TECHNICAL STUDY 11

THUNDERSTORMS IN SOUTHEAST ASIA

BY

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SCIENTIFIC SERVICES
DETACHMENT 1, 1ST WEATHER WING
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I. Introduction

The purpose of this study is to present a comprehensive survey of thunderstorms in Southeast Asia (defined in this study as the Republic of Vietnam, Cambodia, Thailand, Laos and North Vietnam). Thunderstorm information available in previous climatic studies of this area is limited to short discussions of thunderstorm activity and tables giving the mean number of thunderstorm days at various locations. To the author's knowledge, there is no textbook, report, or other source that gives a detailed discussion of, or extensive statistics on, this subject. Undoubtedly, a limiting factor in the past has been a lack of reliable thunderstorm data for this area. This is still a restricting factor; however, with data now available and some subjective judgement, it is possible to present a fairly complete picture of thunderstorms in Southeast Asia.

Thunderstorms are an important hazard to military operations in Southeast Asia. Since clear air turbulence associated with jet streams or mountain waves is practically non-existent in Southeast Asia, almost all cases of moderate or severe turbulence in this area are associated with thunderstorms. Hail is also an important inflight hazard with more severe thunderstorms especially during the spring transition season (Mar-May). The strong downdrafts associated with thunderstorms are important for several reasons. First, a severe downdraft may put a light aircraft flying at low levels into an unrecoverable position and heavy rain associated with downdrafts may make VFR flight impossible. In addition, these downdrafts are the prime cause of strong gusty surface winds in Southeast Asia. Except for some coastal areas exposed to tropical cyclones and locations subject to channeling effects, almost all surface wind speeds over 30 knots in Southeast Asia are caused by thunderstorm downdrafts. In fact, a recent study of extreme winds in Thailand (1) shows a good correlation between the highest expected wind speed and the average number of thunderstorm days in any month. Thunderstorm lightning is also an associated hazard as it restricts ground refueling and other similar operations.

Because of these effects, it is imperative that meteorologists supporting military plans and operations in Southeast Asia be fully aware of the thunderstorm climatology in their area. A general overview of the comprehensive thunderstorm information presented in this study follows. Part II discusses various Southeast Asian thunderstorm data sources used, the reliability of these sources, and some difficulties involved in obtaining reliable thunderstorm data. Part III gives the monthly and annual frequencies of thunderstorm days for 83 stations in Southeast Asia, in both table and isoline-map forms. Part IV discusses the year to year variations in the numbers of thunderstorms observed monthly and annually. Part V covers the duration and diurnal variation of thunderstorms. Part VI presents a thunderstorm persistency model developed from 10 years of daily thunderstorm records for selected Thailand stations. Finally, Part VII shows how the local thunderstorm climatology can be approximated for a Southeast Asian location where no data are available.

II. Data Sources

All Southeast Asia thunderstorm data available in the 1st Weather Wing climatological files are used in this study. Since 1st Weather Wing has concentrated on collecting Southeast Asia climatological data, these files contain an extensive data base for this area. Unfortunately, for much of Southeast Asia, reliable thunderstorm data are difficult to obtain. Many stations take few or no nighttime observations and nighttime thunderstorms are frequently not recorded. Therefore, records for these stations underestimate the number of days with thunderstorms. Also, there are differences in technical definition, recording, and summarization of thunderstorm days among the various Southeast Asian countries. For example, Thailand stations use the WMO and WBAN definition of a thunderstorm day as a day on which thunder is heard at the station; precipitation need not occur. This means that a thunderstorm must pass within approximately five statute miles of a station (the usual distance thunder can be heard) for a thunderstorm day to be recorded. In the Republic of Vietnam (RVN), however, thunderstorm occurrences are divided into two classes: thunderstorms within 3 kilometers (1.9 miles) of a station and thunderstorms beyond 3 kilometers. It is not known how the distance of a thunderstorm from the station is determined, or if thunder must be heard in either case; nevertheless, the frequencies obtained by adding both classes of thunderstorm occurrence together appear to give a reasonable estimate, in most cases, to the number of thunderstorm days. No information is available to the author on how thunderstorm days are defined, recorded or summarized in Cambodia, Laos and North Vietnam; it is assumed they follow the WMO and WBAN definition of a thunderstorm day. There are, however, some obvious incompatibilities in some of the thunderstorm data for these countries. In general, for the quality of available thunderstorm data based on coverage (number of stations), period of record, compatibility and reliability, Thailand must be rated best, followed by the Republic of Vietnam, North Vietnam, Laos and Cambodia, in that order. Following is a brief description of the major sources of Southeast Asian thunderstorm data used in this study.

National Climatological Summaries

Summaries prepared by the meteorology departments of Thailand (2, 3, 4, 5) and the Republic of Vietnam (6, 7) give the average number of thunderstorm days for the first order meteorological stations in each country for a fairly long period of record (10 to 20 years in most cases). These summaries are used as the primary source for the number of thunderstorm days in these two countries. A climatological summary prepared by the Japan Central Meteorological Observatory (8) includes the number of thunderstorm days for various Southeast Asian stations for the period 1937-39. Even though this source is for only a three year period and is fairly old, it remains a valuable source of thunderstorm data, especially for North Vietnam, Laos and Cambodia. A French publication on the climate of Indochina (9) also contains a table giving the average number of thunderstorm days for Southeast Asian stations; however, the period of record is not specified and the values appear too low for many of the stations.

N Summaries

N Summaries are climatological summaries prepared from 3-hourly synoptic observations by ETAC's Data Processing Division. These summaries contain some information on thunderstorms; however, there are definite limitations on the accuracy and usefulness of these data. For example, N Summary 26 gives an estimate of the mean number of thunderstorm days at each location based on days which had available four or more of the eight possible 3-hourly synoptic observations. If four of the observations used were 6-hourlies (0000Z plus every 6 hours) this method would give a reliable estimate of the thunderstorm days if the period of record is long enough (thunderstorms occurring at a station within the previous 6 hours are recorded in the past or present weather on the 6-hourly observation). However a thunderstorm could easily go unreported on a day with four synoptic observations if one or more of these observations are 3-hourlies (0300Z plus every 6 hours), since 3-hourly observations record the predominant weather only during the preceding 3 hours. For example, if synoptic observations were available for 0000Z, 0300Z, 0600Z, 0900Z and 1800Z, a thunderstorm occurring between 0900Z and 1200Z would not be summarized. For this reason, N Summary 26 underestimates the mean number of thunderstorm days for stations in Southeast Asia, except for one country. In North Vietnam, estimates of the mean number of thunderstorm days from N Summary 26 appear high compared with data from all other sources. The reason for this incompatibility is not readily apparent, unless observations of lightning or thunderstorms within sight are included as thunderstorms in the observations.

N Summary 14 gives the mean number of days per month with thunderstorm occurrence at various synoptic hours. With few exceptions, these values also appear too high when compared to the mean number of thunderstorm days and hourly data on thunderstorm occurrence from the Uniform Summary of Surface Weather Observations.

1st Weather Wing Summaries

In 1963, the 1st Weather Wing Climatological Division prepared General Weather Summaries similar to ETAC's Uniform Summary of Surface Weather Observations for 18 RVN and 3 Laotian stations from approximately 5 years of hourly observations. These summaries include the average frequency of thunderstorms at the station and thunderstorms within sight for each hour observations were available.

1st Weather Wing Form 80s

1st Weather Wing detachments prepare a monthly climatological summary (1st Weather Wing Form 80) for supported bases. This form includes the frequency of thunderstorm days. Up to four years of Form 80 data are now available for the major air bases in the RVN and Thailand. For stations operating 24 hours a day, these data provide a reliable source for the number of thunderstorm days. Because of the fairly large year to year variation in the number of thunderstorm days (discussed later), however, a period of record longer than four years is required to establish reliable means. Therefore, the Form 80 data are used primarily as a check on the long period means available from the Thailand and RVN climatological summaries.

Uniform Summary of Surface Weather Observations

Uniform Summaries prepared from hourly observations are now available for many of the major air bases and airports in the RVN and Thailand. These summaries give the average frequency of thunderstorm occurrence by hour (or by 3-hourly periods in the Revised Uniform Summary) and by month; however, they do not give the mean number of thunderstorm days.

III. Mean Number of Thunderstorm Days

Figure 1 shows the location and index number of Southeast Asian stations for which reliable thunderstorm data are available. The coordinates and elevations of these stations are given in 1st Weather Wing Manual 105-1. Some data are available on the number of thunderstorm days at other Southeast Asian stations; however, these other stations are omitted for a variety of reasons (too short a period of

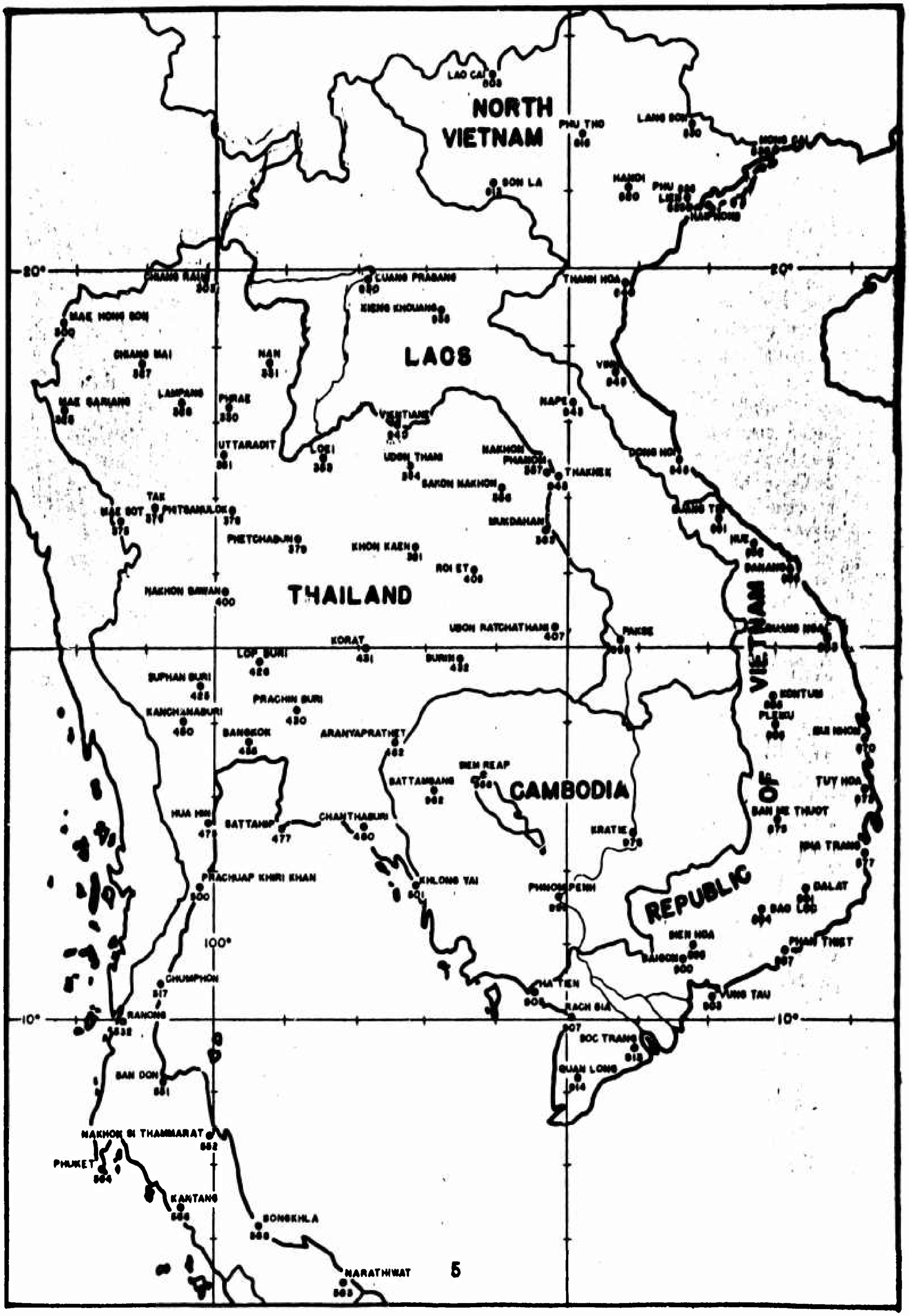


Figure 1. Station locations and index numbers

record, few or no nighttime observations available, data not compatible with surrounding stations with no obvious local effects to explain the differences, mean values for separate periods of record were not compatible, etc.).

To delineate regions with similar thunderstorm patterns, Southeast Asia is divided into the 14 geographical areas shown in Figure 2. These areas are determined subjectively using the annual number of thunderstorm days and their distribution throughout the year. Topography and national borders also are used. The average annual number of thunderstorm days and/or their seasonal distribution in each area differ somewhat from those in surrounding areas.

Table 1 gives the mean monthly and annual number of thunderstorm days for stations shown on Figure 1, arranged according to the areas delineated by Figure 2. Table 2 gives the mean monthly and annual number of thunderstorm days in each area obtained by averaging the values for all stations in that area. To illustrate the seasonal distribution of thunderstorms in each area, the percentage of the annual number of thunderstorm days which occur each month is computed. These percentages are given in Table 3 and shown graphically in Figure 3. With two exceptions, Area I (Red River Valley) and Area XIV (Thailand Peninsula - West Coast), May is the month of maximum thunderstorm occurrence. July and August are the months of maximum thunderstorm occurrence in the Red River Valley, while the West Coast of the Thailand Peninsula has its maximum in April because of the earlier onset of the Southwest Monsoon in this area. Many areas have a secondary thunderstorm maximum in September or October associated with the southward movement of the intertropical convergence zone through Southeast Asia. The number of thunderstorm days decreases sharply from December through February. The last graph in Figure 3 shows the curve obtained by averaging the thunderstorm values for all Southeast Asian stations. The May maximum is very pronounced with 20% of the yearly thunderstorm days occurring in this month. In this areal average, April and June through September have approximately the same number of thunderstorm days with 11-12% of the annual total occurring in each of these five months.

Figures 4-16 show the mean monthly and annual number of thunderstorm days in isoline form. The topography of Southeast Asia (Figure 17) and isolines from the previous and following month were used as guidance to draw these maps. Smoothing intervals of up to plus or minus 2 days for the monthly isolines and plus or minus 10 days for the annual isolines were used. Interpolated point values are entered on the maps in closed centers and areas of weak gradients. These maps illustrate the broad scale areal distribution of thunderstorm

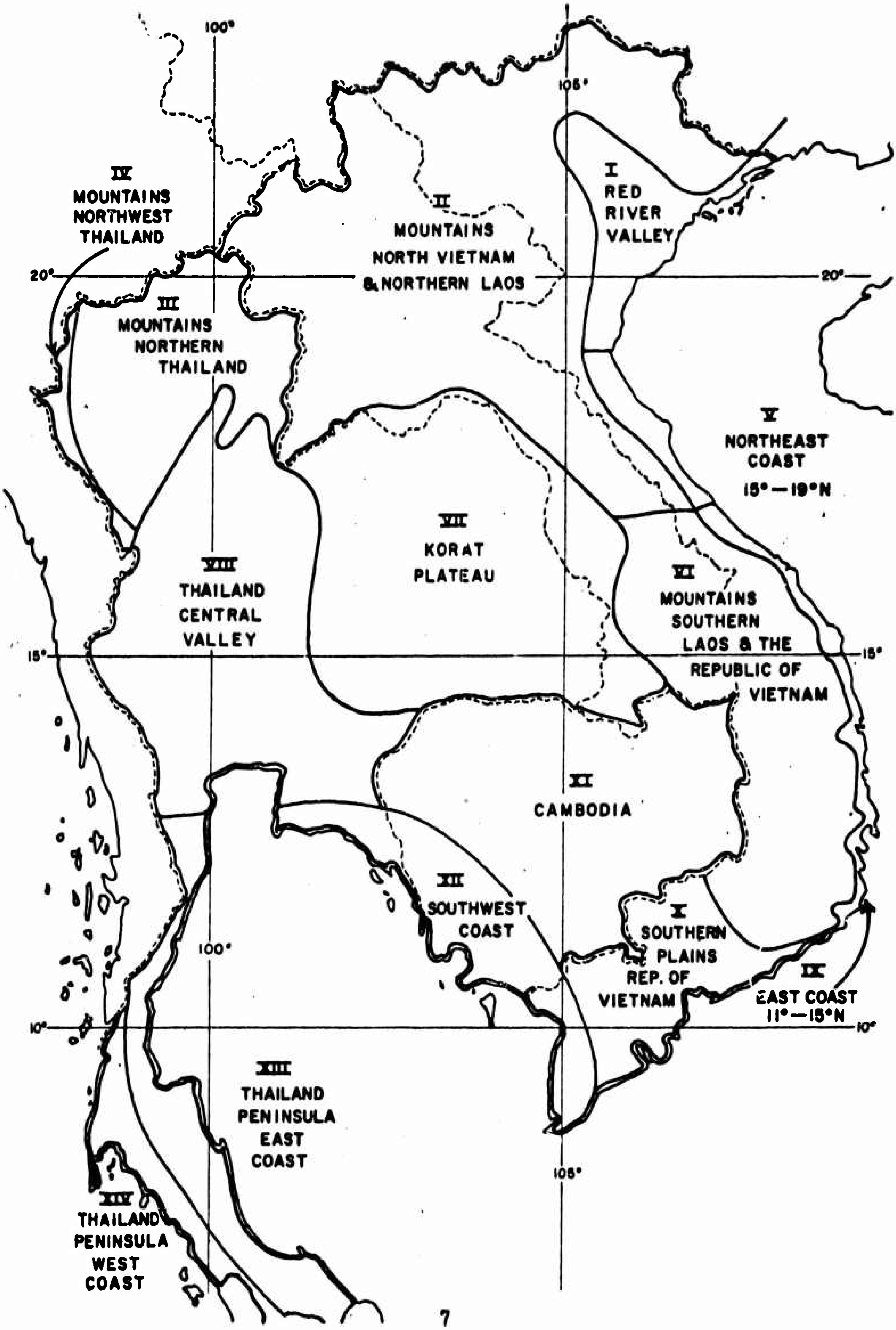


Figure 2. Geographical areas with similar thunderstorm regimes.

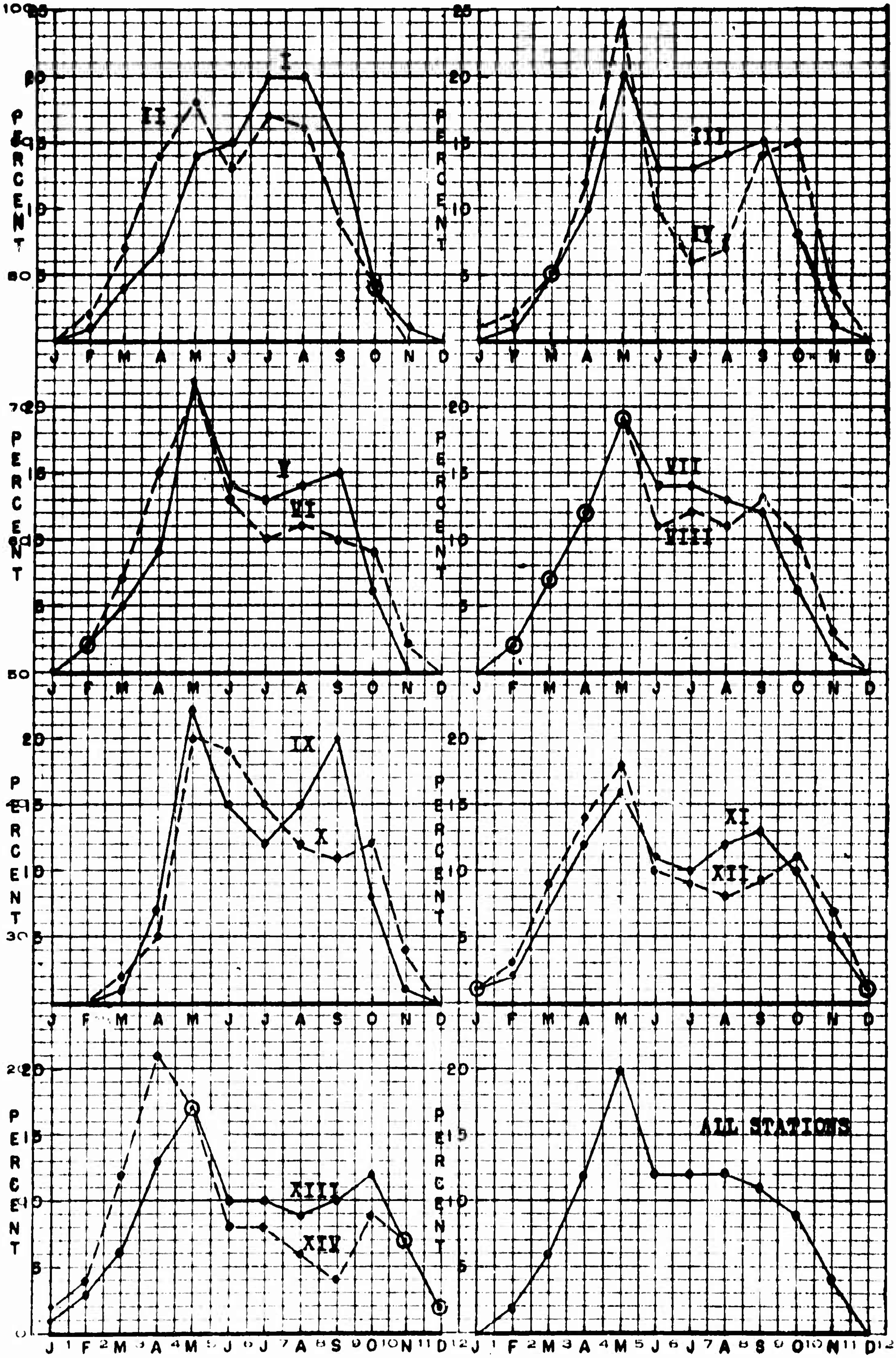


Figure 3. Percent of the average annual number of thunderstorm days occurring each month for each geographical area of Southeast Asia shown in Figure 2.

days in Southeast Asia. Naturally, values for specific locations may vary significantly from those shown by the isolines, especially for locations that are considerably more exposed or sheltered than the stations used on these maps.

During December, January and February, most Southeast Asian thunderstorm activity is limited to the areas adjacent to the Gulf of Siam. There is a sharp increase in the number of thunderstorm days in March and most areas reach a peak during May with centers of maximum activity located over the Korat Plateau; the mountainous areas in Northern Thailand, Southern Laos and the RVN; the Southwest Coastal area; and the East Coast of the Thailand Peninsula. The isoline patterns and numbers of thunderstorm days remain similar from June through September under the dominating influence of the Southwest Monsoon. In October, the intertropical convergence zone moves southward through Southeast Asia causing a sharp decrease in thunderstorm activity over North Vietnam and Laos. By November, significant thunderstorm activity is again limited to the southern parts of Thailand, Cambodia and the RVN.

Figure 16 shows the mean annual number of thunderstorm days. By comparing the centers of maximum activity with topography (Figure 17), it becomes obvious that many of these centers are associated with higher, mountainous terrain. Exceptions are the maximum centers over the Korat Plateau, Central Thailand and the East Coast of the Thailand Peninsula. The center of maximum activity with approximately 160 thunderstorm days occurring annually is along the Southwest Coast. The locations of minimum activity are over Northern Laos and along the RVN East Coast. There is a pronounced gradient of thunderstorm activity from stations immediately on the RVN East Coast to those a few miles inland. For example, the ratio of thunderstorms greater than 3 kilometers from the station to those within 3 kilometers of the station given in RVN summaries is approximately 3 to 1 for Qui Nhon (870), Tuy Hoa (873) and Nha Trang (877) along the east coast. Most of the thunderstorm observed beyond 3 kilometers probably occur inland from these stations. As an additional example of this coastal thunderstorm gradient, An Khe, which is approximately 40 miles inland, reported 54 thunderstorm days during the period Feb-Sep 1966 compared to 22 days during the same period at Qui Nhon, which is immediately adjacent to the South China Sea.

Additional comments are added on the number of thunderstorm days given for the stations in Area X (RVN Southern Plains) because of the broad scope of military activity in this region. There is considerable disagreement between the RVN summaries and 4 years of 1WW Form 80 data on the number of thunderstorm days at Saigon (900) and Bien Hoa (896). In addition, the numbers from each source are not

Table 1. Mean monthly and annual number of thunderstorm days for Southeast Asian stations arranged according to the geographical areas shown in Figure 2. Asterisk denotes less than 0.5 day; zero means that thunderstorms have not occurred during the period of record.

I. RED RIVER VALLEY

STATION NO.	NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	PERIOD OF RECORD (YEARS)
816	PHU THO	*	*	3	7	13	14	15	11	8	2	*	0	73	3
819	HANOI	*	1	3	4	8	8	11	11	7	3	1	0	57	10
826	PHU LIEN	*	1	2	4	7	9	14	14	11	3	*	0	65	10
825	HAIPHONG	*	1	3	4	7	9	11	11	9	2	1	0	58	8
840	THANH HOA	0	1	2	5	10	10	12	12	9	3	*	0	64	NA
838	MON CAI	0	*	2	4	11	8	14	16	10	2	*	0	67	3

II. MOUNTAINS NORTH VIETNAM & NORTHERN LAOS

STATION NO.	NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	PERIOD OF RECORD (YEARS)
803	LAO CAI	*	2	3	7	6	4	10	9	4	1	0	0	46	3
930	LUANG PRABANG	*	1	2	4	9	5	5	5	4	1	*	*	37	9
935	XIENG KHOUANG	0	1	1	7	8	5	5	6	4	1	0	0	38	3
813	SON LA	*	1	3	5	7	5	6	4	2	2	*	0	35	NA
830	LANG SON	*	1	3	3	5	4	8	9	4	2	0	0	39	NA
943	NAPE	*	1	5	7	9	8	6	6	5	2	1	0	50	NA

III. MOUNTAINS NORTHERN THAILAND

STATION NO.	NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	PERIOD OF RECORD (YEARS)
303	CHIANGRAI	1	1	4	8	18	16	14	15	13	7	1	*	98	20
327	CHIANGMAI	1	1	4	10	22	13	11	14	16	10	2	*	104	20
328	LAMPANG	*	1	5	8	16	10	10	10	13	7	1	*	80	15
331	NAN	*	1	5	9	18	9	11	11	13	7	1	0	85	15

IV. MOUNTAINS NORTHWEST THAILAND

STATION NO.	NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	PERIOD OF RECORD (YEARS)
300	MAE HONG SON	1	1	3	8	15	7	5	5	10	10	2	*	67	20
325	MAE SARIANG	*	1	1	5	12	4	3	4	7	9	2	1	49	15
375	MAE SOT	*	2	4	9	17	7	3	4	8	9	3	0	66	15

V. NORTHEAST COAST (15°-19°N)

STATION NO.	NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	PERIOD OF RECORD (YEARS)
845	VINH	*	2	4	4	11	7	6	9	9	3	*	0	55	NA
848	DONG HOI	0	1	4	4	11	4	3	5	8	3	*	0	43	NA
851	QUANG TRI	0	*	1	5	13	5	5	4	4	2	*	0	40	7
852	HUE	0	*	2	6	11	7	8	7	6	2	*	0	49	16
855	DANANG	0	*	1	4	7	6	6	7	6	3	*	0	41	16
863	QUANG NGAI	0	*	1	3	7	10	9	8	7	3	*	0	48	9

VI. MOUNTAINS SOUTHERN LAOS & THE REPUBLIC OF VIETNAM

STATION NO.	NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	PERIOD OF RECORD (YEARS)
866	PLEIKU	0	1	4	10	15	7	6	6	6	6	*	0	61	7
875	BAN ME THOUT	0	*	2	8	16	11	8	7	7	4	*	0	63	11
884	BAO LOC	*	1	7	13	11	5	8	5	6	10	4	*	70	5
881	DALAT	*	1	5	16	22	13	11	10	10	9	1	*	98	11
865	KONTUM	*	3	11	16	24	16	8	15	12	7	3	0	115	2
**865	KONTUM (Adjusted)	(*)	(2)	(8)	(17)	(24)	(15)	(12)	(13)	(12)	(10)	(2)	(*)	(115)	

VII. KORAT PLATEAU

STATION NO.	NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	PERIOD OF RECORD (YEARS)
940	VIENTIANE	0	1	8	13	17	13	13	13	12	5	1	0	96	9
353	LOEI	*	2	10	16	24	16	16	16	13	6	*	0	120	8
354	UDON THANI	*	2	7	15	22	17	17	17	15	4	1	*	118	20
356	SAKON NAKHON	*	2	7	13	22	16	15	15	12	4	*	0	106	10
357	NAKHON PHANOM	*	1	6	11	21	19	18	19	14	5	*	0	114	10
945	THAKHEK	0	3	8	13	23	16	13	17	10	3	1	0	107	3
381	KHON KAEN	*	2	8	14	23	16	17	10	9	8	1	0	108	15
405	ROI ET	0	2	7	12	19	12	13	11	14	8	1	0	99	10
383	MUKDAHAN	*	1	6	13	20	14	15	14	13	4	1	0	101	15
431	KORAT	*	3	11	16	21	11	11	10	11	8	2	0	104	20
432	SURIN	*	1	6	11	20	15	17	18	14	10	2	0	114	5
407	UBON RATCHATHANI	*	1	4	12	20	15	15	15	13	7	2	*	105	20
955	PAKSE	*	1	9	13	16	12	15	12	9	7	3	0	97	4

** Adjusted because of the short period available by multiplying the mean annual number of thunderstorm days by the Area VI percentages given in Table 3.

VIII. THAILAND CENTRAL VALLEY

STATION NO.	NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	PERIOD OF RECORD (YEARS)
330	PHRAE	*	*	3	7	16	11	10	11	12	9	1	0	80	7
351	UTTARADIT	*	1	4	8	16	13	11	13	13	8	1	0	88	20
376	TAK	*	1	4	11	18	12	9	7	9	7	1	0	79	9
378	PHITSANULOK	*	2	7	10	18	15	13	14	15	12	2	*	108	20
379	PHETCHABUN	1	2	9	16	23	11	11	9	12	8	2	0	104	13
400	NAKHON SWAN	*	2	5	10	15	10	10	9	11	7	1	*	80	20
426	LOP BURI	1	3	9	13	19	12	12	11	14	9	3	*	106	15
425	SUPHANBURI	*	2	8	10	19	8	13	13	14	11	3	0	102	10
450	KANCHANABURI	*	2	8	11	15	6	7	6	10	9	2	0	76	10
455	BANGKOK	*	2	5	11	17	11	11	11	13	11	4	*	96	20
462	ARANYAPRATHET	1	3	10	16	19	11	10	9	10	9	3	*	101	20
430	PRACHINBURI	1	3	11	17	21	13	13	12	12	9	3	*	115	15

IX. EAST COAST (11°-15°N)

870	QUI NHON	0	*	*	2	5	3	3	4	5	2	*	0	25	10
873	TUY HOA	0	*	*	2	6	4	3	3	4	2	*	0	25	10
877	NHA TRANG	0	*	*	1	6	4	3	4	6	2	*	0	27	16

X. SOUTHERN PLAINS REP. OF VIETNAM

887	PHAN THIET	0	0	*	3	9	9	8	7	7	5	1	0	49	6
896	BIEN HOA	*	*	1	4	13	12	9	9	8	8	5	1	70	9
900	SAIGON	*	*	1	5	15	12	11	9	8	11	4	1	77	12
903	VUNG TAU	0	0	1	1	12	13	10	7	6	4	1	0	55	4
913	SOC TRANG	*	*	2	4	15	14	10	8	8	9	2	*	73	16

XI. CAMBODIA

962	BATTAMBANG	*	2	10	14	18	11	10	15	14	12	6	*	113	NA
966	SIEM REAP	1	3	3	8	10	8	7	8	11	9	3	1	72	NA
976	KRATIE	*	*	6	10	13	10	9	9	11	6	4	*	78	NA
990	PHNOM PENH	1	1	4	9	17	10	9	11	10	10	6	*	88	NA

STATION NO.	NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	PERIOD OF RECORD (YEARS)
	XII. SOUTHWEST COAST														
477	SATTAHIP	1	4	9	13	14	5	5	5	8	12	7	1	84	15
480	CHANTHABURI	2	8	17	20	24	14	18	14	17	17	7	1	159	15
501	KHLONG YAI	3	7	18	23	25	17	14	12	11	16	9	1	156	15
907	RACH GIA	*	1	6	12	25	10	11	8	7	11	9	1	101	
914	QUAN LONG	*	*	3	10	20	12	9	6	7	8	3	1	79	
905	HA TIEN	2	2	12	17	17	9	7	7	9	9	12	1	104	3
	XIII. THAILAND PENINSULA EAST COAST														
475	HUA HIN	1	1	6	13	20	9	10	9	12	14	6	1	102	20
500	PRACHUAP KHIRI KHAN	1	3	8	14	18	8	7	6	8	11	6	1	91	20
517	CHUMPHON	2	4	10	17	20	10	9	6	9	12	9	4	112	20
551	BAN DON	3	5	12	21	22	13	14	12	11	17	10	4	144	20
552	NAKHON SITHAMMARAT	2	3	5	16	19	10	9	11	13	15	10	5	118	20
568	SONGKHLA	1	1	3	14	19	11	13	11	13	13	8	2	109	20
583	NARATHIWAT	*	1	2	7	15	13	13	12	11	8	4	1	87	15
	XIV. THAILAND PENINSULA WEST COAST														
532	RANONG	1	2	8	16	13	7	7	6	3	8	4	1	76	15
564	PHUKET	2	4	9	13	10	4	4	2	2	5	5	2	62	15
566	KANTANG	2	3	10	18	15	6	7	5	5	9	6	2	88	15

Table 2. Average number of thunderstorm days for each area shown in Figure 2 obtained by averaging the values at all stations in that area.

AREA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
I	*	1	3	5	9	10	13	13	9	3	1	0	67
II	*	1	3	5	7	5	7	7	4	2	*	0	41
III	*	1	5	9	19	12	12	12	13	8	1	*	92
IV	*	1	3	7	15	6	4	4	8	9	2	*	59
V	*	1	2	4	10	7	6	7	7	3	*	0	47
VI	*	1	6	13	18	10	8	9	8	7	2	*	82
VII	*	2	7	13	21	15	15	14	12	6	1	*	106
VII	*	2	7	11	18	11	11	10	12	9	3	*	94
IX	0	*	*	2	6	4	3	4	5	2	*	0	26
X	*	*	1	3	13	12	10	8	7	7	3	*	64
XI	1	2	6	10	15	10	9	11	12	9	5	*	90
XII	1	4	11	16	21	11	11	9	10	12	8	1	115
XIII	1	3	7	15	19	11	11	10	11	13	8	3	112
XIV	2	3	9	16	13	6	6	4	3	7	5	2	76
Average All Stations	*	2	5	10	16	10	10	10	9	7	3	*	82

* Less than 0.5 day

Table 3. Percent of the average annual number of thunderstorm days occurring each month for each area shown in Figure 2.

AREA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
I	*	1	4	7	14	15	20	20	14	4	1	0	100%
II	*	2	7	14	18	13	17	16	9	4	0	0	100%
III	*	1	5	10	20	13	13	14	15	8	1	*	100%
IV	1	2	5	12	24	10	6	7	14	15	4	*	100%
V	0	2	5	9	22	14	13	14	15	6	*	0	100%
VI	*	2	7	15	21	13	10	11	10	9	2	*	100%
VII	*	2	7	12	19	14	14	13	12	6	1	*	100%
VIII	*	2	7	12	19	11	12	11	13	10	3	*	100%
IX	0	0	1	7	22	15	12	14	20	8	1	0	100%
X	*	*	3	5	21	17	13	11	11	13	5	1	100%
XI	1	2	7	12	16	11	10	12	13	10	5	1	100%
XII	1	3	9	14	18	10	9	8	9	11	7	1	100%
XIII	1	3	6	13	17	10	10	9	10	12	7	2	100%
XIV	2	4	12	21	17	8	8	6	4	9	7	2	100%
Average All Stations	*	2	6	12	20	12	12	12	11	9	4	*	100%

* Less than 0.5%

compatible for these two stations which are only 15 miles apart in an area of flat terrain. These differences are illustrated in Table 4 which shows the mean annual number of thunderstorm days at Saigon and Bien Hoa from each source.

Table 4. Mean annual number of thunderstorm days at Saigon and Bien Hoa.

	Saigon	Bien Hoa
RVN Summary	91	40
1WW Form 80 Data	63	99
Average	77	70

To solve this dilemma, the thunderstorm days from the two sources were averaged at each station. This gives a reasonable number of thunderstorm days compared to surrounding stations and makes these two stations compatible with each other.

The number of thunderstorm days given for Soc Trang (913) appear reliable since similar values are obtained from each source for this station. Also, Soc Trang has taken both day and night observations for a long period. However, the average annual number of thunderstorm days at Binh Thuy (911) and Vinh Long (910) as shown by 1WW Form 80 data appears too low (48 and 54 days respectively) when compared to Soc Trang and Saigon. This is probably because observations for Binh Thuy and Vinh Long are limited to daylight hours during most of the period.

The above examples are sufficient to illustrate some of the problems involved in determining the mean number of thunderstorm days at Southeast Asian stations. Undoubtedly, some of subjective decisions made on which thunderstorm data to accept or reject will be proved incorrect by later observations. Nevertheless, because of the time and effort spent comparing all available sources of Southeast Asian thunderstorm data, these subjective decisions probably improve the thunderstorm climatology of this region.

In addition to the average number of thunderstorm days, it is important to know the year to year variation in the number of monthly and annual thunderstorm days that can be expected at each station.

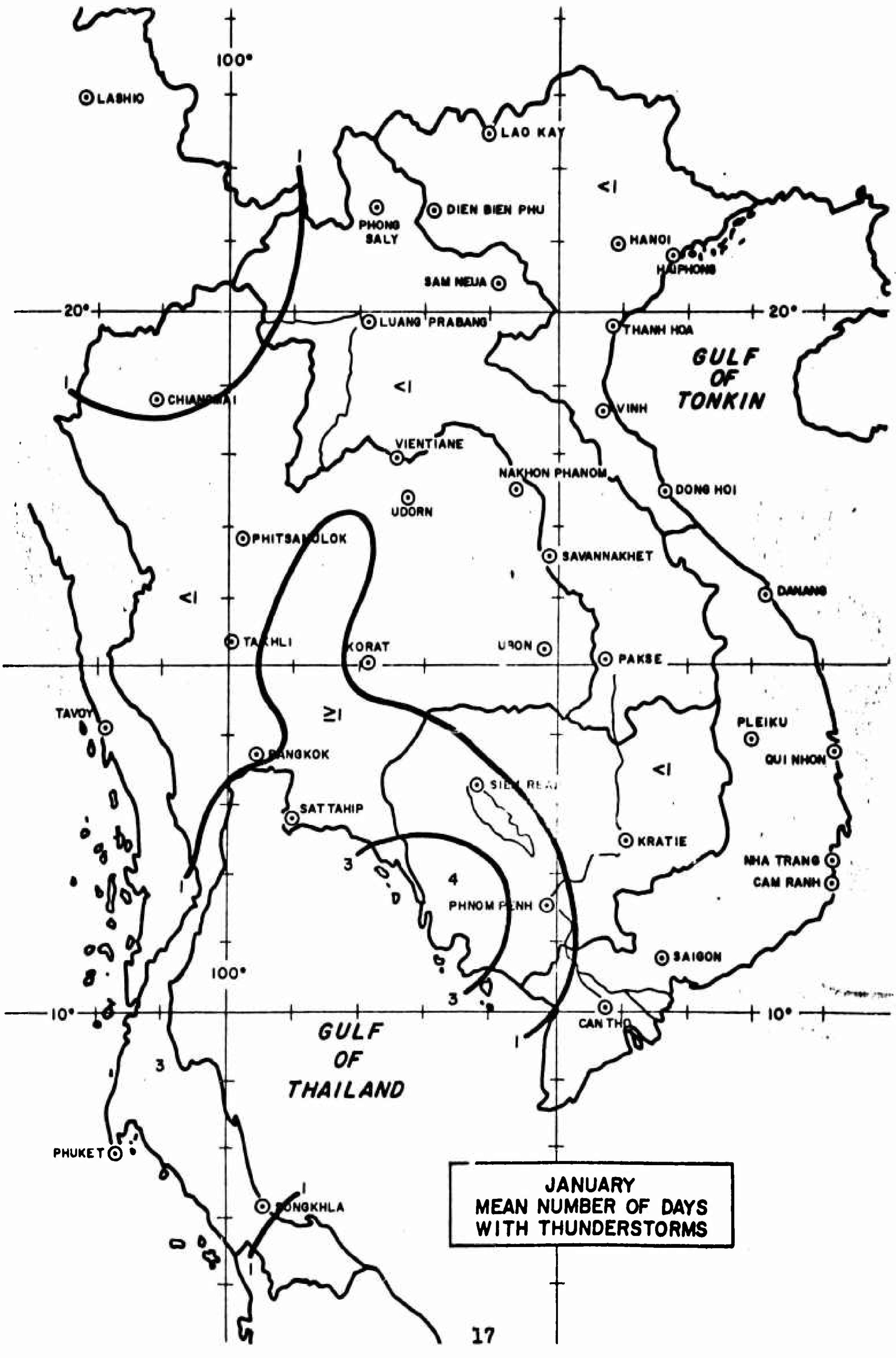
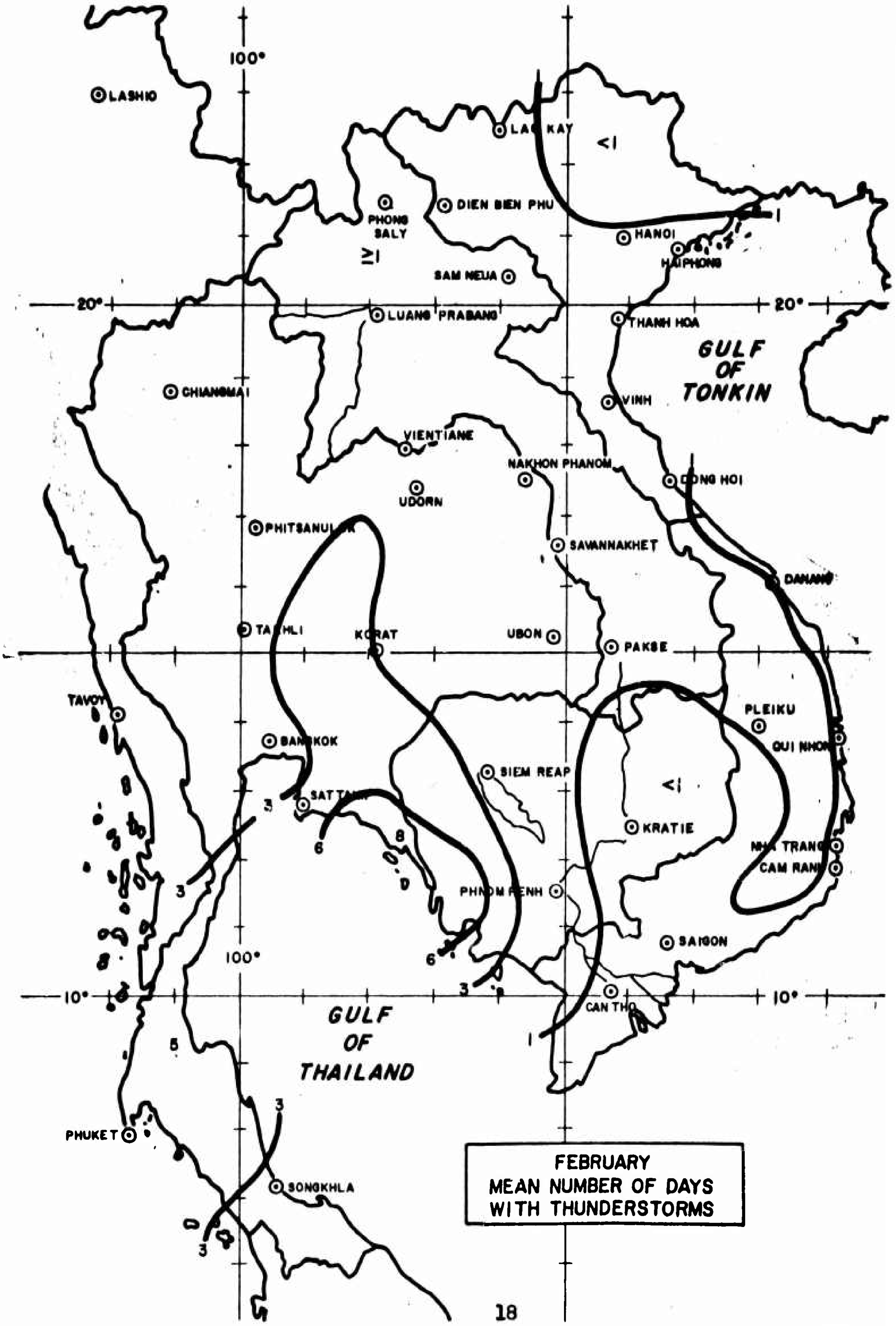
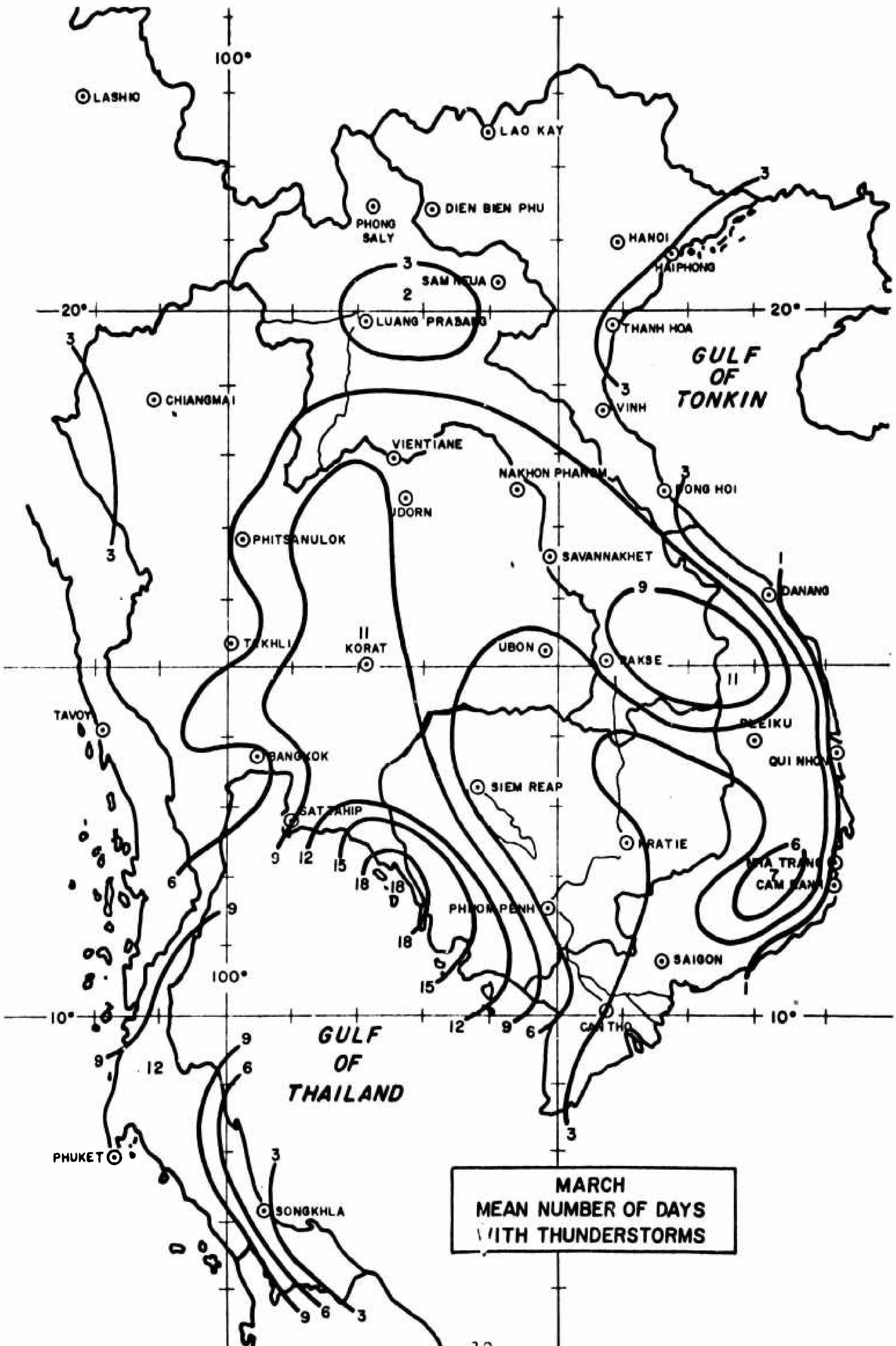

JANUARY
MEAN NUMBER OF DAYS
WITH THUNDERSTORMS
GULF OF TONKIN
GULF OF THAILAND
LASHIO
LAO KAY
DIEN BIEN PHU
PHONG SALY
HANOI
HAIPHONG
SAM NEUA
LUANG PRABANG
THANH HOA
CHIANGMAI
VINH
VIENTIANE
NAKHON PHANOM
DONG HOI
UDORN
PHITSANULOK
SAVANNAKHET
DANANG
TAKHLI
KORAT
UBON
PAKSE
TAVOY
PLEIKU
BANGKOK
QUI NHON
SATTAHIP
KRATIE
NHA TRANG
CAM RANH
PHNOM PENH
SAIGON
CAN THO
PHUKET
SONGKHLA
100°
20°
10°
<1
≥1

Figure 4



100°
LASHIO
LAO KAY
<1
PHONG SALY
DIEN BIEN PHU
HANOI
HAIPHONG
≥1
SAM NEUA
20°
LUANG PRABANG
THANH HOA
GULF OF TONKIN
CHIANGMAI
VINH
VIENTIANE
NAKHON PHANOM
DONG HOI
UDORN
PHITSANULOK
SAVANNAKHET
DANANG
KORAT
UBON
PAKSE
TAVOY
PLEIKU
BANGKOK
QUI NHON
SIEM REAP
SATTAHIP
<1
KRATIE
NHA TRANG
CAM RANH
PHNOM PENH
SAIGON
100°
10°
CAN THO
GULF OF THAILAND
PHUKET
SONGKHLA
FEBRUARY
MEAN NUMBER OF DAYS
WITH THUNDERSTORMS

Figur



100°
LASHIO
LAO KAY
DIEN BIEN PHU
PHONG SALY
HANOI
HAIPHONG
SAM NEUA
LUANG PRABANG
20°
THANH HOA
GULF OF TONKIN
CHIANGMAI
VINH
VIENTIANE
NAKHON PHANOM
DONG HOI
UDORN
PHITSANULOK
SAVANNAKHET
DANANG
KORAT
UBON
PAKSE
TAKHLI
TAVOY
PLEIKU
QUI NHON
BANGKOK
SIEM REAP
SATTAHIP
KRATIE
NHA TRANG
CAM RANH
PHNOM PENH
SAIGON
CAN THO
10°
GULF OF THAILAND
PHUKET
SONGKHLA
MARCH
MEAN NUMBER OF DAYS
WITH THUNDERSTORMS

Figure 6

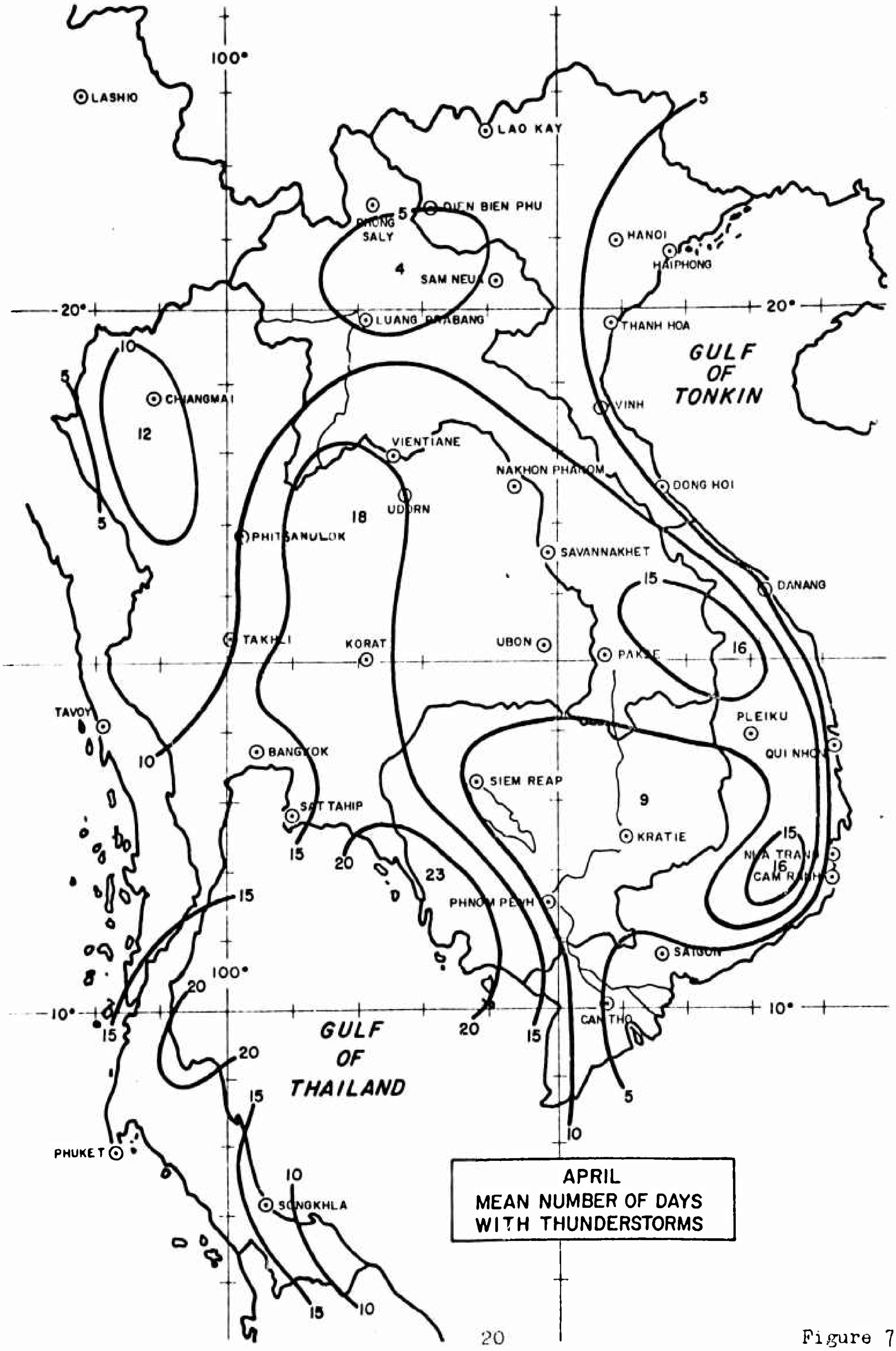
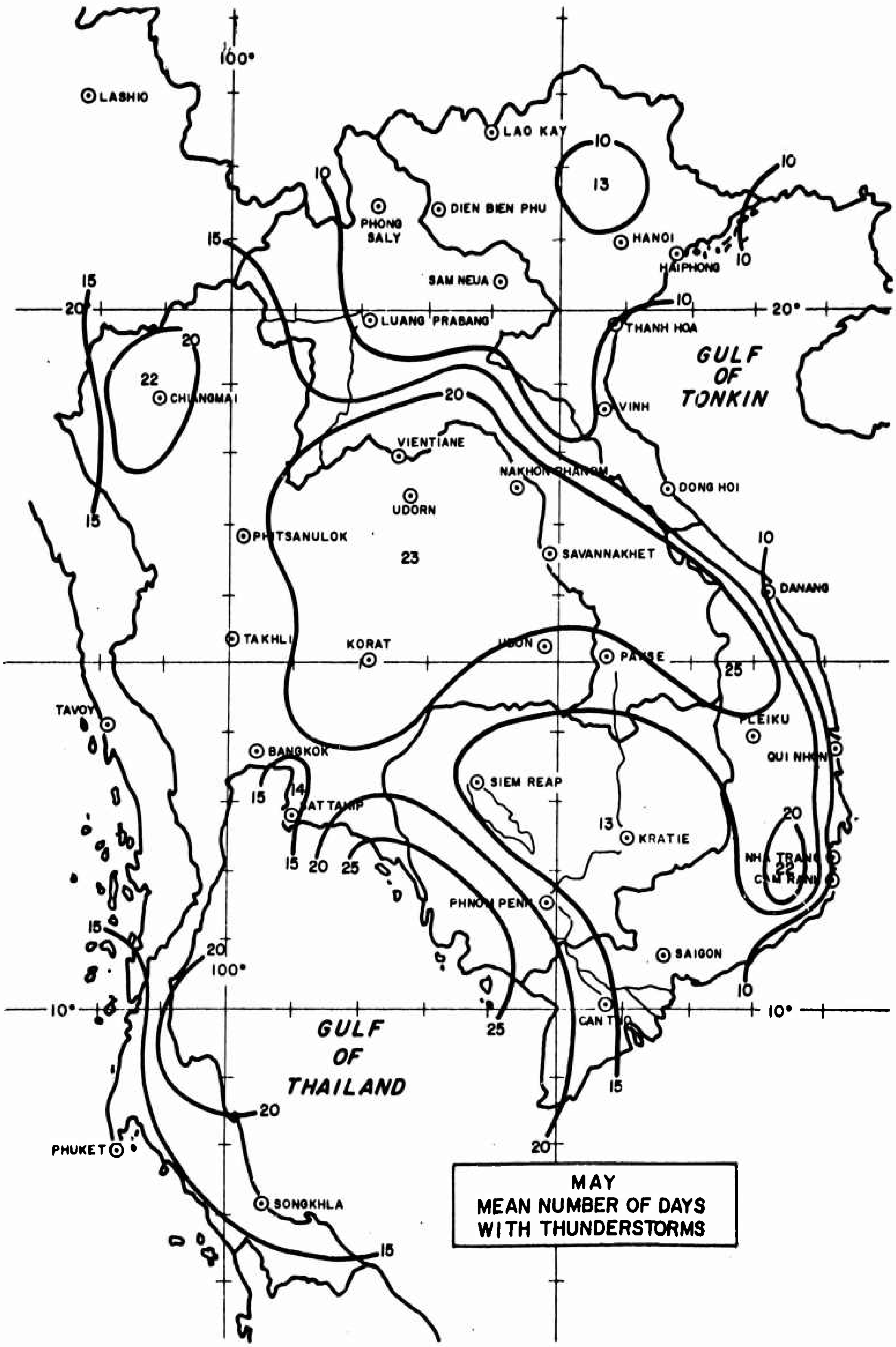

APRIL
MEAN NUMBER OF DAYS
WITH THUNDERSTORMS
100°
20°
10°
LASHIO
LAO KAY
DIEN BIEN PHU
PHONG SALY
SAM NEUA
LUANG PRABANG
HANOI
HAIPHONG
THANH HOA
GULF OF TONKIN
VINH
CHIANGMAI
VIENTIANE
NAKHON PHANOM
DONG HOI
UDORN
PHITSANULOK
SAVANNAKHET
DANANG
TAKHLI
KORAT
UBON
PAKSE
PLEIKU
TAVOY
BANGKOK
QUI NHON
SIEM REAP
SATTAHIP
KRATIE
NHA TRANG
CAM RANH
PHNOM PENH
SAIGON
CAN THO
GULF OF THAILAND
PHUKET
SONGKHLA
5
4
10
12
18
15
16
9
20
23

Figure 7



LASHIO
LAO KAY
DIEN BIEN PHU
PHONG SALY
HANOI
HAIPHONG
SAM NEUA
LUANG PRABANG
THANH HOA
GULF OF TONKIN
CHIANGMAI
VINH
VIENTIANE
NAKHON PHANOM
DONG HOI
UDORN
PHITSANULOK
SAVANNAKHET
DANANG
TAKHLI
KORAT
UBON
PAKSE
PLEIKU
TAVOY
BANGKOK
QUI NHON
SIEM REAP
SATTAHIP
KRATIE
NHA TRANG
CAM RANH
PHNOM PENH
SAIGON
CAN THO
GULF OF THAILAND
PHUKET
SONGKHLA
100°
20°
10°
MAY
MEAN NUMBER OF DAYS
WITH THUNDERSTORMS

Figure 8

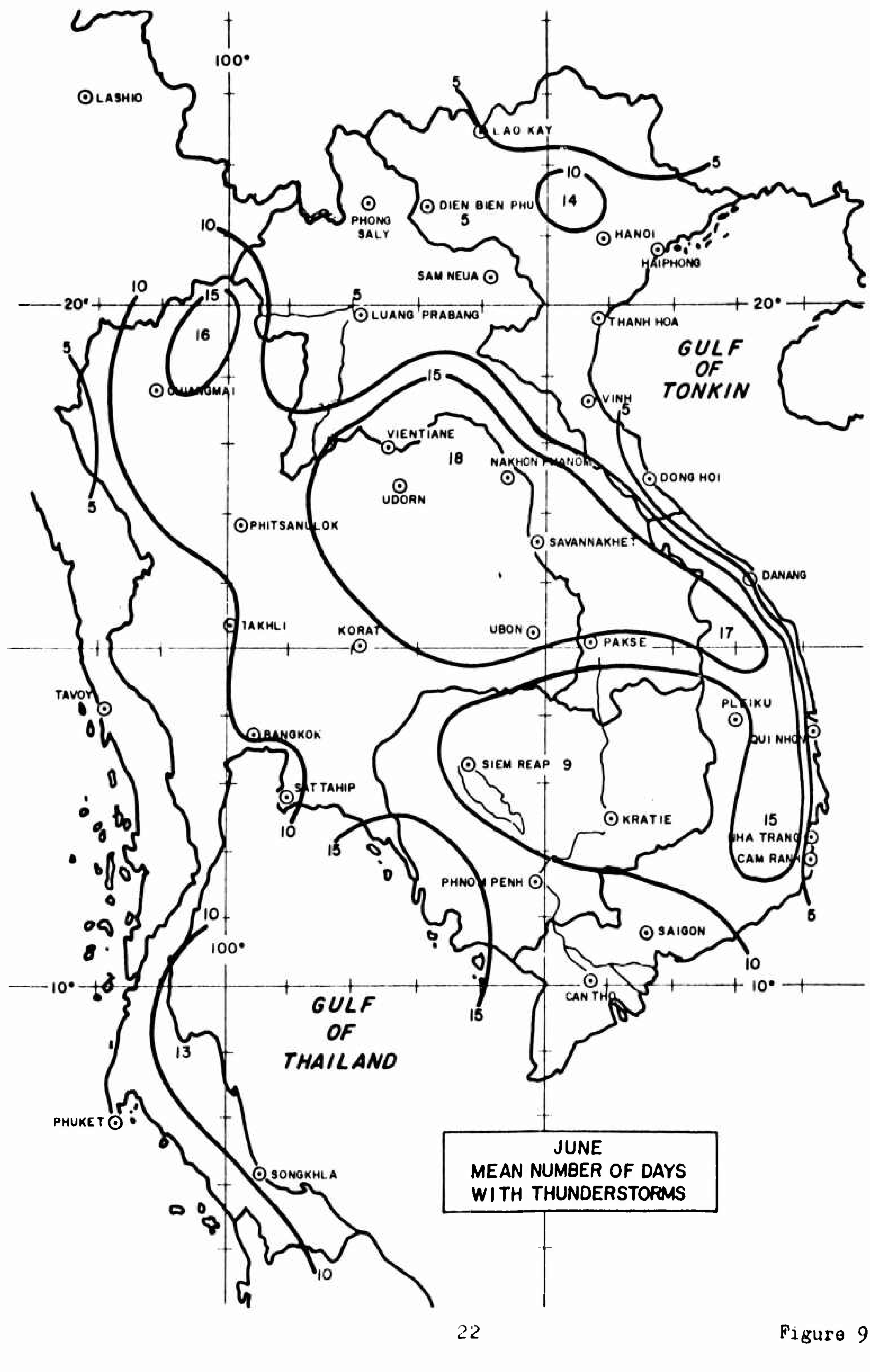

JUNE
MEAN NUMBER OF DAYS
WITH THUNDERSTORMS
GULF OF TONKIN
GULF OF THAILAND
LASHIO
LAO KAY
PHONG SALY
DIEN BIEN PHU
HANOI
HAIPHONG
SAM NEUA
LUANG PRABANG
THANH HOA
VINH
VIENTIANE
NAKHON PHANOM
UDORN
DONG HOI
PHITSANULOK
SAVANNAKHET
DANANG
TAKHLI
KORAT
UBON
PAKSE
TAVOY
PLEIKU
BANGKOK
QUI NHON
SIEM REAP
SATTAHIP
KRATIE
NHA TRANG
CAM RANH
PHNOM PENH
SAIGON
CAN THO
PHUKET
SONGKHLA
100°
20°
10°

Figure 9

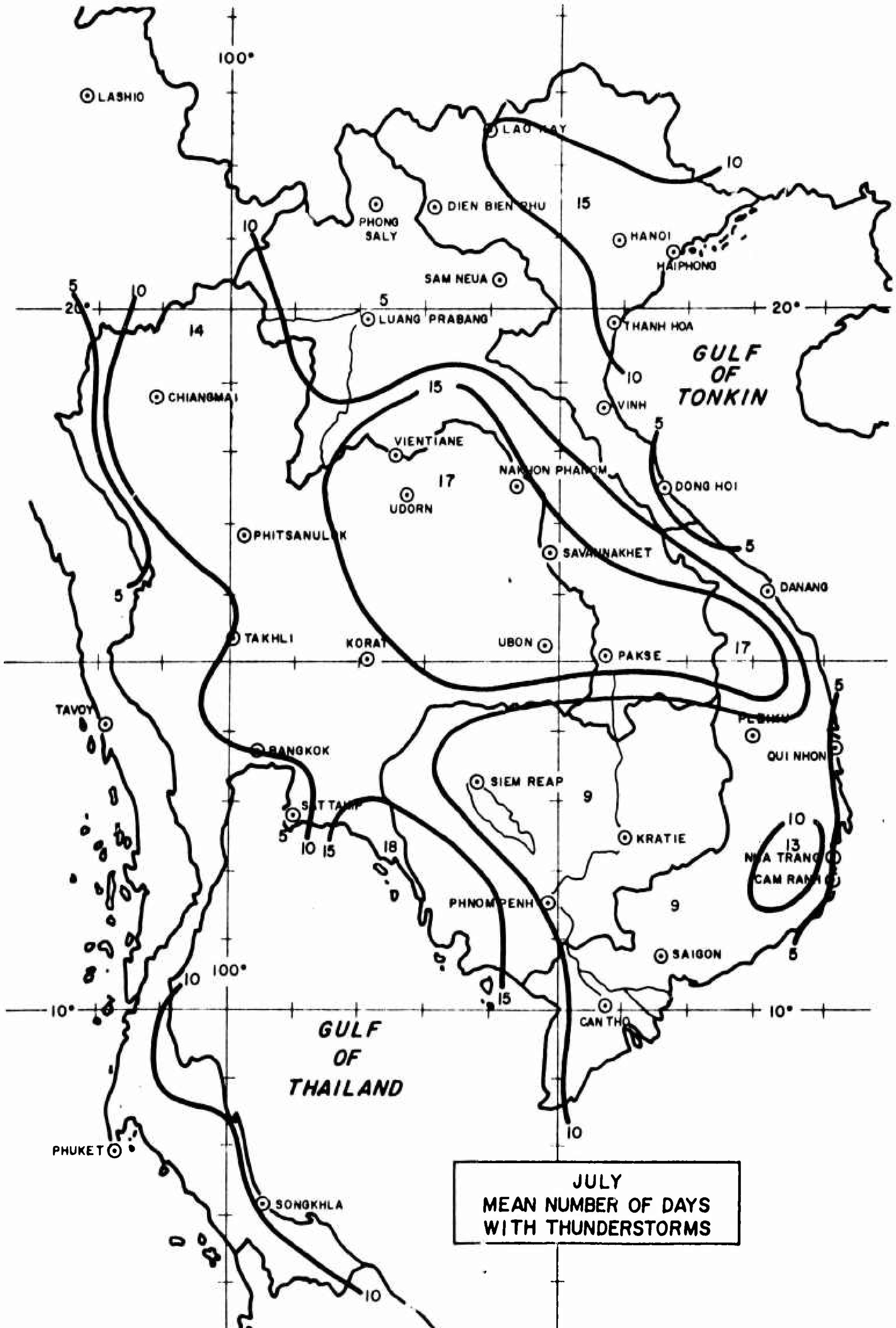

LASHIO
100°
LAO KAY
10
15
PHONG SALY
DIEN BIEN PHU
HANOI
HAIPHONG
SAM NEUA
5
LUANG PRABANG
20°
THANH HOA
14
GULF OF TONKIN
CHIANGMAI
VINH
VIENTIANE
17
NAKHON PHANOM
UDORN
DONG HOI
PHITSANULOK
SAVANNAKHET
DANANG
TAKHLI
KORAT
UBON
PAKSE
TAVOY
PLEIKU
QUI NHON
BANGKOK
SIEM REAP
9
SATTAHIP
18
KRATIE
13
NHA TRANG
CAM RANH
PHNOM PENH
SAIGON
10°
CAN THO
GULF OF THAILAND
PHUKET
SONGKHLA
JULY
MEAN NUMBER OF DAYS
WITH THUNDERSTORMS

Figure 10

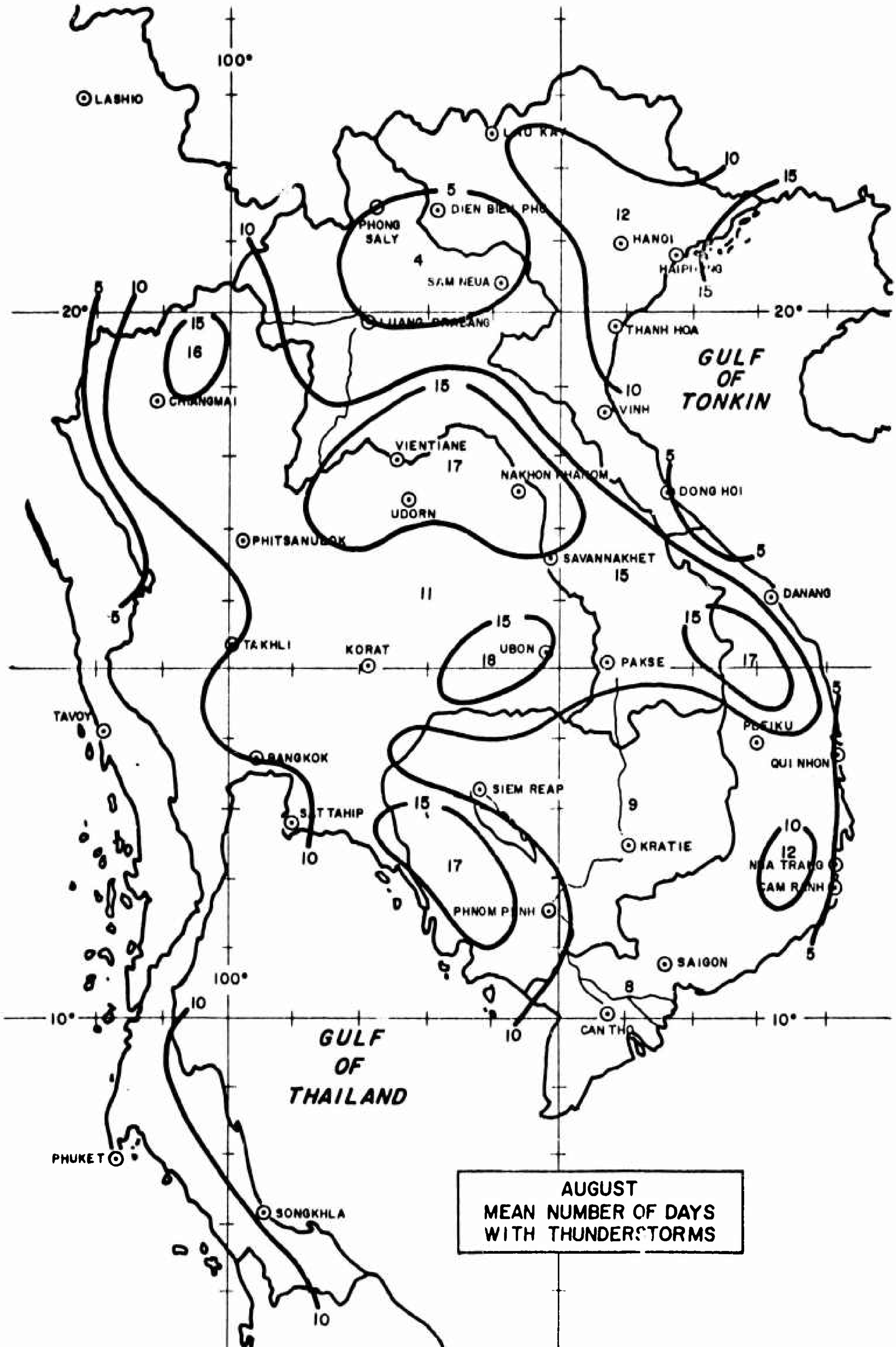

AUGUST
MEAN NUMBER OF DAYS
WITH THUNDERSTORMS
GULF OF TONKIN
GULF OF THAILAND
LASHIO
DIEN BIEN PHU
PHONG SALY
SAM NEUA
HANOI
THANH HOA
VINH
CHIANGMAI
VIENTIANE
NAKHON PHANOM
UDORN
PHITSANULOK
DONG HOI
SAVANNAKHET
DANANG
TAKHLI
KORAT
UBON
PAKSE
PLEIKU
QUI NHON
TAVOY
BANGKOK
SIEM REAP
KRATIE
PHNOM PENH
SAIGON
CAN THO
PHUKET
SONGKHLA
100°
20°
10°

Figure 11

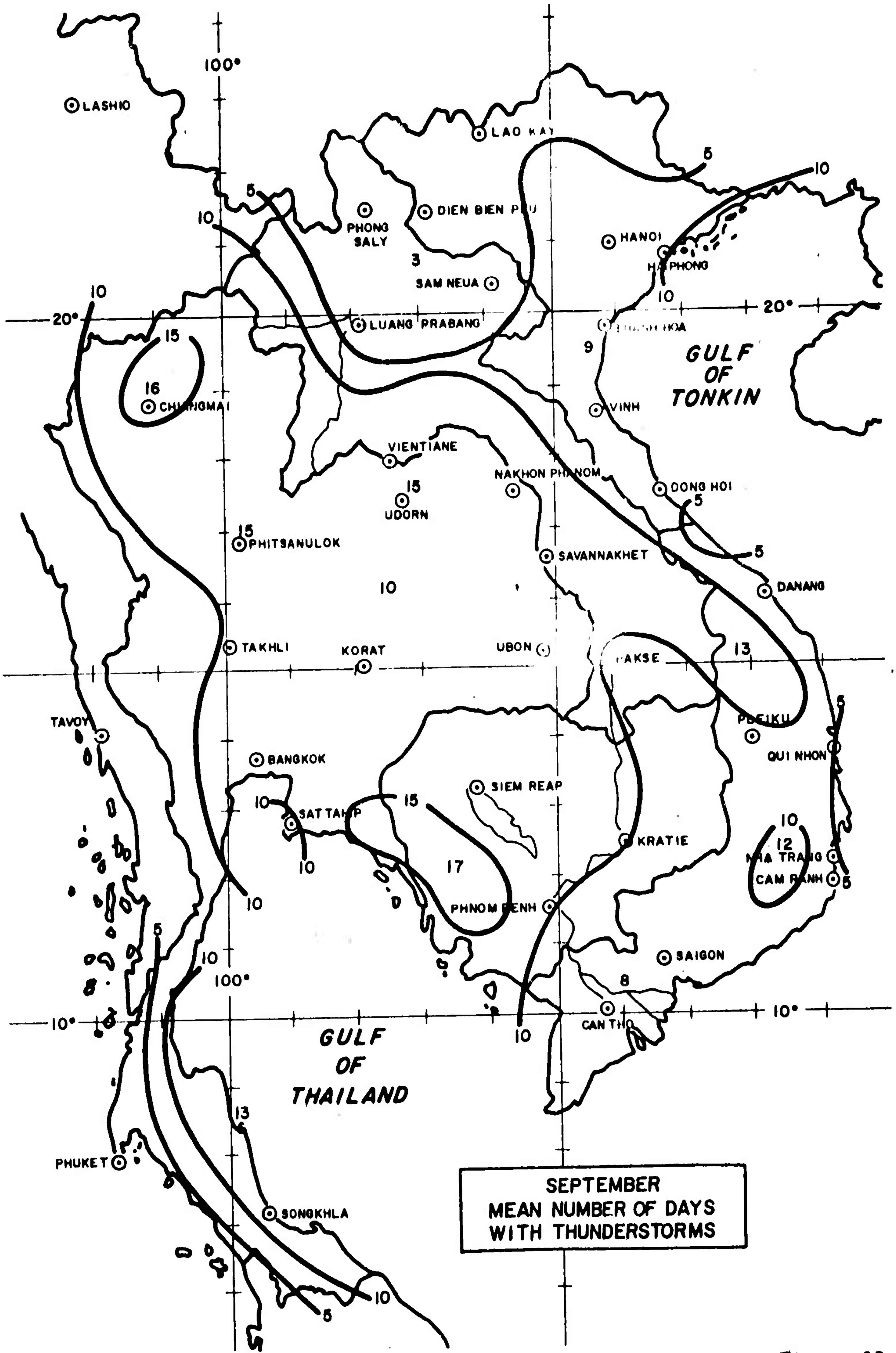

SEPTEMBER
MEAN NUMBER OF DAYS
WITH THUNDERSTORMS
GULF OF TONKIN
GULF OF THAILAND
LASHIO
LAO KAY
DIEN BIEN PHU
PHONG SALY
SAM NEUA
HANOI
HAIPHONG
LUANG PRABANG
CHIENGMAI
VINH
VIENTIANE
NAKHON PHANOM
DONG HOI
UDORN
PHITSANULOK
SAVANNAKHET
DANANG
TAKHLI
KORAT
UBON
PAKSE
PLEIKU
TAVOY
QUI NHON
BANGKOK
SIEM REAP
SATTAHIP
KRATIE
NHA TRANG
CAM RANH
PHNOM PENH
SAIGON
CAN THO
PHUKET
SONGKHLA
100°
20°
10°

Figure 12

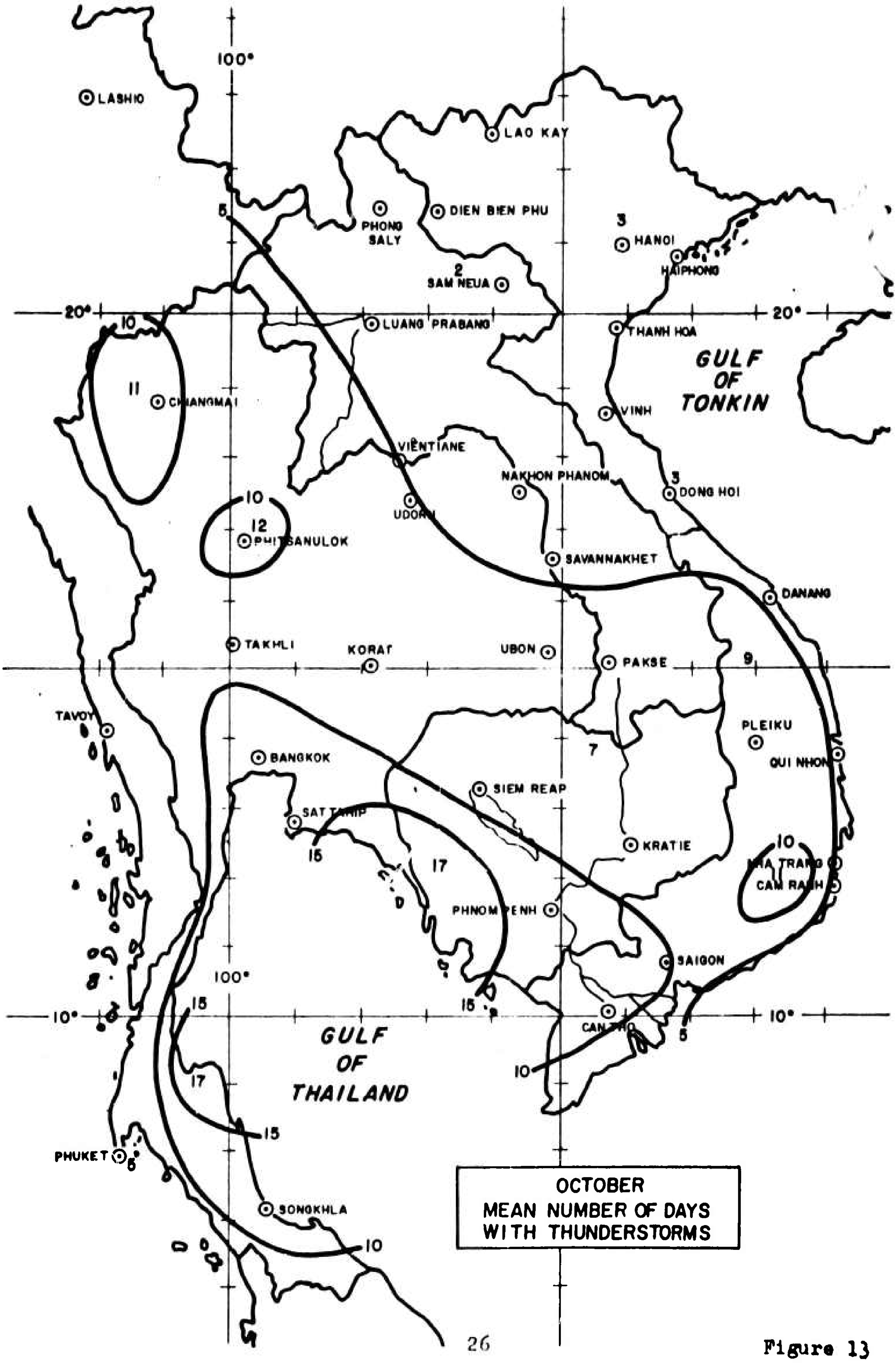
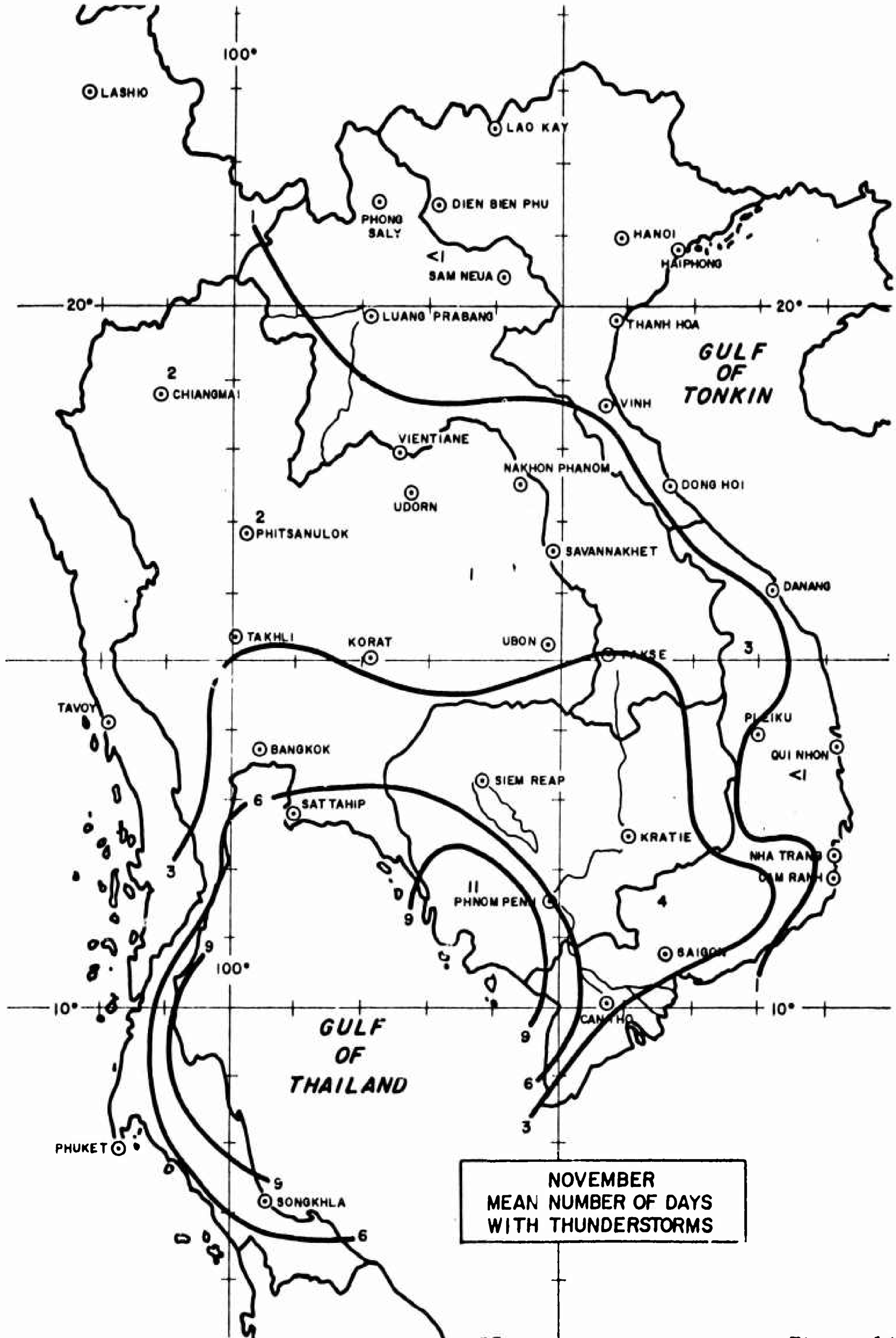
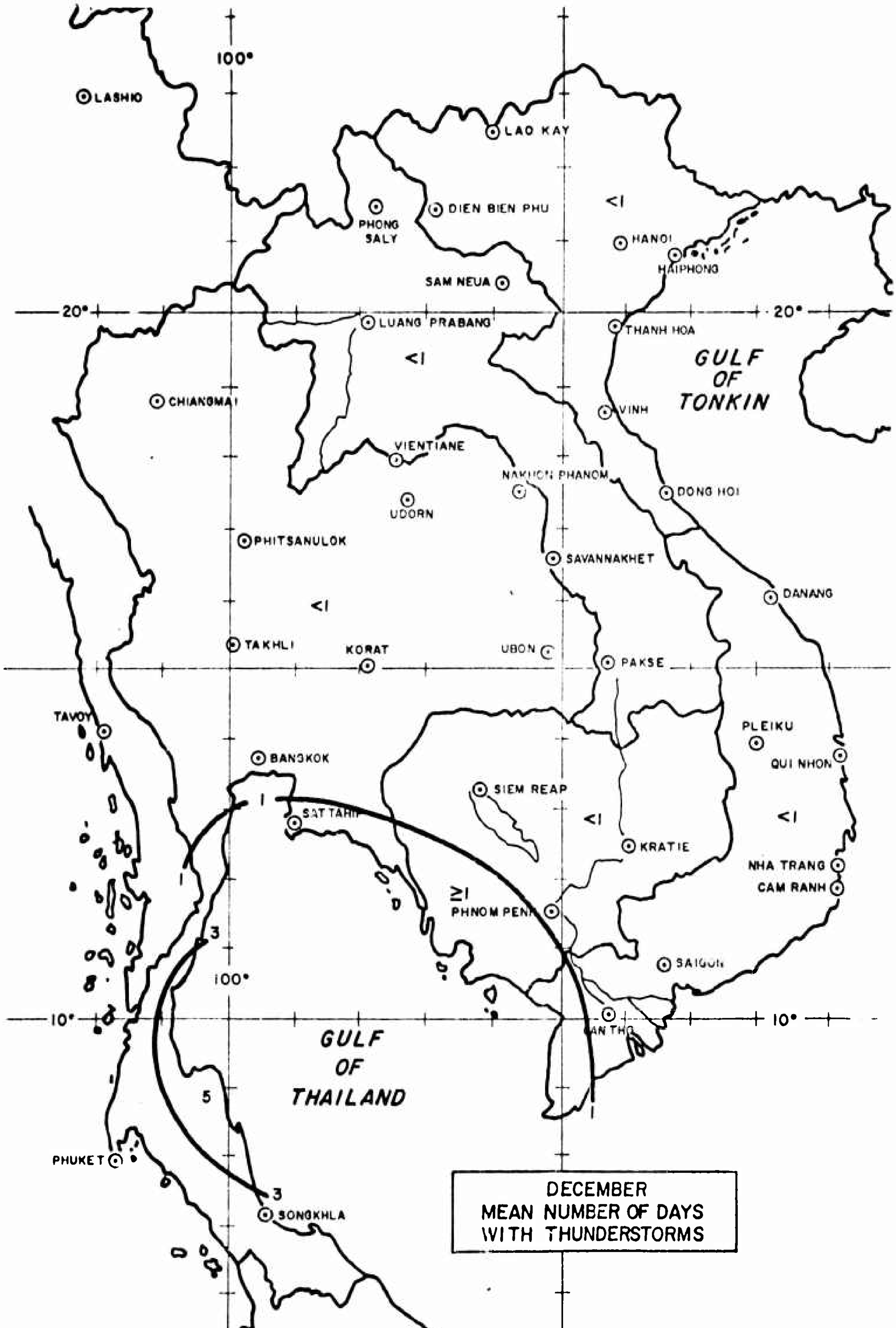

100°
LASHIO
LAO KAY
PHONG SALY
DIEN BIEN PHU
HANOI
HAIPHONG
SAM NEUA
LUANG PRABANG
THANH HOA
20°
GULF OF TONKIN
CHIANGMAI
VINH
VIENTIANE
NAKHON PHANOM
DONG HOI
UDORN
PHITSANULOK
SAVANNAKHET
DANANG
TAKHLI
KORAT
UBON
PAKSE
TAVOY
PLEIKU
BANGKOK
QUI NHON
SIEM REAP
SAT TAHIP
KRATIE
NHA TRANG
CAM RANH
PHNOM PENH
SAIGON
10°
CAN THO
GULF OF THAILAND
PHUKET
SONGKHLA
OCTOBER
MEAN NUMBER OF DAYS
WITH THUNDERSTORMS

Figure 13



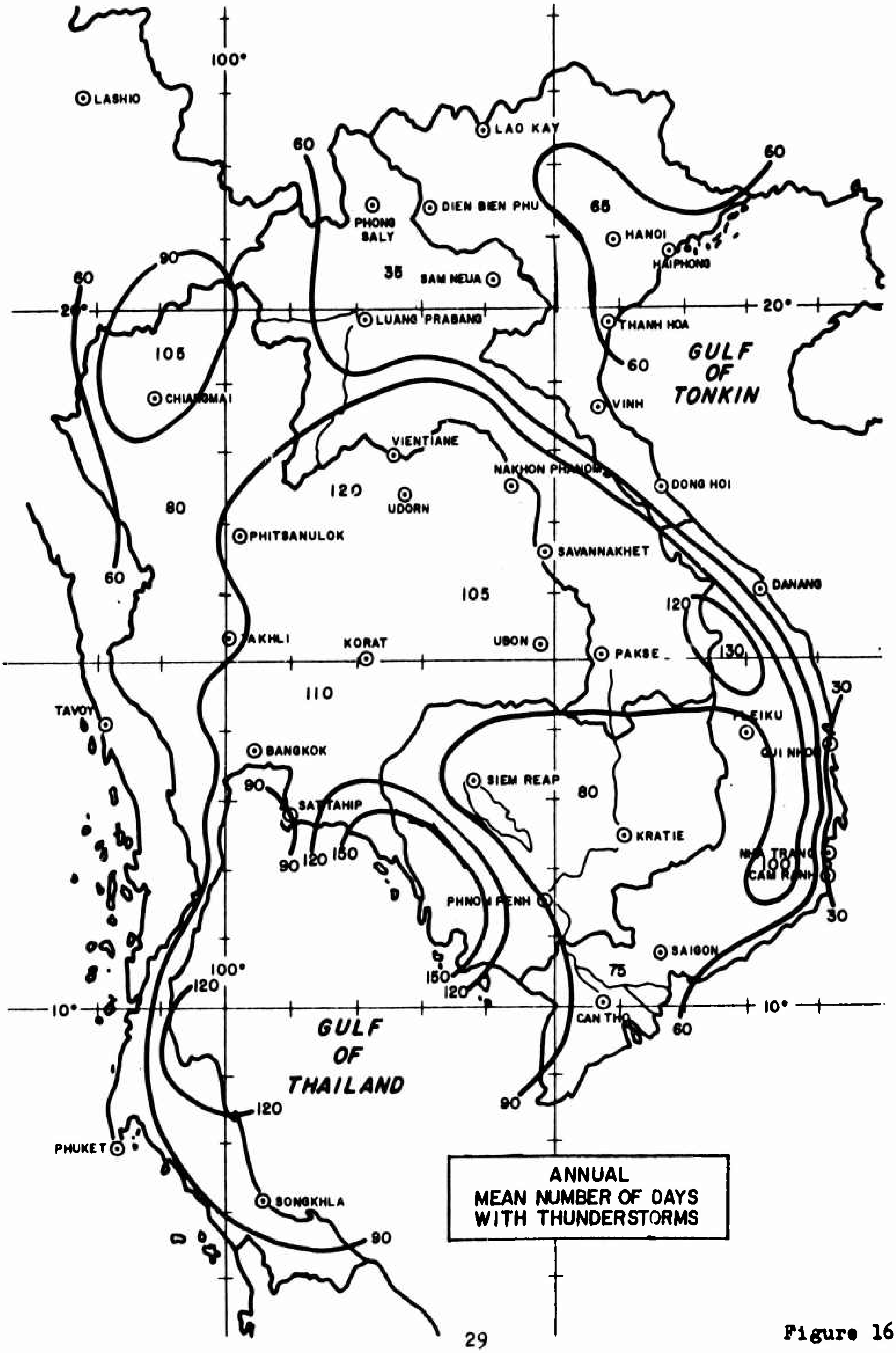
NOVEMBER
MEAN NUMBER OF DAYS
WITH THUNDERSTORMS

Figure 14



100°
LASHIO
LAO KAY
DIEN BIEN PHU
PHONG SALY
<1
HANOI
HAIPHONG
SAM NEUA
20°
LUANG PRABANG
THANH HOA
<1
GULF OF TONKIN
CHIANGMAI
VINH
VIENTIANE
NAKHON PHANOM
DONG HOI
UDORN
PHITSANULOK
SAVANNAKHET
DANANG
<1
TAKHLI
KORAT
UBON
PAKSE
TAVOY
PLEIKU
BANGKOK
QUI NHON
SIEM REAP
1
<1
<1
1
KRATIE
NHA TRANG
≥1
CAM RANH
PHNOM PENH
3
100°
10°
GULF OF THAILAND
5
1
PHUKET
3
SONGKHLA
DECEMBER
MEAN NUMBER OF DAYS
WITH THUNDERSTORMS

Figure 15



ANNUAL
MEAN NUMBER OF DAYS
WITH THUNDERSTORMS
GULF OF TONKIN
GULF OF THAILAND
LASHIO
LAO KAY
DIEN BIEN PHU
PHONG SALY
SAM NEUA
HANOI
HAIPHONG
LUANG PRABANG
THANH HOA
CHIANGMAI
VINH
VIENTIANE
NAKHON PHANOM
UDORN
DONG HOI
PHITSANULOK
SAVANNAKHET
DANANG
TAKHLI
KORAT
UBON
PAKSE
TAVOY
PLEIKU
QUI NHON
BANGKOK
SIEM REAP
SATTAHIP
KRATIE
NHA TRANG
CAM RANH
PHNOM PENH
SAIGON
CAN THO
PHUKET
SONGKHLA
100°
20°
10°
60
65
35
90
105
120
80
130
110
30
150
75
100

Figure 16

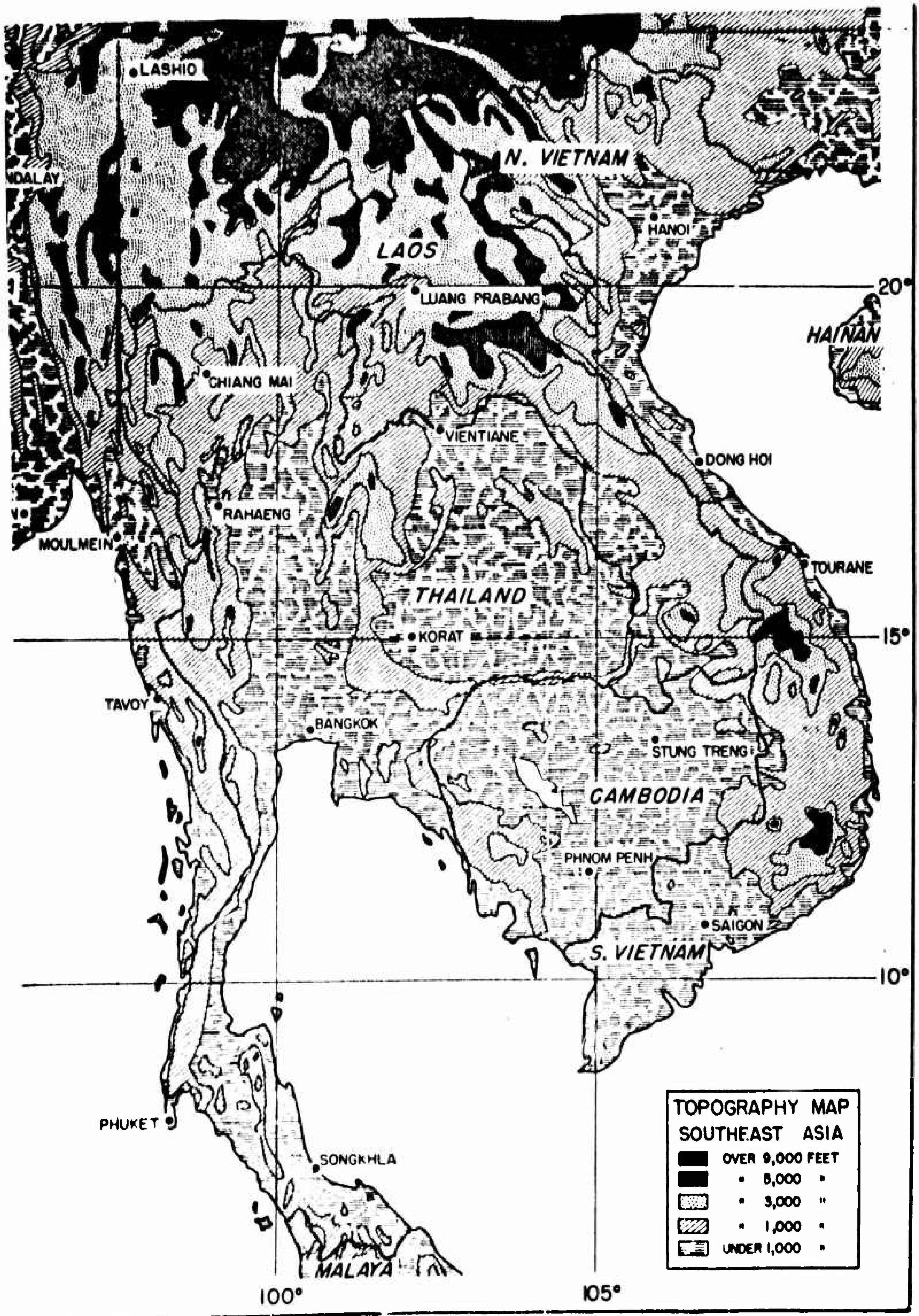

LASHIO
NDALAY
N. VIETNAM
HANOI
LAOS
LUANG PRABANG
20°
HAINAN
CHIANG MAI
VIENTIANE
DONG HOI
RAHAENG
MOULMEIN
TOURANE
THAILAND
KORAT
15°
TAVOY
BANGKOK
STUNG TRENG
CAMBODIA
PHNOM PENH
SAIGON
S. VIETNAM
10°
PHUKET
SONGKHLA
MALAYA
100°
105°
TOPOGRAPHY MAP
SOUTHEAST ASIA
OVER 9,000 FEET
" 6,000 "
" 3,000 "
" 1,000 "
UNDER 1,000 "

Figure 17

IV. Year to Year Thunderstorm Day Variation

There is a fairly large year to year variation in the numbers of thunderstorm days at Southeast Asian stations. Meteorologists should be aware of the magnitude of this variation and provide military planners with the range of values to expect, as well as the mean value. Following is a discussion of the development of models which relate the standard deviation of the monthly (annual) number of thunderstorm days and the expected range of thunderstorm days to the mean monthly (annual) values.

The number of thunderstorm days by month, by year, is available for 28 Thailand stations for the 12 year period 1946-1950 and 1956-1962. These data are used to compute the means and standard deviations for each station month. Months which average less than 3 thunderstorm days are excluded. Figure 18 shows the mean for each station month plotted against its standard deviation. Initially, inland stations were separated from maritime stations, but later were combined since no significant differences in thunderstorm variations were found at these two sets of stations. The initial values were also separated by month to determine if the standard deviations were dependent on the month used. Again, there appeared to be no significant relationship so the values for all station months were combined. As shown by Figure 18, there is a fair correlation between the means and standard deviations; however, this relationship is not linear, and there is a large scatter in the individual values. Much of this scatter is undoubtedly because of the short record available. Therefore, to reduce the scatter, the yearly values for station months with similar monthly means are combined, and the means and standard deviations of these grouped values computed. The results of this grouping are illustrated by Figures 19 and 20. Bar graphs of the frequency distribution of individual yearly values for six of the groups are shown in Figure 19. All yearly values for station months showing a mean within a one day class increment are included. For example, the group with a mean of 10.4 day includes all station months showing means of 10.0 to 10.9 days. Figure 20 shows the monthly mean plotted against the standard deviation for each group of station months and the line fitted by eye to these points. As shown by this line, the means and standard deviation increase together to a mean of approximately 16 days from which point the standard deviation decreases for further increases in the mean. Also shown in Figure 20 is a line representing standard deviations corresponding to binomial distributions. Note that computed standard deviations are much higher than those obtained from binomial distributions. This is because of the persistency in thunderstorm day occurrence, e.g., the probability of thunderstorm occurrence on any day varies according to whether or not a thunderstorm occurred the previous day. This persistency factor is covered in detail in Part VI. The line derived from the grouped values in Figure 20 is also shown on Figure 18, along with dashed lines corresponding to a variation of ±1.0 day;

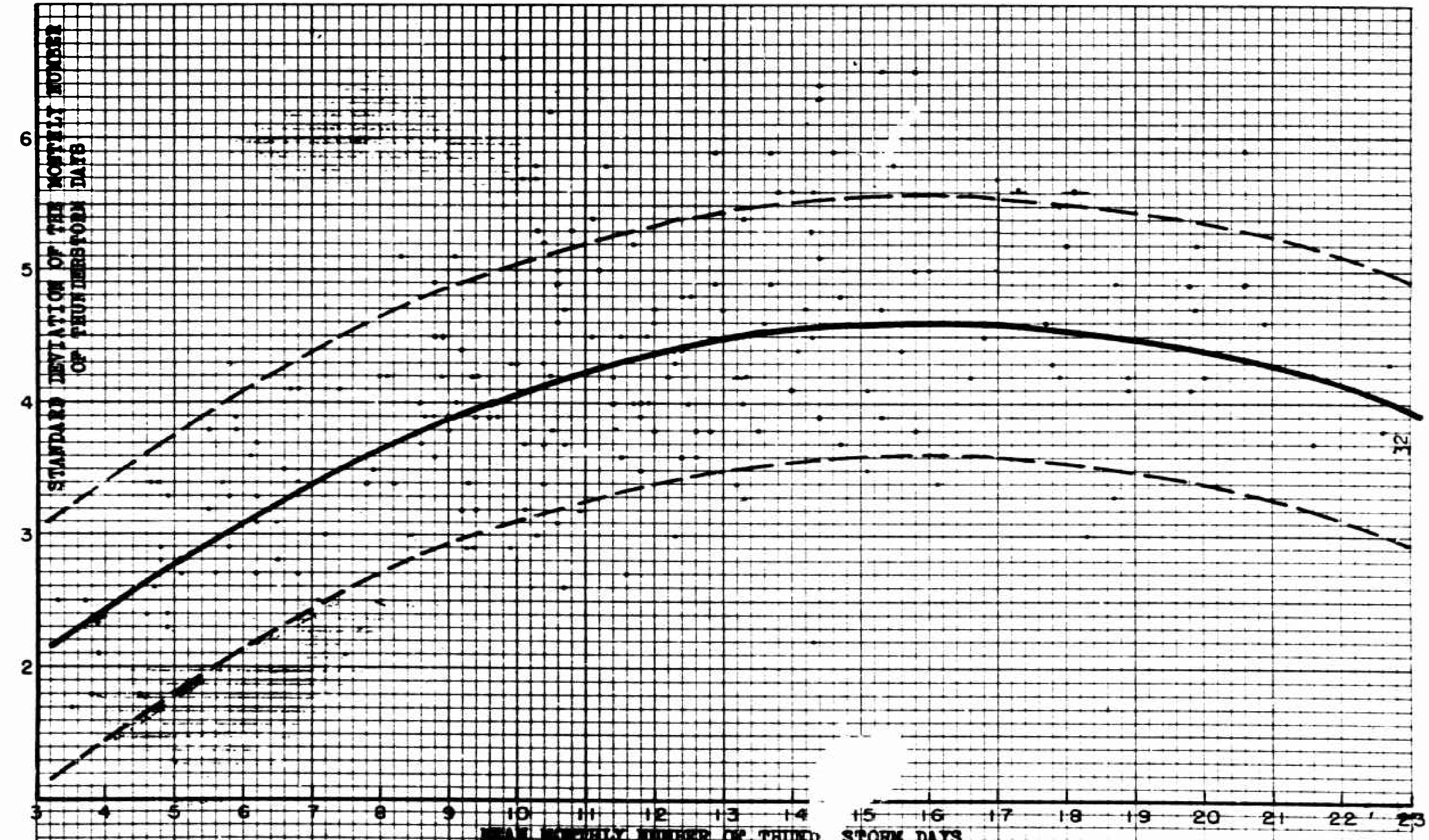


Figure 18. Mean monthly number of thunderstorm days versus the standard deviation of the monthly number of thunderstorm days computed for 28 Thailand stations.

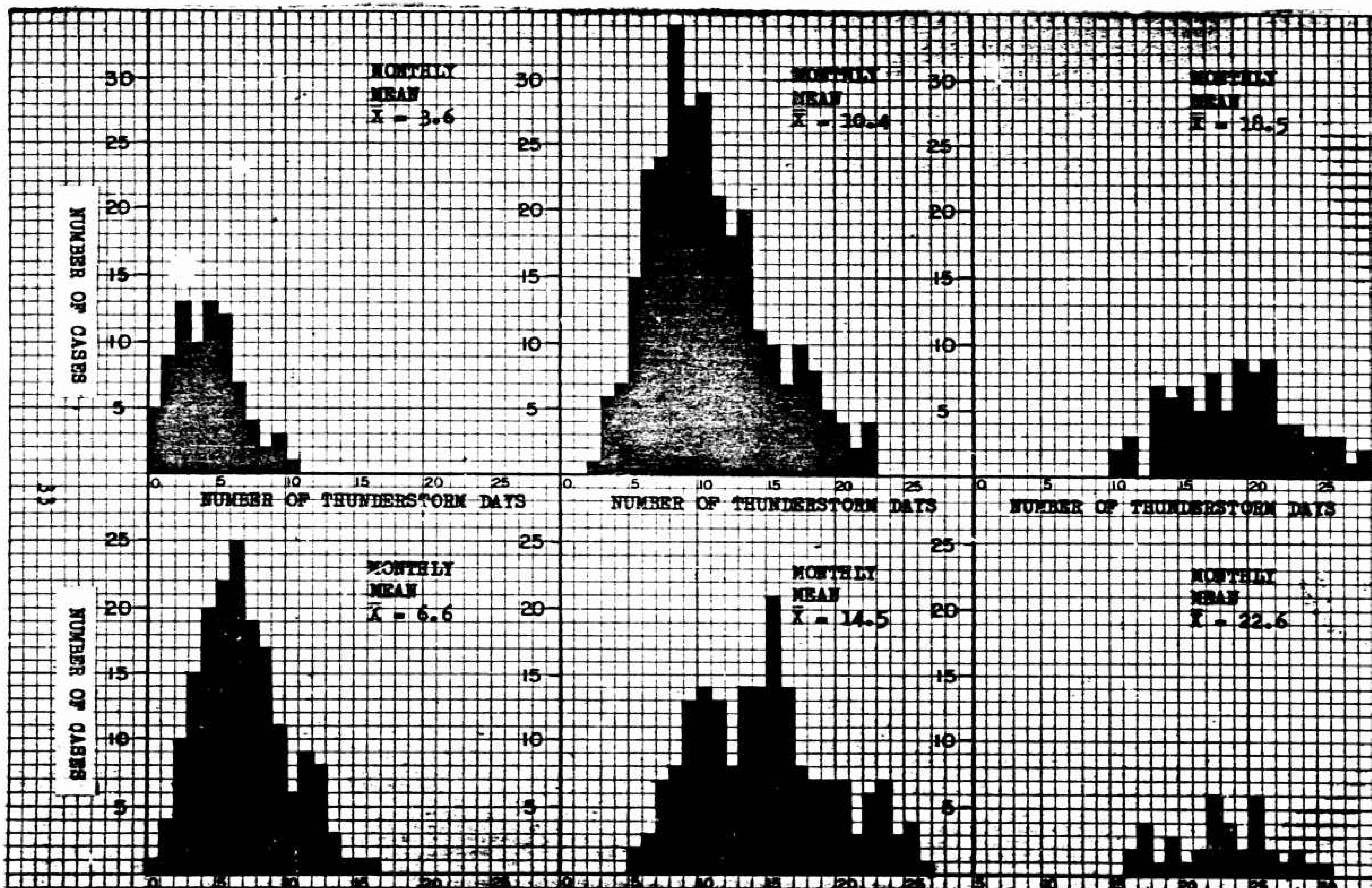

MONTHLY
MEAN
$\bar{X}$ = 3.6
MONTHLY
MEAN
$\bar{X}$ = 10.4
MONTHLY
MEAN
$\bar{X}$ = 18.5
MONTHLY
MEAN
$\bar{X}$ = 6.6
MONTHLY
MEAN
$\bar{X}$ = 14.5
MONTHLY
MEAN
$\bar{X}$ = 22.6
NUMBER OF CASES
NUMBER OF CASES
NUMBER OF THUNDERSTORM DAYS
NUMBER OF THUNDERSTORM DAYS
NUMBER OF THUNDERSTORM DAYS
30
25
20
15
10
5
0
5
10
15
20
25

Figure 19. [illegible]

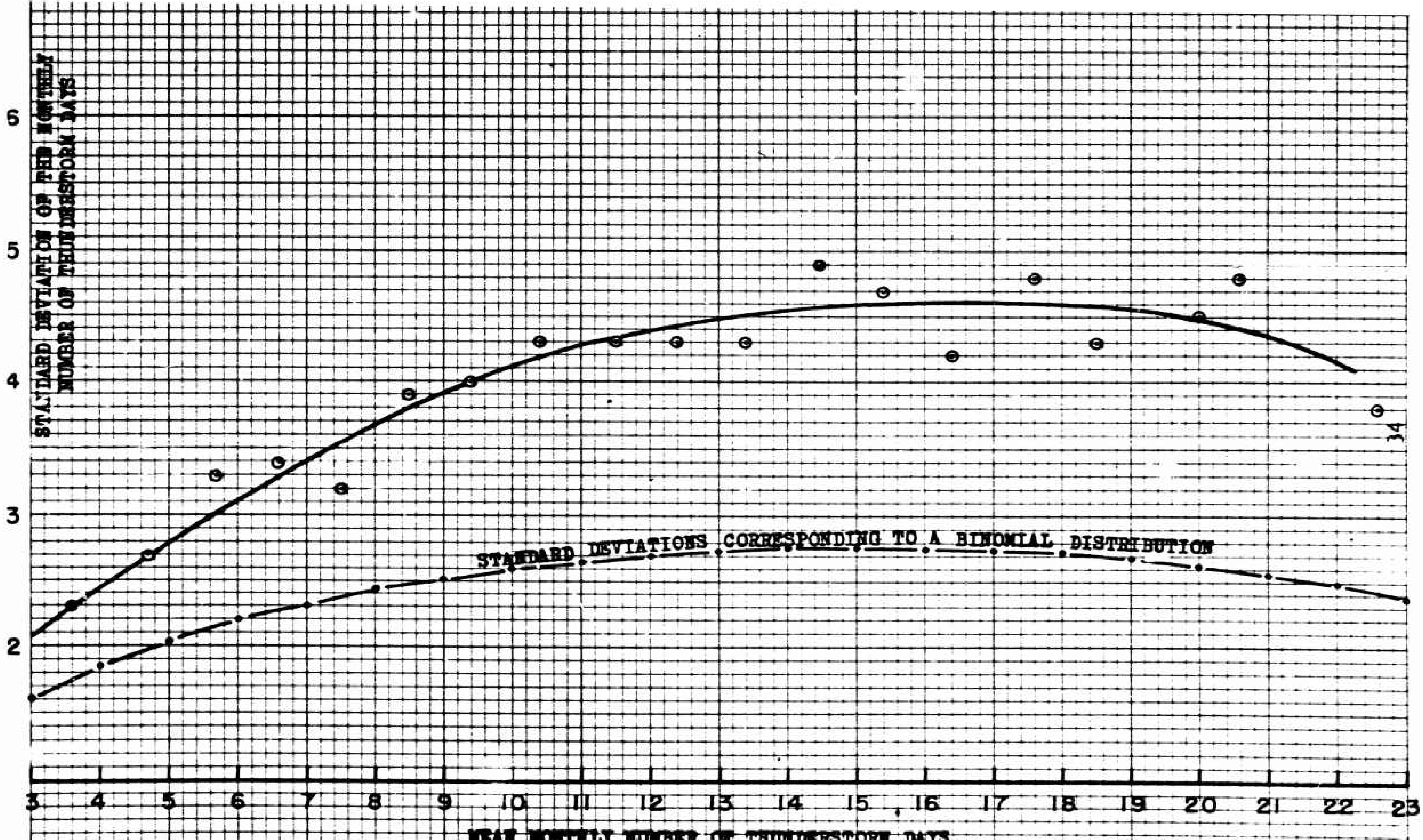


Figure 20. Mean monthly number of thunderstorm days versus the standard deviation of the monthly number of thunderstorm days for 28 Thailand stations grouped in one day class intervals according to the monthly means (solid line). The dash-dot line is the standard deviations corresponding to a binomial distribution.

80% of the values for individual station months lie within this interval.

This same procedure is used to relate the standard deviation of annual thunderstorm days to the mean annual value. Naturally, the sample size is much smaller, since only one value is available at each station. The yearly totals of thunderstorm days for individual station years also are grouped for stations with similar means. Figure 21 shows means versus standard deviations for the annual number of thunderstorm days. Both individual stations and grouped values are shown along with the best fitting straight line. The dashed lines indicate a variation of ± 5 days from this line of best fit; 72% of the individual station year values are included within this interval. A line representing standard deviations of yearly thunderstorm days obtained from binomial distributions also is shown on Figure 21. Again, the computed standard deviations are much higher than those corresponding to binomial distributions.

Figures 20 and 21 can be used to estimate the standard deviations of thunderstorm days from mean monthly and annual values at Southeast Asian stations. These standard deviations can be used to determine the reliability of the mean number of thunderstorm days available for any station.

For example, suppose a station has an old summary showing the mean number of thunderstorm days in June during a 10 year period of record to be 7 days, yet in the past 4 years, 8, 14, 9 and 13 thunderstorm days occurred in June for an average of 11 days. Since the thunderstorm day variation is near normally distributed (see Figure 19), we can use "student's" t distribution (covered in any introductory book on statistics) to test the hypothesis that these two samples came from the same population. The "t" value is computed by

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{N_1S_1 + N_2S_2}{N_1 + N_2 - 2}\left(\frac{1}{N_1} + \frac{1}{N_2}\right)}}$$

where $\bar{X}_1$ and $\bar{X}_2$ are the sample means (7 and 11 in this case), N_1 and N_2 are the sample sizes (10 and 4) and S_1 and S_2 are the sample standard deviations. Since we do not have the yearly values of our 10 year sample, we estimate S_1 from Figure 20 as 3.40 corresponding to our sample mean of 7 days. S_2 is computed to be 2.55 from the four values in our second sample. Using these values, $t = 1.97$. From a table of percentile values for the t distribution using 12 degrees of freedom ($N_1 + N_2 - 2$), we find that there is only a 7.2% chance that these two samples came from the same population. Therefore, we should probably reject the earlier mean of 7 days in June as being too low and use our new sample mean of 11 days as the best estimate of the true mean.

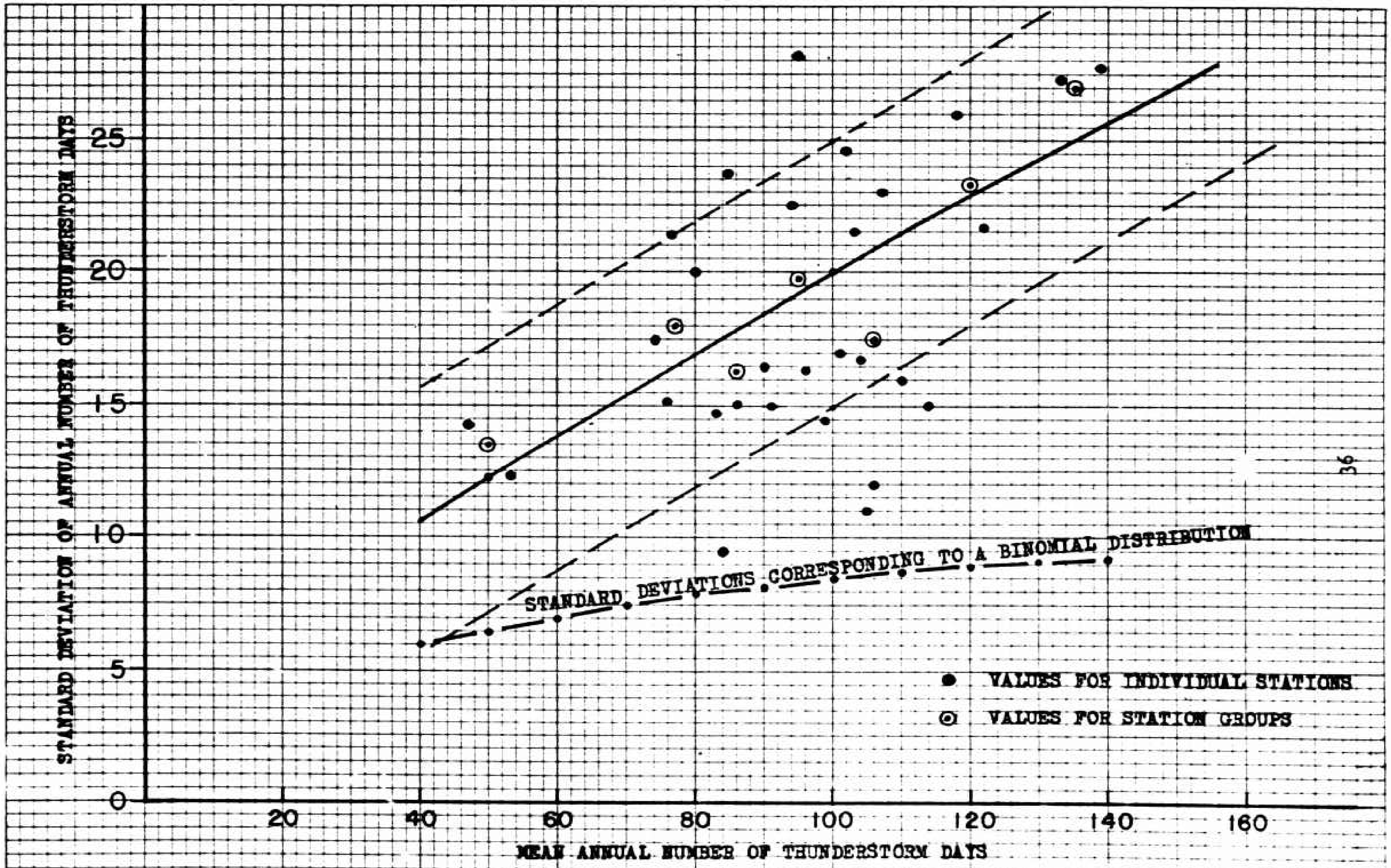


Figure 21. Mean annual number of thunderstorm days versus the standard deviation of annual number thunderstorm days for 28 Thailand stations. Dashed line shows a deviation of ±5 days from the best fitting straight line. The dash-dot line is the standard deviations corresponding to a binomial distribution.

To determine the percentage range in thunderstorm days that can be expected in any month, cumulative frequency distributions of the yearly values for station months with similar means were plotted. This initial family of curves were smoothed slightly and used to interpolate the percentage values for monthly means of 3 to 24 thunderstorm days. This derived family of curves is shown in Figure 22 and can be used as a model to estimate the year to year variation in thunderstorm days for any month from the mean monthly value. Illustrations of the application of this model follow. Assume we want to know the probability of observing 15 thunderstorm days in a month showing a long term mean of 9 days. We move upward along the curve representing a mean of 9 days until it intersects the horizontal line corresponding to 15 days and read the percentage of occurrence from the top scale (in this case - 10%). Thus, one year out of 10, on the average, we could expect 15 or more thunderstorm days during this month. As another example, assume we want the 90% range of thunderstorm days that will occur at a station showing a mean of 16 days for a certain month. Entering the curve representing a mean of 16 days we read the number of thunderstorm days at the 95th and 5th percentile (in this case 9 and 24 days). Thus in 90% of the years, this station can expect between 9 and 24 thunderstorm days during this month.

The same procedure as above is used to develop a model (Figure 23) relating the variation in yearly number of thunderstorm days to the mean annual value. The family of curves in this model are limited to the 90% range of values (from the 95th to the 5th percentile) because of the small sample size used, which gives much larger errors of estimate at the extreme percentiles. The model is interpreted in the same manner as the one for the monthly values, so no examples of its application are required.

We now turn to a subject which will be of more use in day to day thunderstorm forecasting - the diurnal variation and duration of thunderstorms in Southeast Asia.

V. Diurnal Variation and Duration of Thunderstorms

A. Diurnal Variation

There is a pronounced diurnal variation in thunderstorm activity throughout Southeast Asia. Thunderstorms are most frequent during late afternoon and early evening hours and least frequent during daylight morning hours. There are significant differences, however, in diurnal frequency curves between various geographical areas shown by Figure 2. The diurnal variation of Southeast Asian thunderstorm activity is illustrated by Figure 24 which gives representative diurnal curves for each area. These curves have been

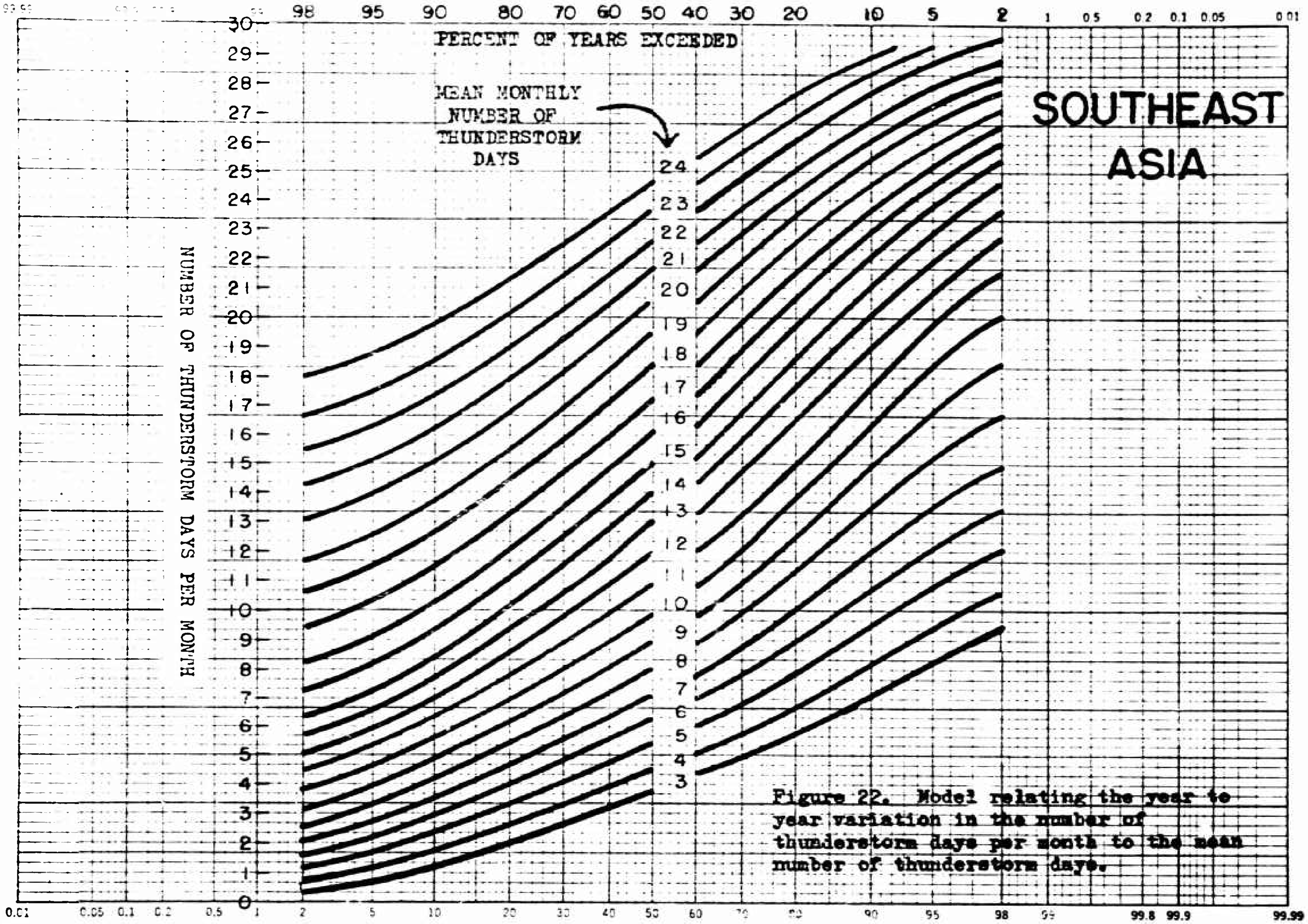


Figure 22. Model relating the year to year variation in the number of thunderstorm days per month to the mean number of thunderstorm days.

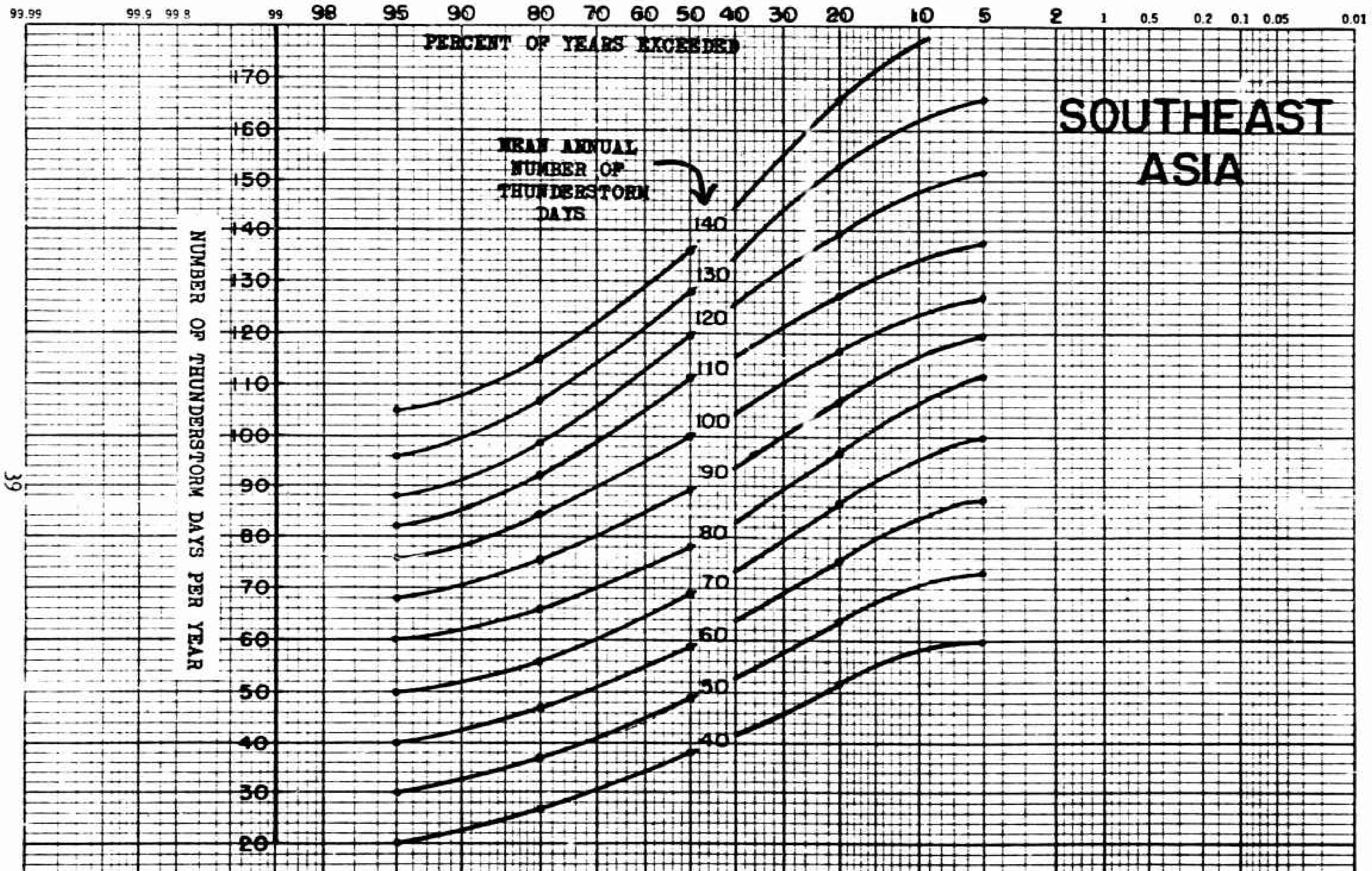


Figure 23. Model relating the year to year variation in the annual number of thunderstorm days to the mean annual number of thunderstorm days.

normalized so that areas under each curve are equal and represent 100% of the hourly observations. These curves are derived by fitting smooth curves to thunderstorm frequencies given in N Summary 14 for 3-hourly synoptic observations. At most stations, there is little difference in diurnal thunderstorm variation from month to month so values at synoptic hours for all months are combined to derive a representative curve for each station. Then, stations in each of the 14 geographical areas are combined to derive a representative diurnal curve for each area. Finally, areas which have similar diurnal curves are combined to derive the final curves shown in Figure 24 and discussed below.

The diurnal variation of thunderstorms in North Vietnam and mountains of northern Laos (top set of curves) is much less pronounced than in the remainder of Southeast Asia. Note the secondary maximum of thunderstorm activity between midnight and 0500 LST in Area I (Red River Valley). In the remainder of Southeast Asia, thunderstorm activity reaches a peak between 1500 and 1700 LST and a minimum between 0700 and 1000 LST. Note the afternoon maximum is much more pronounced in the southern part of Area V (RVN Northeast Coast) and Area VI (Mountains - Southern Laos and RVN) than in other areas. In fact, 60% of the thunderstorm activity in these two areas occurs in the 4 hour period from 1400 to 1800 LST.

B. Duration.

The duration of individual thunderstorm cells is approximately one hour; however, continous thunderstorm activity at any station often lasts longer than one hour due to development of additional thunderstorm cells. Most climatological summaries are limited to data derived from hourly or 3-hourly observations, so to determine actual durations of thunderstorms for specific stations, it is necessary to consider all observations including locals and specials. Figure 25, prepared for a report on thunderstorm activity at Mactan AB, Philippines, illustrates the occurrence and duration of thunderstorms at Mactan (derived from WBAN 10A observations for June, July and August 1965). This type of representation is extremely useful to acquaint newly assigned forecasters with the thunderstorm activity pattern at any station. Figure 26 shows the frequency distribution of thunderstorm durations at Mactan for the period Jun-Nov 65 and May-Nov 66. This graph is prepared using graphs similar to Figure 25. In Figure 26, each period of thunderstorm activity is counted as a separate occurrence regardless of the time between successive periods. A similar graph, which may be more meaningful operationally, is shown in Figure 27. This graph is prepared by considering successive periods of thunderstorm activity separated by less than two hours as one occurrence. Thus, when the short periods (less than 2 hours) between thunderstorms are omitted, we obtain a larger

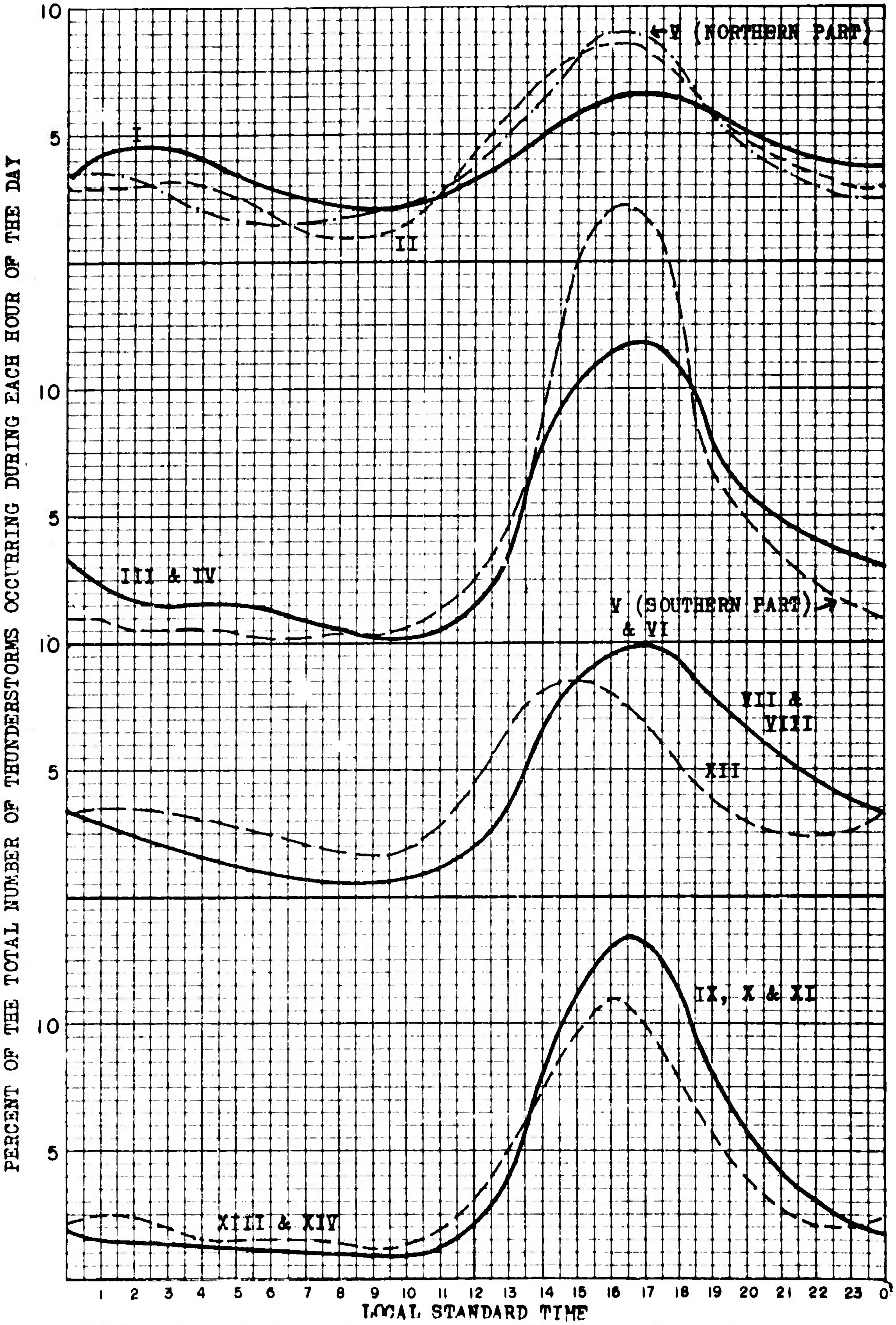
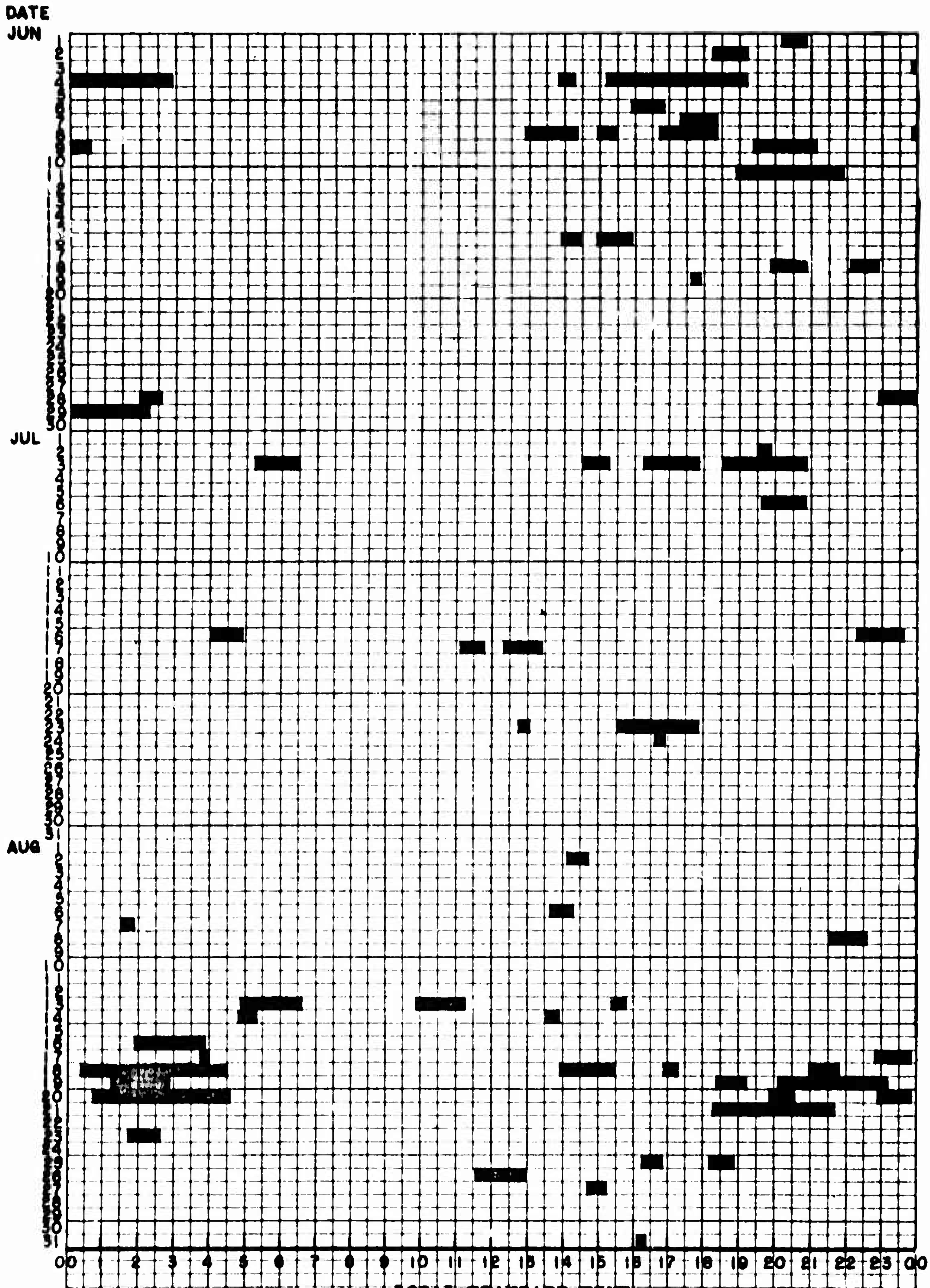


Figure 24. Representative curves of the diurnal variation in thunderstorm activity in each geographic area of Southeast Asia shown on Figure 2.



Fire 25. Thunderstorm occurrence at Mactan AB, Philippines during the period Jun-Aug 1965.

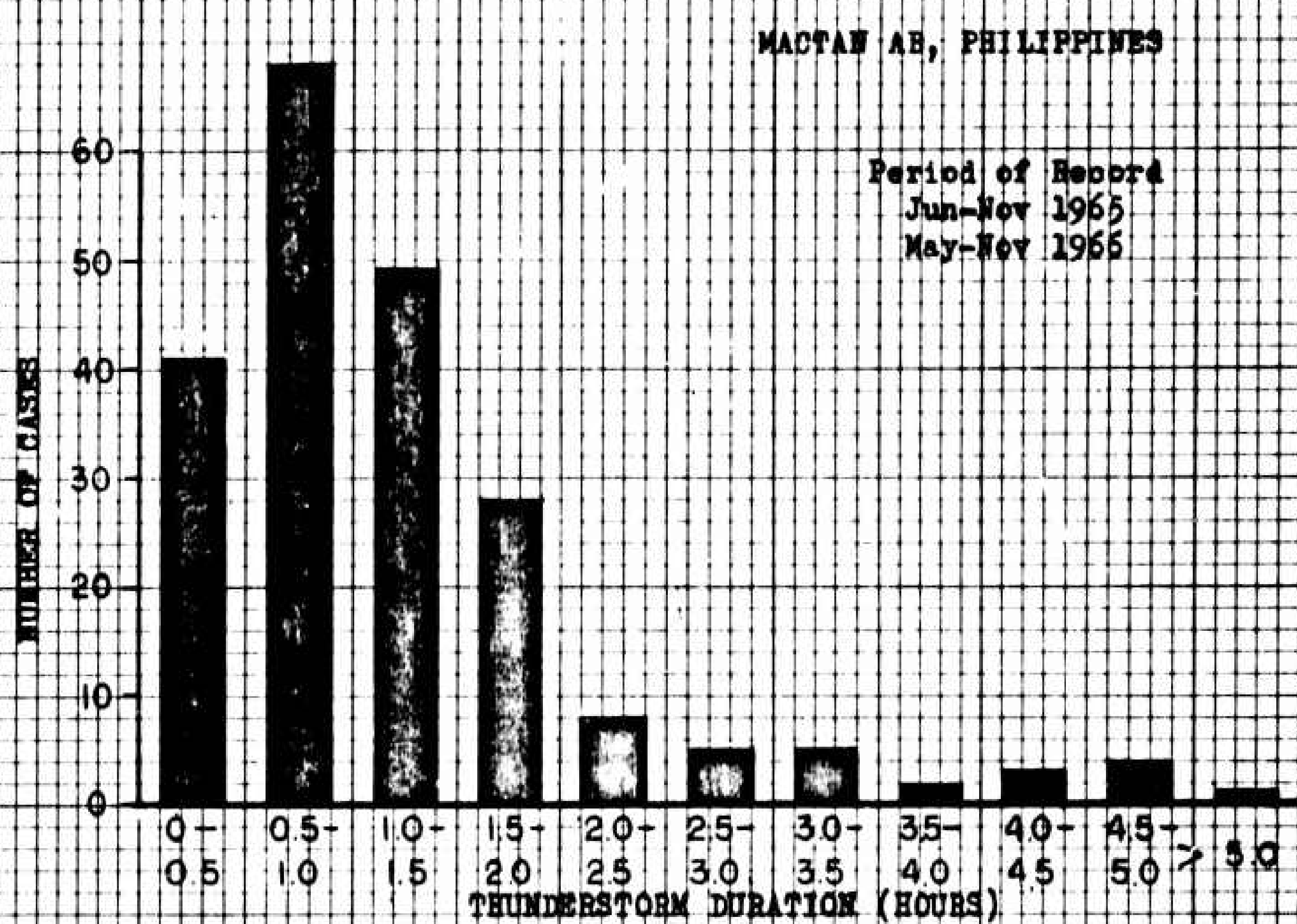


Figure 26. Frequency distribution of thunderstorm durations at Mactan AB, Philippines.

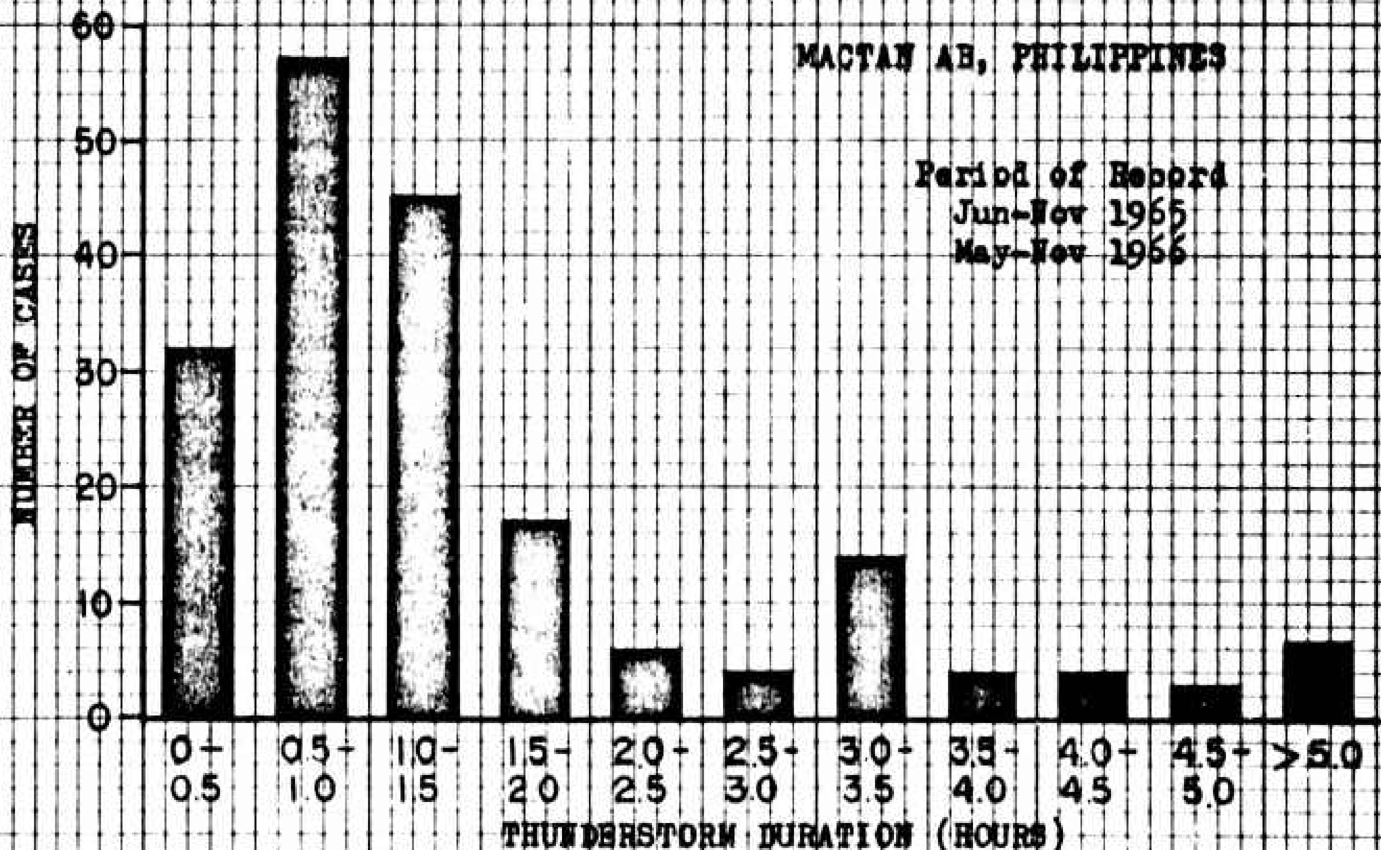


Figure 27. Frequency distribution of the durations of thunderstorm periods at Mactan AB, Philippines prepared by considering successive periods of thunderstorm activity separated by less than 2 hours as one occurrence.

number of long runs. These two figures show that the most frequent thunderstorm duration at Maotan is from 30 minutes to 1 hour and that thunderstorm durations greater than 2 hours occur infrequently.

We can estimate the average thunderstorm duration at any location by dividing the mean number of hourly observations reporting thunderstorms in any period (i.e. month, season, year, etc.) by the mean number of thunderstorm days in that period. Table 5 shows the ratio of the mean annual number of hourly observations reporting thunderstorms obtained from Uniform Summaries to the mean annual number of thunderstorm days for selected Southeast Asian stations (including two in the Philippines). The range of average thunderstorm durations is from 0.9 hours at Chiangmai and Songkhla to 2.1 hours at Bangkok. The average duration at all stations is 1.5 hours.

Table 5. Ratio of the mean annual number of hourly observations reporting thunderstorms to the mean annual number of thunderstorm days for selected Southeast Asian stations.

Thailand		Republic of Vietnam		Philippines	
Chiangmai	0.9	Pleiku	1.6	Clark AB	1.5
Korat	1.5	Saigon	1.5	Cebu	1.7
Bangkok	2.1	Soc Trang	1.6		
Songkhla	0.9				

Graphs similar to those shown for Maotan in Figures 25 to 27 are easily prepared from WBAN observations. One or two years of thunderstorm data may be sufficient to depict typical thunderstorm patterns and compute average thunderstorm duration at any station. Studies of local thunderstorm climatology may be a valuable supplement to this report, which gives only a broad-scale picture of Southeast Asian thunderstorm activity.

VI. Thunderstorm Persistency Model for Southeast Asia

The mean climatological probability (P_0) of a thunderstorm day is the mean monthly number of thunderstorm days divided by the number of days in the month. Table 6 gives the mean climatological probabilities for months with 30 and 31 days. If thunderstorm day occurrences were independent then the climatological probability of a thunderstorm on any day would always be P_0 regardless of thunderstorm occurrence or nonoccurrence on preceding days. This is not the case, however, due to the persistency of thunderstorm occurrence or nonoccurrence. For example, the actual climatological probability of a thunderstorm occurrenc is higher than P_o if a thunderstorm occurred the preceding day and lower than P_o if a thunderstorm did not occur the preceding day. Therefore, the climatological probability of a thunderstorm occurring on any day will never equal the mean climatological probability (P_o). In this section, a thunderstorm persistency model is developed for Southeast Asia which enables

Table 6. Climatological probability of a thunderstorm day according to the mean monthly number of thunderstorm days ($\bar{X}$) and the number of days in the month (N).

$\bar{X}$	N=30	N=31	$\bar{X}$	N=30	N=31	$\bar{X}$	N=30	N=31	$\bar{X}$	N=30	N=31
0	.00	.00	8	.27	.26	16	.53	.52	24	.80	.77
1	.03	.03	9	.30	.29	17	.57	.55	25	.83	.81
2	.07	.06	10	.33	.32	18	.60	.58	26	.87	.84
3	.10	.10	11	.37	.35	19	.63	.61	27	.90	.87
4	.13	.13	12	.40	.39	20	.67	.65	28	.93	.90
5	.17	.16	13	.43	.42	21	.70	.68	29	.97	.94
6	.20	.19	14	.47	.45	22	.73	.71	30	1.00	.97
7	.23	.23	15	.50	.48	23	.77	.74	31	-	1.00

forecasters to determine the climatological probability of a thunderstorm occurring on any day using the mean climatological probability (P_o) of a thunderstorm day and the pattern of thunderstorm occurrence on the preceding two days.

A simple Markov chain model where the probability of an event depends only on what happened in the preceding period has been used successfully by several authors to describe daily rainfall occurrences (10, 11, 12, 13). This simple model may be used when persistence is limited to the effect of one time interval on the next. When persistence extends over several time intervals, however, a modified Markov probability model should be used. Wiser (14) discusses four possible modifications of the simple Markov chain model and shows that these modified models provide a better fit to sequences of wet and dry days at a number of stations throughout the world than the simple model. Most of the previous meteorological applications of Markov models are limited to daily rainfall occurrence; however, they can be applied to any meteorological parameter for any interval of time when there is persistency between succeeding periods. In this study, we applied Wiser's third modification of the simple Markov model to the occurrence of thunderstorm days in Southeast Asia.

The data used in this study are the daily occurrence or nonoccurrence of thunderstorms during the 10 year period 1955-1964 for the months April through September for the following seven Thailand stations.

327	Chiangmai	431	Korat
354	Udon Thani	455	Bangkok
357	Nakhon Phanom	477	Sattahip
407	Ubon Ratchathani		

Following are definitions of the parameters used:

P_o = Mean climatological probability of a thunderstorm day.
Q_o = Mean climatological probability of a non-thunderstorm day = $1-P_o$.
P_n = Conditional probability of a thunderstorm day given that thunderstorms occurred on the preceding n days.
Q_n = Conditional probability of a non-thunderstorm day given that thunderstorms did not occur on the preceding n days.
X_n = Number of runs of exactly n thunderstorm days.
S_n = Number of runs of at least n thunderstorm days. $S_n = \sum_{i=n}^{\infty} X_n$
N = Total number of days.

Initially, the P_n values were computed for all station months from the following equation:

$$P_n = 1 - \frac{S_n}{\sum_{i=n}^{\infty} S_i} \qquad n \geq 1$$

The mean climatological probability (P_o) was also computed for each station month.

$$P_o = \frac{1}{N} \sum_{i=1}^{\infty} S_i$$

Table 7 shows the computation of the P_n values for Ubon Ratchathani where the mean June climatological probability of a thunderstorm day is .51 (153 thunderstorm days during June for a 10 year period - 300 days). In this case, the P_n values are almost equal for n=1,2,3 and increase slightly for n=4. P_n values are not computed when S_n is less than 10. As illustrated by Table 7, even 10 years of data for a month in which thunderstorms occur on 51% of the days do not show a large number of runs exceeding 4 or 5 days.

Table 7. Computation of P_n values for Ubon Ratchathani in June (P_o=.51)

n	X_n	S_n	ΣS_n	$S_n/\Sigma S_n$	$P_n = 1 - S_n/\Sigma S_n$
1	23	59	153	.39	.61
2	14	36	94	.38	.62
3	11	22	58	.38	.62
4	4	11	36	.31	.69
5	1	7	25	-	-
6	2	6	18	-	-
7	1	4	12	-	-
8	1	3	8	-	-
9	1	2	5	-	-
10	0	1	3	-	-
11	0	1	2	-	-
12	1	1	1	-	-

A study of the P_n values for the 42 station months used showed that similar P_n values are obtained for months with similar P_o values. Therefore, to develop a generalized model, the thunderstorm data for the 42 station months were combined into 6 groups according to the P_o values and P_n values computed for each group. The number of station months used, the average P_o and the range of P_o values in each group are shown below:

GROUP	NO. OF STATION MONTHS	AVERAGE P_o	RANGE OF P_o
I	3	.19	.18 - .20
II	11	.32	.28 - .35
III	10	.40	.37 - .44
IV	8	.50	.46 - .54
V	6	.58	.56 - .61
VI	4	.66	.63 - .70

The same procedure as above was followed for runs of non-thunderstorm days to compute the Q_n values. The Q_n values are then used to compute the probability of a thunderstorm day following a run of one or more non-thunderstorm days. For example, Q_2 gives the probability of a non-thunderstorm day following two successive non-thunderstorm days, so $(1 - Q_2)$ is the probability of a thunderstorm day occurring after the same cycle.

The P_n and $(1 - Q_n)$ values for the grouped data are shown graphically in Figure 28. Note that P_n values generally show a large increase from P_o to P_1, a smaller increase from P_1 to P_2 and then are relatively constant for increasing n. The $(1 - Q_n)$ values exhibit the same characteristic*. This shows that persistency in thunderstorm day occurrence or nonoccurrence is generally limited to the preceding two days. Thus, straight lines were fitted to the P_n and $(1 - Q_n)$ values on Figure 28 using the assumption that for any initial P_o, and P_n and $(1 - Q_n)$ remain constant for $n \geq 2$. The final step in the development of the model is to interpolate between the lines on Figure 28 for various P_o values to determine P_n and $(1 - Q_n)$ values for P_o = .20, .30, .40, .50, .60 and .70. These values are given in Table 8 and shown graphically in Figure 29.

Figure 29 can be used to determine the climatological probability of a thunderstorm occurring on any day at any station by knowing the mean monthly number of thunderstorm days (to determine P_o) and whether or not thunderstorms occurred the preceding two days. For example, a station which has a mean of 18 thunderstorm days during June (P_o=.60), has had two consecutive non-thunderstorm days. What is the climatological probability of a thunderstorm occurring today? To answer this question we follow the P_o=.60 line on Figure 29 until it intersects the horizontal line $(1 - Q_2)$ corresponding to two consecutive non-thunderstorm days and read the climatological probability of a thunderstorm day given along the top scale - in this case $(1 - Q_2)$=0.40. Conversely, if we had two or more consecutive thunderstorm days preceding the forecast day in the same month, the climatological probability of a thunderstorm occurring today would be 0.71. This persistency model is most useful f' stations reporting monthly means of 10 to 20 thunderstorm days. Note that for a station showing a P_o=0.50 the climatological thunderstorm day probabilities range from 0.32 (approximately 1 chance out of 3) to 0.67 (2 chances out of 3) depending on the sequence of events in the preceding two days. The model is less useful for station months with monthly means of less than 7 days (P_o=.23) or greater than 21 days (P_o=.69). In the former case, the climatological probability of a thunderstorm day would never exceed 0.50 and in the latter case it would never be less than 0.50.

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* The P_n and $(1 - Q_n)$ values in Figure 28 are discontinuous at the line P_o = $1-Q_o$ even though they are derived from the same sample. This is because runs of both thunderstorm and non-thunderstorm days which would have been truncated by the last day of the month were allowed to continue into the following month. Also, the number of runs of thunderstorm and non-thunderstorm days in each station month were made equal by omitting runs which were in progress at the beginning of each month. Thus, in summarizing runs of thunderstorm day occurrence in each month, we started with a run of non-thunderstorm days and finished with a run of thunderstorm days and vice versa in summarizing runs of non-thunderstorm days.

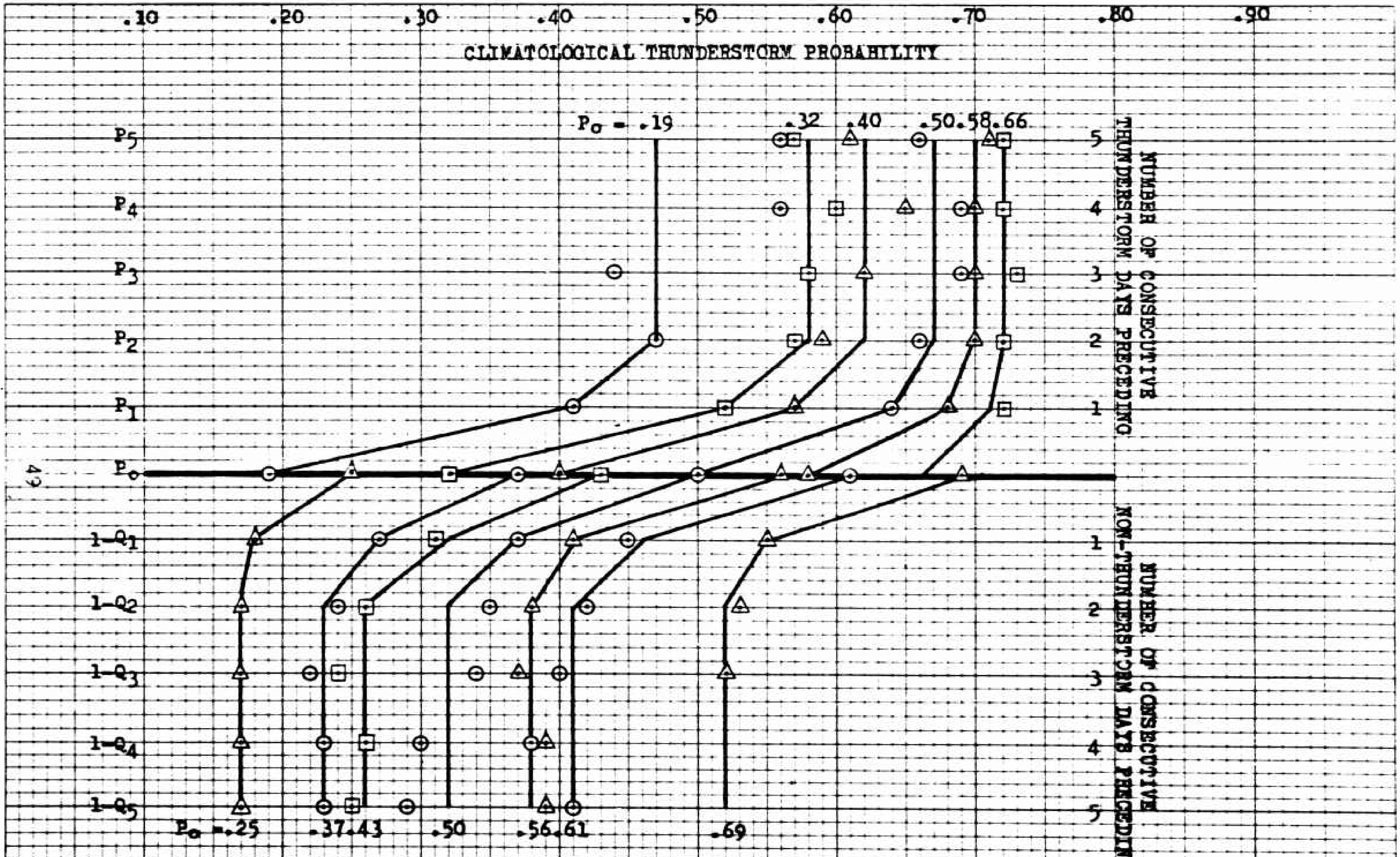

Figure 28. Computed P_n and $(1-Q_n)$ values for station months grouped according to P_o and lines of best fit drawn with the assumption that P_n and $(1-Q_n)$ are constant for $n \geq 2$.

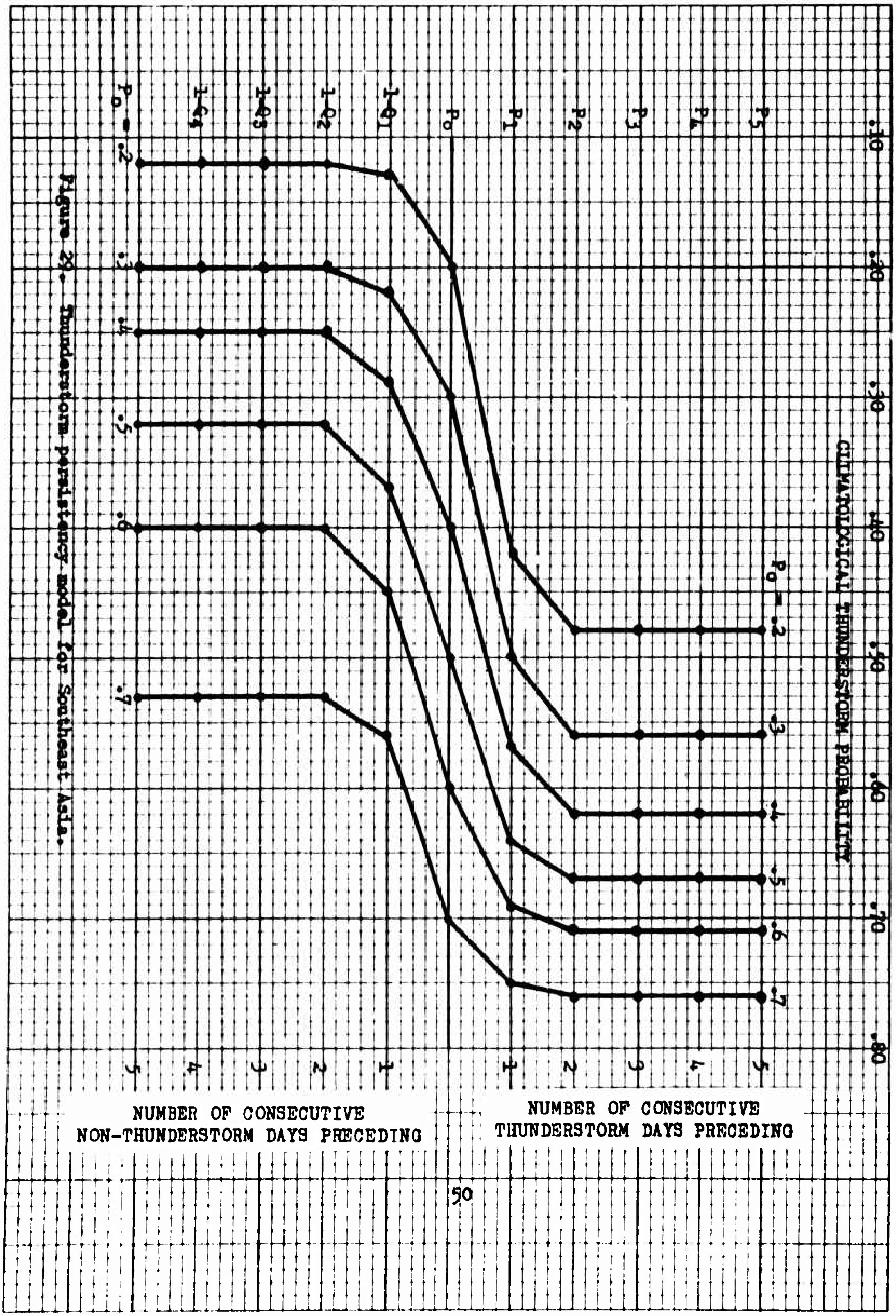

Figure 29. Thunderstorm persistency model for Southeast Asia.

Table 8. Climatological probability of a thunderstorm occurring at a station on any day based on the mean climatological probability (P_o) and whether or not thunderstorms occurred at the station in the preceding days.

	MEAN CLIMATOLOGICAL THUNDERSTORM PROBABILITY (P_o)					
	.20	.30	.40	.50	.60	.70
P_3	.48	.56	.62	.67	.71	.76
P_2	.48	.56	.62	.67	.71	.76
P_1	.42	.50	.57	.64	.69	.75
$1 - Q_1$	.13	.22	.29	.37	.45	.56
$1 - Q_2$	.12	.20	.25	.32	.40	.53
$1 - Q_3$	.12	.20	.25	.32	.40	.53

Following are several comments on the use of this model in daily thunderstorm forecasting. The climatological probability derived from the model can be the starting point to determine the actual probability of a thunderstorm occurring on any day. If there has been no discernible change in the air mass or synoptic situation from the preceding day, then the climatological probability derived from the model can be used as the actual thunderstorm probability. If discernible changes have occurred, then the climatological thunderstorm probability can be modified accordingly, depending on whether the observed changes make thunderstorm occurrence more or less likely. For example, a certain Southeast Asian station which has had two consecutive thunderstorm days shows a climatological probability of a thunderstorm occurring today of 0.70; however, the morning RAOB shows that the low level winds have shifted from southwest to northwest and there has been a large decrease in moisture aloft. In this case, the actual probability of a thunderstorm is much less than the climatological probability.

Due to the nature of thunderstorm activity in Southeast Asia during the Southwest Monsoon it is generally impossible to state with much confidence that a thunderstorm definitely will or will not occur on any day. When thunderstorms do occur it is difficult to forecast their time of occurrence more than a few hours (or in some cases one hour) in advance. For this reason, many detachments forecast the expected areal coverage of thunderstorms in the vicinity of a station (isolated, few, scattered, numerous) during the time period that thunderstorms are most likely. This type of forecast is more realistic and provides more information to the users since it gives the relative number of thunderstorms expected around the station. If required, the specified coverage can be used to estimate the chance of a thunderstorm hitting the station during any period. Conservely, the estimated thunderstorm probability for a station, derived using the climatological probability and modified according to the synoptic situation, can be used as a guide to specify the areal coverage around the station. For example, if the probability of a thunderstorm is only 0.20, then the corresponding areal coverage should be isolated or few, whereas if the probability is 0.50 or greater then scattered or numerous thunderstorms in the vicinity is more appropriate. It is difficult to put precise limits on this relationship due to the many complex factors involved for any station, e.g., thunderstorm size, movement, duration, local terrain effects, etc.; however, the following ranges of station thunderstorm probabilities associated with various areal coverages are offered as a guide.

Station Thunderstorm Probability	Associated Areal Coverage
< 30%	isolated - few
30 - 50%	few - scattered
50 - 80%	scattered
> 80%	scattered - numerous

To this point, we have presented a fairly comprehensive thunderstorm climatology of Southeast Asia prepared from available thunderstorm data. Many new Southeast Asian weather stations, however, which have begun operation during the past few years do not have reliable information on their local thunderstorm climatology. Therefore, the next section presents techniques to derive the thunderstorm climatology for any Southeast Asian location from information contained in this study.

VII. Derivation of Local Thunderstorm Climatology

This section shows how a fairly complete thunderstorm climatology can be derived for a Southeast Asian station where few or no past weather observations are available. For example, to derive the local thunderstorm climatology for Tay Ninh, a station in the Southern part of RVN located 50 miles northwest of Saigon near the Cambodia border, the following procedures apply.

First, estimate the mean annual number of thunderstorm days at Tay Ninh. This should be done as carefully as possible since all other derived thunderstorm parameters depend on this estimate. From the isoline map showing mean annual number of thunderstorm days note that Tay Ninh lies in an area with more than 60 but less than 90 thunderstorm days; however, for a closer estimate, plot the mean annual number of thunderstorm days at surrounding stations from Table 1: Saigon (77), Kratie, Cambodia (78) and Phnom Penh, Cambodia (88). An examination of the topography in the immediate proximity of Tay Ninh shows the terrain is fairly level, and there appears to be no local effects to cause the number of thunderstorm days to differ appreciably from surrounding stations. Therefore, estimate Tay Ninh to have an annual mean of 80 thunderstorm days. To determine the distribution of these thunderstorm days throughout the year, multiply 80 days by the percentages given in Table 3 for Area X. Also determine the 90% range of thunderstorm days that can be expected monthly and annually for months with 3 or more thunderstorm days by using the 95th and 5th percentile values in Figures 22 and 23. The above computations give the following thunderstorm day values for Tay Ninh.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Mean	*	*	2	4	17	14	10	9	9	10	4	1	80
90% Range				1-9	13-25	7-23	4-18	4-17	4-17	4-18	1-9		60-112

For the average duration of thunderstorms at Tay Ninh, use the average duration for all Southeast Asian stations given in Table 5 — 1.5 hours. Therefore the mean monthly number of hourly observations reporting a thunderstorm at the station will be the mean monthly number of thunderstorm days times 1.5, e.g., the mean monthly number of hourly observations in May reporting a thunderstorm at the station is 26 or 3.5% of the total hourly observations in May.

Now derive the probability of a thunderstorm occurring at the station on any hourly observation. From the diurnal thunderstorm curve for Areas IX, X and XI given in Figure 24, the average percent during any hour of the total number of hourly observations a month reporting thunderstorms is as follows.

TIME (LST)	%	TIME (LST)	%	TIME (LST)	%	TIME (LST)	%
00	1.8	06	1.1	12	2.0	18	11.2
01	1.5	07	1.0	13	4.0	19	8.2
02	1.4	08	0.9	14	8.0	20	5.7
03	1.4	09	0.8	15	11.0	21	4.2
04	1.3	10	0.8	16	13.0	22	3.1
05	1.2	11	1.1	17	13.2	23	2.1

Multiply these percentages by the mean monthly number of hourly observations with thunderstorms in May to obtain the mean number of days a month reporting thunderstorms at any hour during May. Then convert the mean number of days to percent of days by multiplying by 100/31 to obtain the following results.

TIME (LST)	%	TIME (LST)	%	TIME (LST)	%	TIME (LST)	%
00	1.6	06	1.0	12	1.6	18	9.3
01	1.4	07	1.0	13	3.2	19	6.7
02	1.3	08	0.6	14	6.7	20	4.8
03	1.3	09	0.6	15	9.3	21	3.5
04	1.2	10	0.6	16	10.8	22	2.6
05	1.0	11	1.0	17	10.9	23	1.6

Thus, the probability of a thunderstorm in May on the 1700 LST observation, the time of maximum occurrence, is only 10.9%. This may seem to be a low figure, however, remember that this percentage is for thunderstorms actually occurring at the station at a specified time. The number of thunderstorms in the vicinity of a station (within a 25 mile radius) or within sight will be much greater (perhaps by a factor of 5 or more). The percentages derived above for May can be derived in same manner for all other months.

The thunderstorm persistency model presented in section VI can be used for Tay Ninh by deriving the P_0 values from Table 6 according to the mean monthly number of thunderstorm days and observing the sequence of thunderstorm day occurrences or nonoccurrences at Tay Ninh for the preceding two days.

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References:

1. G. D. Atkinson, "A Preliminary Estimate of Extreme Wind Speeds in Thailand," Technical Study 3, Technical Services, Det 1, 1st Weather Wing, October 1966.

2. Annual Meteorological Data (for the years 1946-1950), Thailand Department of Meteorology.

3. Climatological Data (for 10 year period 1943-52), Vol. 7, Thailand Department of Meteorology.

4. Monthly Meteorological Bulletin, Thailand Department of Meteorology, Vols 21-27, 1956-62.

5. "Mean Number of Thunderstorm Days For Thailand Stations 1948-57," Thailand Department of Meteorology.

6. Annual Weather Summary, 1957-1962, Republic of Vietnam, Directorate of Meteorology.

7. Climatological Mean Values, Republic of Vietnam, Directorate of Meteorology, 1965.

8. Meteorological Data of Eastern Countries, Vol. II, Philippines, Indo-China, Thailand, Burma, Malaya, India, Japan Central Meteorological Observatory, November 1941.

9. E. Gruzon, P. Carton and A. Romer, Le Climat De L'Indochine (The Climate of Indochina), Haut Commissariat De France En Indochine, 1950.

10. K. R. Gabriel and J. Newmann, "A Markov Chain Model for Daily Rainfall Occurrence at Tel Aviv," Quarterly Journal of the Royal Meteorological Society, Vol. 88, No. 375, January 1962, pp. 90-95.

11. J. E. Caskey, Jr., "A Markov Chain Model for the Probability of Precipitation Occurrence in Intervals of Various Length," Monthly Weather Review, Vol. 91, No. 6, June 1963, pp. 298-301.

12. L. L. Weiss, "Sequences of Wet or Dry Days Described by a Markov Chain Probability Model," Monthly Weather Review, Vol. 92, No. 4, April 1964, pp. 169-176.

13. J. R. Green, "Two Probability Models for Sequences of Wet or Dry Days," Monthly Weather Review, Vol. 93, No. 3, March 1965, pp. 155-156.

14. E. H. Wiser, "Modified Markov Probability Models of Sequences of Precipitation Events," Monthly Weather Review, Vol. 93, No. 8, August 1965, pp. 511-516.

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This seven part study presents a comprehensive survey of thunderstorms in Southeast Asia (Republic of Vietnam, Cambodia, Thailand, Laos and North Vietnam). Part I introduces the subject. Part II discusses various Southeast Asian data sources used, the reliability of these sources and the difficulties involved in obtaining reliable thunderstorm data. Part III gives the monthly and annual frequencies of thunderstorm days for 83 stations in Southeast Asia, in both table and isoline-map forms. Part IV discusses the year to year variations in the numbers of thunderstorms observed monthly and annually. Part V covers the duration and diurnal variation of thunderstorms. Part VI presents a thunderstorm persistency model developed from ten years of daily thunderstorm records for selected Thailand stations. Finally, Part VII shows how the local thunderstorm climatology can be approximated for a Southeast Asian location where no data are available.

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