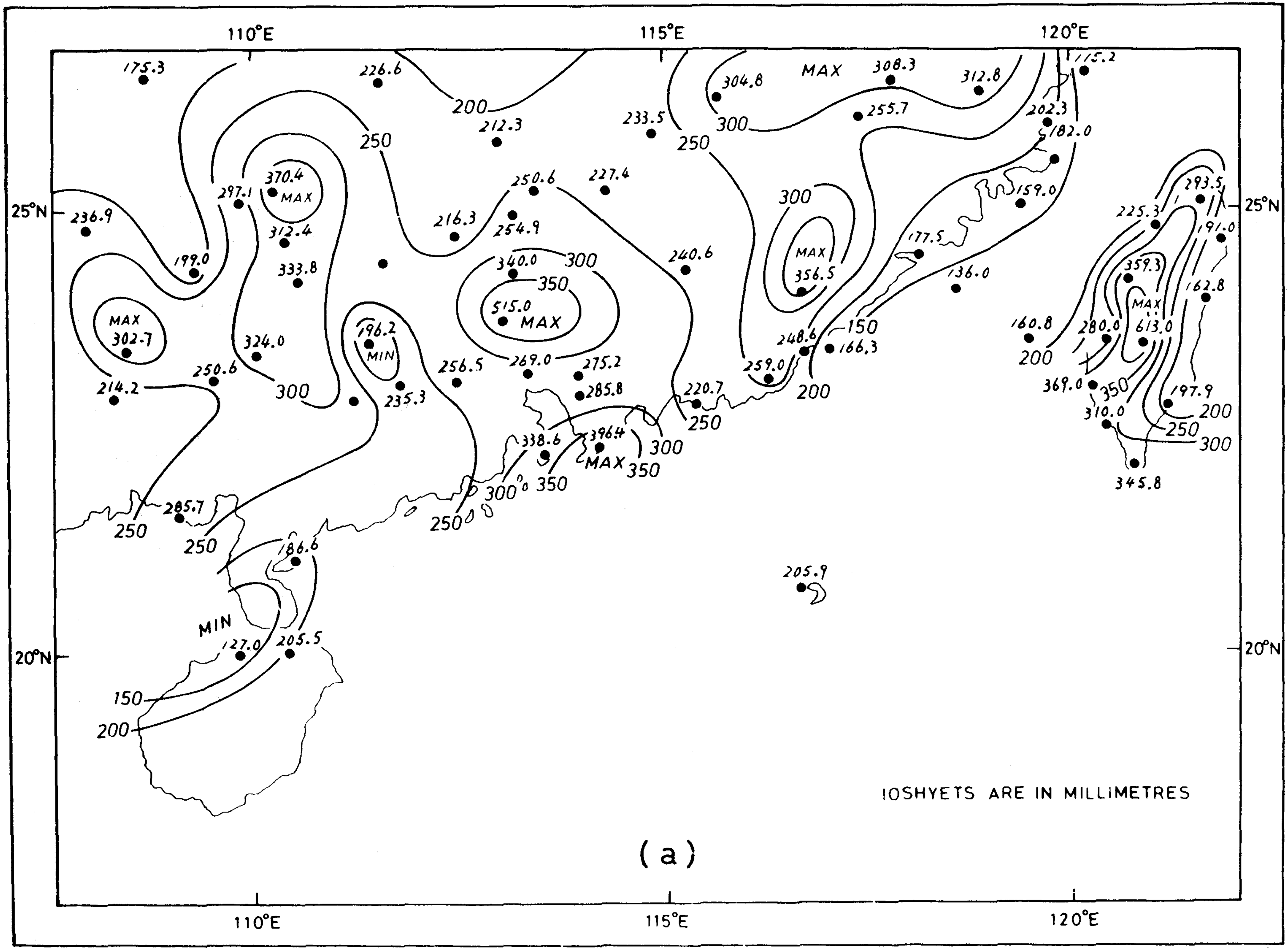


Figure 3 (a) Mean rainfall map over south China for June

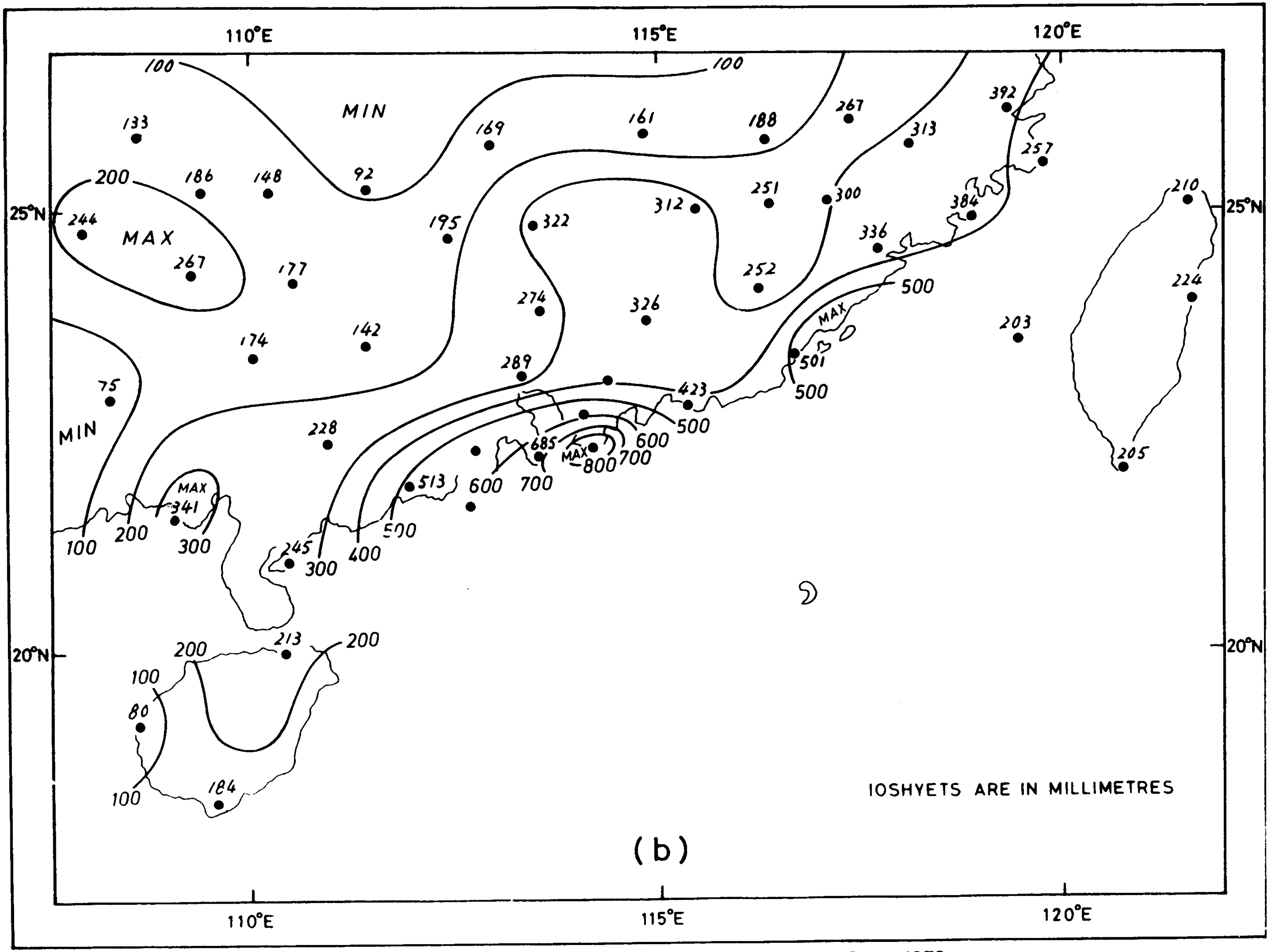


Figure 3 (b) Rainfall map over south China, June 1972

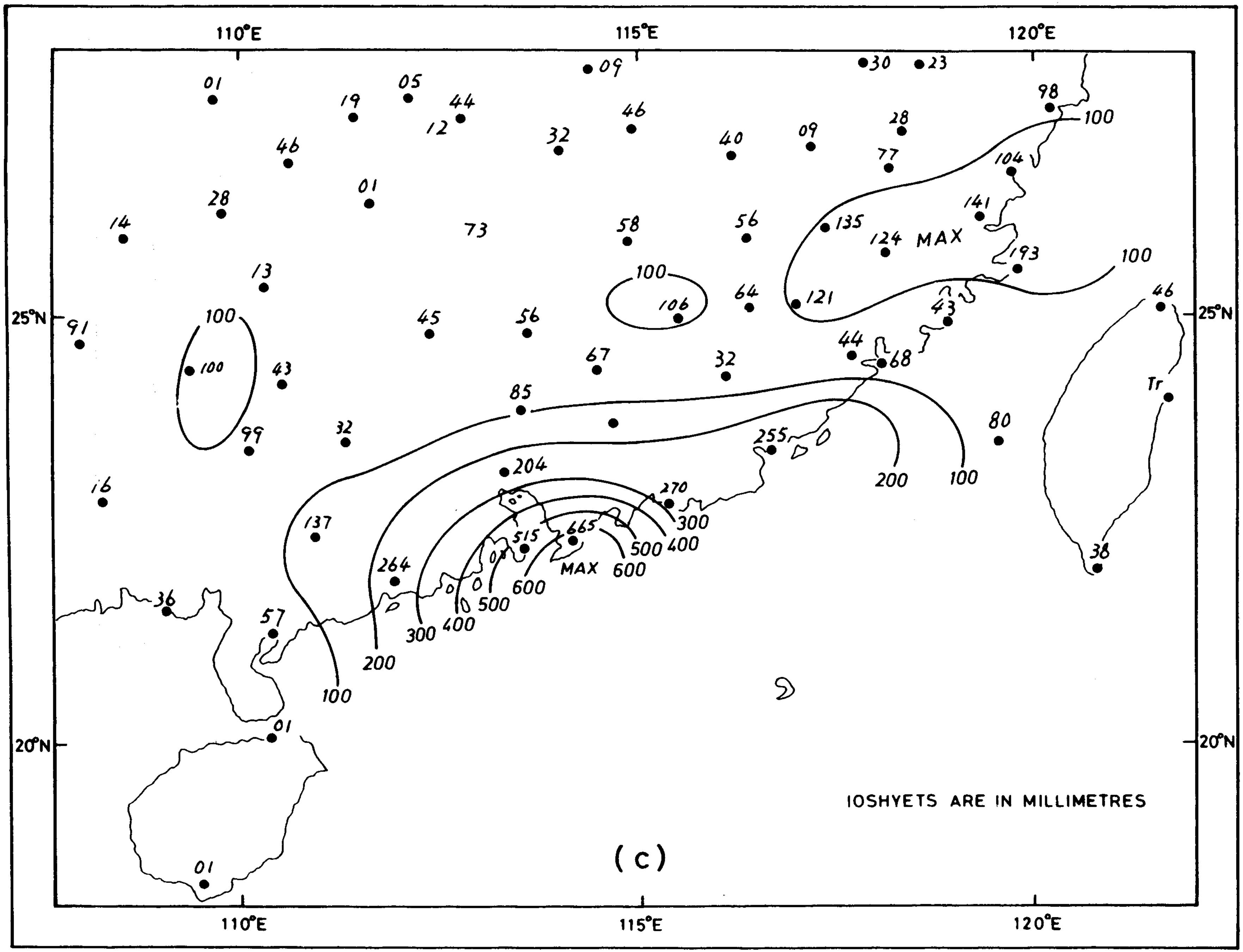


Figure 3 (c) Rainfall map over south China, 15/0000 GMT to 19/0000 GMT June 1972

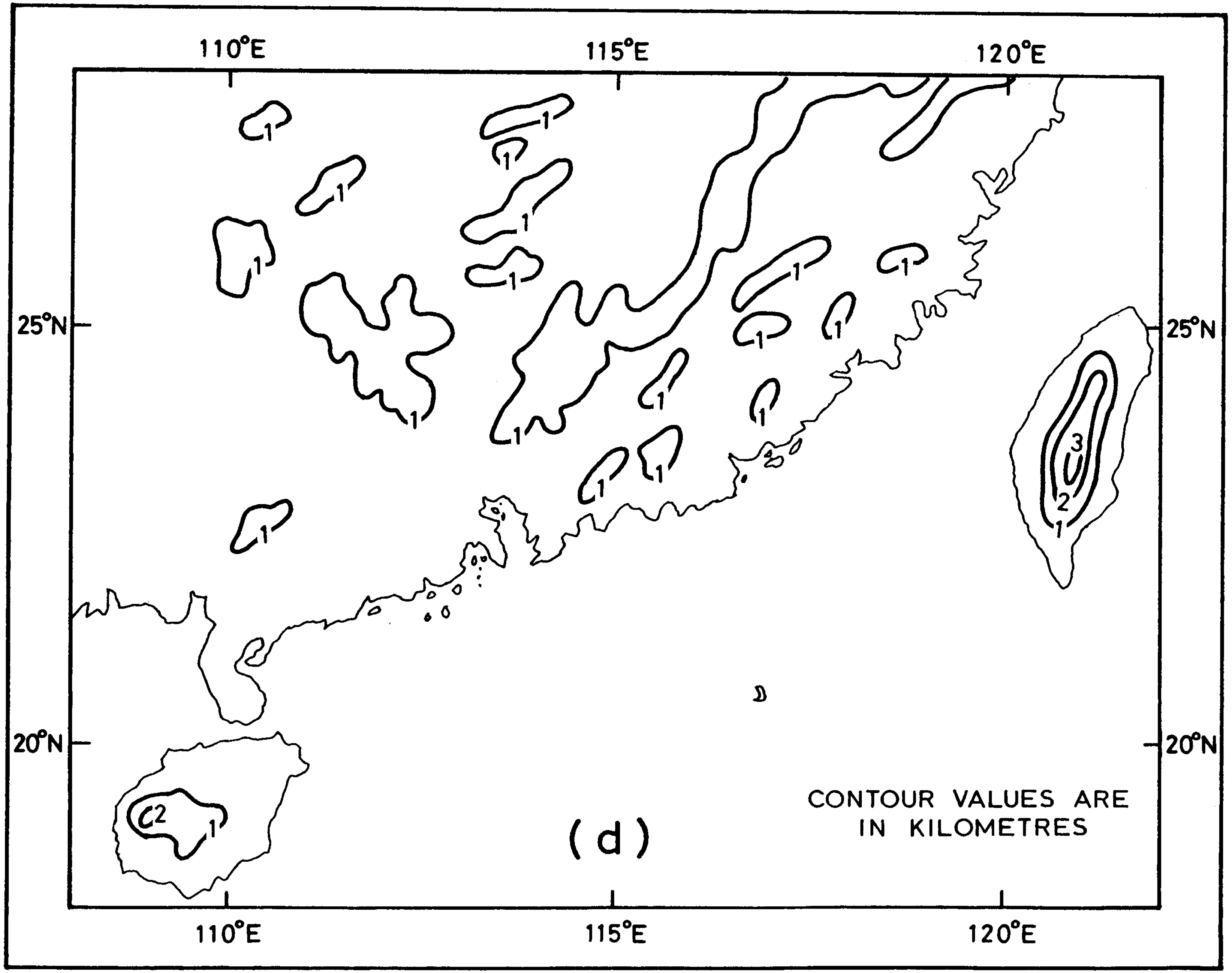


Figure 3 (d) Topographical map of south China

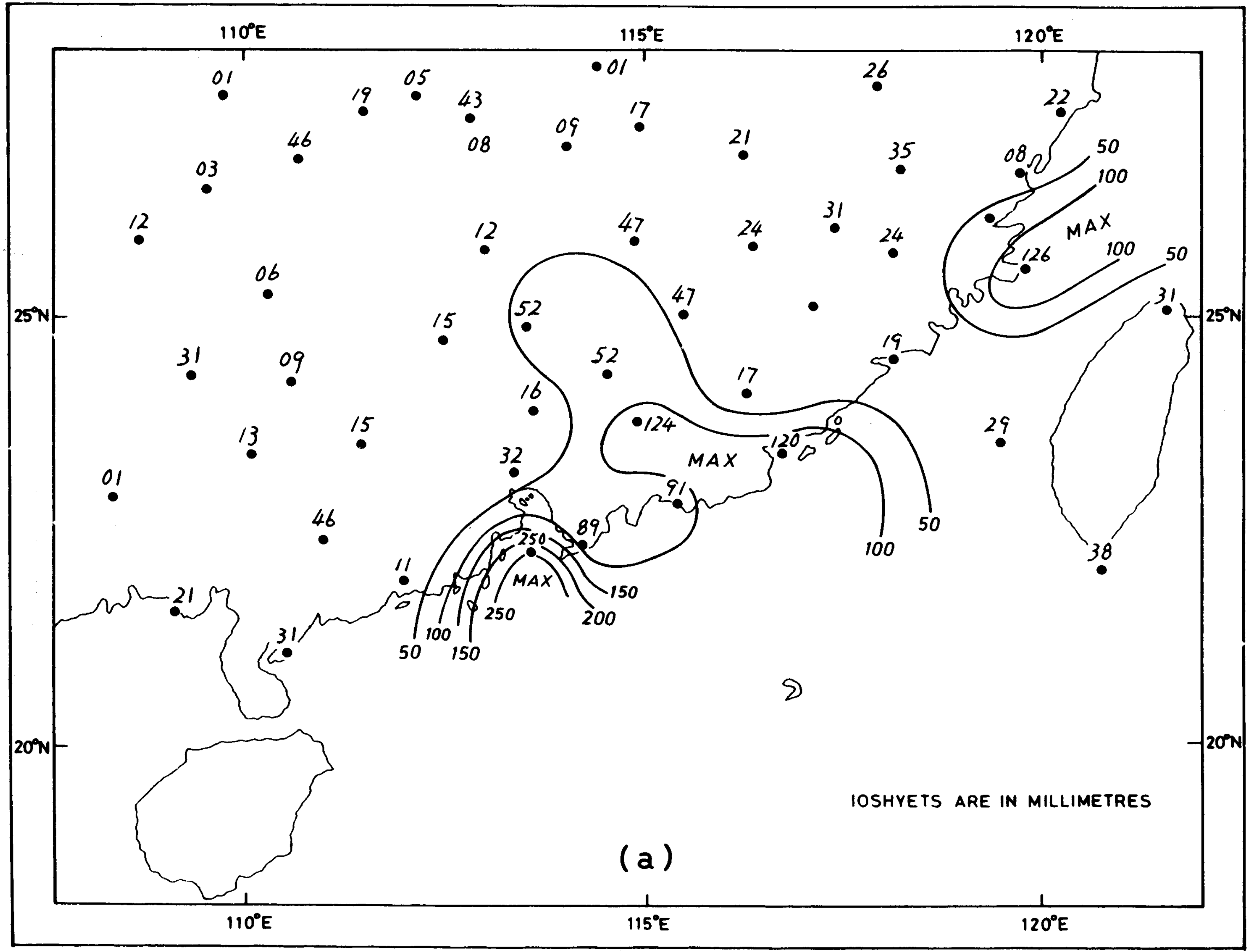


Figure 4 (a) Rainfall distribution over south China in June 1972 for the 24-hour period ending 16/0000 GMT

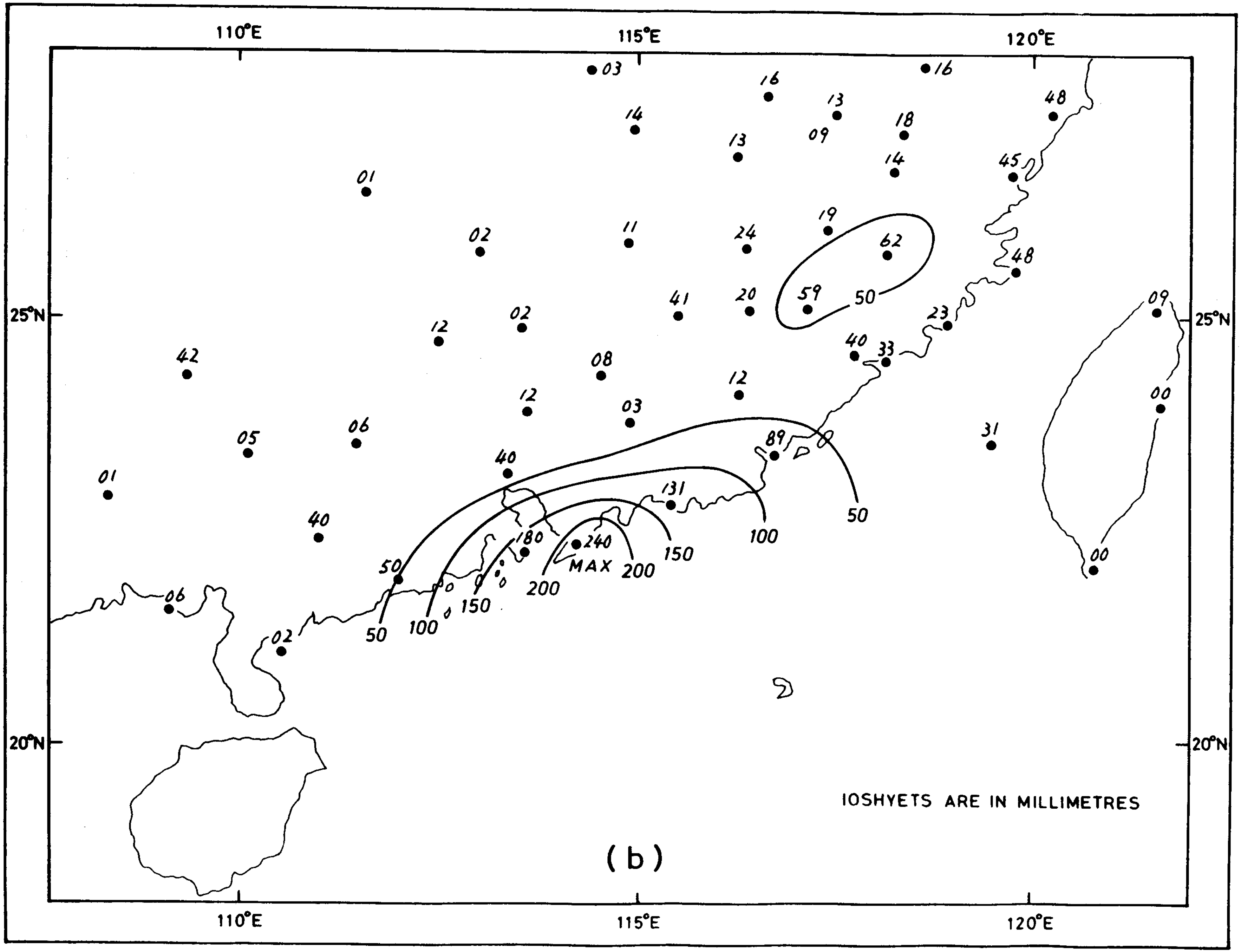


Figure 4 (b) Rainfall distribution over south China in June 1972 for the 24-hour period ending 17/0000 GMT

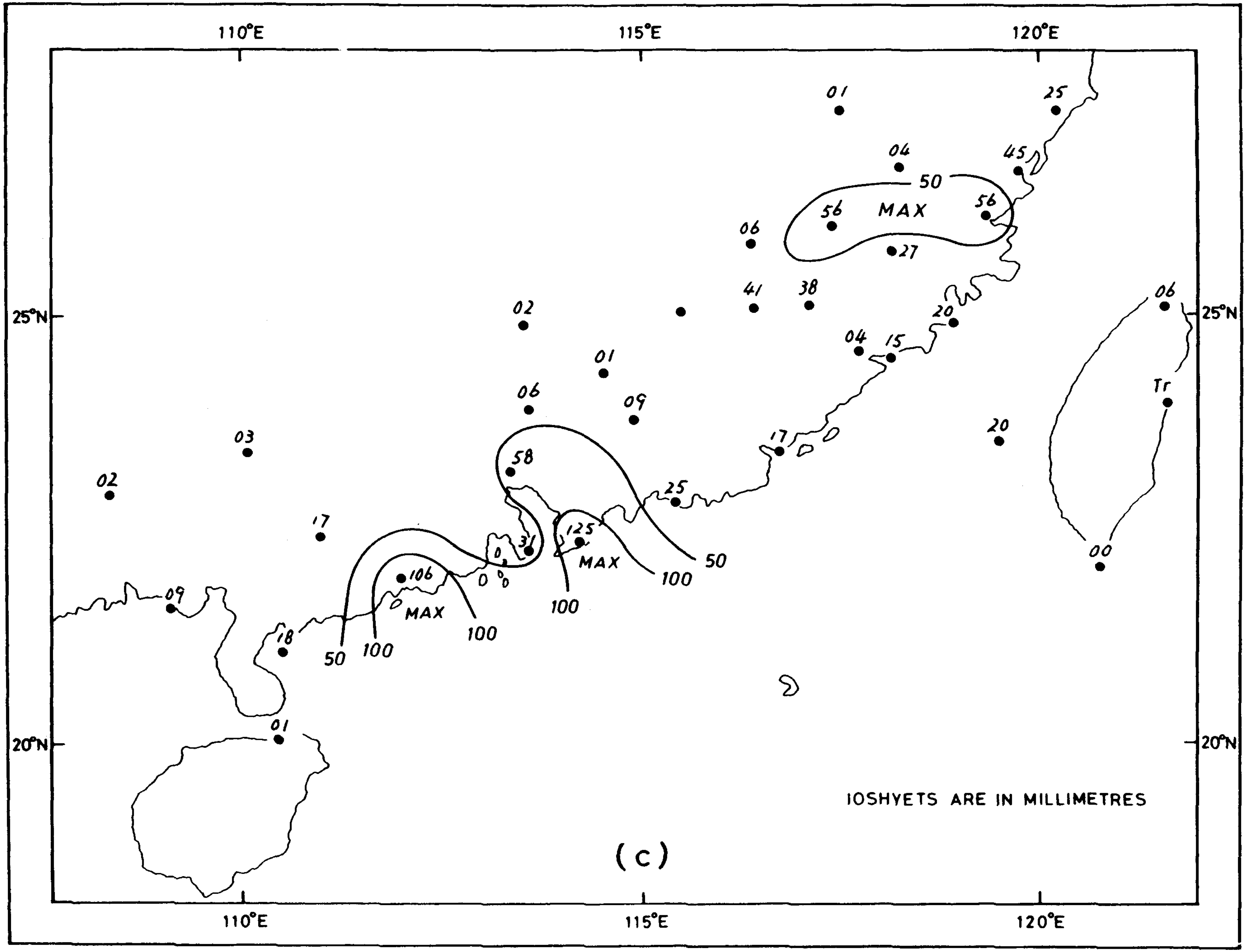


Figure 4 (c) Rainfall distribution over south China in June 1972
for the 24-hour period ending 18/0000 GMT

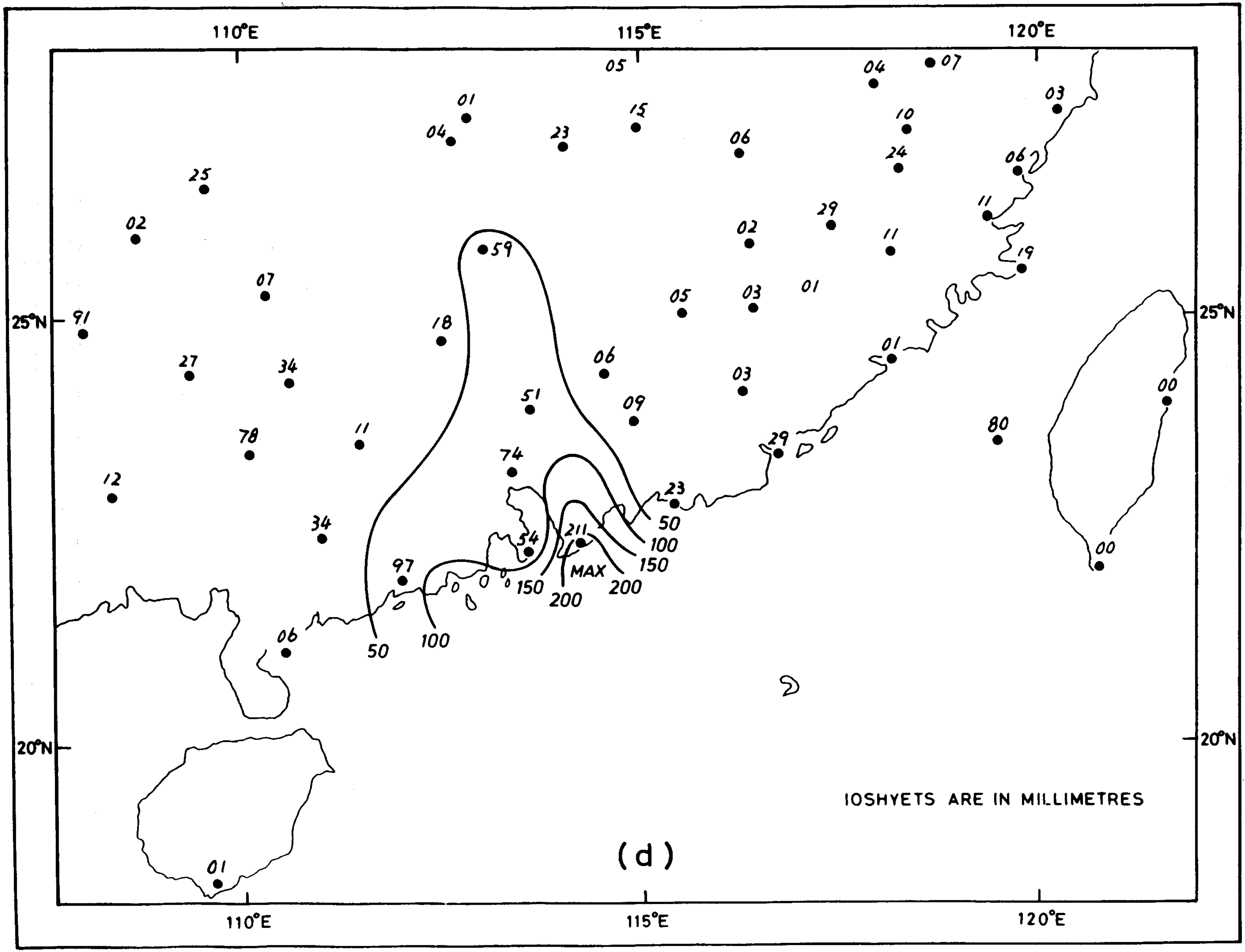


Figure 4 (d) Rainfall distribution over south China in June 1972 for the 24-hour period ending 19/0000 GMT

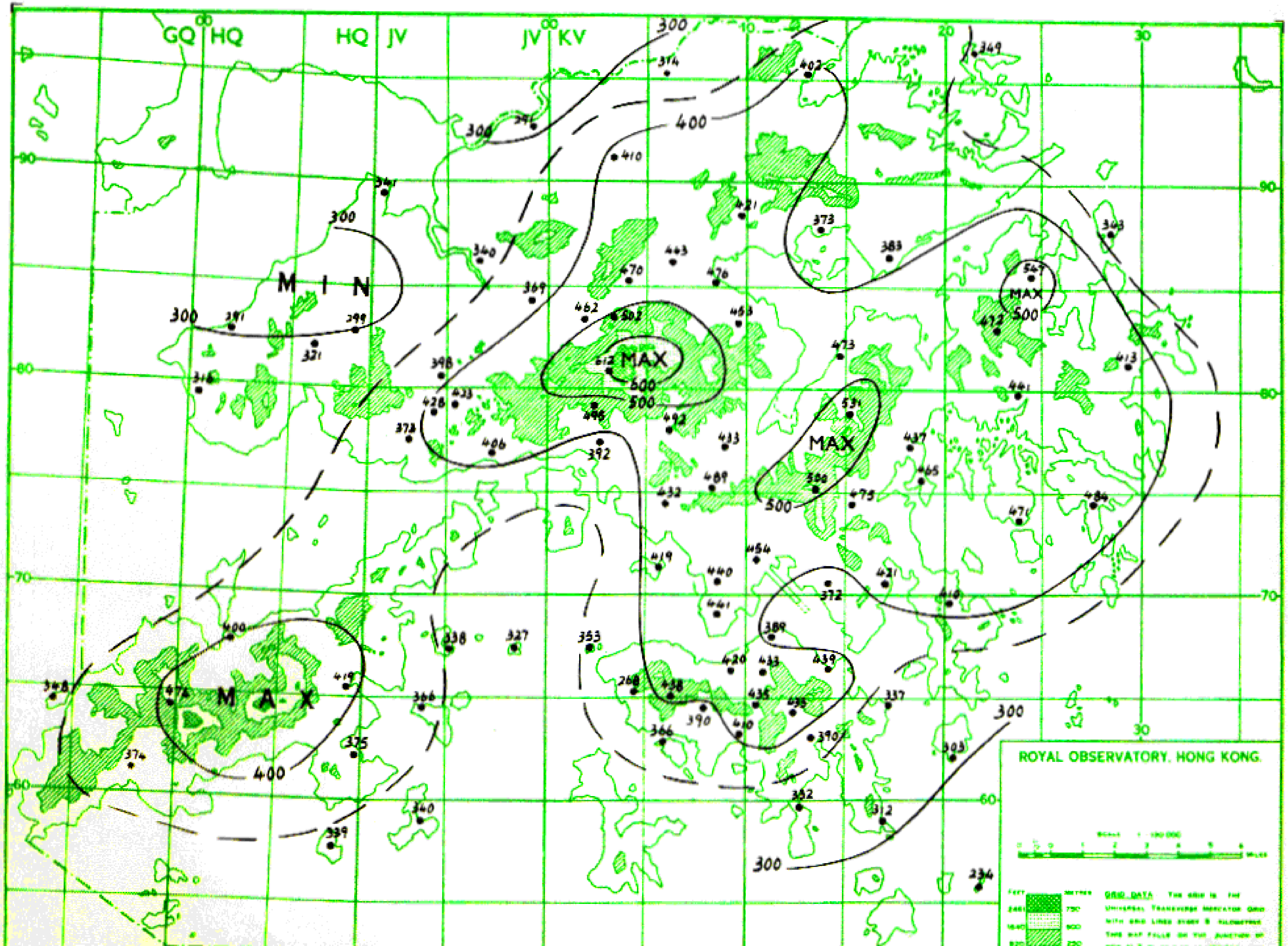


Figure 5 (a) Monthly mean rainfall over Hong Kong, June

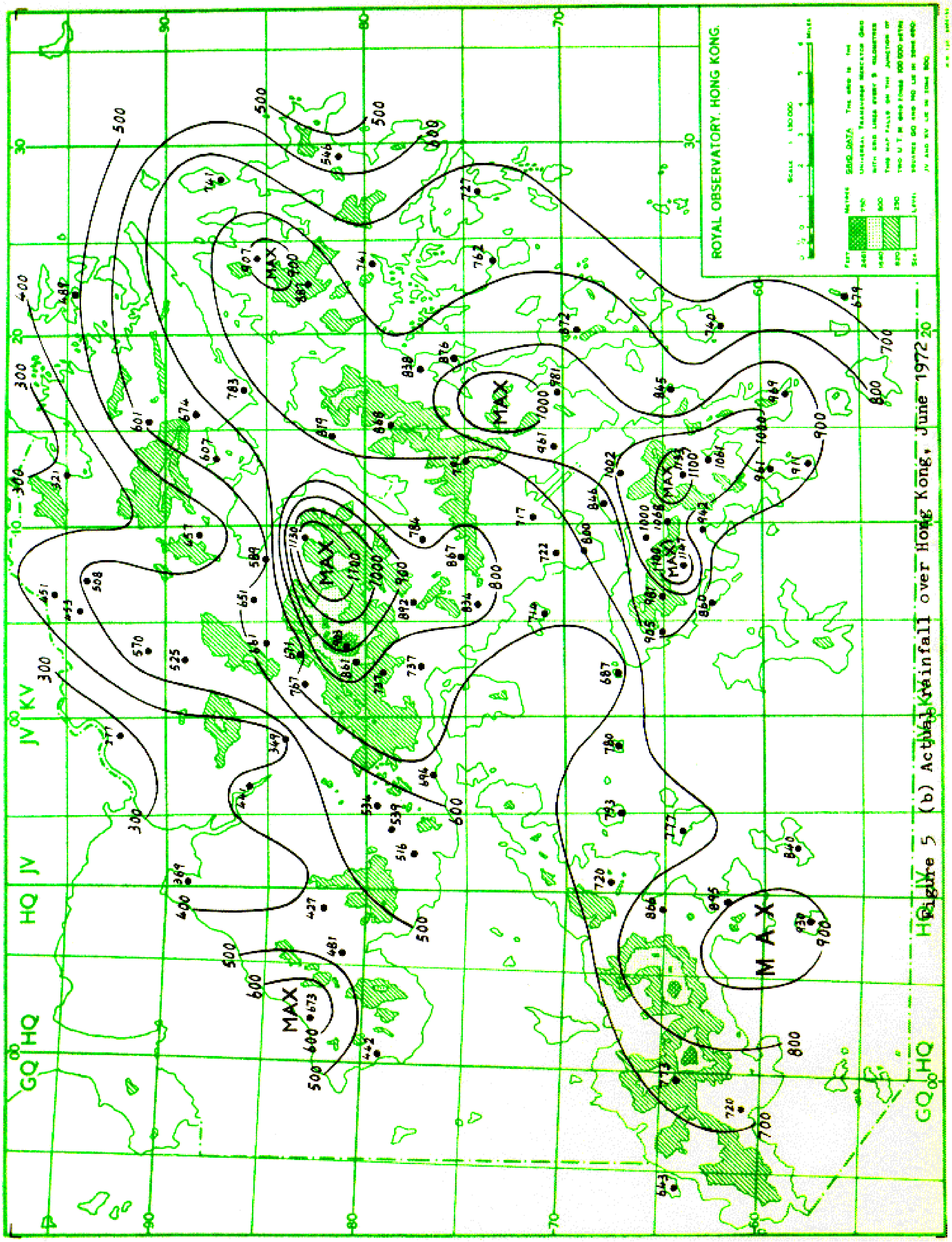


Figure 5 (b) Actual rainfall over Hong Kong, June 1972

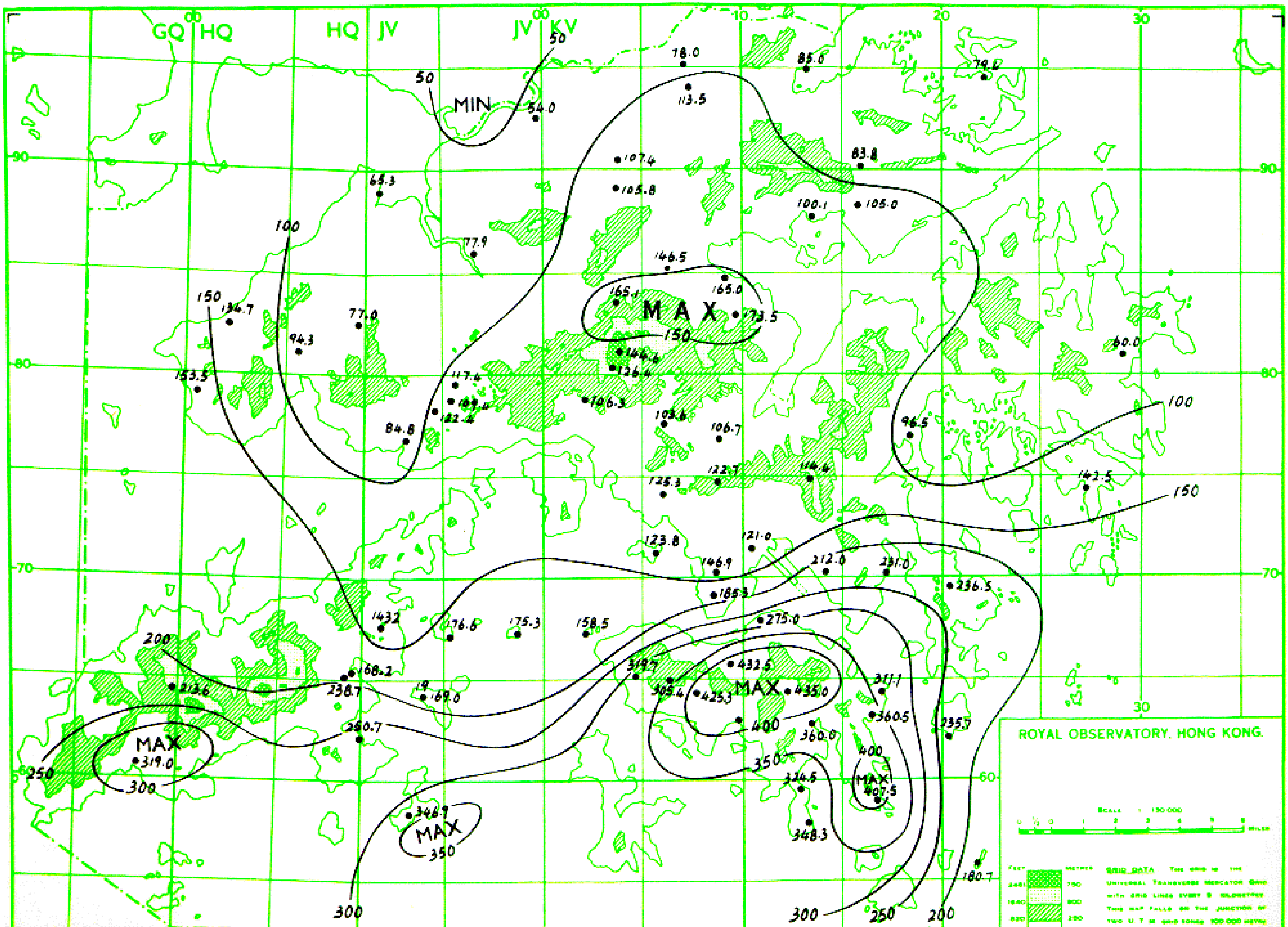


Figure 6 (a) 24-hour rainfall distribtion over Hong Kong in June 1972 on Day 1

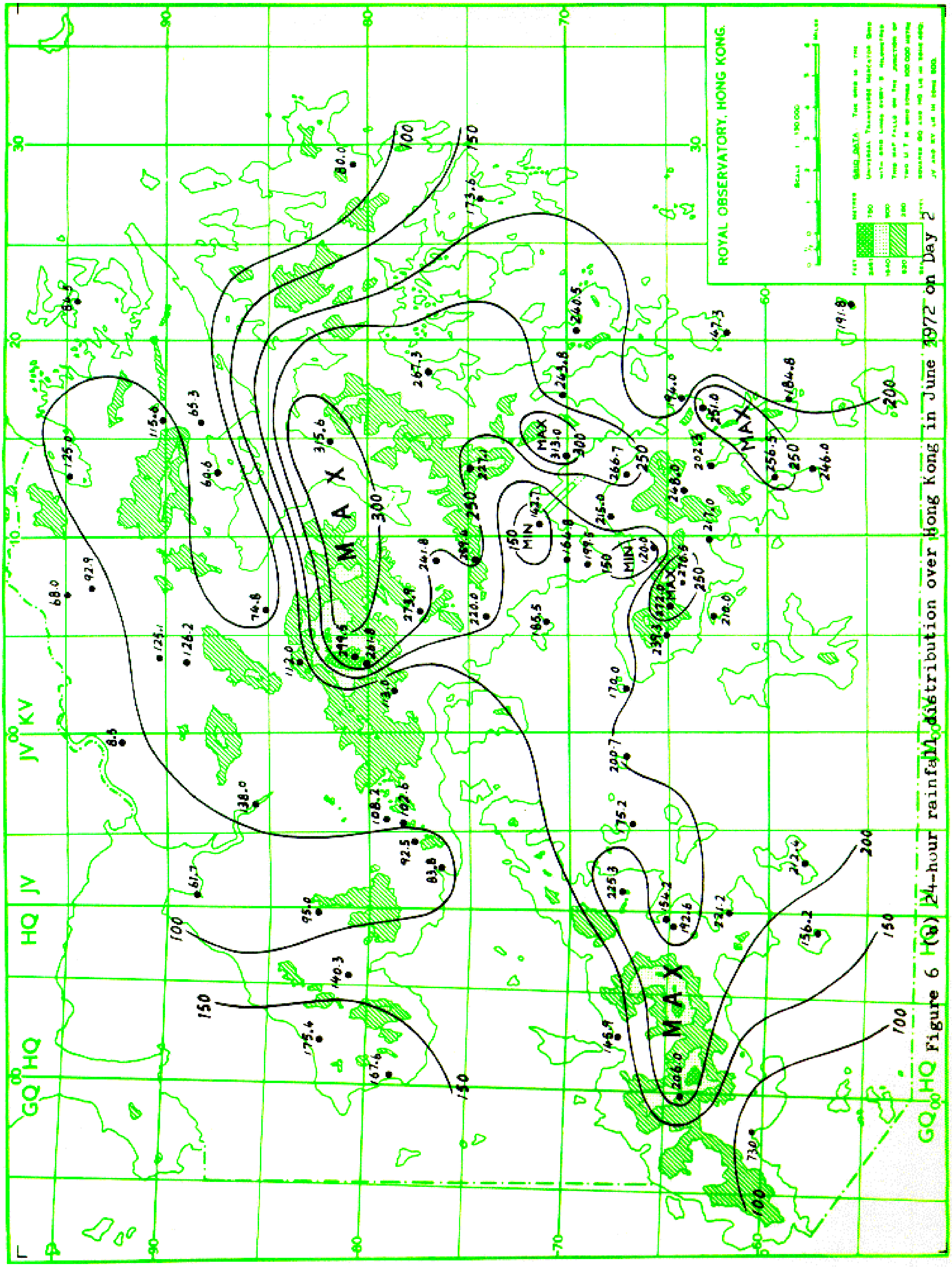


Figure 6 (b) 24-hour rainfall distribution over Hong Kong in June 1972 on Day 2

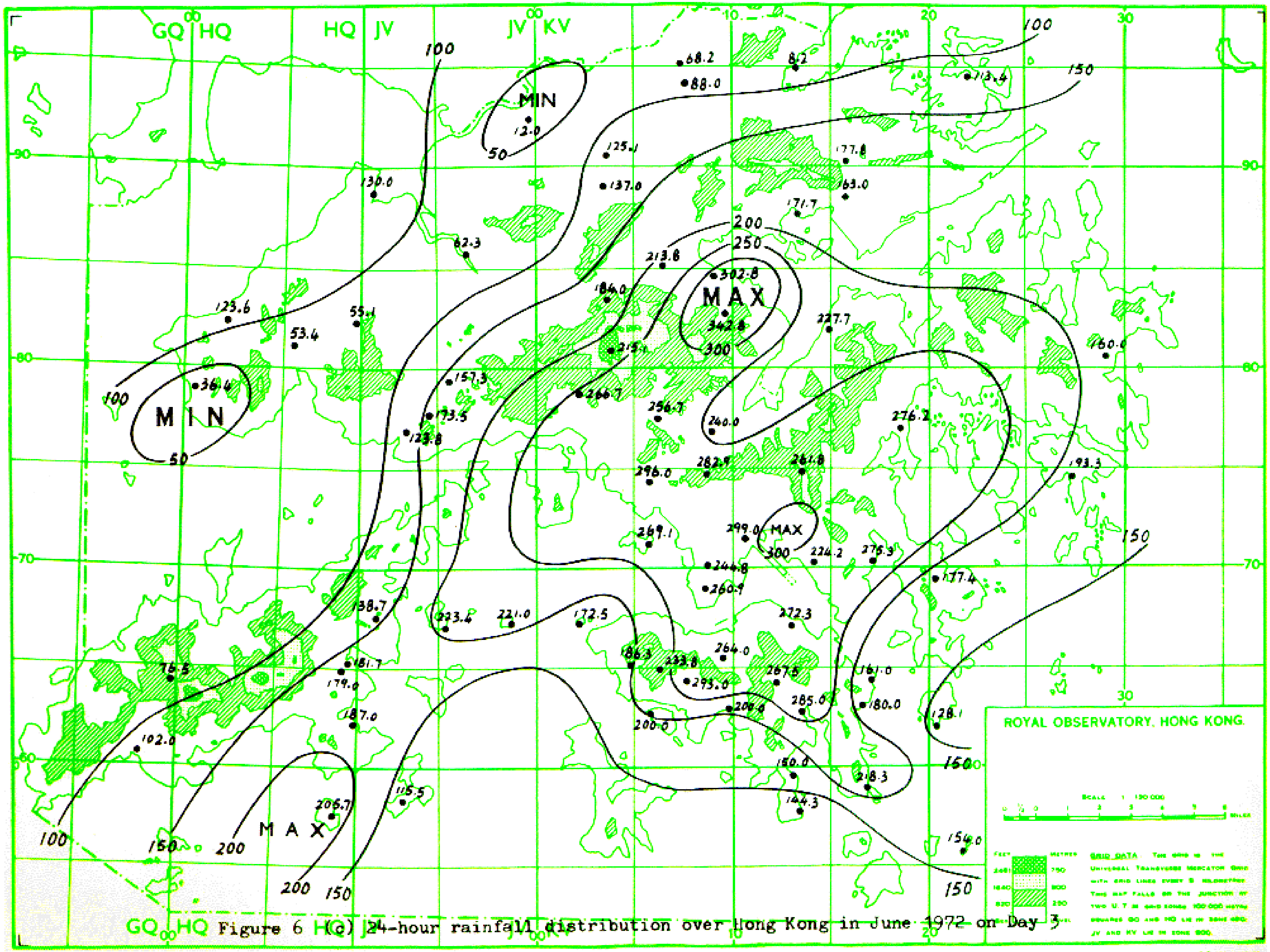


Figure 6 (c) 24-hour rainfall distribution over Hong Kong in June 1972 on Day 3

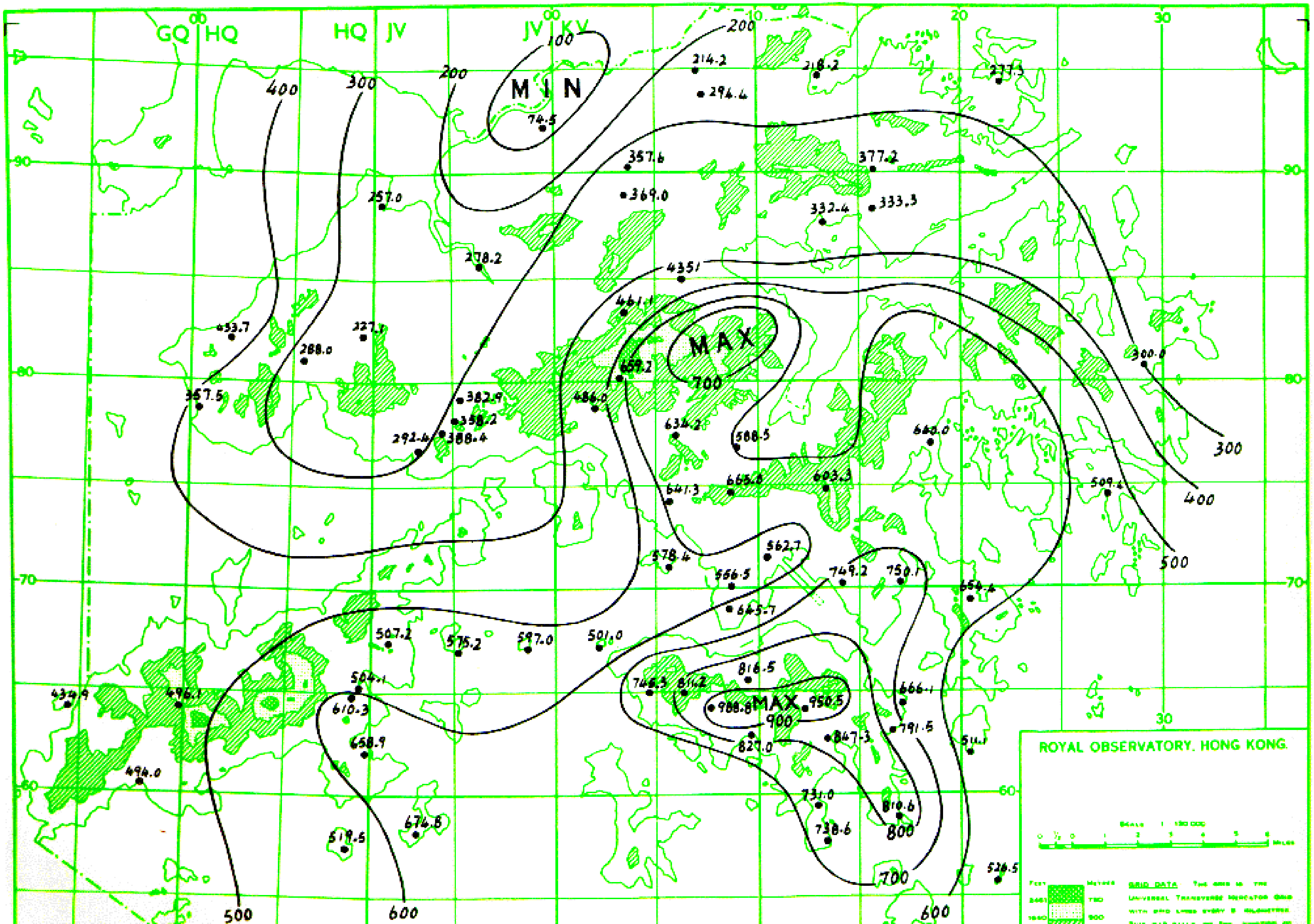


Figure 6 (d) 24-hour rainfall distribution over Hong Kong in June 1972 for all three days

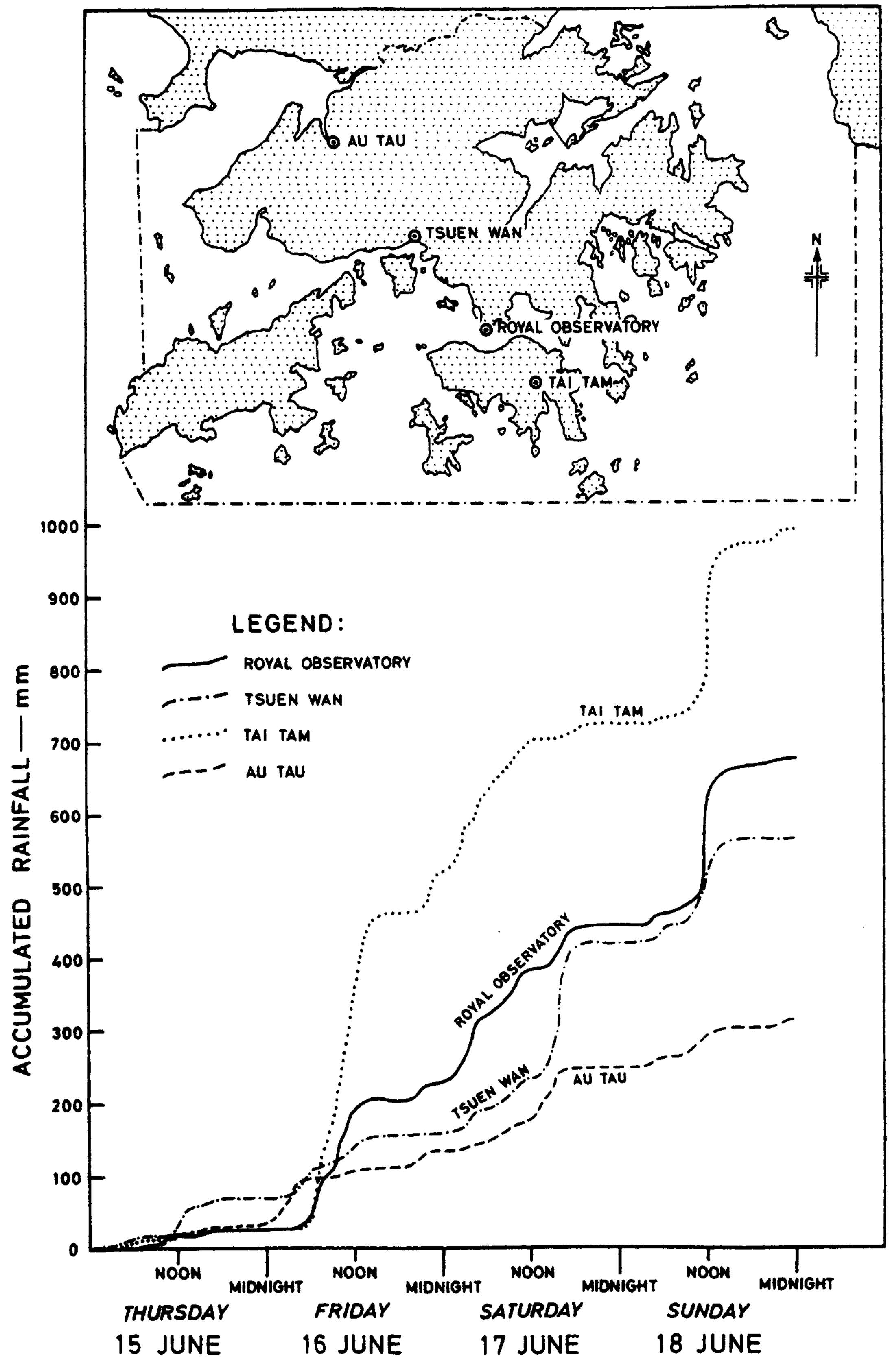


Figure 7 Four-day accumulated rainfall amounts for four selected stations beginning midnight, 15 June 1972

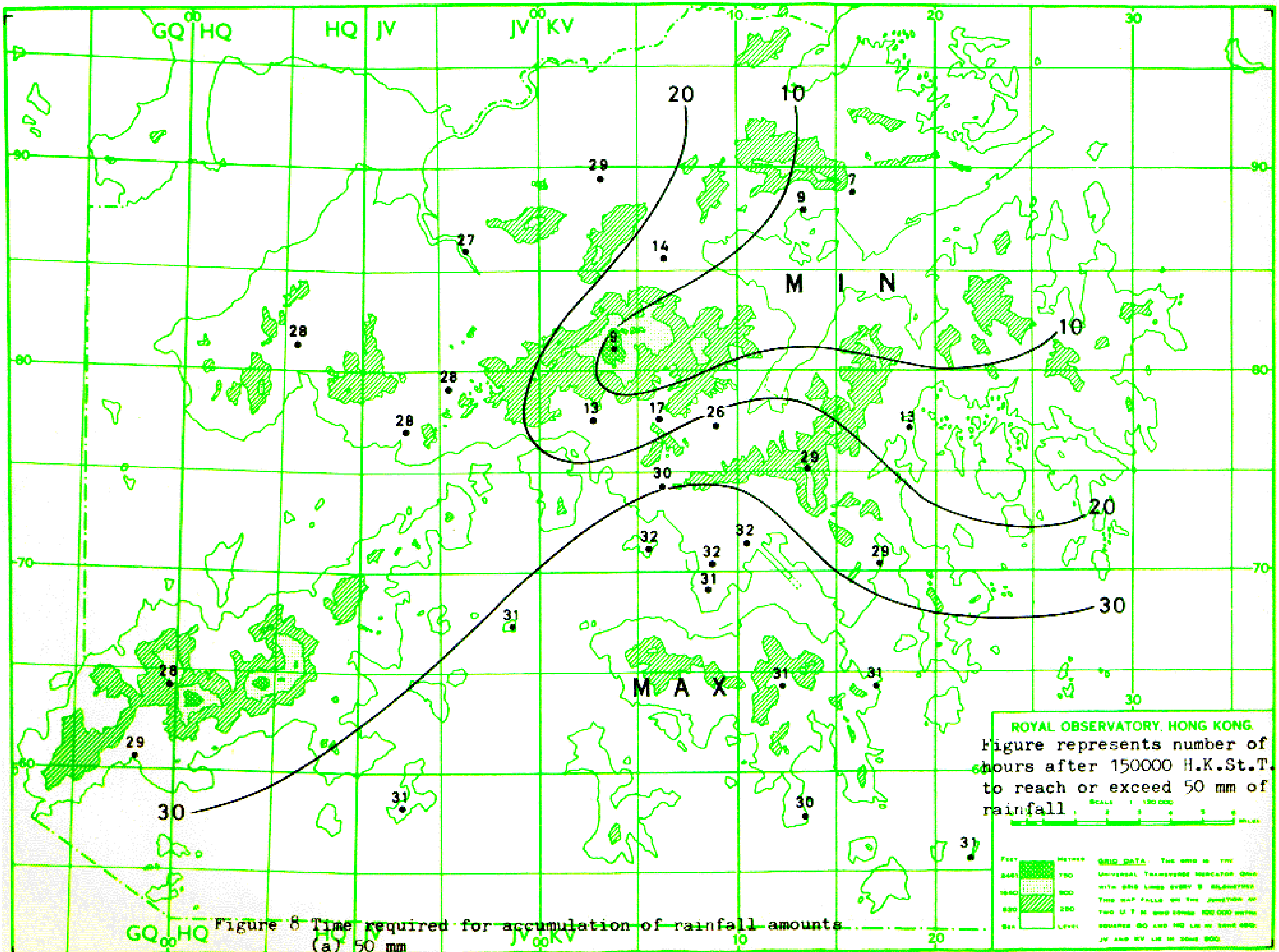


Figure 8 Time required for accumulation of rainfall amounts
(a) 50 mm

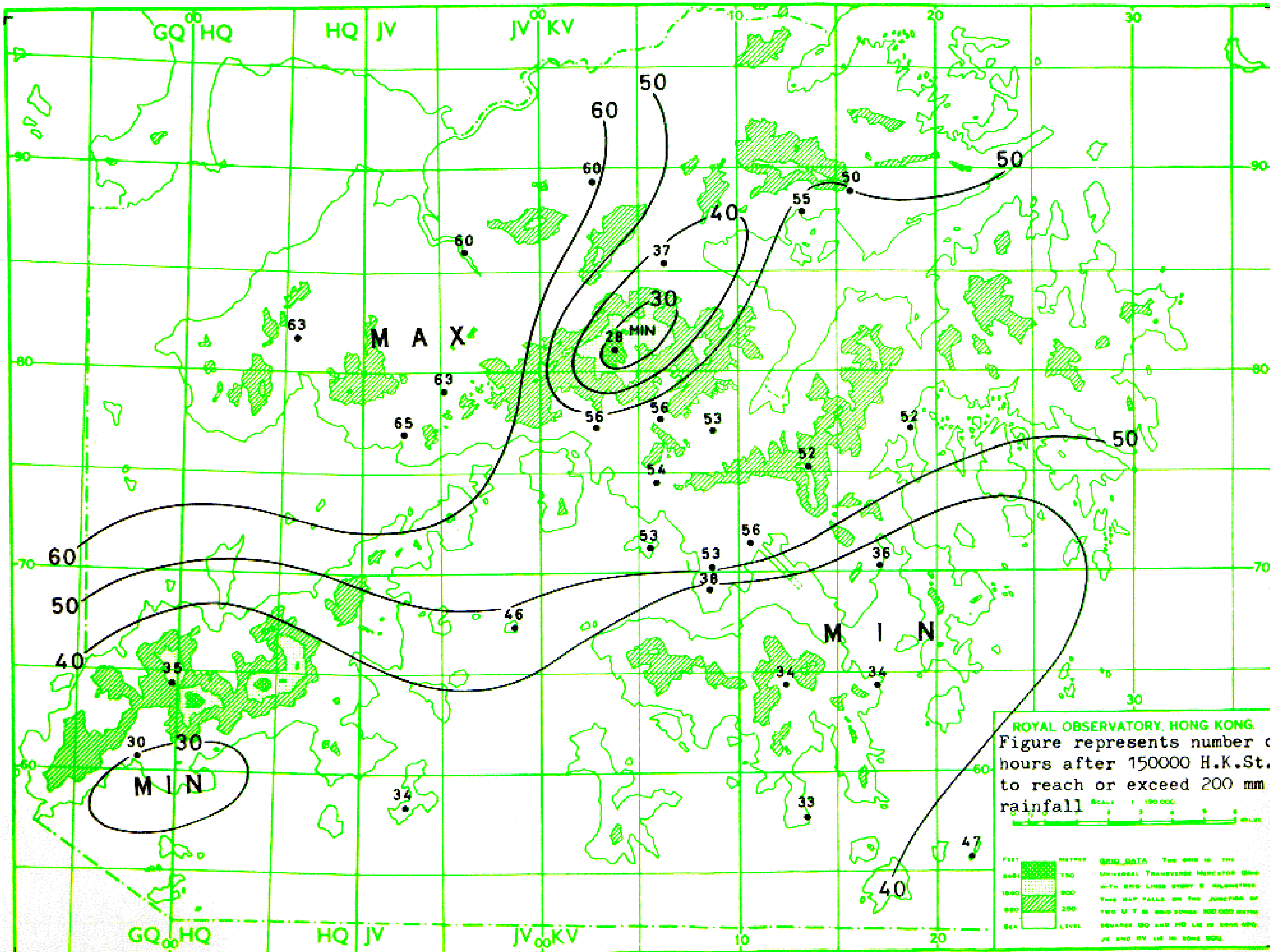


Figure 8 (b) 200 mm

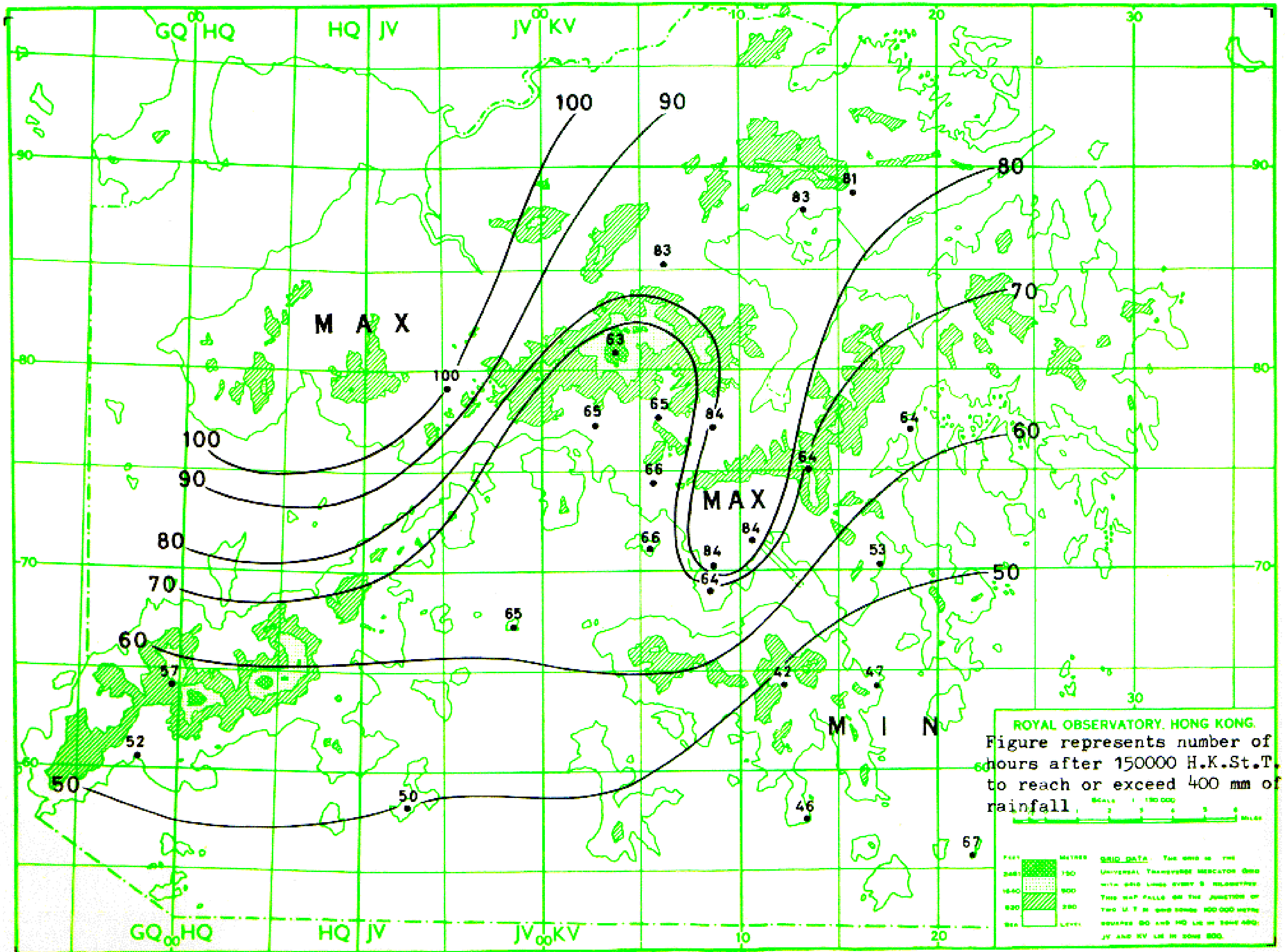


Figure 8 (c) 400 mm

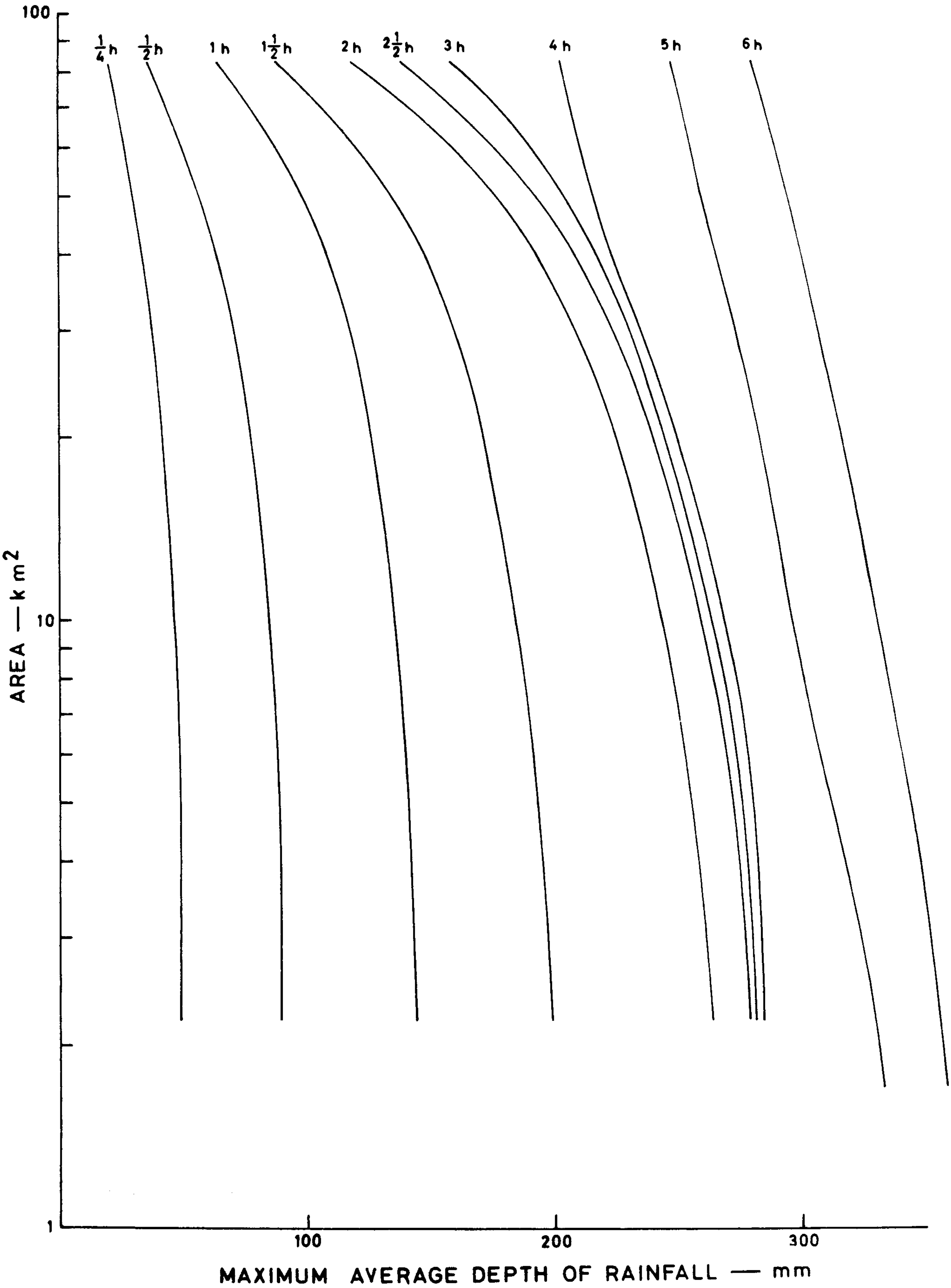


Figure 9 (a) Maximum depth-area-duration curves for periods of 15 minutes to 6 hours

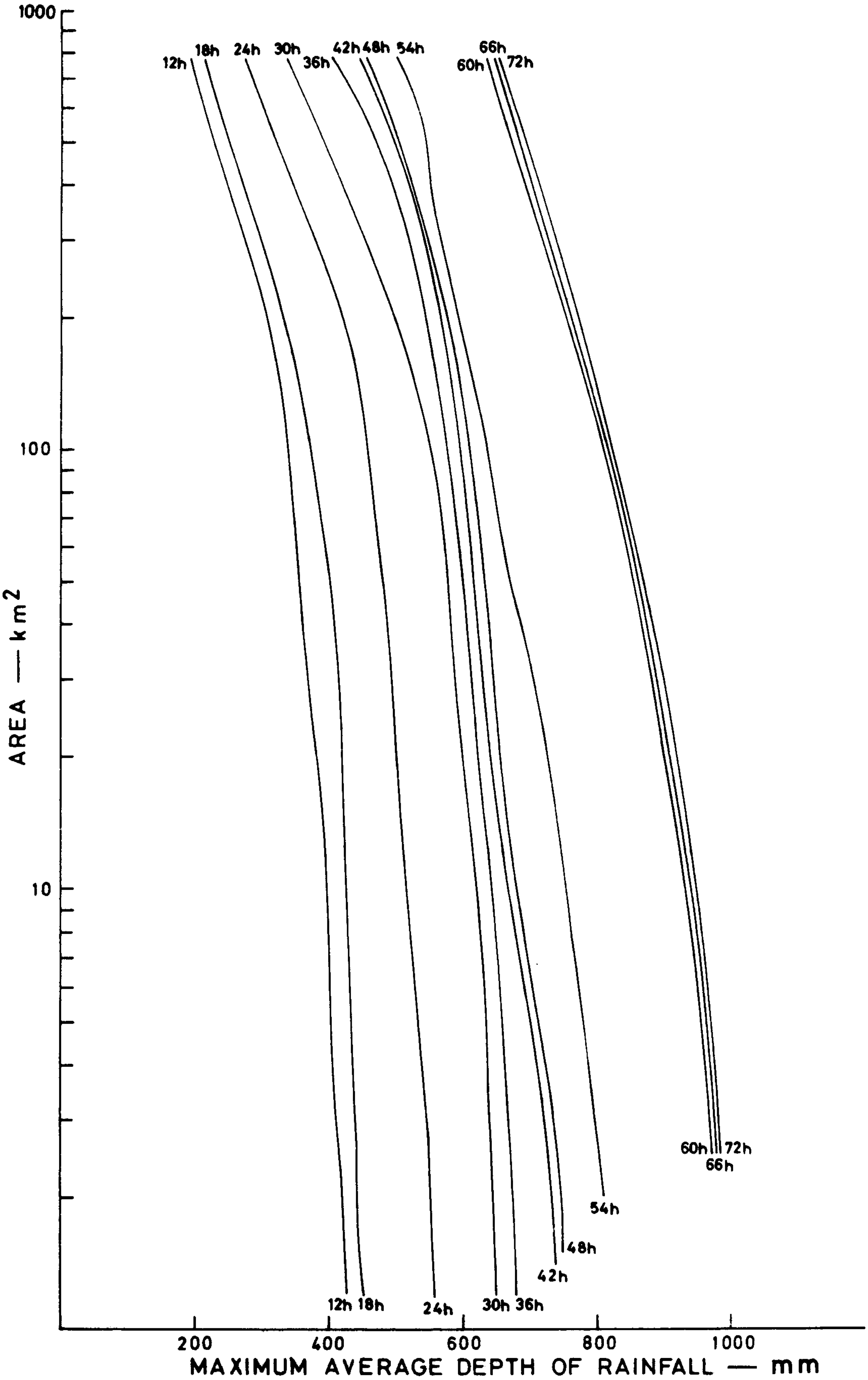


Figure 9 (b) Maximum depth-area-duration curves for periods of 12 to 72 hours

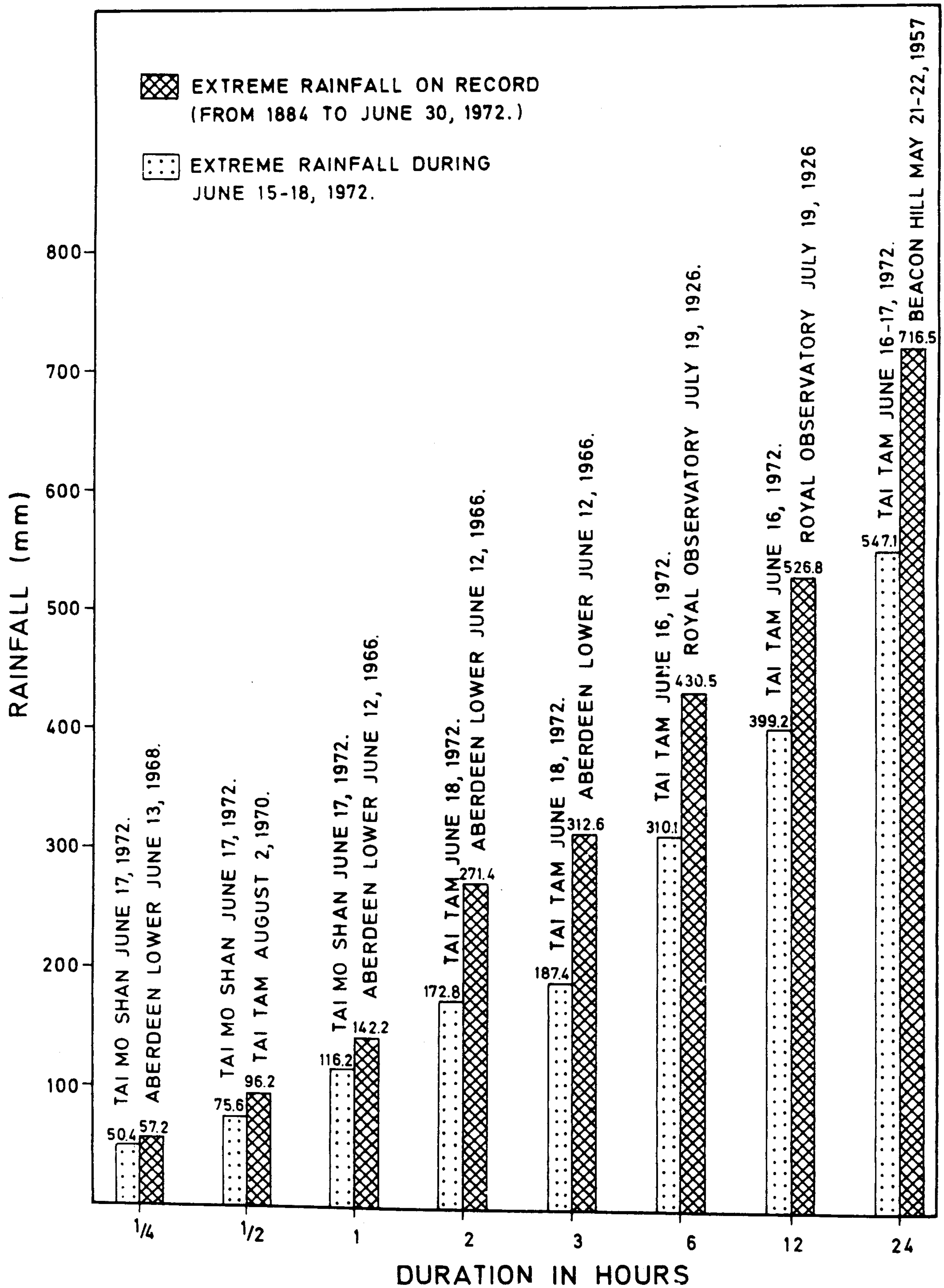


Figure 10 Comparison of extreme rainfall over specified time intervals for 15 to 18 June 1972 with records since 1884 for all stations in Hong Kong

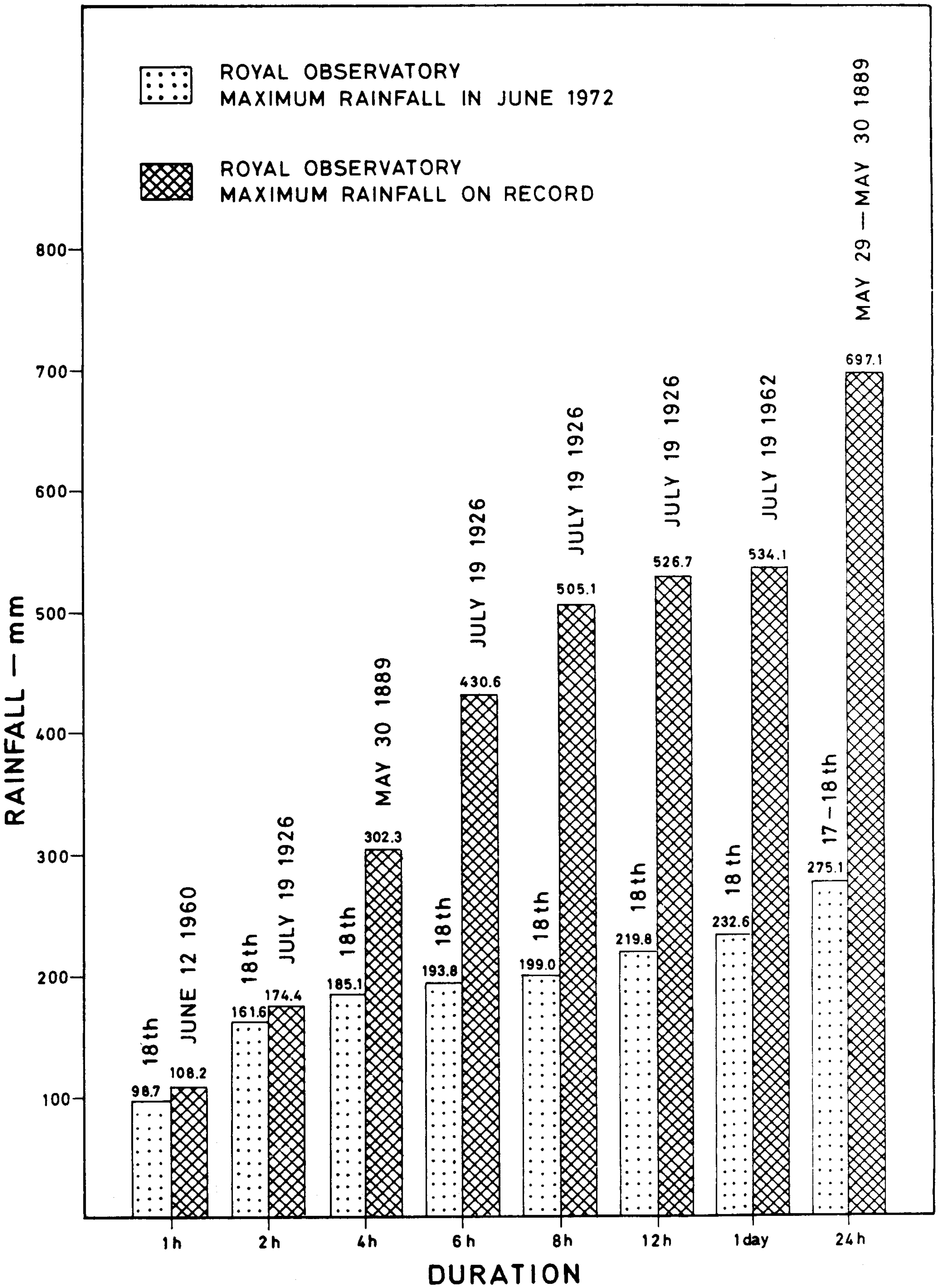


Figure 11 Comparison of extreme rainfall over specified time intervals for 15 to 18 June 1972 with records since 1884 at the Royal Observatory headquarters.

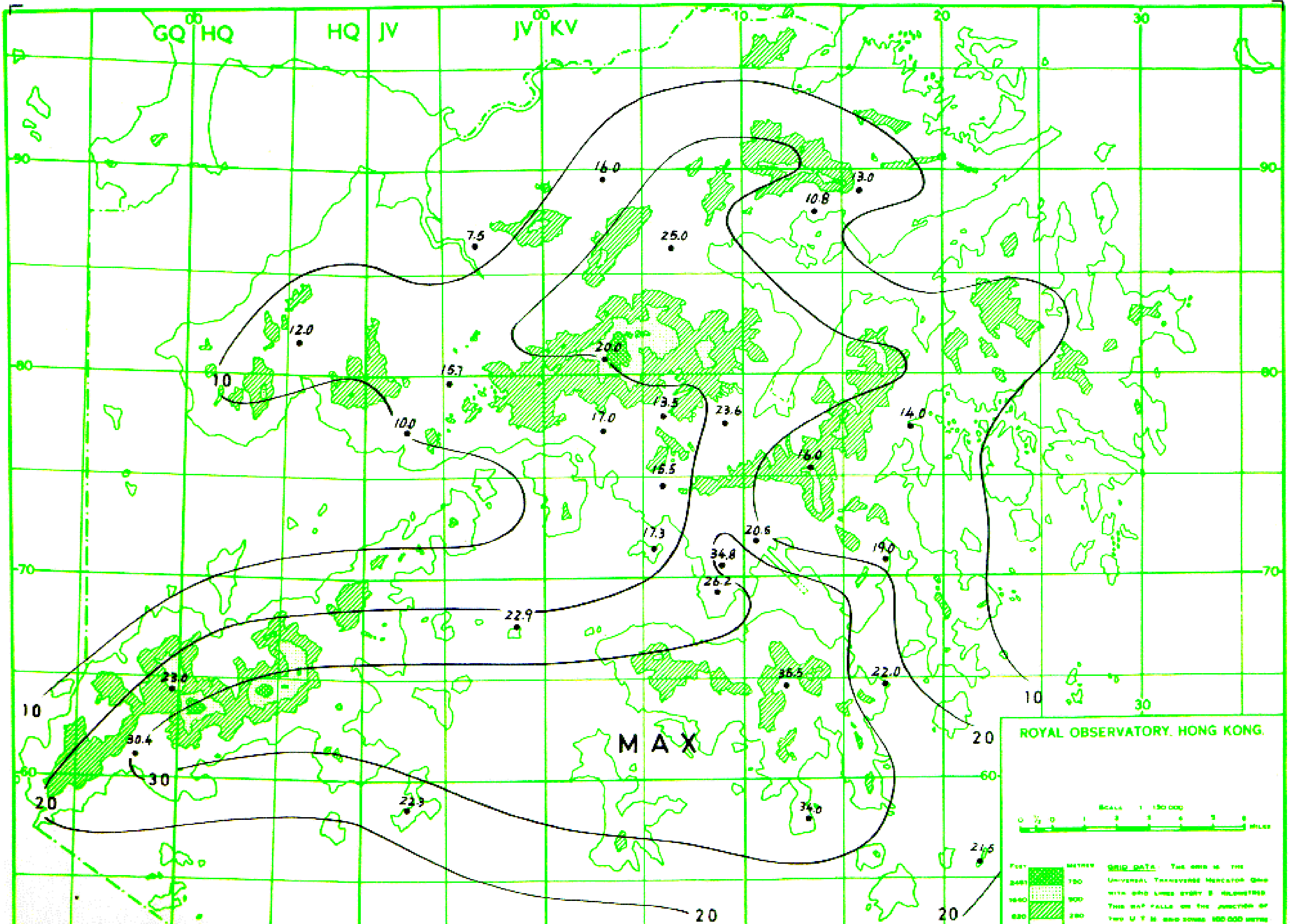


Figure 12 (a) Maximum rainfall over Hong Kong for Day 1 for 15 minutes

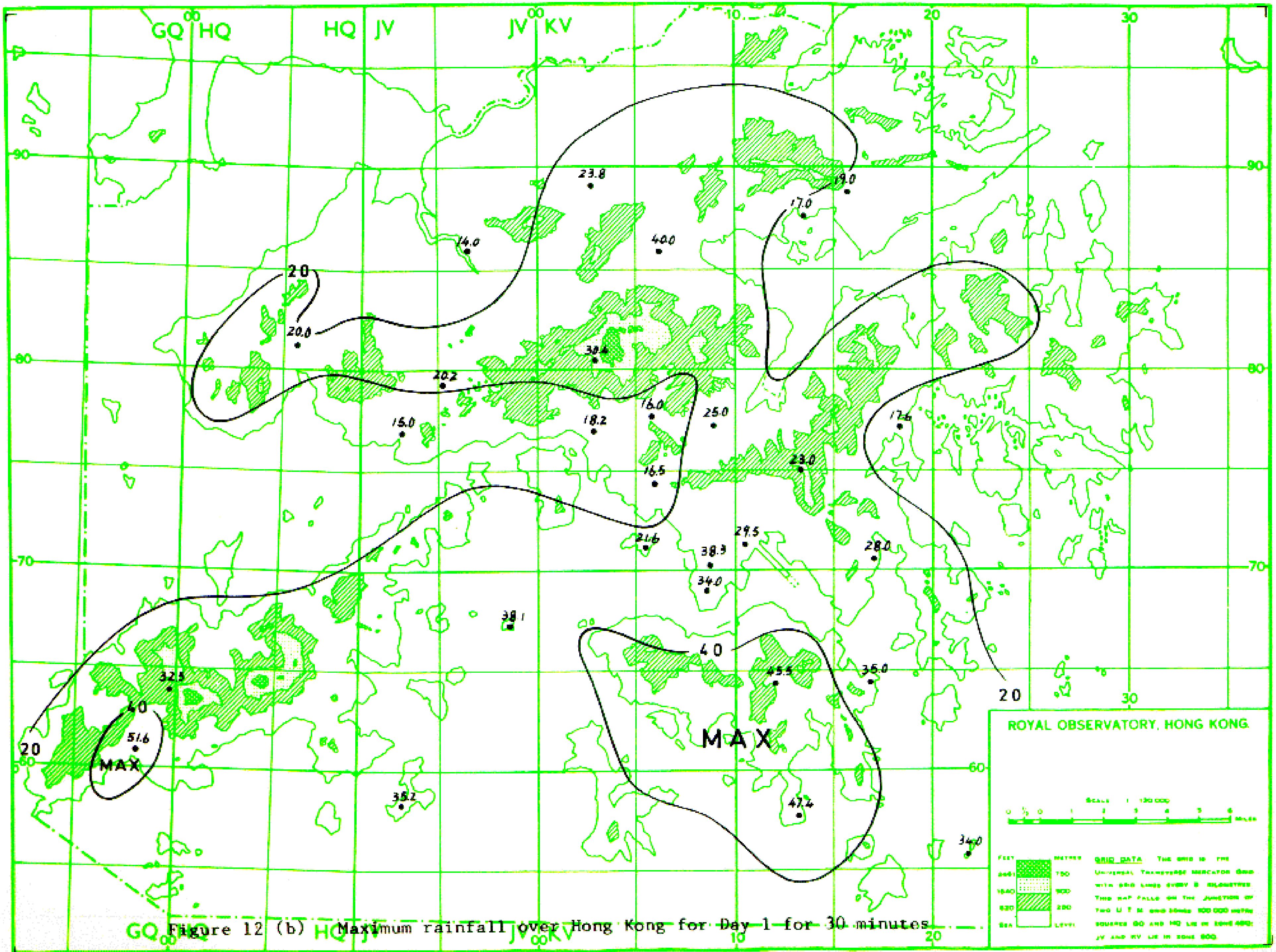


Figure 12 (b) Maximum rainfall over Hong Kong for Day 1 for 30 minutes

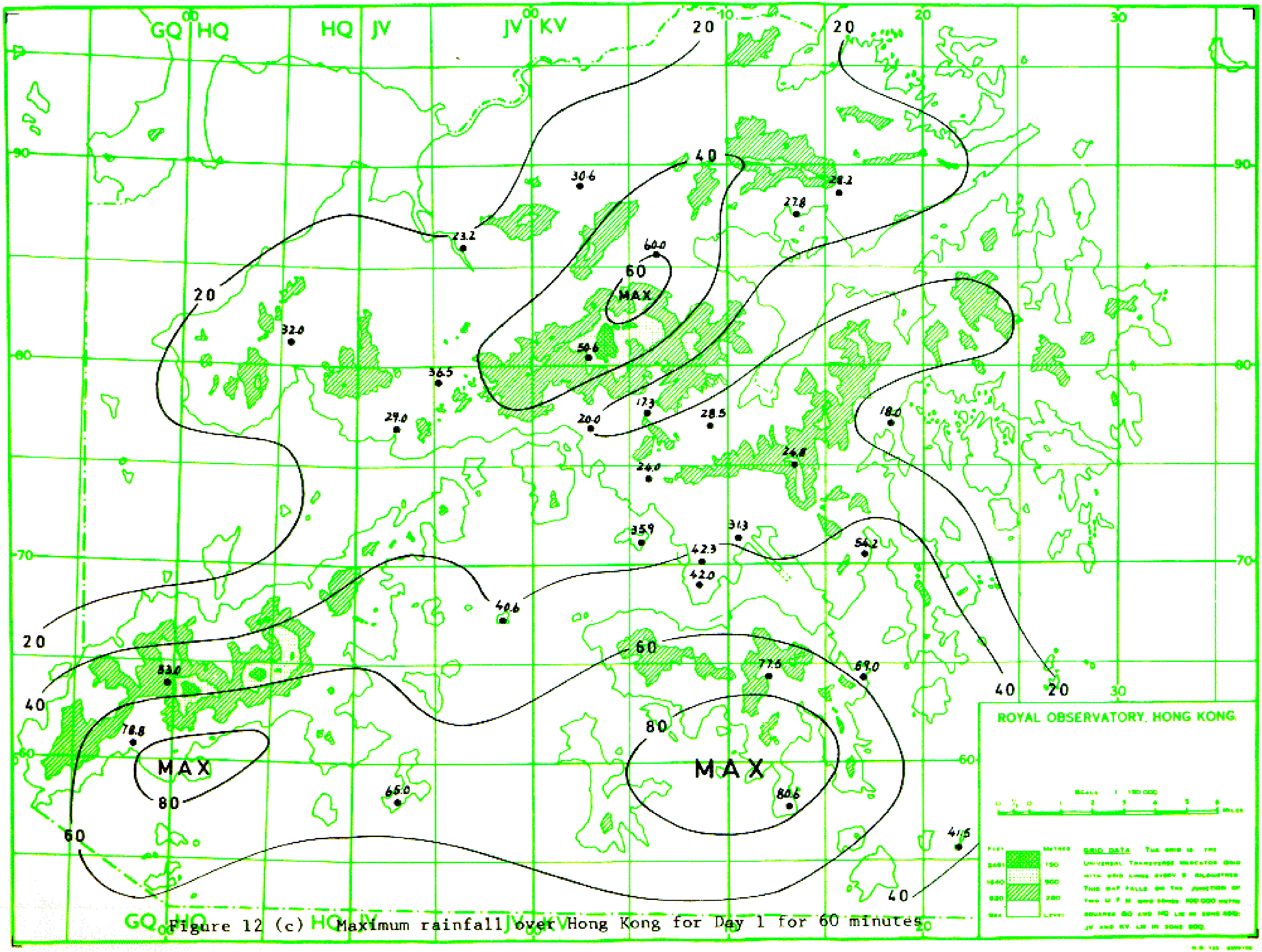


Figure 12 (c) Maximum rainfall over Hong Kong for Day 1 for 60 minutes

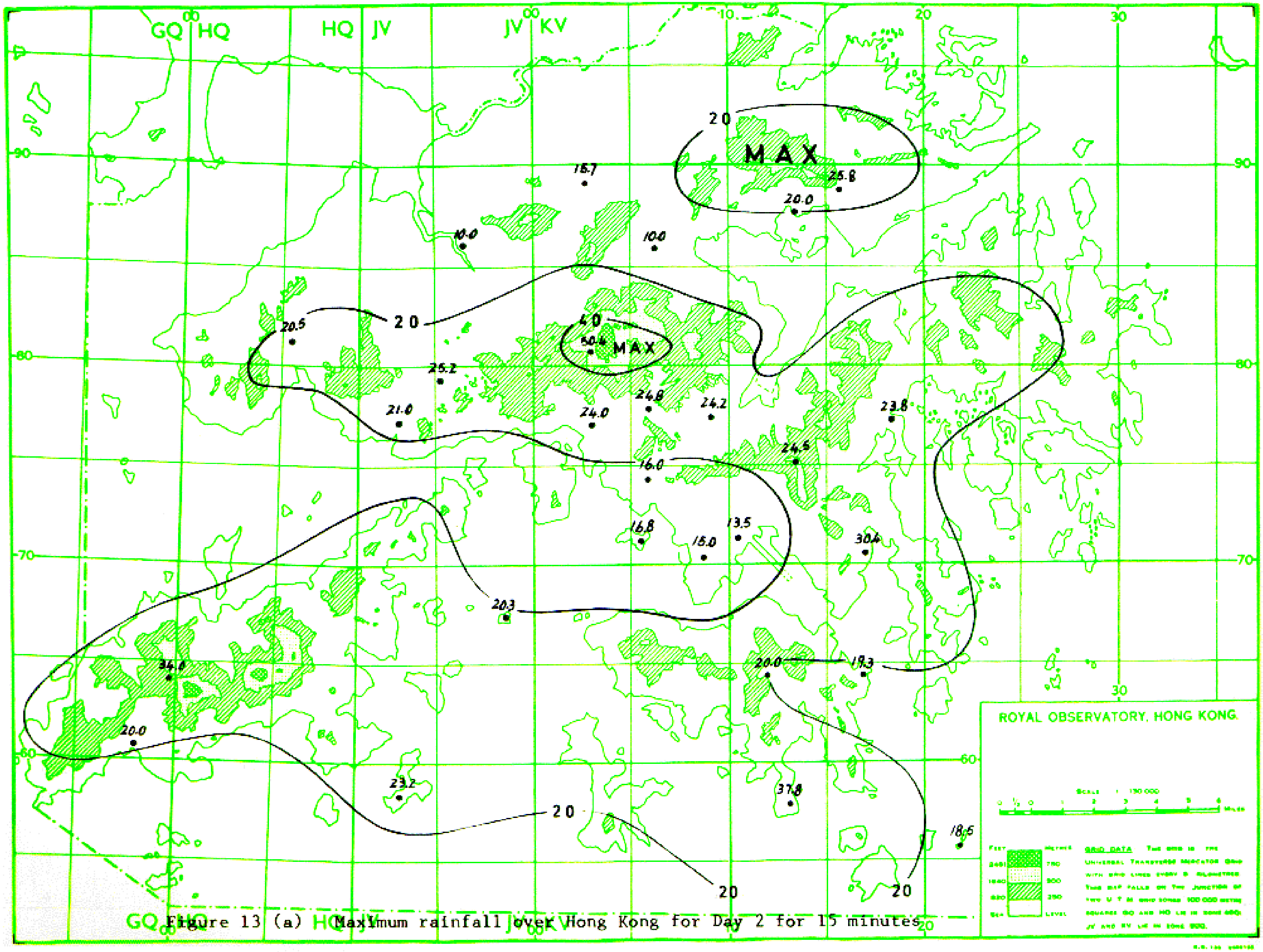


Figure 13 (a) Maximum rainfall over Hong Kong for Day 2 for 15 minutes

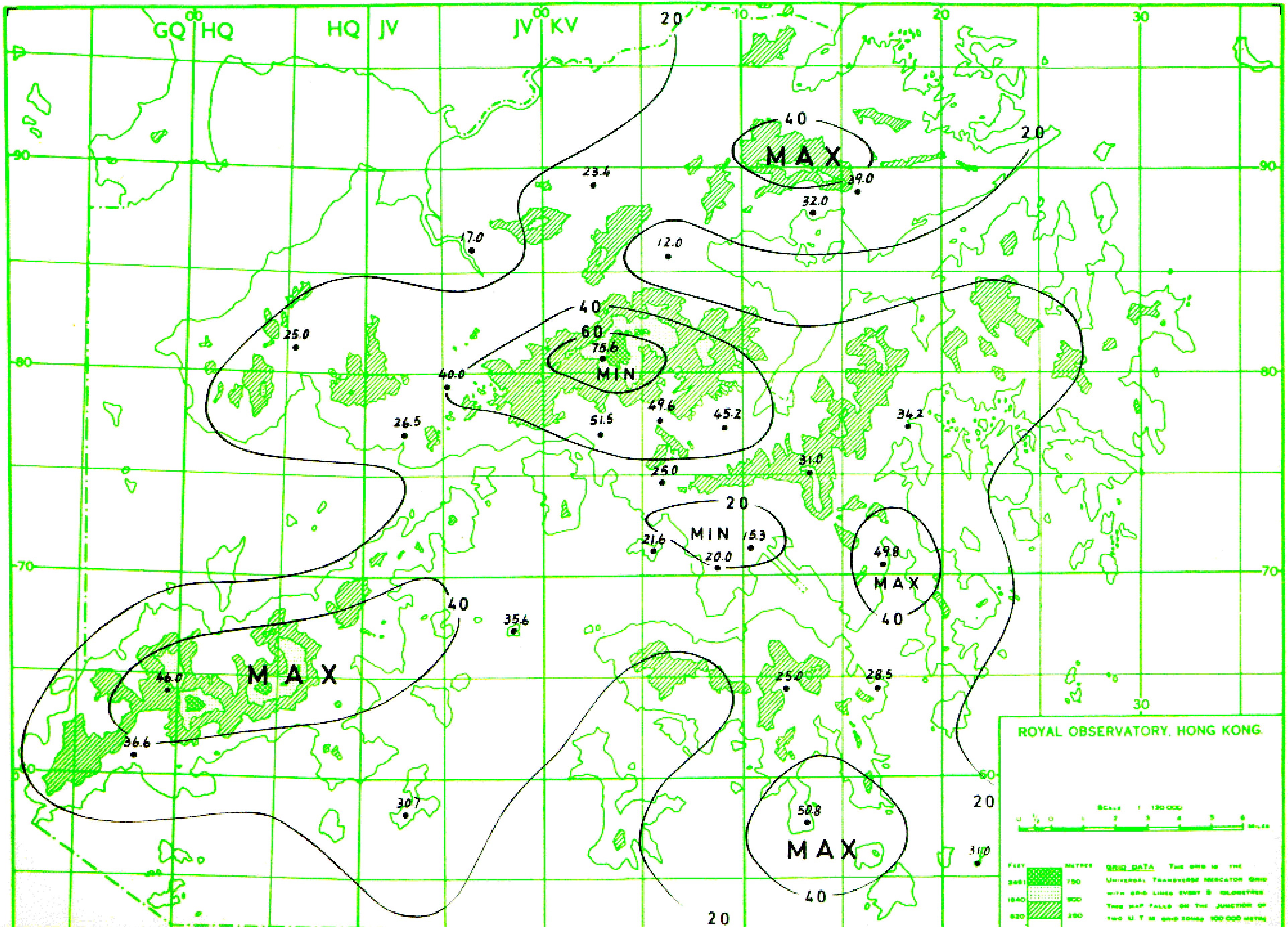


Figure 13 (b) Maximum rainfall over Hong Kong for Day 2 for 30 minutes

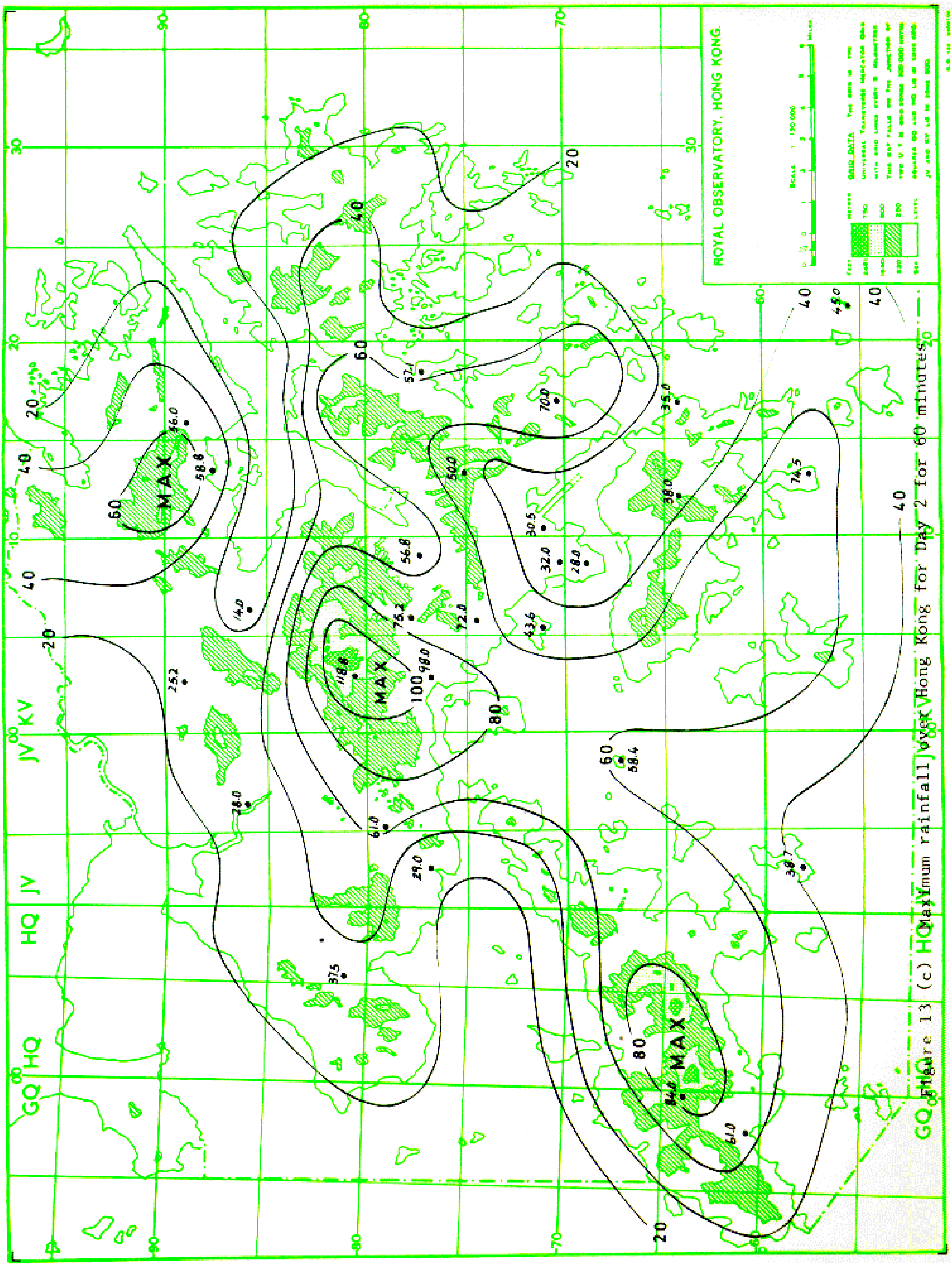


Figure 13 (c) Maximum rainfall over Hong Kong for Day 2 for 60 minutes

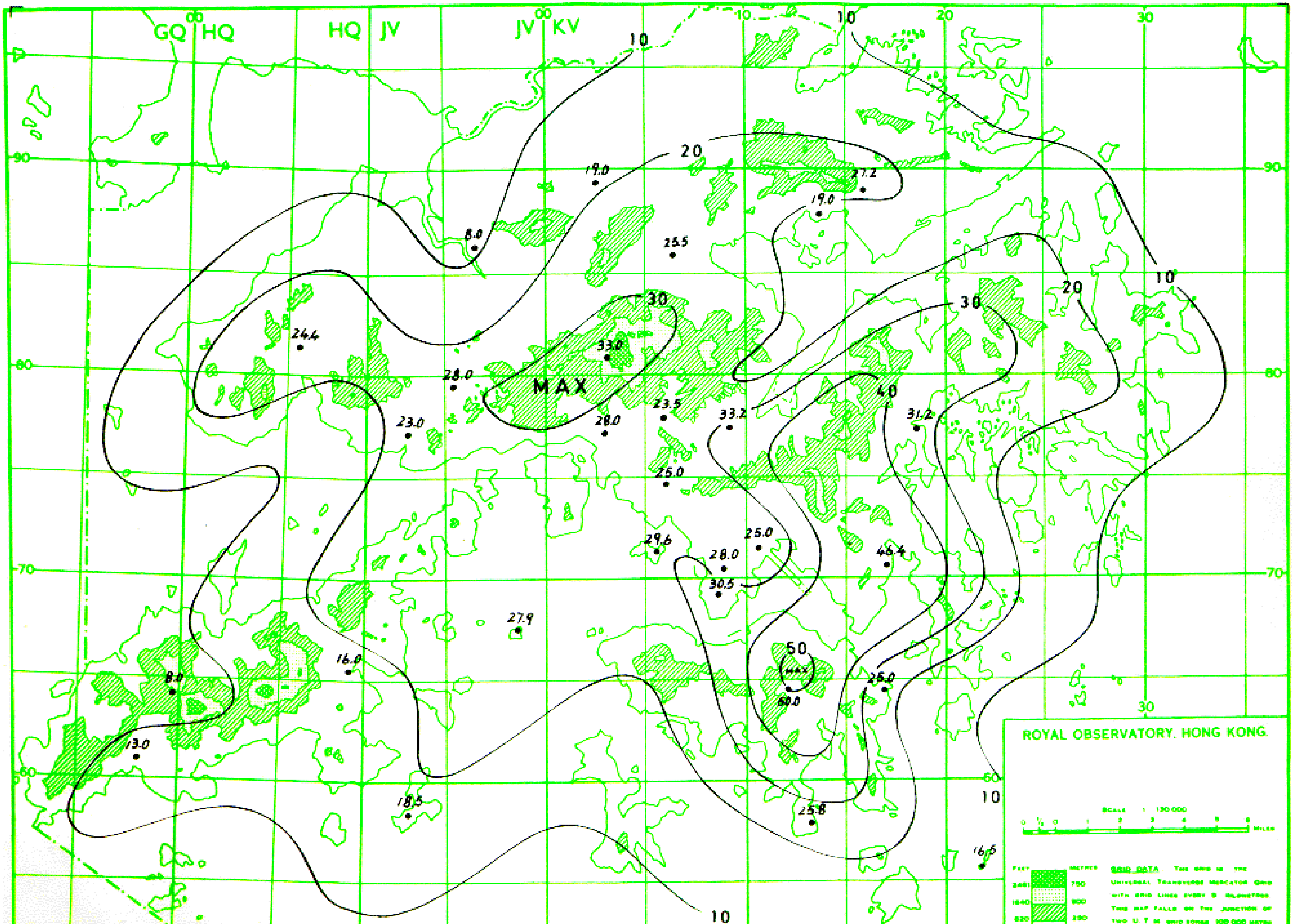


Figure 14 (a) Maximum rainfall over Hong Kong for Day 3 for 15 minutes

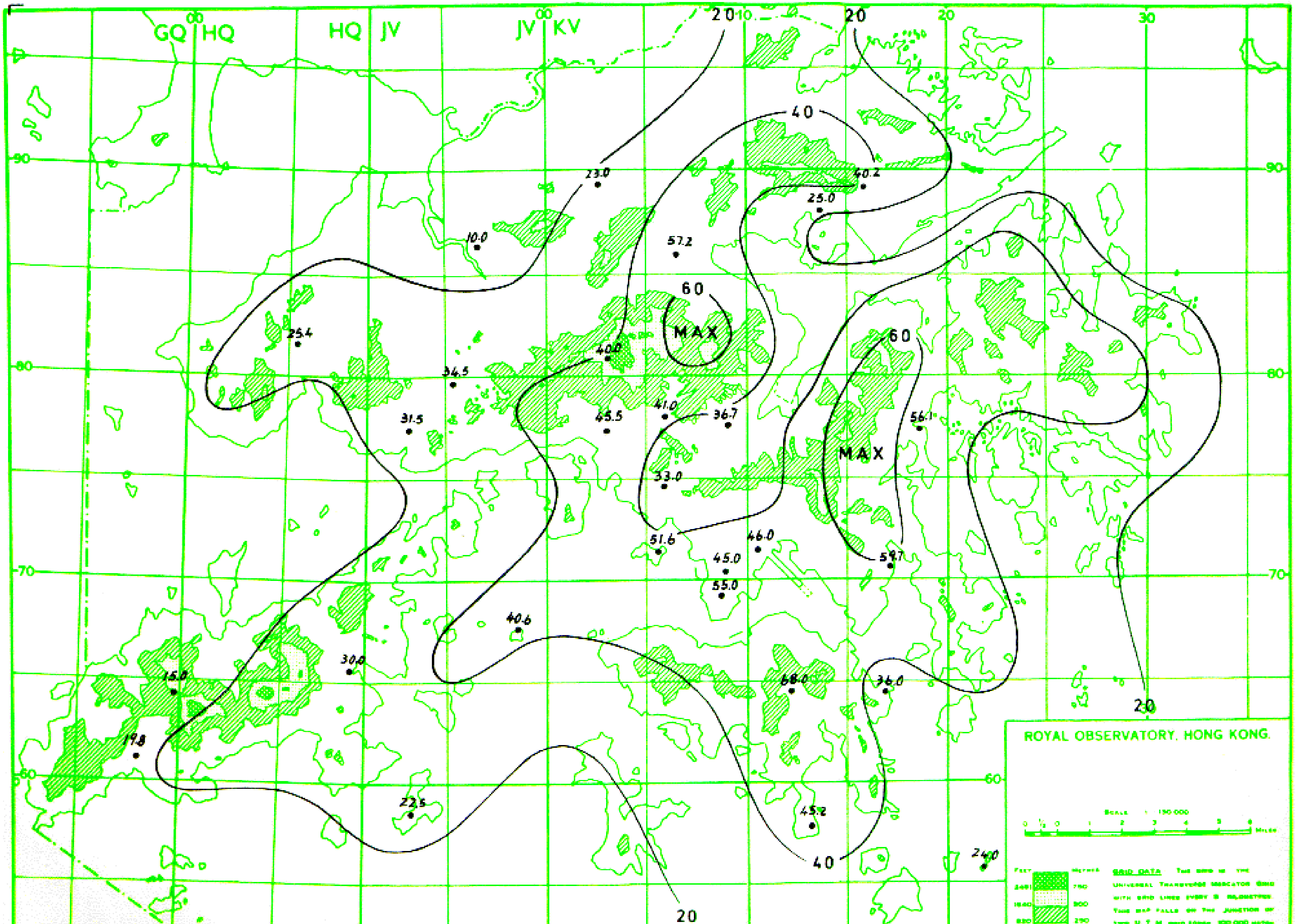


Figure 14 (b) Maximum rainfall over Hong Kong for Day 3 for 30 minutes

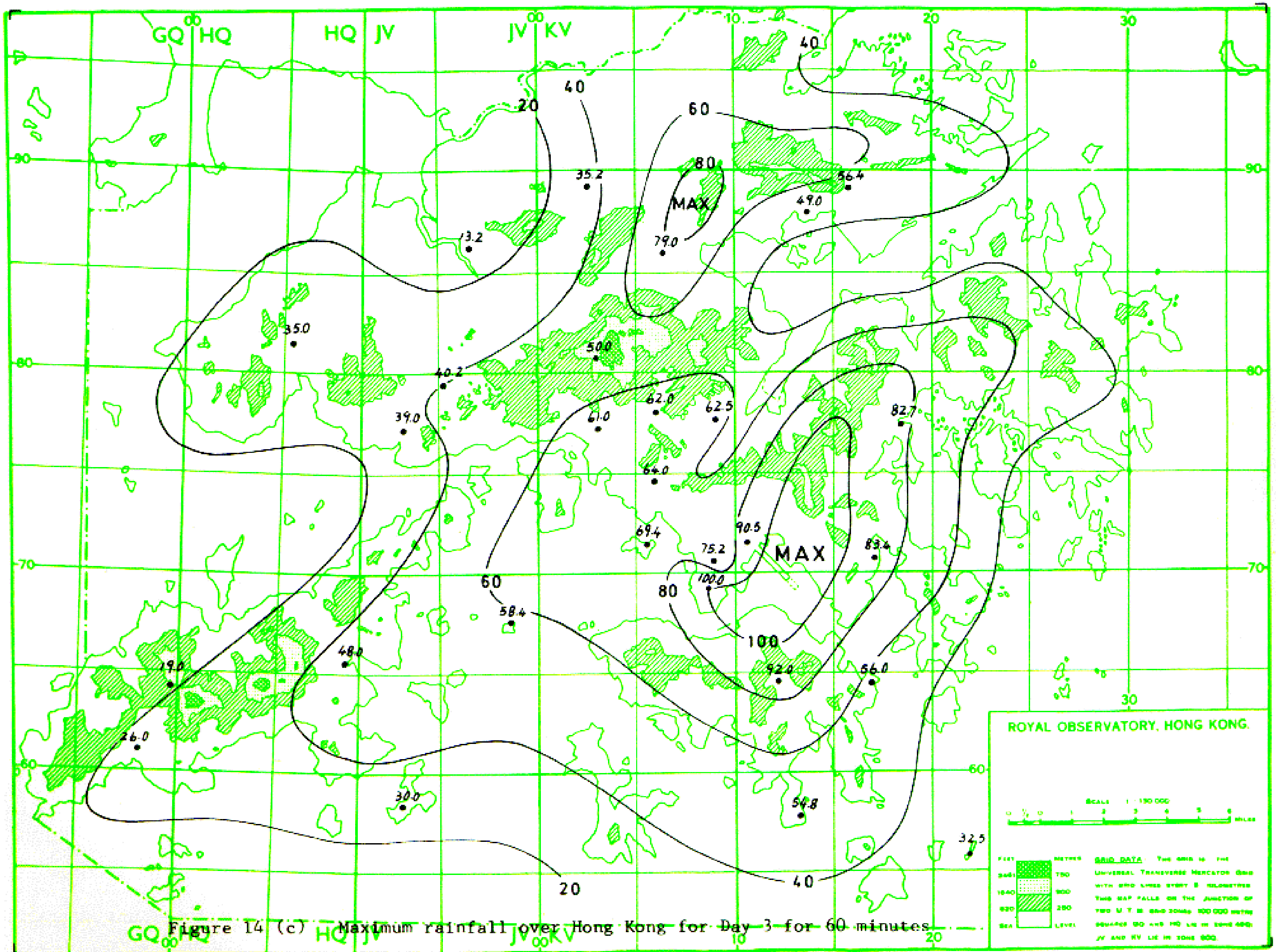


Figure 14 (c) Maximum rainfall over Hong Kong for Day 3 for 60 minutes

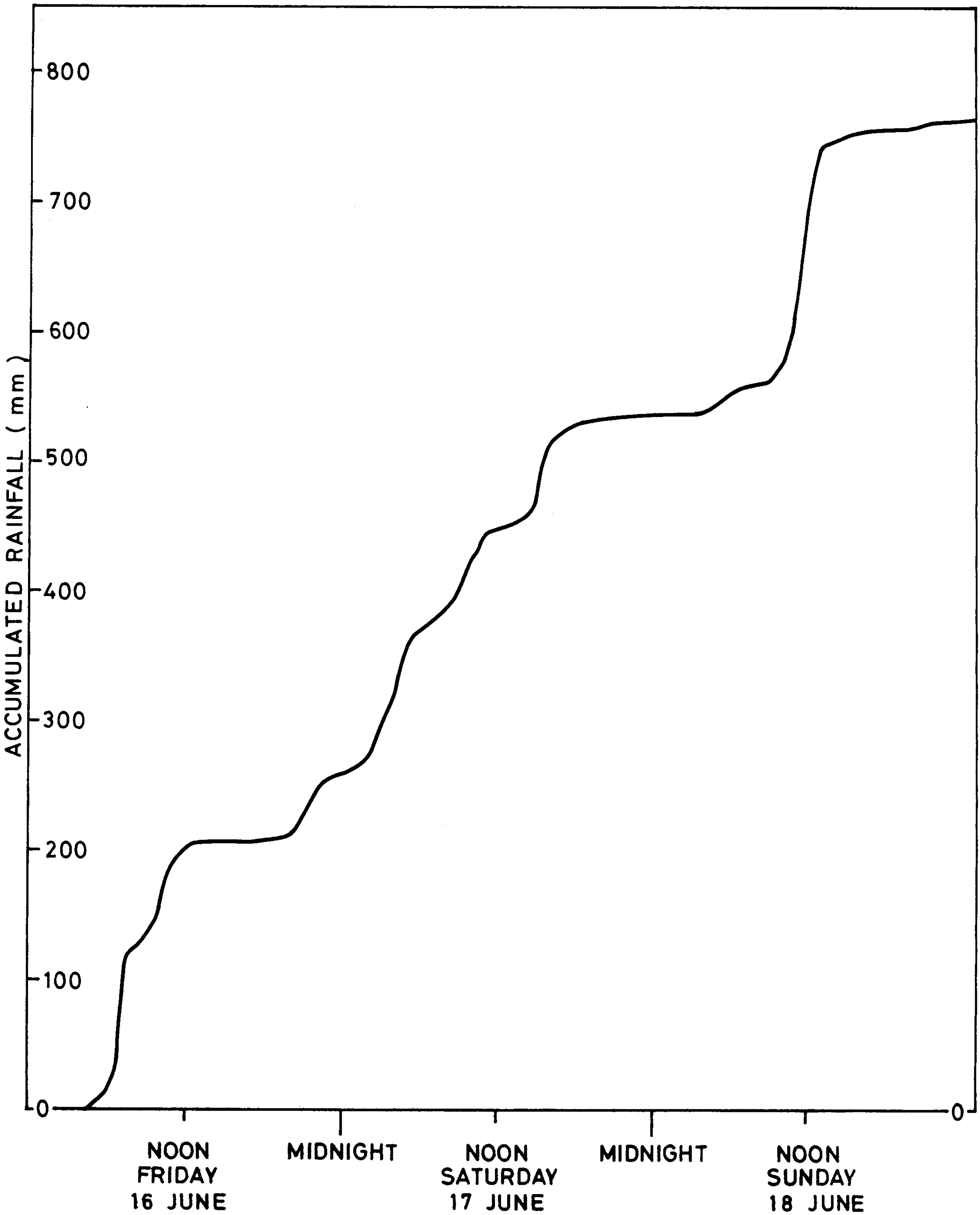


Figure 15 Estimated mass curves at Sau Mau Ping for 16 to 18 June 1972

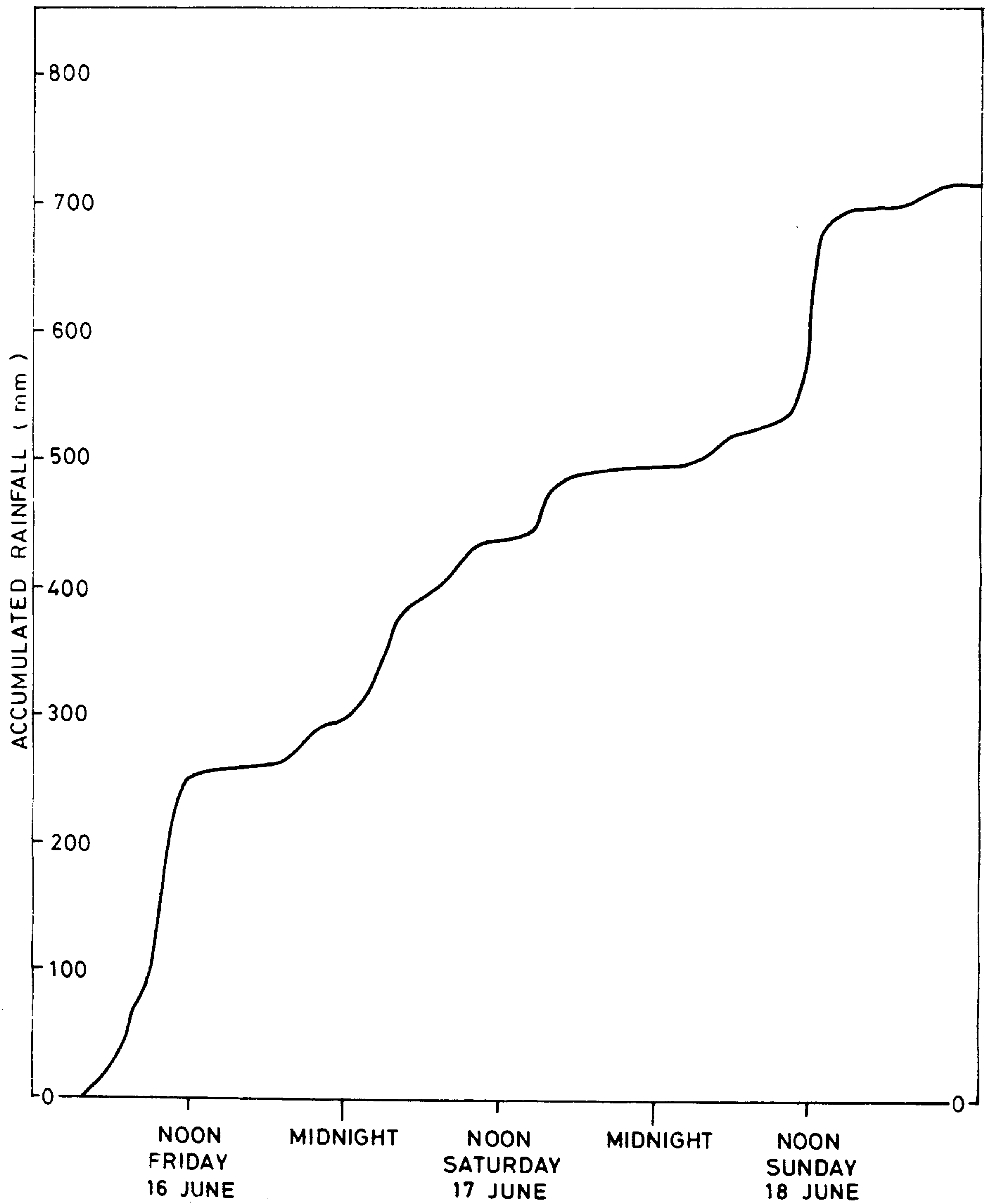


Figure 16 Estimated mass curves at Po Shan Road for 16 to 18 June 1972

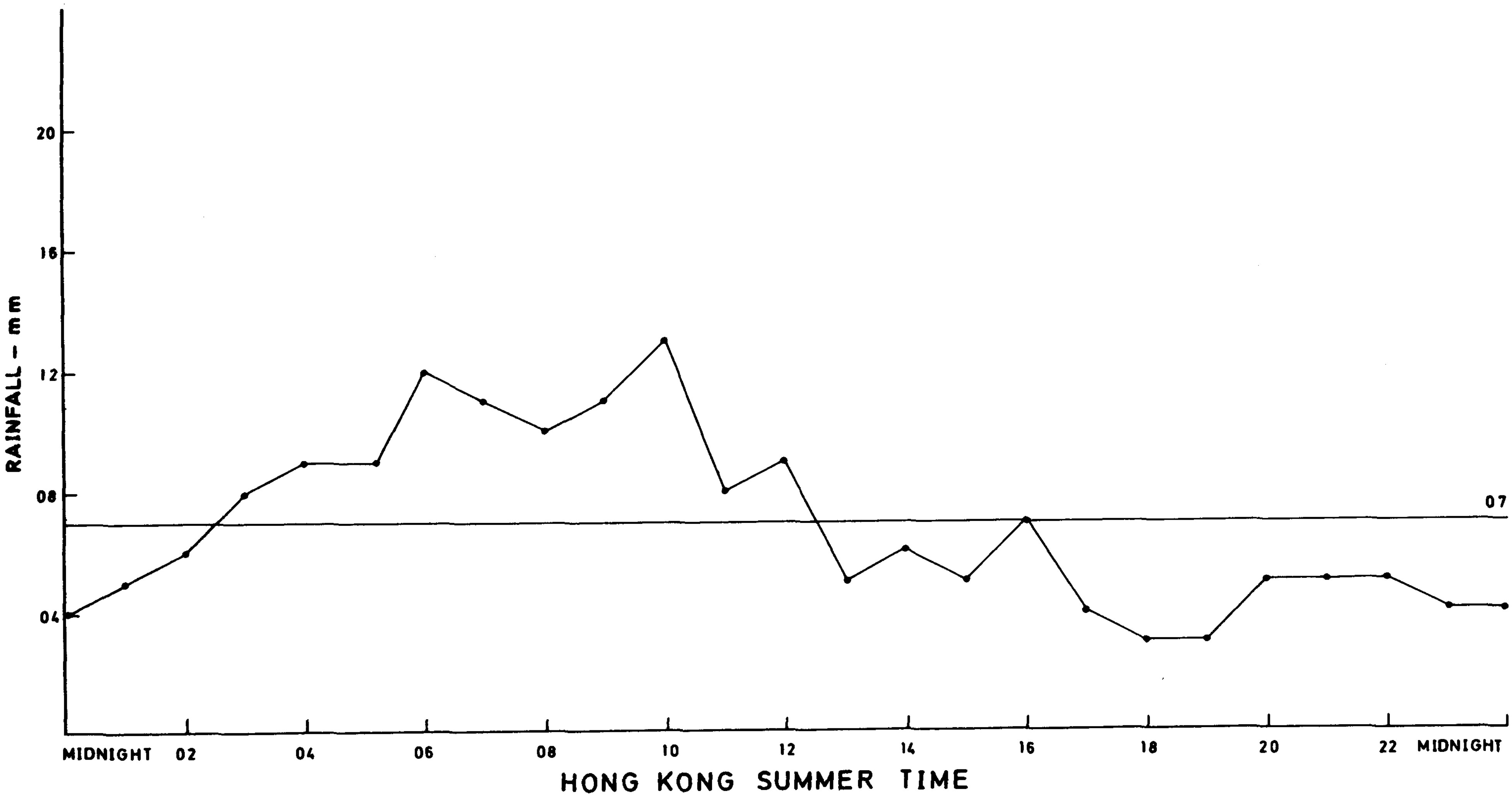


Figure 17 Mean hourly rainfall at Royal Observatory for month of June (1965 to 1976)

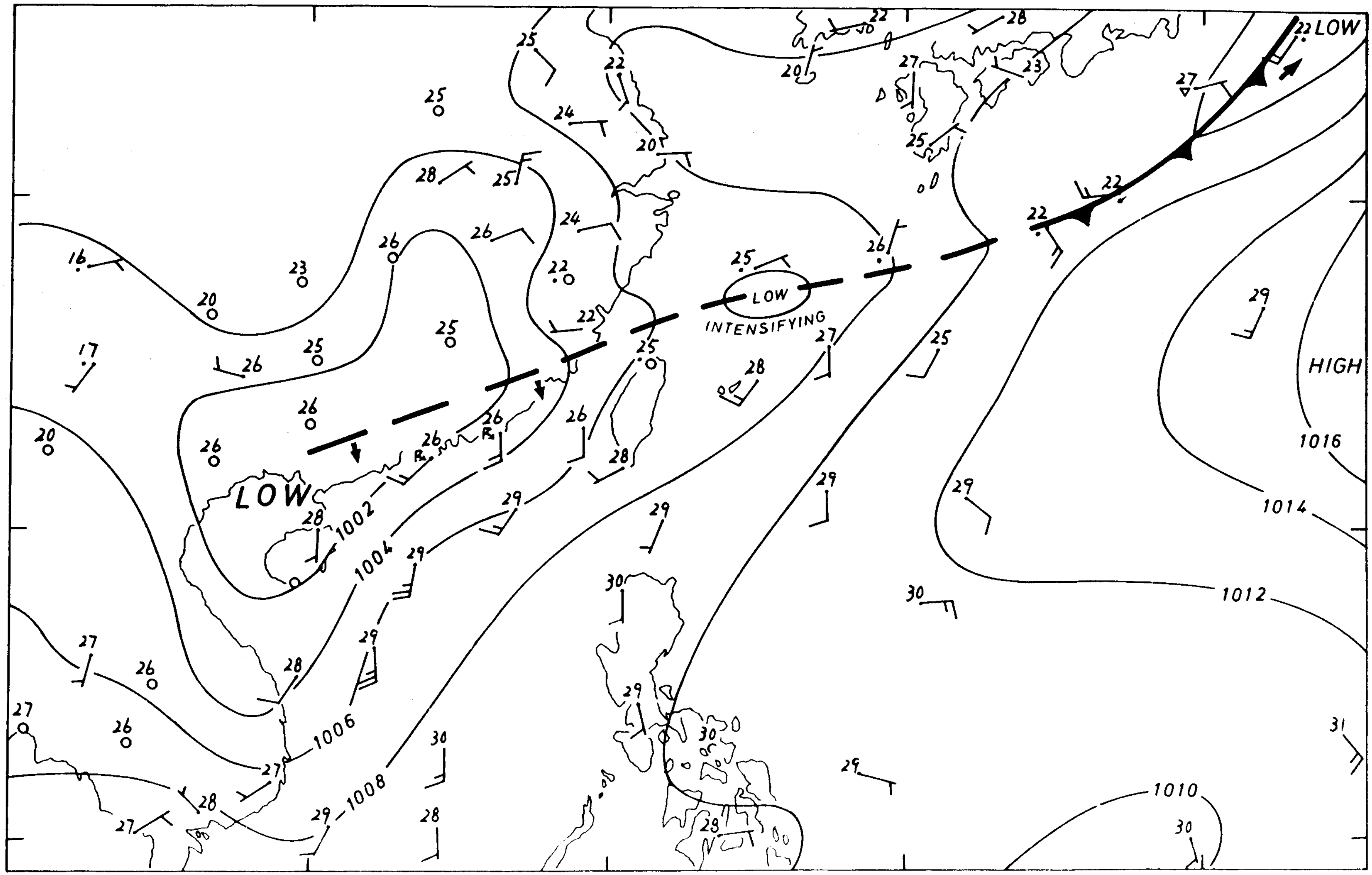


Figure 18 Surface synoptic analysis for 0000 GMT on 16 June 1972.

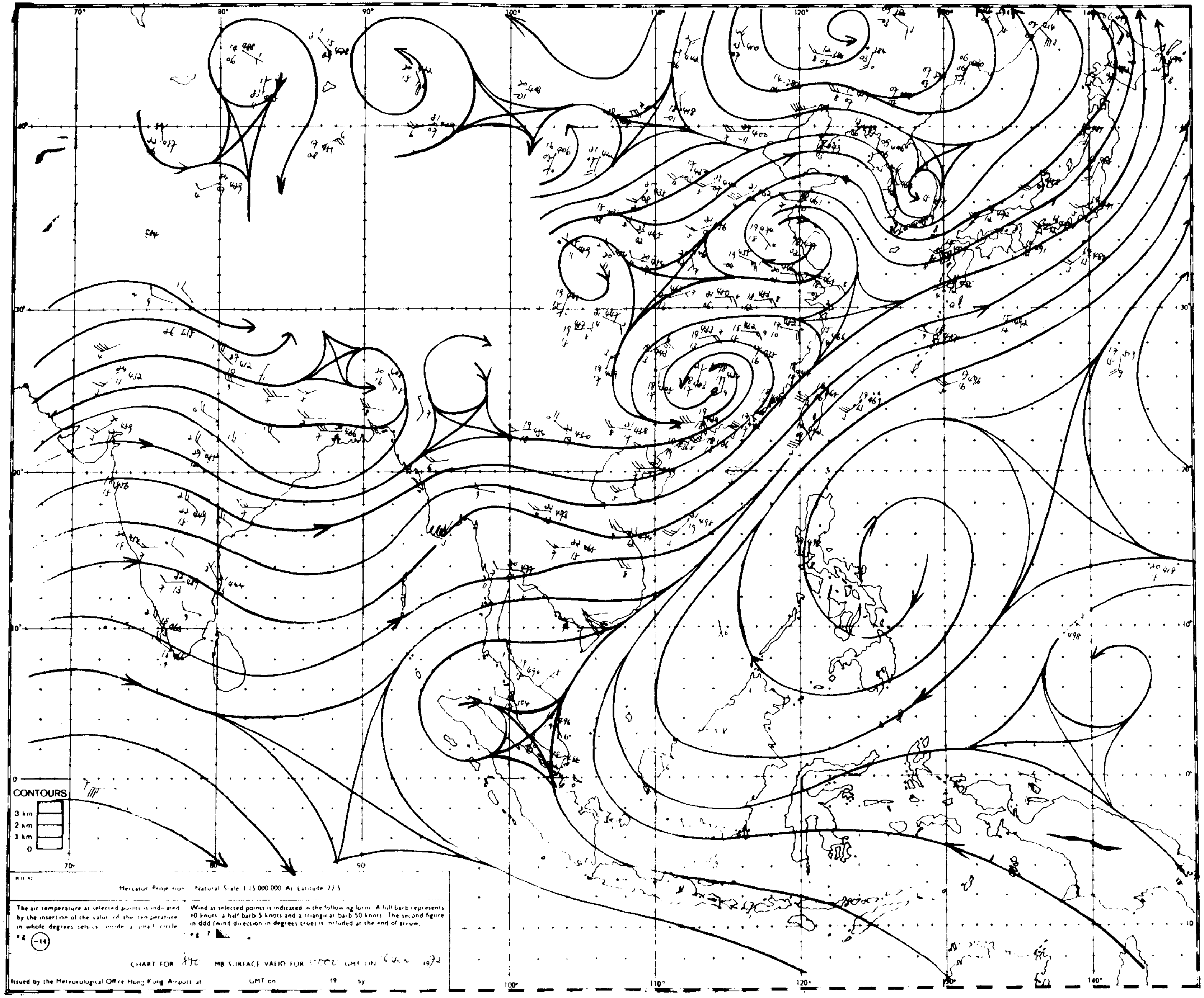


Figure 19 Streamline analysis at 850 mbar for 0000 GMT on 16 June 1972.

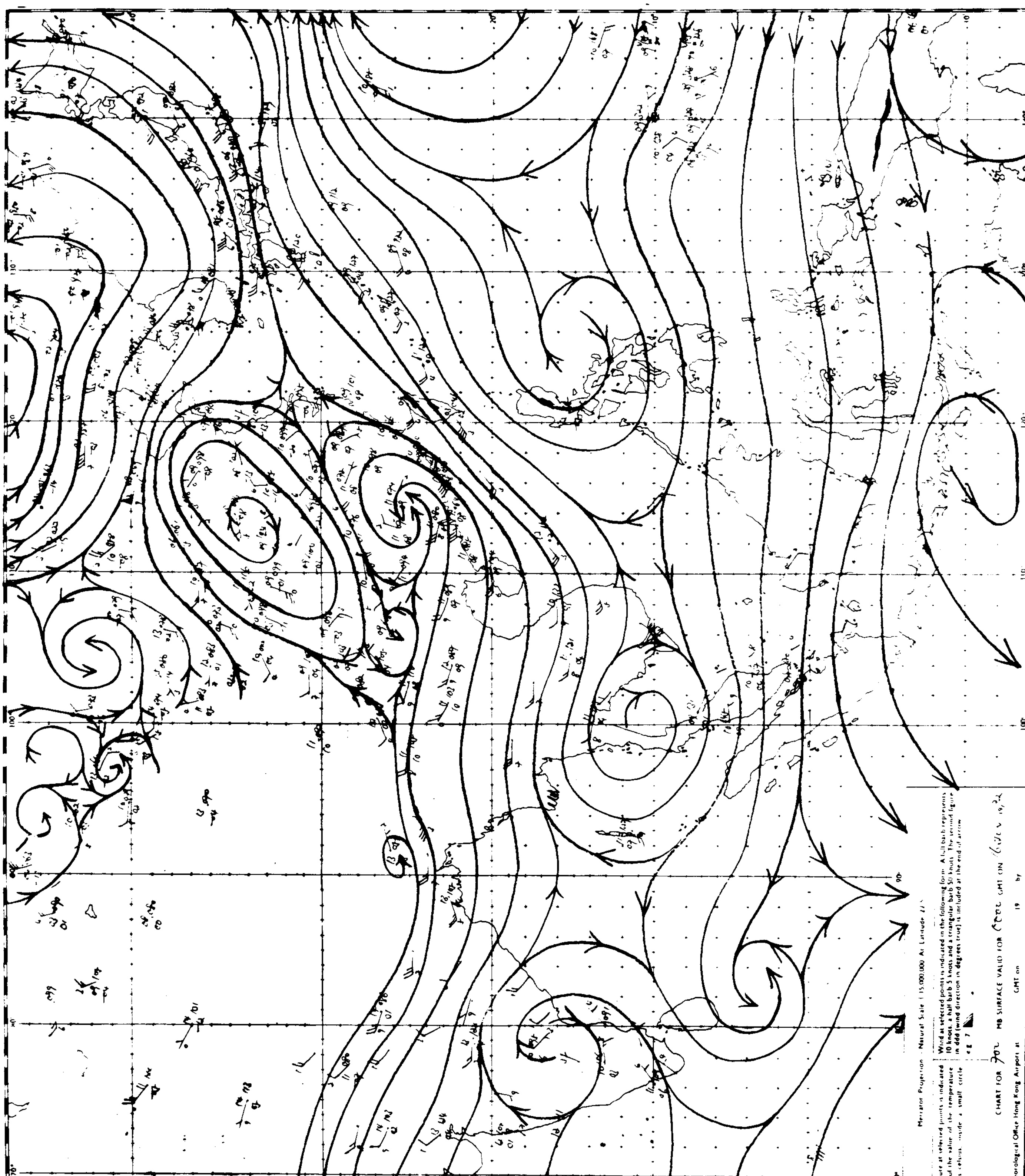


Figure 20 Streamline analysis at 700 mbar for 0000 GMT on 16 June 1972.

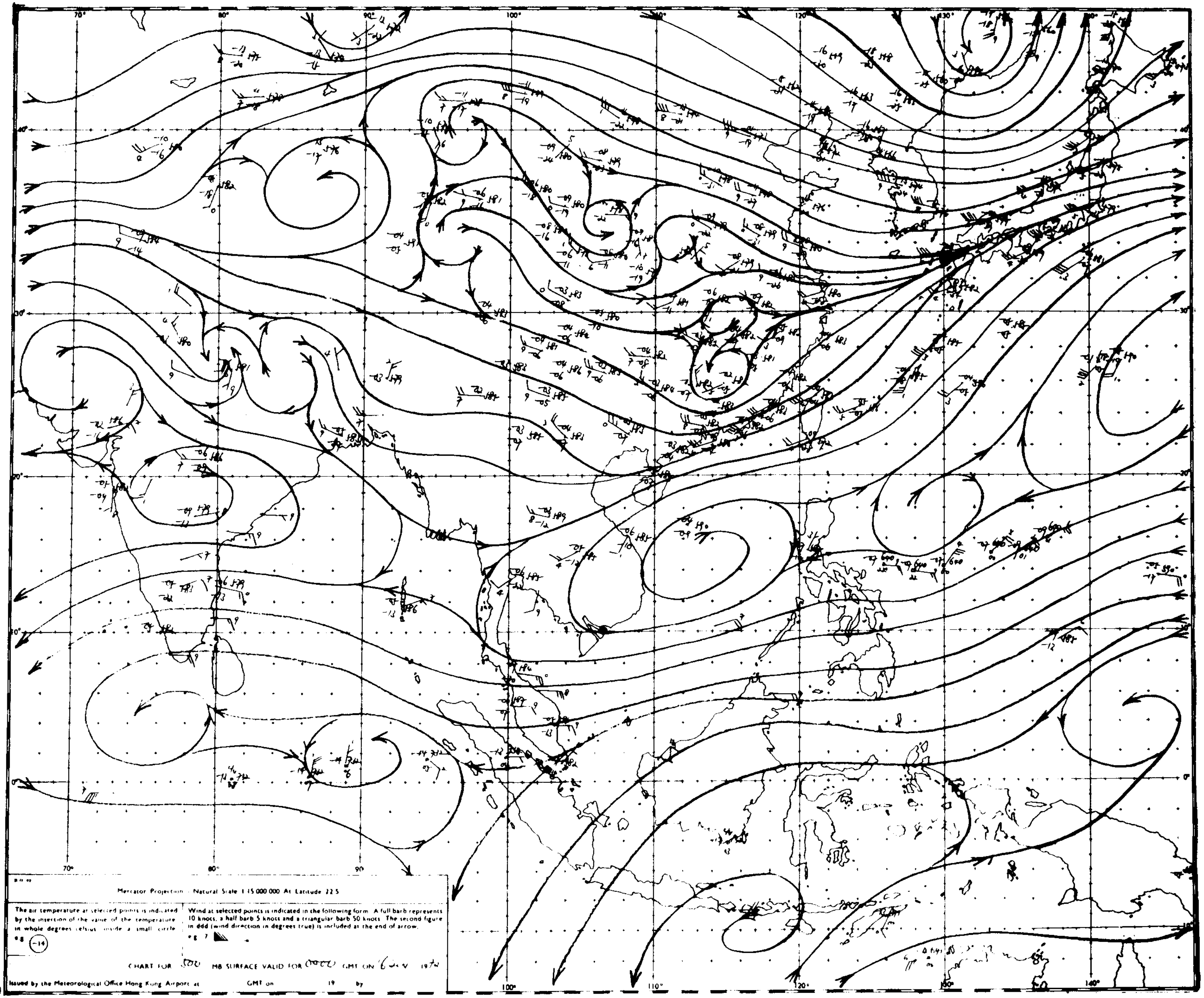


Figure 21 Streamline analysis at 500 mbar for 0000 GMT on 16 June 1972.

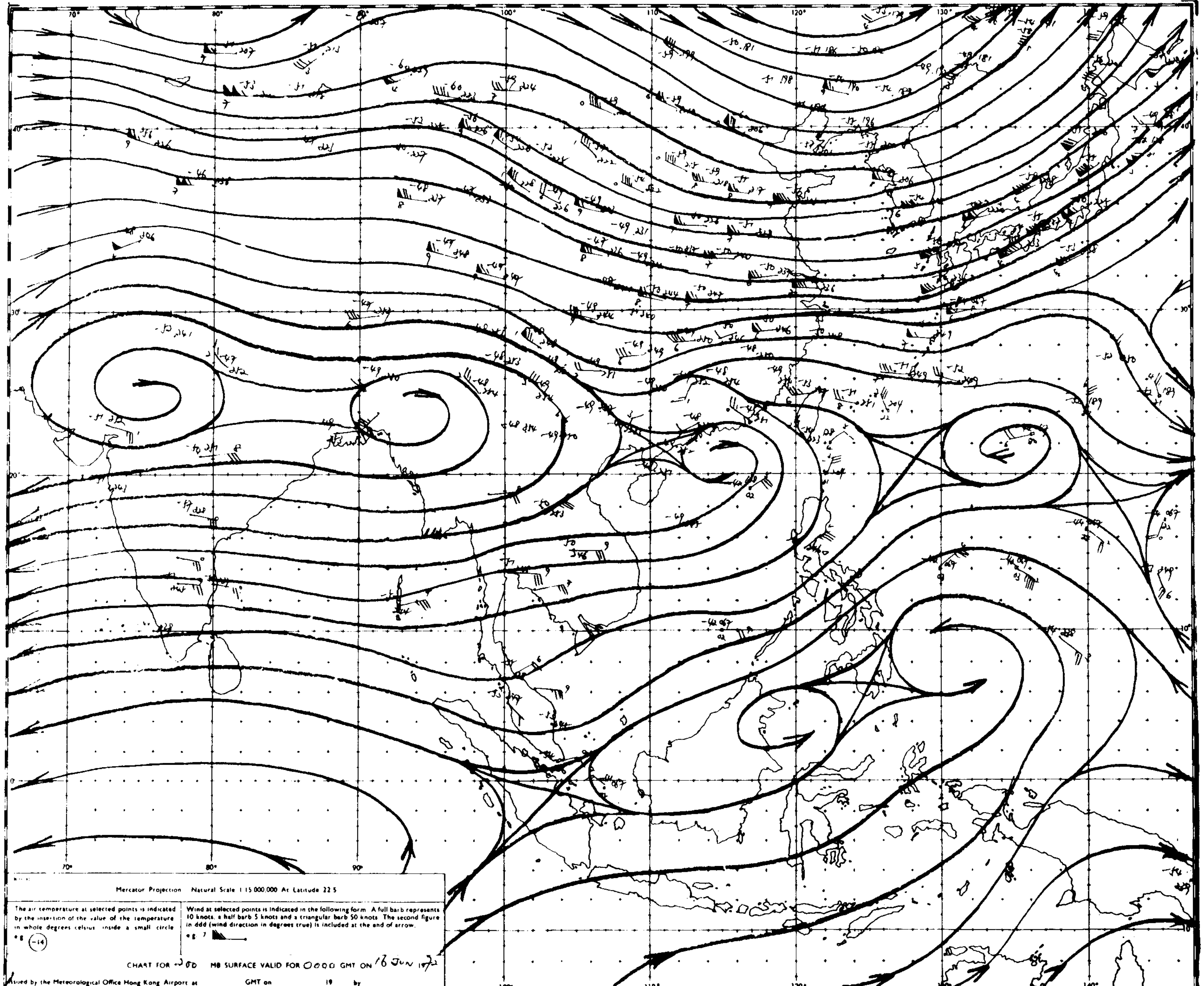
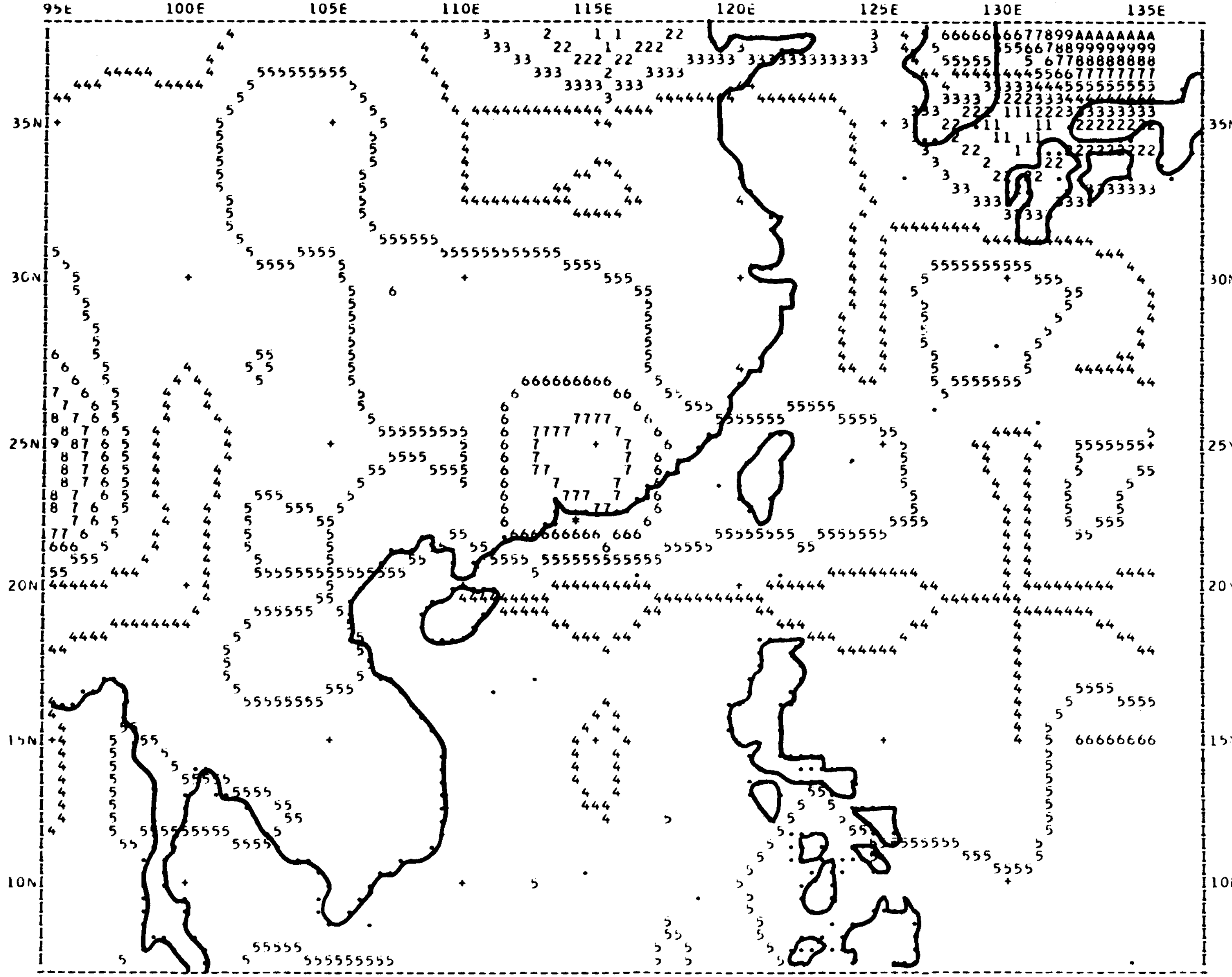


Figure 22 Streamline analysis at 200 mbar for 0000 GMT on 16 June 1972.

ISOPLETH FOR 7206 1600 50 VT LAG= 0 HR AT 8 INTERVAL, RMSE OF 0 OBS= 0.00 16



SYMBOL TABLE

0=	-40	1=	-32	2=	-24	3=	-16	4=	-8	5=	0	6=	8	7=	16	8=	24	9=	32
A=	40	B=	48	C=	56	D=	64	E=	72	F=	80	G=	88	H=	96	I=	104	J=	112
K=	120	L=	128	M=	136	N=	144	O=	152	P=	160	Q=	168	R=	176	S=	184	T=	192
U=	200	V=	208	W=	216	X=	224	Y=	232	Z=	240	*=	248						

Figure 23 Computer analysis of 500-mbar vorticity pattern over south China at 0000 GMT on 16 June 1972.

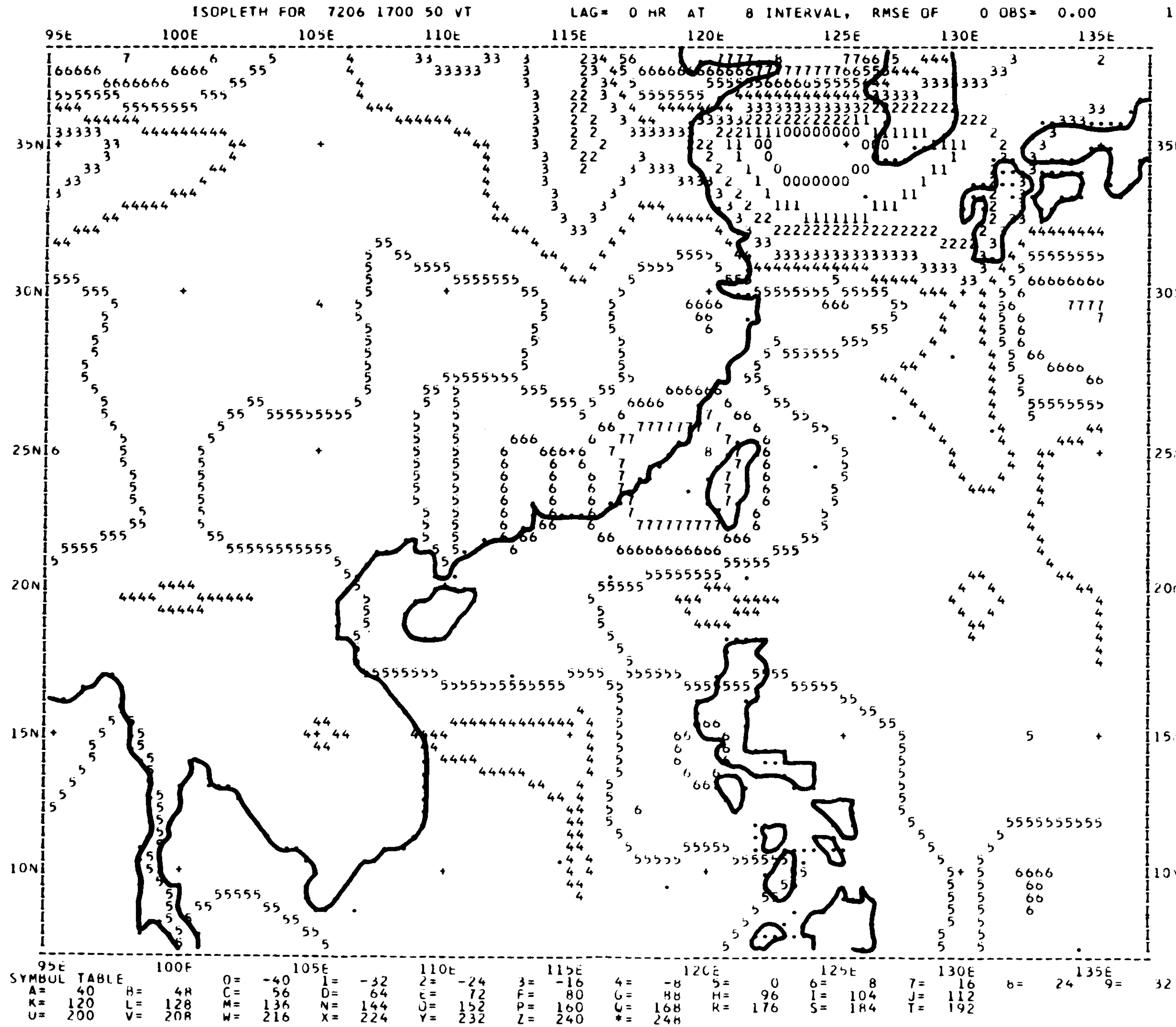


Figure 24 Computer analysis of 500-mbar vorticity pattern over south China at 0000 GMT on 17 June 1972.

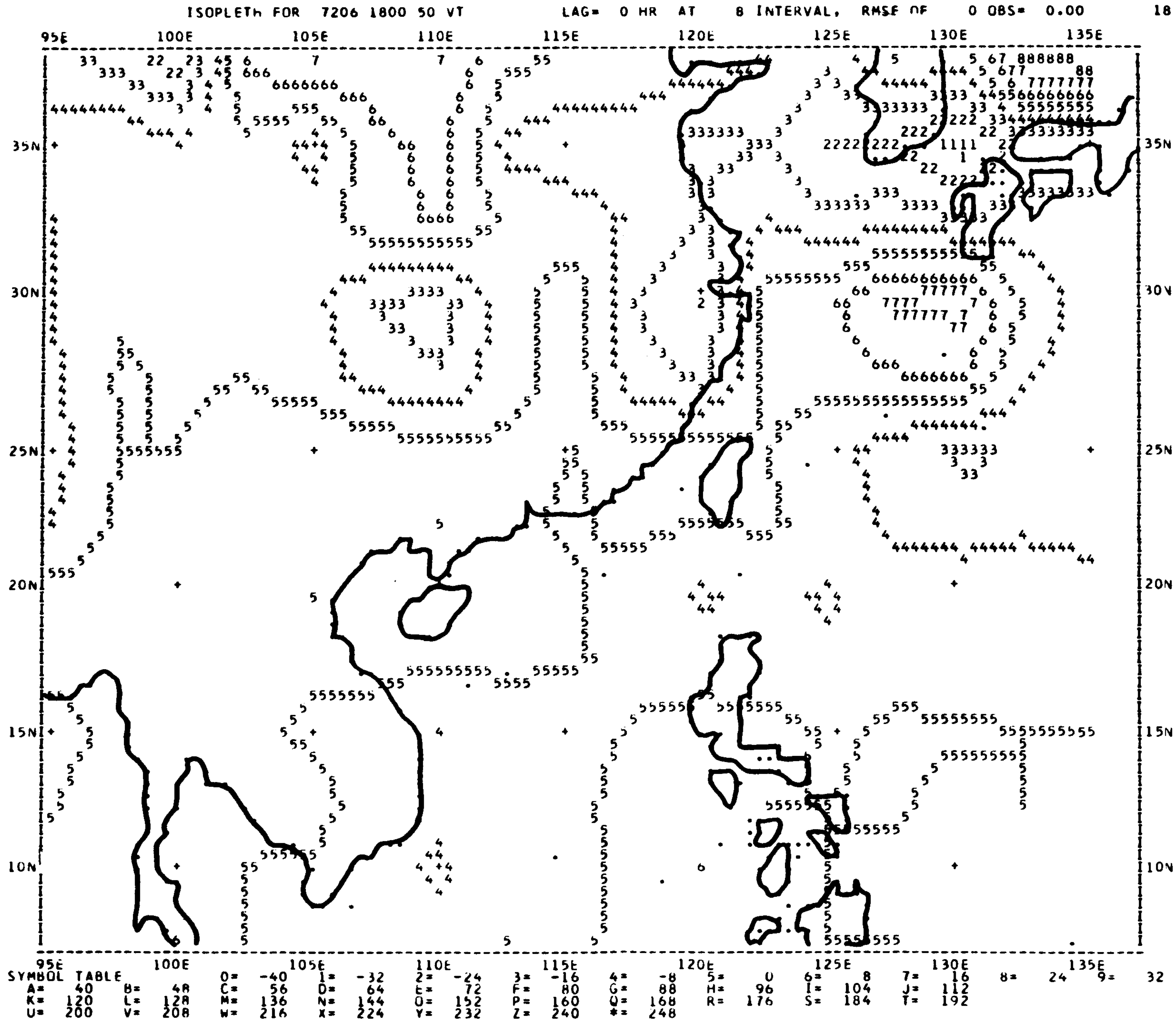


Figure 25 Computer analysis of 500-mbar vorticity pattern over south China at 0000 GMT on 18 June 1972.

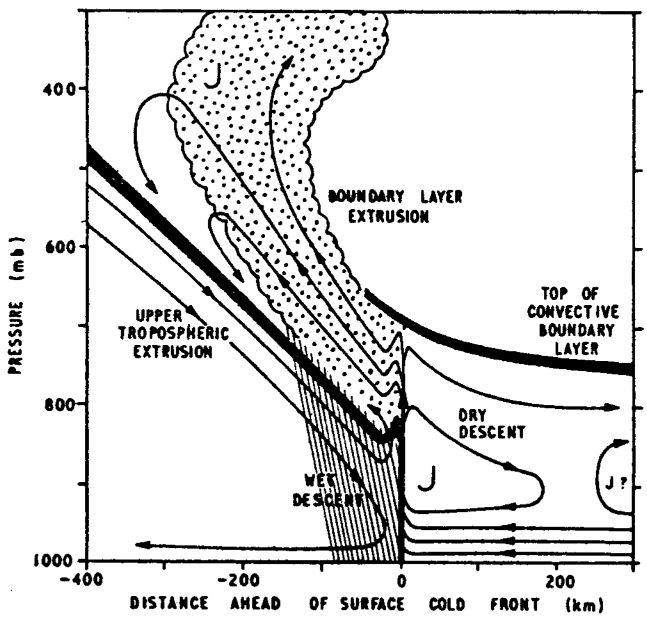


Figure 26 Model of vertical motions associated with a low-level jet core in advance of ana-cold front in mid-latitudes (after Browning and Pardoe, 1973)

Thin lines are streamlines relative to the moving system. Thick lines represent the cold frontal zone and the top of the convective boundary layer. Regions of saturated ascent are stipped.

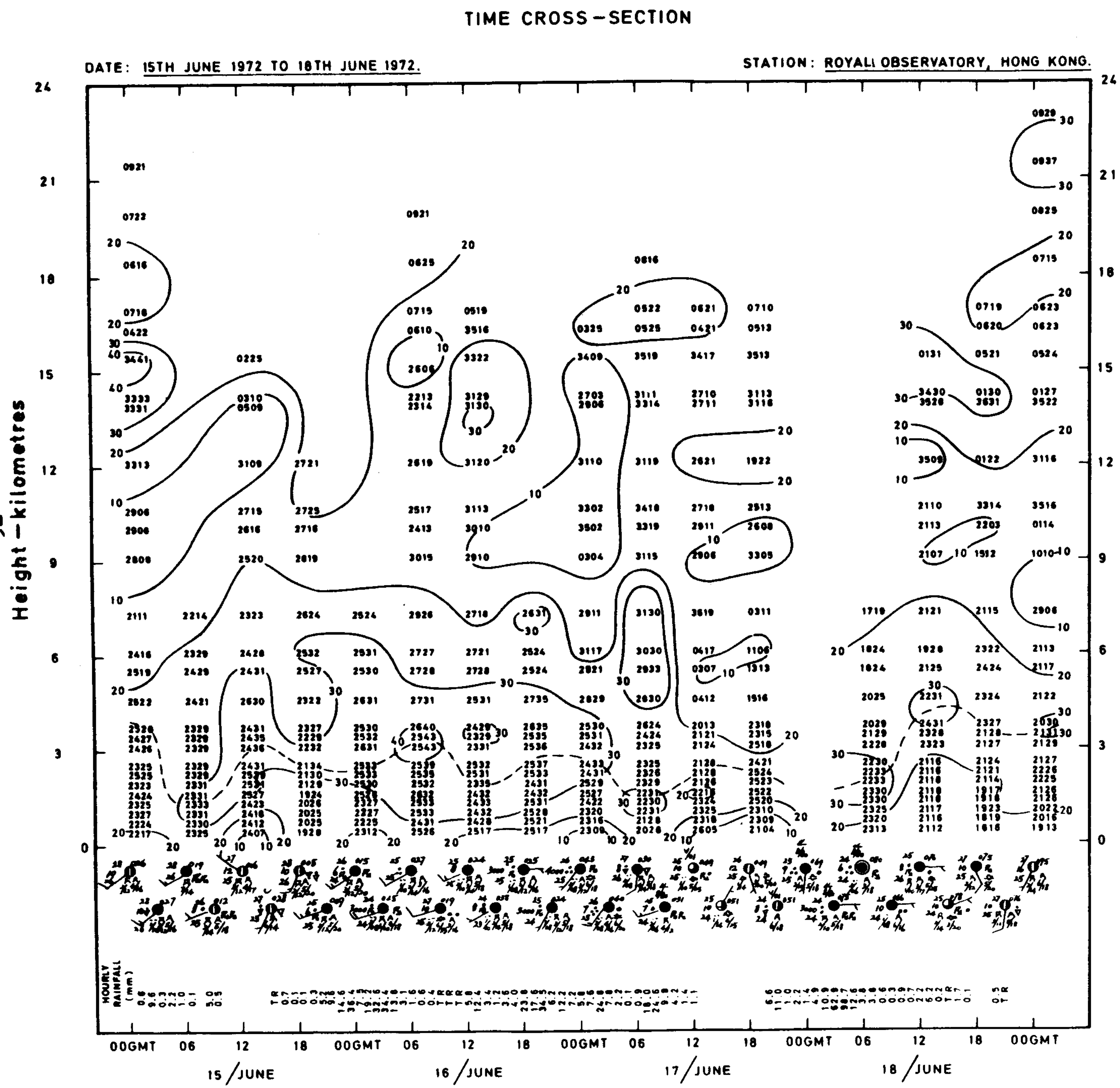


Figure 27 Time cross-section for the Royal Observatory from 0000 GMT 15 June 1972 to 0000 GMT 19 June 1972.

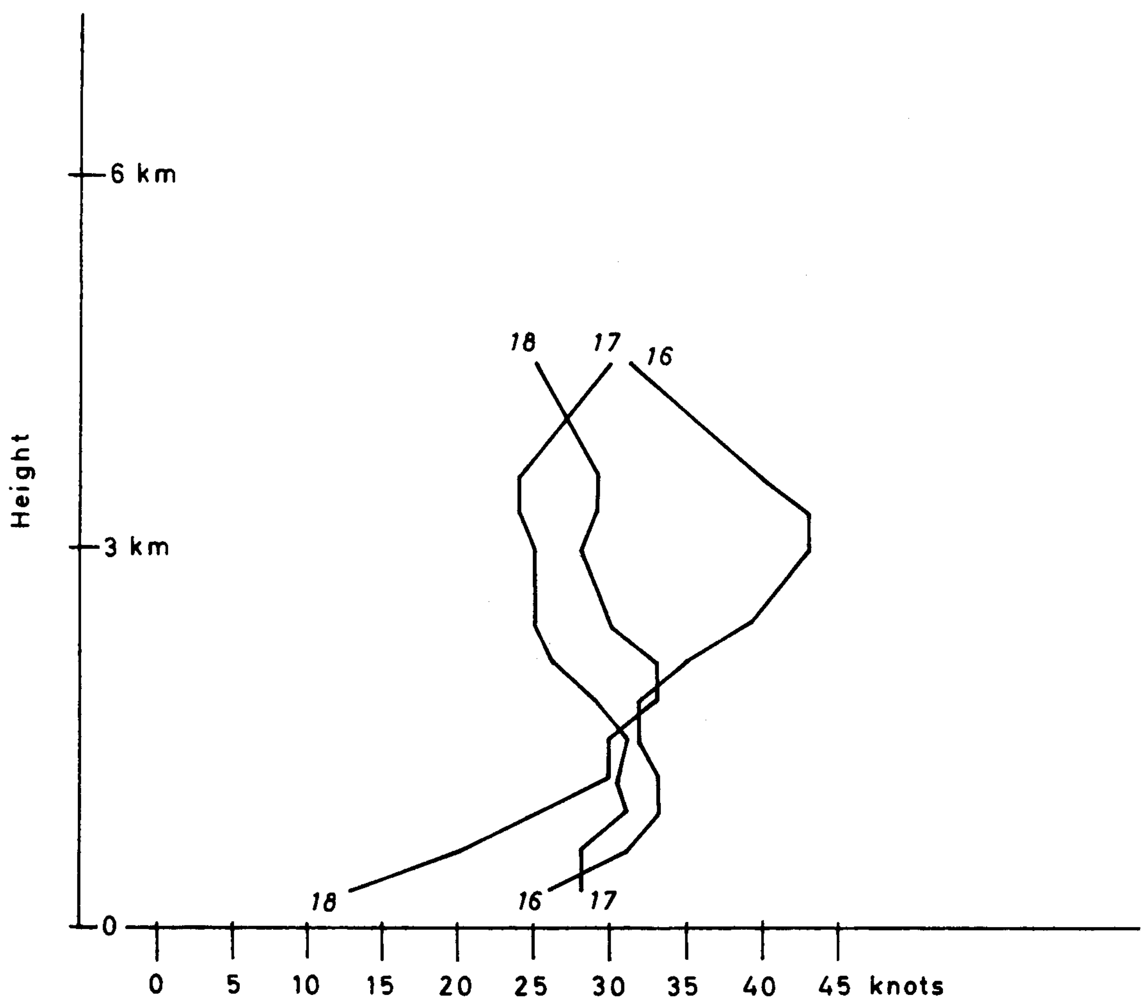


Figure 28 **Low level wind speeds over Hong Kong from 0600 GMT 16 June to 0600 GMT 18 June 1972**

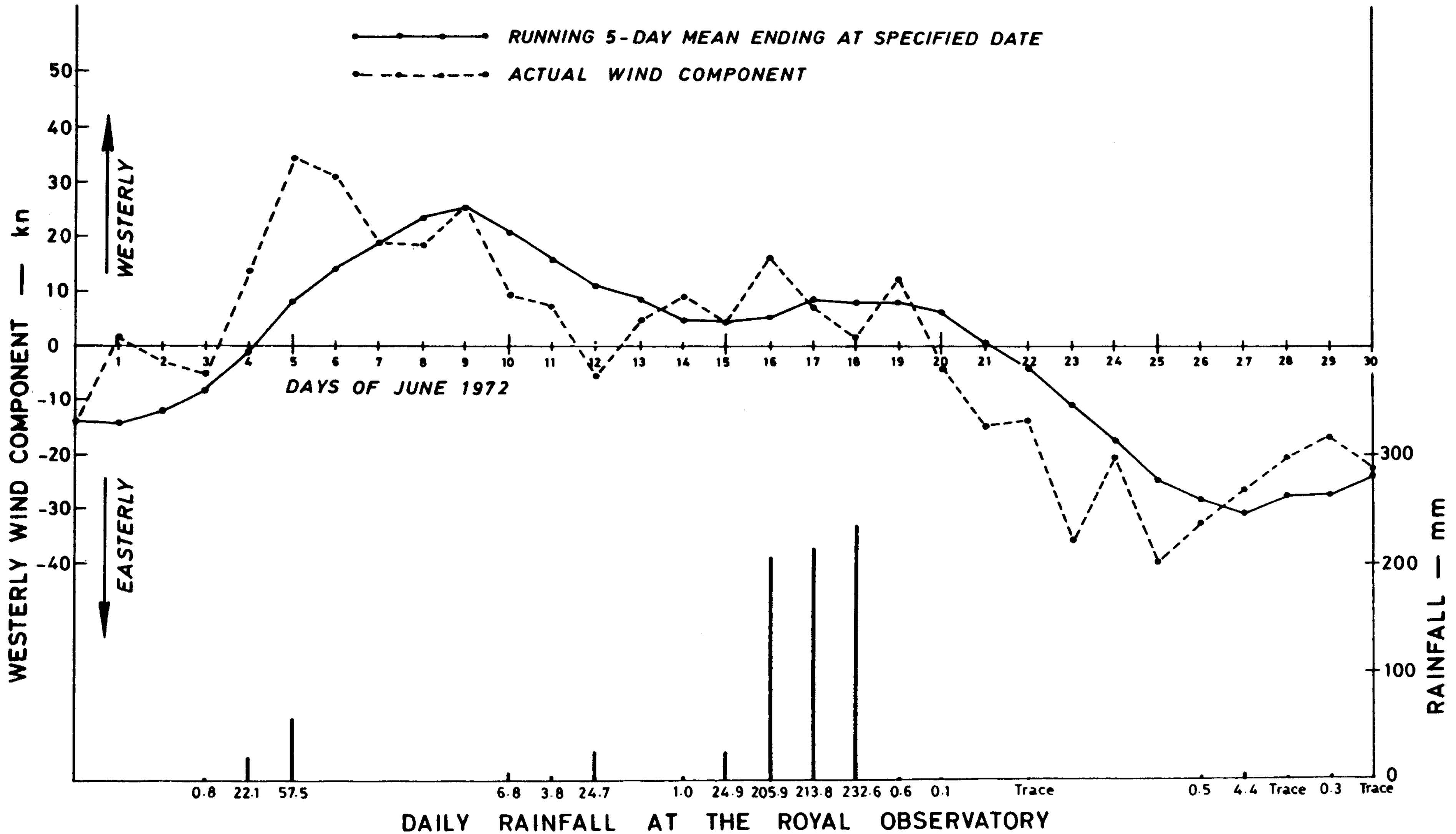


Figure 29 Daily and running 5-day mean of 200-mbar westerly wind component over Hong Kong, June 1972.

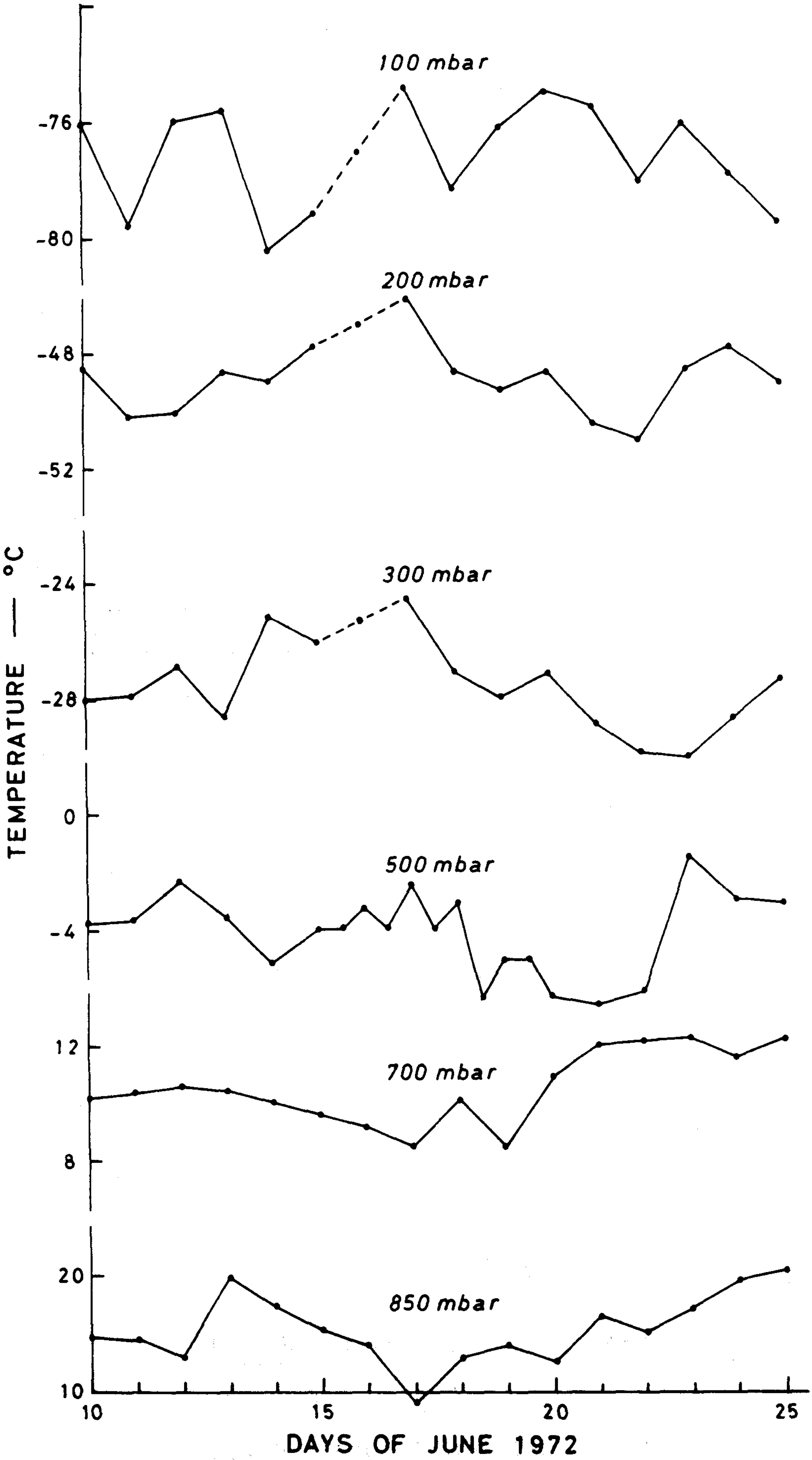


Figure 30 Temperatures at six standard pressure levels over Hong Kong at 0000 GMT from 10 June to 25 June 1972.

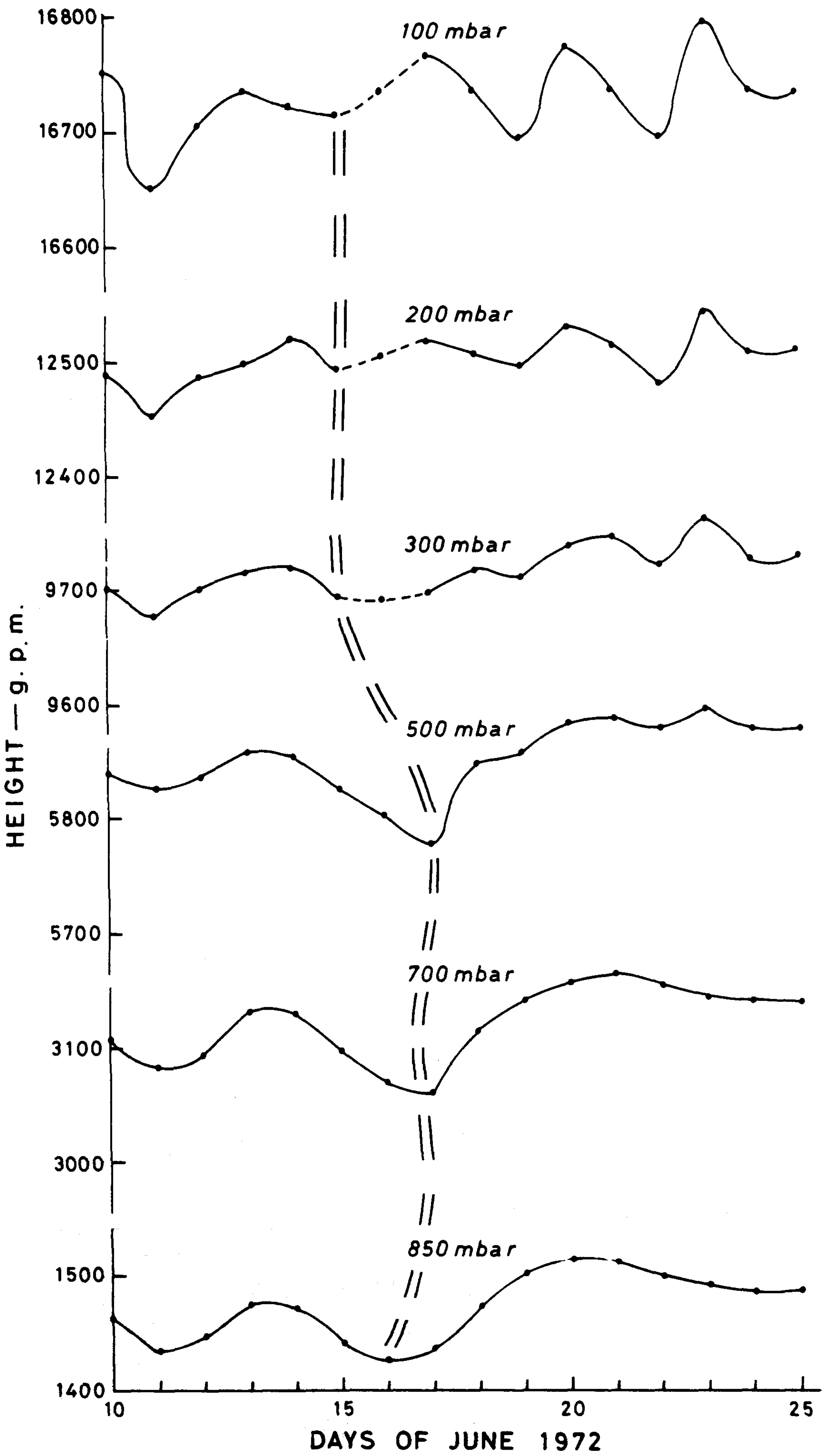


Figure 31 **Heights of six standard pressure levels over Hong Kong at 0000 GMT from 10 June to 25 June 1972.**

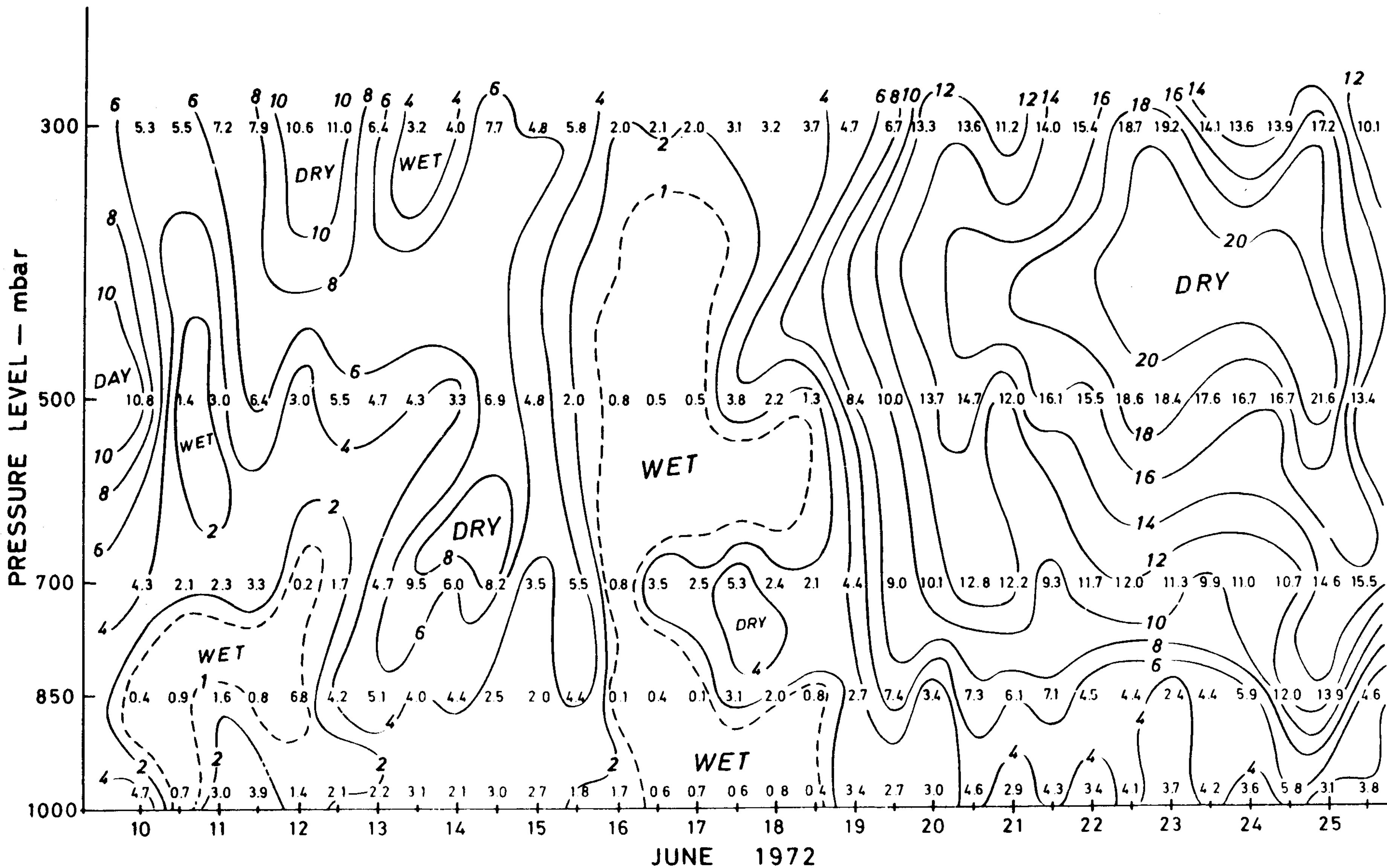


Figure 32 Dew-point depressions over Hong Kong from 10 June to 25 June 1972.

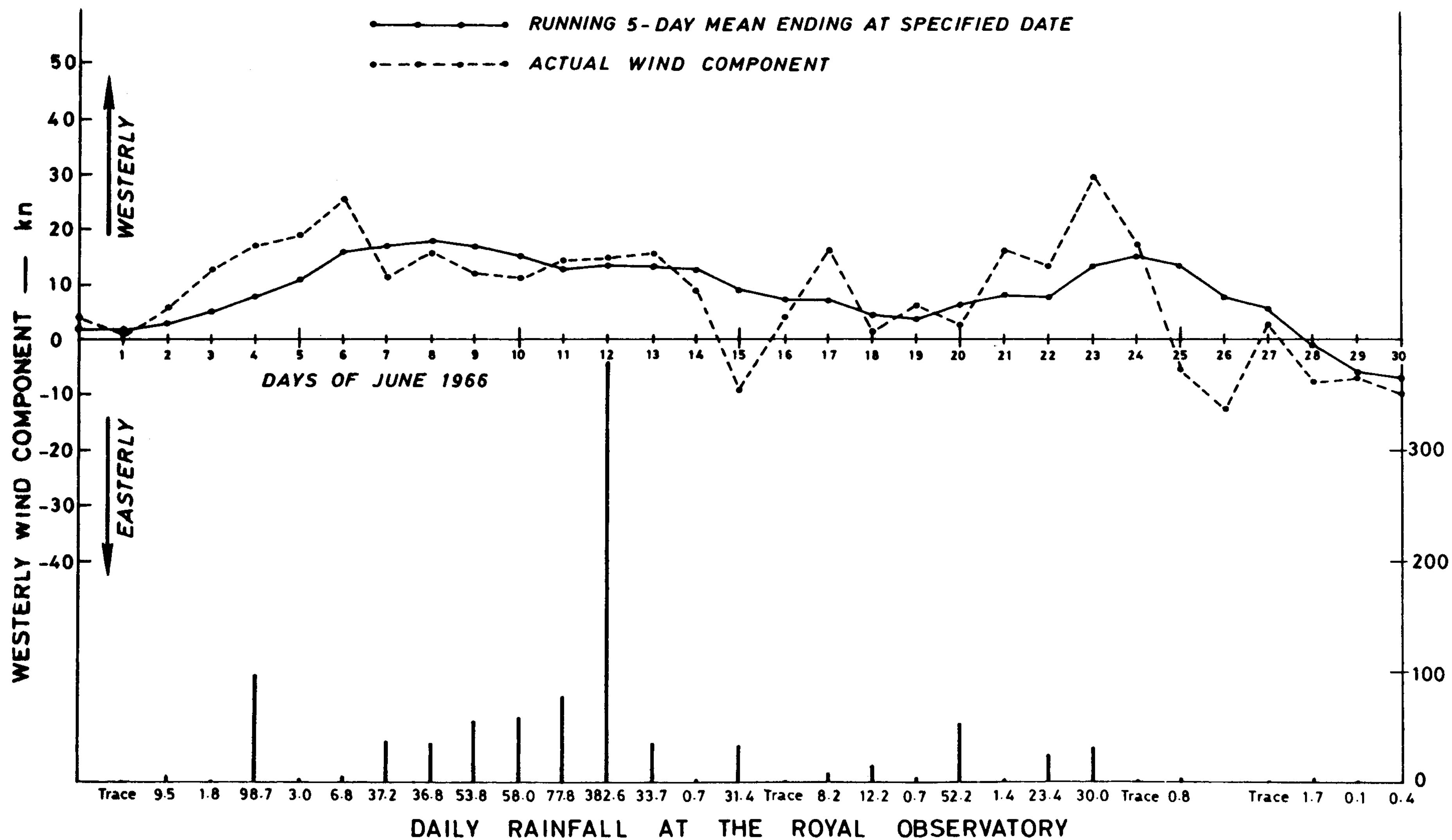


Figure 33 Daily and running 5-day mean of 200-mbar westerly wind component over Hong Kong, June 1966.

TABLE 1. THEORETICAL RETURN PERIODS OF THE RAINFALL INTENSITIES ACTUALLY RECORDED AT THE ROYAL OBSERVATORY DURING MAY AND JUNE 1972

Duration	Maximum Depth of Rainfall (mm)	Maximum Mean Rate of Rainfall ($mm\ hr^{-1}$)	Return Periods (For Royal Observatory) (Years)	Maximum Depth of Rainfall in Other Locations (mm)	Station
15 seconds	1.1	276.0	4	7.0	Tate's Cairn
15 minutes	30.5	122.0	4	50.4	Tai Mo Shan Farm
30 minutes	55.0	110.0	6	75.6	- " -
1 hour	98.7	98.7	15	118.8	- " -
2 hours	161.6	80.8	28	172.8	Tai Tam Reservoir
4 hours	185.1	46.3	10	231.1	- " -
6 hours	193.8	32.3	6	310.1	- " -
8 hours	199.0	24.9	4 - 5	381.5	- " -
12 hours	219.8	18.3	4	399.2	- " -
24 hours	275.1	11.5	4	547.1	- " -
1 day	232.6	-	2 - 3	435.0	- " -
2 days	446.4	-	12	776.5	Tai Po Kau
3 days	652.3	-	45	988.8	Aberdeen Reservoir
4 days	677.2	-	38	1014.6	- " -
5 days	678.2	-	29	1025.5	- " -
7 days	702.9	-	20	1025.9	- " -
15 days	793.1	-	14	1124.2	- " -
May (31 days)	654.5	-	2	687.9	Tai Mo Shan No. 2
June (30 days)	799.8	-	4	1147.0	Aberdeen Reservoir

TABLE 2 FREQUENCY OF DAILY RAINFALL EQUAL TO OR ABOVE SPECIFIED AMOUNTS (1947-1970)

Rainfall (mm) / Time period	Trace	0.1	1.0	2.5	5.0	10.0	25.0	50.0	100.0	200.0
Jan	22/3 12.5	13/0 6.0	11/0 3.5	6/0 2.3	5/0 1.5	4/0 0.9	1/0 0.2	1/0 0.04	0/0 0	0/0 0
Feb	26/2 14.5	19/0 8.3	11/0 4.6	8/0 3.5	7/0 2.4	7/0 1.3	2/0 0.4	1/0 0.1	0/0 0	0/0 0
Mar	26/10 18.5	17/4 9.4	10/1 5.6	9/0 4.0	8/0 1.7	6/0 1.7	3/0 0.5	1/0 0.04	0/0 0	0/0 0
Apr	27/11 18.7	19/5 11.8	14/1 7.7	10/1 5.6	8/0 4.0	6/0 3.0	4/0 1.8	3/0 0.5	1/0 0.1	0/0 0
May	28/6 20.9	26/4 14.9	20/2 11.5	18/1 9.5	16/0 7.7	14/0 5.6	10/0 3.1	6/0 1.5	2/0 0.4	1/0 0.1
Jun	29/8 24.3	28/10 21.1	23/8 16.7	19/5 14.0	16/3 11.9	15/2 8.7	11/1 5.4	6/0 2.1	3/0 0.7	1/0 0.2
Jul	31/14 22.9	29/10 19.3	26/9 15.7	21/6 13.0	16/3 10.3	13/2 7.2	10/1 4.2	5/0 1.7	2/0 0.5	0/0 0
Aug	27/11 20.9	26/9 18.7	24/7 15.8	24/5 13.5	20/4 11.4	16/4 9.2	9/1 5.0	6/0 2.3	3/0 0.7	1/0 0.04
Sep	25/8 18.5	24/4 15.7	21/3 12.7	19/3 11.0	17/2 9.7	15/1 7.5	11/0 4.3	8/0 2.0	2/0 0.6	1/0 0.1
Oct	23/5 13.5	20/2 8.2	11/1 5.7	10/0 4.0	9/0 2.9	8/0 1.7	5/0 0.8	3/0 0.4	1/0 0.04	1/0 0.04
Nov	23/3 10.2	12/1 5.5	8/0 3.0	4/0 2.1	4/0 1.4	3/0 0.9	2/0 0.5	2/0 0.2	1/0 0.04	0/0 0
Dec	21/3 11.0	11/0 5.1	8/0 2.3	7/0 1.3	4/0 0.7	2/0 0.3	1/0 0.1	1/0 0.04	0/0 0	0/0 0
Year	242/160 206.4	176/105 144.0	131/71 104.8	106/58 83.8	87/45 65.6	62/24 48.0	35/10 26.3	17/2 10.9	7/0 3.1	2/0 0.5

Number of days given by MAXIMUM/MINIMUM / MEAN

TABLE 3.

EXTRACT OF METEOROLOGICAL OBSERVATIONS MADE AT THE ROYAL OBSERVATORY, HONG KONG, DURING THE MONTH OF JUNE, 1972

Date	Mean Pressure at M.S.L.	Air Temperature			Mean Dew Point	Mean Relative Humidity	Mean Amount of Cloud	Total Bright Sunshine*	Total Rainfall	Prevailing Wind Direction	Mean Wind Speed	Total Evaporation*
		Max.	Mean	Min.								
June	mb	°C	°C	°C	°C	%	%	hours	mm	points	knots	mm
1	1011.1	29.0	25.9	23.8	21.8	79	50	9.5	—	E	6.2	5.1
2	10.1	31.4	27.3	24.5	23.4	80	36	10.1	—	E	5.0	6.3
3	08.3	31.9	28.0	25.9	25.2	85	61	10.0	0.8	E	5.0	6.3
4	05.2	28.4	26.2	24.6	24.5	91	84	—	22.1	E	3.0	1.1
5	999.1	26.9	25.4	24.2	24.4	95	98	0.1	57.5	SSE	1.5	5.6
6	99.1	31.4	27.1	23.3	21.9	74	28	12.2	—	W	3.3	6.8
7	1002.5	31.9	28.2	25.3	24.1	79	19	11.8	—	W	2.6	6.2
8	04.5	31.9	28.2	25.7	24.7	82	43	7.9	—	E	3.3	6.3
9	06.3	31.0	28.2	26.5	23.9	78	62	8.8	—	E	6.3	7.8
10	04.5	30.1	27.1	24.9	23.9	83	80	0.8	6.8	ENE	10.6	2.6
11	01.5	31.3	27.4	25.0	24.6	85	79	5.8	3.8	E	3.1	3.7
12	03.5	31.6	27.8	25.3	25.7	89	82	5.5	24.7	W	3.3	4.5
13	05.1	32.4	29.0	27.4	26.0	84	78	5.4	—	WSW	4.0	5.4
14	04.2	30.7	28.7	27.6	25.7	84	72	5.4	1.0	SW	5.2	5.4
15	02.2	29.2	27.4	25.0	25.3	88	86	0.1	24.9	SW	7.0	2.0
16	02.0	28.2	25.7	23.6	24.8	95	98	—	205.9	WSW	8.8	1.4
17	03.7	27.5	25.6	23.8	24.7	95	94	—	213.8	SSW	6.2	1.5
18	06.6	26.1	24.8	23.3	24.2	97	96	—	232.6	E	2.3	1.2
19	09.0	30.1	27.7	24.6	25.4	87	82	2.7	0.6	S	5.5	3.6
20	10.3	31.0	28.3	26.4	25.1	83	58	10.2	0.1	S	3.3	6.2
21	09.2	31.6	28.5	26.5	24.7	80	64	11.7	—	S	4.3	6.3
22	07.2	32.3	29.0	27.2	25.0	79	53	11.9	Trace	SW	4.7	9.3
23	07.2	32.5	29.2	27.3	25.0	79	51	11.5	—	WSW	3.5	7.2
24	06.7	32.2	29.0	26.6	24.5	77	21	12.0	—	WSW	3.3	7.5
25	07.9	32.8	29.0	26.6	24.9	79	31	10.6	—	E	2.9	6.4
26	05.6	31.2	28.3	26.2	24.3	80	64	5.0	0.5	E	7.7	6.5
27	04.4	30.6	27.7	26.1	24.1	81	74	4.1	4.4	SE	7.2	3.2
28	04.4	32.0	28.7	26.8	25.3	82	69	9.7	Trace	S	4.8	7.0
29	06.4	32.5	28.8	26.7	25.5	83	54	9.1	0.3	ESE	2.8	5.1
30	09.6	33.1	29.4	26.9	26.2	83	44	11.7	Trace	E	4.5	7.6
Mean	1005.6	30.8	27.7	25.6	24.6	84	64	—	—	E	4.7	—
Total	—	—	—	—	—	—	—	203.6*	799.8	—	—	155.1*

NORMALS FOR JUNE (1884–1939; 1947–1960):—

	1005.9	29.8	27.3	25.4	24.2	84	78	159.9	401.2	E	7.6	159.4*†

The lowest reading of the barometer (M.S.L.) was 996.9 mb at 1600 H.K.St.T. and at 1800 H.K.St.T. on the 5th.
The maximum gust peak speed as recorded by the Dines anemograph was 51 knots from SW at 1241 H.K.St.T. on the 15th.
The maximum instantaneous intensity of rainfall as recorded by the Jardi recorder was 254 mm per hour at 0957 H.K.St.T. on the 18th.*

* These readings were made at King's Park Meteorological Station. The figures for evaporation are the total amounts measured during the 24 hours from 0800 H.K.St.T. on the date tabulated.

† 1958–1967.

G. J. Bell,
Director,
Royal Observatory.
4th July, 1972.

TABLE 4. COMPARISON OF RAINFALL DURING JANUARY-JUNE 1972 WITH RECORDS SINCE 1884 DURING THE SAME PERIOD

INTERVAL	RANK	YEAR	DATE	RAINFALL (mm)	REMARKS
6 months, Jan. to June	1	1889		1899.0	
	2	1972		1658.6	
	3	1966		1656.8	
3 months, Apr. to June	1	1889		1799.0	
	2	1972		1588.3	
	3	1966		1440.3	
2 months, May & June	1	1889		1487.3	
	2	1972		1453.5	
	3	1957		1356.5	
1 month, June	1	1966		962.9	
	2	1959		913.7	
	3	1892		873.1	
	4	1916		817.4	
	5	1972		799.8	
15 days	1	1889	May 19-Jun 2	1238.4	
	2	1959	Jun 1- 15	858.1	
	3	1966	Jun 4- 18	840.9	
	4	1972	May 19-Jun 2	793.1	
7 days	1	1889	May 25- 31	924.6	
	2	1959	Jun 9- 15	753.8	
	3	1972	Jun 12- 18	702.9	
5 days	1	1889	May 26- 30	908.9	
	2	1959	Jun 11- 15	753.4	
	3	1926	Jul 18- 22	682.6	
	4	1972	Jun 14- 18	678.2	
4 days	1	1889	May 27- 30	870.6	
	2	1959	Jun 12- 15	724.6	
	3	1972	Jun 15- 18	677.2	
3 days	1	1889	May 28- 30	854.9	
	2	1972	Jun 16- 18	652.3	First occasion in 82 years when each of three consecutive days recorded more than 200 mm
2 days	1	1889	May 29- 30	841.2	
	2	1926	Jul 19- 20	561.2	
	3	1966	Jun 11- 12	460.4	
	4	1959	Jun 14- 15	452.0	
	5	1972	Jun 17- 18	446.4	
1 day	1	1926	Jul 19	534.0	Does not rank in top five
	-	1972	Jun 18	232.6	
24 hours	1	1889	May 30	697.1	- " -
	-	1972	Jun 17- 18	275.1	
12 hours	1	1926	Jul 19	526.7	- " -
	-	1972	Jun 18	219.8	
8 hours	1	1926	Jul 19	505.1	- " -
	-	1972	Jun 18	199.0	
6 hours	1	1926	Jul 19	430.6	- " -
	-	1972	Jun 18	193.8	
4 hours	1	1889	May 30	302.3	- " -
	-	1972	Jun 18	185.1	
2 hours	1	1926	Jul 19	174.4	
	2	1889	May 30	167.7	
	3	1966	Jun 12	165.9	
	4	1972	Jun 18	161.6	
1 hour	1	1966	Jun 12	108.2	
	2	1926	Jul 19	100.7	
	3	1968	Jun 13	100.0	
	4	1972	Jun 18	98.7	

TABLE 5 MAXIMUM AVERAGE DEPTH (mm) OF RAINFALL FROM THE ENVELOPE DEPTH-DURATION-AREA CURVES DURING 16-18 JUNE 1972

(a)

Area \ Time (hour)	¼	½	1	1½	2	2½	3	4	5	6
Sq. miles*	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
2	49	89	142	194	256	273	276	281	312	345
3	48	87	138	189	250	266	270	275	303	337
5	45	82	133	181	238	254	258	263	293	327
10	40	74	122	166	217	232	247	242	278	312
15	35	64	110	150	195	212	220	226	268	302
20	30	57	97	132	174	190	203	216	261	295
30	22	39	70	97	128	148	167	206	252	284

(b)

Area \ Time (hour)	12	18	24	30	36	42	48	54	60	66	72
Sq. miles*	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
2	400	431	530	636	658	700	711	780	958	967	972
3	399	429	520	630	650	680	692	766	945	950	960
5	391	421	509	613	636	656	670	747	926	930	942
10	374	419	498	591	618	634	650	713	890	900	910
15	366	410	490	582	608	623	640	690	870	880	890
20	358	402	482	578	600	617	632	670	855	866	871
30	348	388	470	567	588	607	620	653	832	840	847
50	331	360	450	540	568	590	603	627	794	802	810
100	290	312	400	472	533	554	564	580	734	744	755
150	252	275	353	428	500	527	530	559	700	710	722
200	228	250	320	390	470	500	504	547	672	690	699
250	209	232	299	367	440	472	480	530	655	670	678
300	197	218	280	342	411	450	462	508	645	655	662

* 1 square mile = 2.59 km^2

TABLE 6 PROBABLE MAXIMUM RAINFALL OVER HONG KONG

Area \ Time (hour)	¼	½	1	1½	2	2½	3	4	5	6	7	8	9	12	15	18
Sq. miles*	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
3	78	145	220	267	332	387	450	522	606	677	694	734	776	865	975	1055
5	75	137	210	266	330	385	443	509	589	654	674	712	759	850	957	1045
10	70	125	195	263	324	374	428	488	563	616	638	678	728	841	945	1035
15	68	117	187	259	317	365	415	477	544	592	618	658	707	832	934	1024
20	67	111	180	255	312	359	405	469	530	577	605	645	693	825	926	1016
30	65	104	175	250	305	351	390	451	512	560	590	628	674	812	913	1000
50	62	96	174	242	296	340	377	434	492	547	577	615	656	792	890	975
100	55	89	170	230	285	334	372	423	472	528	555	590	632	754	848	927
150	47	86	165	220	277	327	365	415	456	509	532	565	610	720	814	884
200	40	85	159	212	269	319	356	404	440	490	512	544	589	693	782	848
250		83	152	205	262	310	345	390	426	470	492	525	569	666	755	818
300		80	150	200	254	300	335	376	415	455	476	510	550	645	730	790
400		76	135	190	238	280	314	352	389	427	447	480	518	605	686	746

* 1 square mile = 2.59 km^2

TABLE 7 MAXIMUM AVERAGE DEPTH OF RAINFALL DURING SEVERE RAINSTORMS OF 12 JUNE 1966 (0300-2100 H.K.St.T.)

Time (hour) / Area	$\frac{1}{4}$	$\frac{1}{2}$	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	4	5	6	9	12	15	18
Sq. miles*	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
2	53	88	163	233	285	316	336	369	412	422	433	480	527	537
3	53	87	162	232	284	315	335	367	410	420	431	475	521	530
5	52	85	158	226	280	312	330	362	407	415	426	469	508	518
10	50	84	153	221	270	301	317	348	394	402	412	450	488	498
15	49	82	150	217	262	290	305	340	382	392	402	431	470	480
20	48	80	148	212	254	280	297	335	372	384	395	418	455	462
30	45	74	142	201	240	265	280	328	360	370	380	392	430	435
50	39	62	128	167	211	234	255	300	320	330	356	373	405	414
100	24	42	78	116	145	163	175	212	231	242	287	353	380	392
150	22	40	72	102	130	147	165	200	219	230	267	337	370	380
200	20	38	65	95	118	135	159	193	212	222	255	325	360	370
250	18	34	62	89	110	128	152	187	205	215	247	314	350	360
300	17	30	59	84	105	120	145	179	199	210	239	300	338	350
400	14	27	53	78	96	114	137	167	189	201	228	275	315	325

* 1 square mile = 2.59 km^2

TABLE 8 COMPARISON OF RAINFALL INTENSITIES AT TAI MO SHAN FARM AND TAI TAM RESERVOIR DURING JUNE 1972

Duration	Tai Mo Shan Farm			Tai Tam Reservoir		
	Rainfall (mm)	Date	Time of beginning of period (H.K.St.T.)	Rainfall (mm)	Date	Time of beginning of period (H.K.St.T.)
15 minute	50.4	June 17	2.20 p.m.	50.0	June 18	12.30 p.m.
30 minute	75.6	June 17	2.05 p.m. & 2.20 p.m.	68.0	June 18	12.25 p.m.
60 minute	118.8	June 17	2.05 p.m.	92.0	June 18	11.05 a.m.
1 hour	116.2	June 17	2.00 p.m.	90.1	June 18	11.00 a.m.
2 hour	141.8	June 17	1.00 p.m.	172.8	June 18	11.00 a.m.
3 hour	156.3	June 17	1.00 p.m.	181.4	June 18	10.00 a.m.
6 hour	170.5	June 17	1200 noon	310.1	June 16	7.00 a.m.
9 hour	189.2	June 17	7.00 a.m.	392.5	June 16	5.00 a.m.
12 hour	222.8	June 17	4.00 a.m.	399.2	June 16	4.00 a.m.

TABLE 9 MAXIMUM RATE OF RAINFALL RECORDED BY JARDI RECORDERS, 16 TO 18 JUNE 1972

Station	June 16		June 17		June 18	
	Rate (mm/h)	Time	Rate (mm/h)	Time	Rate (mm/h)	Time
Royal Observatory	278	9.55 a.m.	271	3.35 a.m.	301	10.00 a.m.
King's Park Meteorological Station	190	6.20 a.m.	137	10.00 a.m.	251	9.59 a.m.
Hong Kong International Airport	146	6.35 a.m.	132	3.40 a.m.	171	10.15 a.m.
Tate's Cairn Radar Station	276	10.35 a.m.	30	10.10 a.m.	264	11.44 a.m.

TABLE 10 COMPARISON OF MAXIMUM RAINFALL INTENSITIES RECORDED AT THE ROYAL OBSERVATORY DURING THE SEVERE RAINSTORMS OF JUNE 1966 WITH THOSE OBSERVED IN JUNE 1972

Time interval	June 1966		June 1972	
	Highest rainfall amount (mm)	Date and time of occurrence (H.K.St.T.)	Highest rainfall amount (mm)	Date and time of occurrence (H.K.St.T.)
1 hour	108.2	0600-0700 June 12	98.7	1100-1200 June 18
2	165.9	0500-0700 June 12	161.6	1000-1200 June 18
4	273.4	0500-0900 June 12	185.1	0900-1300 June 18
6	318.8	0400-1000 June 12	193.8	0800-1400 June 18
8	330.0	0400-1200 June 12	199.0	0700-1500 June 18
12	340.0	0100-1300 June 12	219.8	0300-1500 June 18
24	401.2	1100 June 11 - 1100 June 12	275.1	1400 June 17 - 1400 June 18
1 day	382.6	June 12	232.6	June 18
2	460.4	June 11-12	446.4	June 17-18
3	518.4	June 10-12	652.3	June 16-18
4	572.2	June 9-12	677.2	June 15-18
5	609.0	June 8-12	678.2	June 14-18
7	679.9	June 7-13	702.9	June 12-18
15	840.9	June 4-18	793.1	June 4-18
1 month	962.9	June 1-30	799.8	June 1-30

TABLE 11(a) ESTIMATED HOURLY RAINFALL (mm) NEAR SAU MAU PING DURING 16-18 JUNE 1972

Time (Hours H.K.Summer Time) \ Day	Hourly rainfall ending at specified time (mm)		
	16 June	17 June	18 June
0100	Nil	2	Nil
0200	Nil	9	Nil
0300	Nil	21	1
0400	Nil	28	3
0500	4	38	8
0600	8	11	6
0700	38	8	5
0800	73	8	3
0900	7	13	2
1000	23	30	14
1100	34	15	40
1200	14	5	82
1300	4	4	44
1400	1	2	5
1500	1	16	3
1600	1	44	2
1700	Nil	8	2
1800	Nil	5	Nil
1900	2	4	Nil
2000	2	2	1
2100	12	1	2
2200	24	2	2
2300	9	Nil	1
2400	3	Nil	1
Total	260	276	227

TABLE 11(b) ESTIMATED HOURLY RAINFALL (mm) NEAR PO SHAN ROAD DURING 16-18 JUNE 1972

Time (Hours H.K.Summer Time) \ Day	Hourly rainfall ending at specified time (mm)		
	16 June	17 June	18 June
0100	Nil	4	Nil
0200	Nil	10	Nil
0300	1	22	2
0400	1	32	4
0500	6	18	10
0600	10	8	7
0700	17	5	3
0800	38	7	2
0900	17	12	4
1000	45	16	5
1100	85	6	8
1200	30	2	40
1300	6	1	94
1400	3	1	15
1500	1	4	4
1600	1	30	3
1700	2	8	1
1800	Nil	5	1
1900	Nil	3	1
2000	2	2	2
2100	10	1	7
2200	14	1	4
2300	6	Nil	1
2400	2	Nil	Nil
Total	297	198	218

TABLE 12 SURFACE TROUGHS IN VICINITY OF HONG KONG (1963 TO 1972)

Year	Total number	Number formed north of Hong Kong	Number passing through Hong Kong	Number with double passage through Hong Kong	Number formed south of Hong Kong	Number passing through Hong Kong	Number with double passage through Hong Kong
1963	5	5	3	1	0	0	0
1964	3	1	0	0	2	1	1
1965	3	2	2	0	1	1	0
1966	2	2	2	1	0	0	0
1967	2	2	1	0	0	0	0
1968	6	4	2	1	2	1	0
1969	6	4	2	0	2	1	1
1970	5	4	3	1	1	0	0
1971	3	3	1	0	0	0	0
1972	5	5	3	0	0	0	0
Total	40	32	19	4	8	4	2

TABLE 13 MEAN WATER VAPOUR FLUX FOR DAY 1 TO DAY 3 AT 1000, 850, 700 AND 500 mbar

VALUES IN $g\,kg^{-1}\ m\,sec^{-1}$

Level	Day 1	Day 2	Day 3
500 mbar	79.15	34.77	52.50
700 "	164.18	117.60	105.80
850 "	221.85	174.28	110.70
1000 "	148.55	14.45	29.76

TABLE 14 DIVERGENCE VALUES FOR STANDARD LEVELS OVER SOUTH CHINA FOR DAY 1 TO 3 (UNITS: $10^{-6}\ sec^{-1}$)

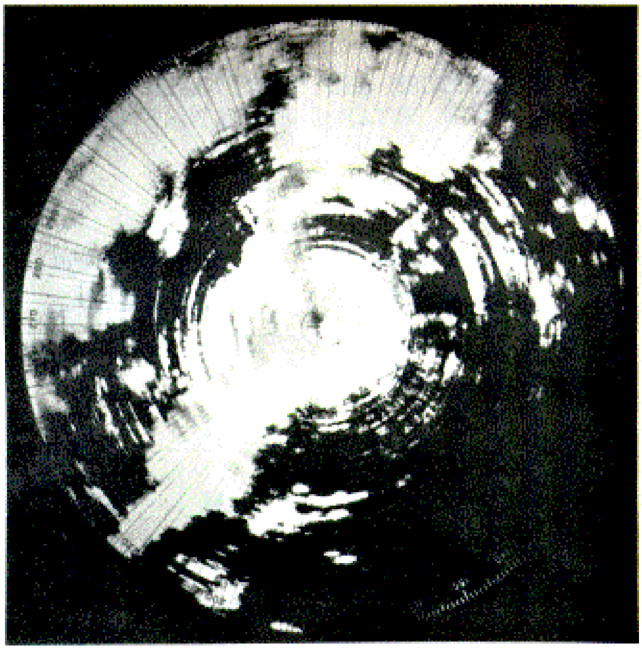
Level	Day 1		Day 2		Day 3	
	0000 GMT	1200 GMT	0000 GMT	1200 GMT	0000 GMT	1200 GMT
200 mbar	12.8	20.3	26.2	10.0	2.2	13.8
300 "	1.2	6.7	13.4	-11.2	-4.0	9.7
500 "	-5.3	4.5	-18.4	-4.3	1.7	3.3
700 "	2.6	2.4	-10.4	-2.6	-1.3	17.3
850 "	-6.5	-9.2	-13.1	0.6	-3.3	4.1
± 6 hours rainfall (mm)	178.3	55.2	126.9	59.1	216.0	16.7

TABLE 15 TWO INSTABILITY INDICES CALCULATED USING THE 0000 GMT HONG KONG SOUNDING FOR 1 TO 20 JUNE 1972

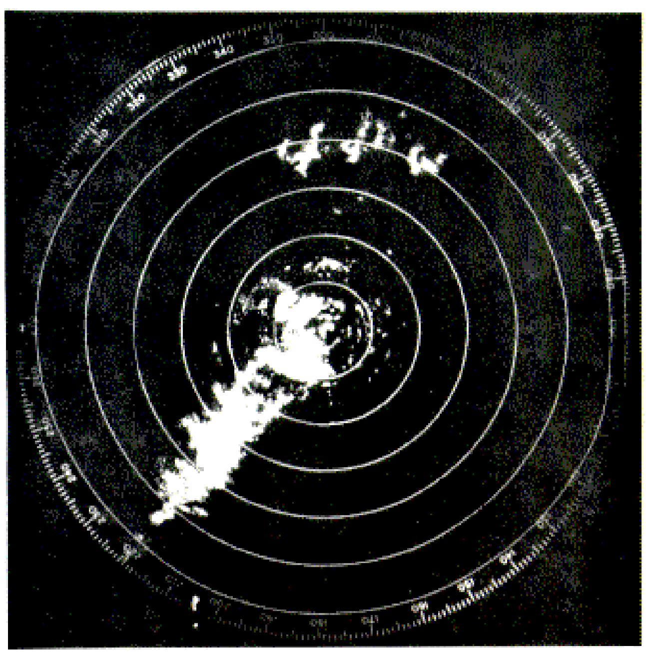
June 1972	Showalter	Wang	Daily Rainfall (mm)
1	6.0	-383	Nil
2	1.4	-252	Nil
3	0.2	-337	0.8
4	0.0	146	22.1
5	2.1	170	57.5
6	5.9	-464	Nil
7	9.3	-604	Nil
8	6.3	-355	Nil
9	5.7	-28	Nil
10	0.0	-110	6.8
11	1.0	54	3.8
12	2.2	96	24.7
13	1.1	-20	Nil
14	0.9	9	1.0
15	0.7	97	24.9
16	1.4	116	205.9
17	3.6	117	213.8
18	2.6	39	232.6
19	0.5	18	0.6
20	2.3	-168	0.1

TABLE 16 THUNDERSTORM AND HEAVY RAIN WARNINGS ISSUED BY THE ROYAL OBSERVATORY (LOCAL TIME)

Type of Warning	Date & Time of Issue		Date & Time of Renewal		Period of Validity
Thunderstorm	15	1115			15 1130 - 15 1730
			15	1700	15 1730 - 16 0800
			16	0730	16 0800 - 16 2000
Thunderstorm and Heavy Rain	16	1100			16 1100 - 16 2400
			16	2330	16 2400 - 17 0800
			17	0645	17 0800 - 17 1800
			17	1730	17 1800 - 17 2400
Thunderstorm	18	1045			18 1100 - 18 1700
	18	1730			18 1730 - 19 1130
Thunderstorm and Heavy Rain	18	1930			18 1930 - 19 1330



(a) Radar display at 8.25 p.m. on 18 June 1972, no attenuation



(b) Radar display at 8.25 p.m. on 18 June 1972, with 45.7 db attenuation

Plate 1

Plate 2 Damage caused by landslip at Sau Mau Ping

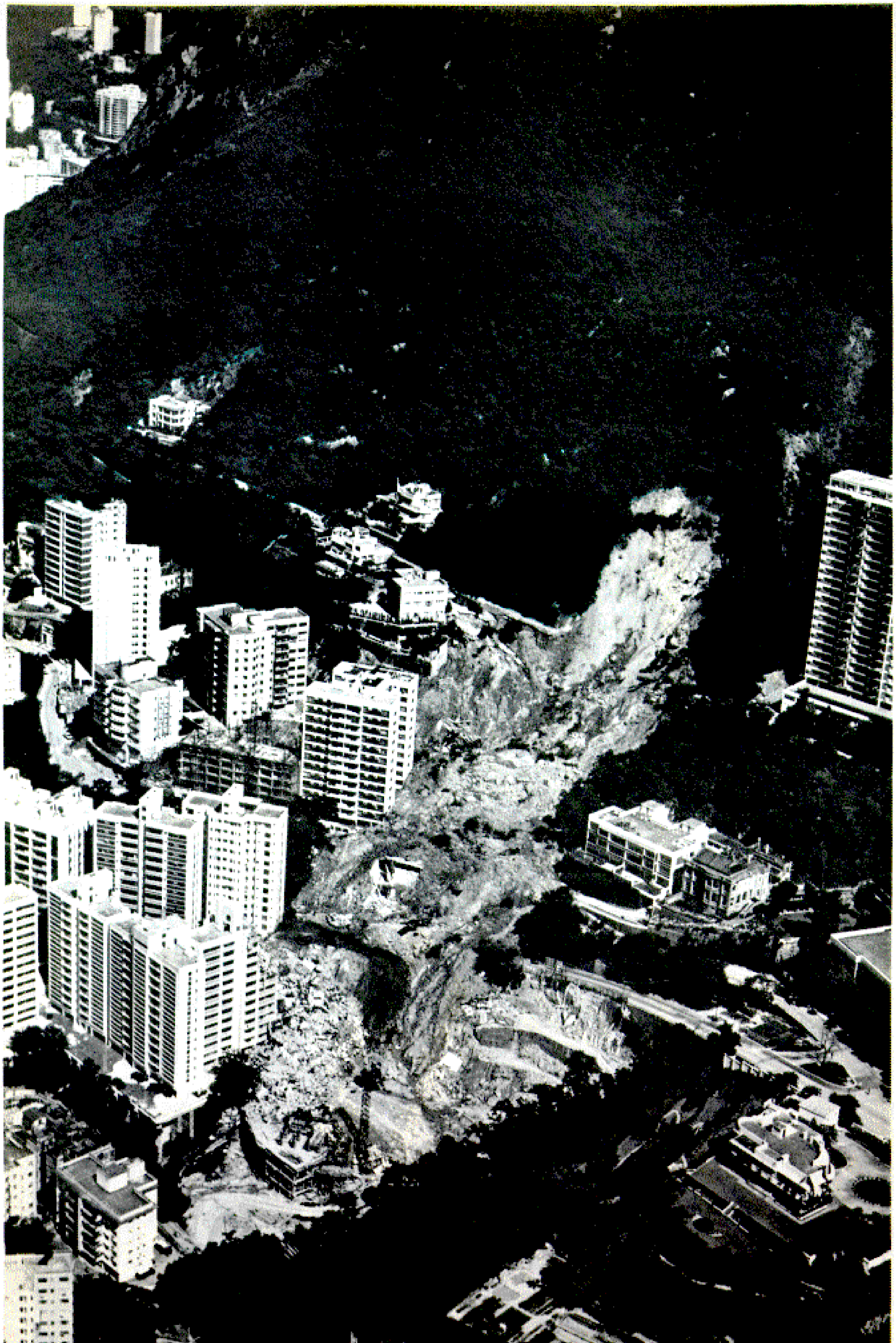


Plate 3 Damage caused by landslip at Po Shan Road