CHAPTER III

JOINT TYPHOON WARNING CENTER STUDIES

A. A COMPARISON OF OBJECTIVE TECHNIQUES FOR TYPHOON MOVEMENT

1. STATUS

The objective methods forecasting and verification project which was begun in 1967 was continued and expanded in 1968. Forecasts were verified for all four warning times as compared to two daily verifications from the most current upper air synoptic fields in 1967. Objective techniques were also applied to 48 hour forecasts for the first time. Availability of a HATRACK program for the FWC Guam computer facilitated operational use of this program.

The older hurricane and typhoon (HAT) steering program, the TSE method and climatology were discontinued as objective techniques because of their poor performance in 1967.

The manual modification technique successfully used in 1967 on the 700mb Prog was used on both the 700mb analysis and the 700mb Prog for 24 hour forecasts and on the 500mb anal for 48 hour forecasts. A new twist was added by using twice the apparent 12 hour error to obtain a 700mb Prog modified forecast for 24 hour movement.

2. 24HR OBJECTIVE TECHNIQUES

a. JTWC - official forecast for comparison.

b. EXTRAPOLATION. a semi objective method by which forecast points are determined by recent past values of speed, direction and intensity.

c. ARAKAWA - Grid overlay values of surface pressure are entered into regression equations and hand computed.

d. 1000mb PROG - HATRACK forecast based on 1000mb SR forecast fields.

e. 700mb PROG - HATRACK forecast based on 700mb SR forecast fields.

f. 500mb PROG - HATRACK forecast based on 500mb SR forecast fields.

g. 700mb ANAL - HATRACK forecast based on 700mb analysis SR field.

h. 700mb ANAL MOD (24HR) - HATRACK forecast of (g) above manually modified for apparent 24 hour error.

i. 700mb PROG MOD (12HR) - HATRACK forecast of (e) above manually modified for twice the apparent 12 hour error.

j. 700mb PROG MOD (24HR) - HATRACK forecast of (c) above manually modified for apparent 24 hour error.

3. 48 HR OBJECTIVE TECHNIQUES

a. JTWC - official forecast for comparison

b. 1000mb PROG - same base as 24 hour forecast

c. 700mb PROG - same base as 24 hour forecast

d. 500mb PROG - same base as 24 hour forecast

e. 500mb ANAL - HATRACK forecast based on 500mb SR analysis field.

f. 700mb ANAL MOD (24HR) - HATRACK forecast based on the 700mb SR analysis field modified for twice the apparent 24 hour error at forecast time.

g. 500mb ANAL MOD (24HR) - HATRACK forecast based on the 500mb SR analysis field modified for twice the apparent 24 hour error at forecast time.

h. 700mb PROG MOD (24HR) - HATRACK forecast based on (c) above modified for twice the apparent 24 hour error at forecast time.

4. DISCUSSION OF MODIFICATION TECHNIQUE

The basic assumption of this technique is that forecast errors of the past will continue to occur in the forecast period. A single correction attempts to compensate for all errors such as the use of the wrong steering level and geostrophic rather than actual wind. Position errors averaging 20 miles exist at all warning times. Full correction for these errors tends to multiply their contribution to the total forecast error. Analysis errors are common in tropical areas and are one of the major causes of forecast error. Finally the computer program designed to steer tropical cyclones may not produce a perfect forecast if given accurate analysis, prognoses and positions.

5. TESTING AND RESULTS FOR 24 HOUR FORECASTS (based on results prior to 25 September)

A homogeneous sample of 390 24 hour forecasts was assembled in 1968. Statistical results are presented in Table 3-1. The following observations are made after a study of 1968 verifications:

a. JTWC official forecasts are significantly better than all objective techniques. An average of 104 NM is calculated for this homogeneous sample.

b. Extrapolation continues to be the most reliable short term forecast technique. The average of 111 NM is the best of all supplementary forecasts.

c. ARAKAWA was the best of the truely objective techniques. The ARAKAWA average of 121 NM was better than the 1967 JTWC official average.

d. The 1000mb PROG was the poorest overall objective technique, but was a good performer on storms in their early stages. The HATRACK program has no logical limit on movement speeds. Illogical 1000mb forecasts are interpreted to move typhoons at speeds of over 70 knots.

e. The 700 MB level again gave better results than the 500 MB and 1000 MB levels. The 700 MB prognostic field again showed skill over the 700 MB analysis field. Stastistical evidence strongly indicates a detrimental change in the basic numerical fields occurred about 25 September. The 700 MB prognosis verification prior to this date was 134NM compared with an average after this date of 254NM. The annual average of 191NM is then unrepresentative of any portion of the year. Displacement of the verification errors showed a large error to the southwest after September.

f. The 500MB SR HATRACK cyclone movement was slow and showed a distinct tendency toward premature recurvature.

g. The 700 MB ANALYSIS was a close second to the 700 MB prog in accuracy. Persistence of the 700 MB field is a reasonably accurate assumption for predicting typhoon tracks in the absense of prognositc fields.

h. The 700 MB ANALYSIS modified for 24 hr error verified equal to the 700 MB Prog similarly modified. The initial size of the error apparently does not have a completely determining effect on the size of the modified error.

i. The 700 MB Prog was the best of hand modified computer progs. The modification method showing best results in the first half was the 12 hour error modification.

j. The 700 MB prognosis was improved by about 15 percent by vector modifying the forecasts for apparent forecast error over the past 12 or 24 hours.

6. TESTING AND RESULTS FOR 48 HOUR FORECASTS (based on results prior to 25 September) See table 3-2

a. The best objective forecast for 48 hours proved to be the 700 MB prog HATRACK. This bettered the official forecast in 5 of 14 tropical cyclones.

b. Modifying the basic 700 MB prog HATRACK forecast for 24 hour error resulted in increased error in 10 of 14 tropical cyclones and in the overall average. Modifying the 700 MB ANAL HATRACK for 24 hour error failed to improve that forecast. The advantage to error bias correction noted at 24 hours does not apparently continue through the 48 hour forecast period.

c. The 700 MB level shows a decided advantage over the 500 MB level for 48 hour forecasts using the HATRACK program.

7. OBJECTIVE TECHNIQUE FOR 1969

Based on analysis of the 1968 season and expected program improvements the following objective techniques will be operationally used and evaluated in 1969:

a. Extrapolation

b. 700 MB PROG HATRACK

c. 500 MB PROG HATRACK

d. 700/500 MB PROG RENARD

e. ARAKAWA

f. TYRACK

g. 700 MB PROG MODIFIED FOR 12 HR ERROR (24 hour forecast only).

OBJECTIVE METHODS STATISTICS 1968

STORM	JTWC	EXTRAP	1000P	ARAKAWA	700P	500P	700A	700A MOD24	700P MOD12	700P MOD24
T.LUCY	88	123	162	186	153	175	135	100	90	100
T.MARY	123	98	171	122	131	125	156	96	99	116
T.S.NADINE	159	175	137	166	159	209	175	166	200	178
T.S.POLLY	176	163	134	120	178	241	208	150	124	144
T.S.ROSE	51	92	108	55	38	67	124	176	72	165
T.SHIRLEY	87	81	173	80	83	57	92	83	87	60
T.S.TRIX	59	118	118	148	102	113	100	158	191	176
T.WENDY	105	104	151	115	142	159	164	133	107	129
T.AGNES	109	112	171	129	132	128	132	125	119	129
T.BESS	73	72	114	109	102	109	139	81	92	90
T.DELLA	99	98	238	85	137	160	133	84	73	68
T.CARMEN	71	90	150	48	86	115	113	104	87	80
FIRST HALF MEAN VALUE	106	110	162	115	134	145	145	120	113	120
T.ELAINE	87	73	285	85	226	226	204	120	206	154
T.FAYE	72	97	245	76	154	126	158	123	108	110
T.GLORIA	89	78	332	101	227	255	238	198	157	185
T.IRMA	254	270	382	206	379	264	369	231	364	243
T.JUDY	86	85	301	75	300	309	292	181	176	207
T.KIT	217	195	390	199	379	318	383	199	280	235
T.LOLA	90	110	232	130	232	301	229	168	157	133
T.MAMIE	81	114	326	144	319	336	316	188	270	204
T.NINA	76	92	199	135	202	298	217	208	280	186
T.ORA	116	104	191	157	186	308	199	157	245	141
LAST HALF MEAN VALUE	99	105	282	122	254	282	255	175	218	179
ANNUAL MEAN	103	108	219	119	191	210	197	146	163	148

TABLE 3-1

48 HOUR OBJECTIVE METHODS STATISTICS 1968

STORM	JTWC	1000P	700P	500P	700A	500A	700A MOD24	500A MOD24	700P MOD24
T.JEAN	490	-	311	474	227	535	288	308	393
T.KIM	154	603	263	390	221	374	243	205	304
T.LUCY	218	308	237	224	230	151	216	219	186
T.MARY	246	278	282	297	321	316	246	273	294
T.S.NADINE	324	298	369	497	318	475	431	529	523
T.S.POLLY	492	282	349	488	389	489	411	407	373
T.S.ROSE	284	378	262	202	320	218	360	264	402
T.SHIRLEY	195	333	152	142	187	256	249	361	180
T.S.TRIX	136	231	281	311	315	268	230	341	250
T.WENDY	184	246	235	292	278	341	306	350	273
T.AGNES	266	321	285	282	290	322	317	311	299
T.BESS	162	261	223	247	276	210	167	239	162
T.DELLA	256	452	323	310	289	331	190	275	214
T.CARMEN	169	328	152	241	265	369	245	220	201
FIRST HALF MEAN VALUE	262	309	277	331	294	352	294	328	298
T.ELAINE	222	505	501	546	504	594	246	384	318
T.FAYE	213	564	402	320	416	451	312	348	263
T.GLORIA	256	641	433	493	485	591	456	441	318
T.IRMA	951	628	576	363	549	423	772	514	778
T.JUDY	238	670	643	618	678	644	415	493	528
T.KIT	408	810	738	547	760	596	427	480	403
T.LOLA	265	595	597	464	525	480	328	320	252*
T.MAMIE	155	653	508	755	622	750	429	456	747
T.NINA	116	398	337	785	388	550	775	773	300*
T.ORA	201	476	331	640	390	576	336	440	296*
LAST HALF MEAN	230	666	582	594	527	595	452	484	435

TABLE 3-2

B. EVALUATION OF RENARD METHOD FOR IMPROVING HATRACK FORECASTS

1. Background: Professor Robert Renard of the U. S. Navy Postgraduate School conducted a study based on 1966 data and tested on 1967 data. The results indicated that an improved forecast of typhoon movement could be made by combining the 500 mb latitude and the 700 mb longitude from the HATRACK prognositc fields. The indicated results were superior to forecasts made from either field.

2. Discussion: Because of the small sample sizes involved in the previous studies, it was resolved to test the Renard method using a large sample of independent data from 1968. Accordingly forecasts were reconstructed for 429 individual forecasts covering 15 of the 20 typhoons of 1968. The errors of the reconstructed forecasts were analyzed by the objective methods verification computer program and compared with results of other objective methods.

3. Results (See table 3-3):

a. Improvement of 12% over the sample average of 500 mb HATRACK forecasts.

b. Improvement of 5% over the sample average of 700 mb HATRACK forecasts

c. Improvement in 10 of the 15 individual typhoons over the 700 mb HATRACK and in 11 of the 15 typhoons over the 500 mb HATRACK.

d. Wide variability in effectiveness from a 52% improvement to a 34% loss in individual typhoons.

4. Follow-up: The results verified Professor Renard's findings and suggested the existance of systematic error in HATRACK forecasts. A study using scatter diagrams was designed to identify systematic error. Scatter diagrams were made of the 700 mb HATRACK, the 500 mb HATRACK and the Renard method.

5. Follow-up Results:

a. The 700 mb forecasts were centered southwest of the zero verification point.

b. The 500 mb forecasts were centered northeast of the zero verification point.

c. The Renard method was much better centered, but retained a systematic error of 45 miles to the south on 24 hour forecasts.

6. Follow-up Discussion: The basic numeric fields from which HATRACK forecasts are computed were apparently modified at FNWC Monterey about September 25th resulting in large errors in subsequent forecasts. Only five of the 15 typhoons in this sample occurred prior to 25 September. The actual values of the errors are not representative of the potential of this method, but the technique of combining the latitude and longitude continued to show improvement over the parent fields.

7. Conclusions:

a. Systematic errors exist in the 700 mb HATRACK, the 500 mb HATRACK and the Renard combination of HATRACK forecasts.

b. The Renard method provides a better estimate than the parent fields in two out of three cases.

c. A possible improvement to the Renard forecast involves compensation for systematic error.

d. Further improvement may result from vector correction for apparent error over the last 12 to 24 hours.

8. Action: This method will be used in operational forecasting during 1969. It will be used and refined until the basic HATRACK program is successfully modified to remove systematic errors.

700MB/500MB NUMERICAL TYPHOON FORECAST EVALUATION

	SAMPLE CASE	JTWC	700MB	500MB	700MB/500MB	IMPROVE % OVER 700
WENDY	46	99	134	150	179	-34%
AGNES	46	121	149	139	143	4%
BESS	19	86	107	111	101	6%
CARMEN	24	87	122	147	71	42%
DELLA	31	111	132	160	115	13%
ELAINE	26	95	232	234	243	-5%
FAYE	25	100	212	233	181	15%
GLORIA	30	105	240	256	179	25%
IRMA	13	203	220	270	260	-18%
JUDY	33	110	324	310	293	10%
KIT	17	180	351	341	394	-12%
LOLA	13	141	242	239	128	47%
MAMIE	47	112	345	357	307	11%
NINA	33	79	213	298	280	-31%
ORA	26	111	181	295	169	7%
SAMPLE MEANS	429	104	214	233	204	5%

TABLE 3-3

C. EVALUATION OF TYRACK, a computerized tropical cyclone movement forecast based on FWC Pearl tropical fields.

1. Background: TYRACK was developed at FWC Pearl by CAPTAIN William HUBERT and LTJG Mark FAZEY. It was completed for operational use in October and was first used at JTWC during Typhoon IRMA. Verification data was gathered from seven typhoons of 1968 and is presented as part of this evaluation.

2. Program Design:

a. The FWC Pearl tropical analysis fields are used to steer point vortex tropical cyclones. The levels used are the 700 mb, 500 mb, 400 mb and 300 mb. In addition to these standard levels a vector mean of the 700 and 500 mb fields is constructed as average #1 and a vector mean of all four levels is constructed as average #2. Operational input to the program is the position of a typhoon at warning time and the 12 hour history position. The reverse steering vector at each of the six levels is used to drive the warning position backward for 12 hours. The smallest vector from the six history forecasts to the 12 hour history position determines the "steering level" for forward motion. The warning position is then driven forward by the selected "steering level" assuming complete persistence of the field during the forecast period. The "error vector" from the 12 hour reverse track is retained and applied to adjust forecast positions. Complete persistence of the error vector and continuation of the selected level as the best steering level are assumed.

3. Evaluation Procedure: A homogeneous sample of 100 forecasts was obtained when the performance of TYRACK could be compared with the JTWC official forecasts and HATRACK forecasts could be made from the same initial points.

4. Results (See Table 3-4):

a. Absolute error was less than unmodified HATRACK fields and the Renard method forecasts, but not quite as good as the bias corrected 700 mb HATRACK forecasts.

b. A scatter diagram of vector error indicated a displacement of the forecast about 140 NM along 230 degrees with a good concentration of points about this displaced center.

5. Discussion:

a. The HATRACK fields were bad during the last three months of 1968. Comparisons in this sample are more favorable to TYRACK than they would be if HATRACK fields had not been unfavorably altered late in September.

b. The scatter of forecast verifications to the southwest seems to indicate a tendency for the circulation around a typhoon to unduely influence the steering flow. Several modifications to TYRACK are currently under development at FWC Pearl. Improved performance in 1969 is anticipated, but the need for continued evaluation is clear.

6. Conclusions:

a. An important new source of tropical cyclone forecasts has been introduced during 1968.

b. TYRACK is still in a developmental stage. Conclusions concerning 1968 performance are clouded by a relatively small sample size and the poor performance of the comparison HATRACK forecasts during the evaluation period.

c. Changes in the program as it develops will require continued evaluation during 1969.

7. Action: TYRACK will be used operationally during 1969. Careful verification records will be continued to aid development of this forecasting tool and to report in the next Annual Typhoon Report.

TYRACK EVALUATION STATISTICS FOR 1968

TYPHOON	Official JTWC Cases	Official JTWC err avg	700MB Cases	700MB err avg	500MB Cases	500MB err avg	Modified 700MB Cases	Modified 700MB err avg	Renard 700/500 Cases	Renard 700/500 err avg	TYRACK Cases	TYRACK err avg
IRMA	5	164	5	406	5	276	5	157	5	373	5	260
JUDY	10	83	10	343	10	321	10	191	10	284	10	130
KIT	10	148	10	333	10	292	6	195	10	342	10	301
LOLA	9	90	9	232	9	301	9	133	9	106	9	207
MAMIE	30	83	30	316	30	374	28	197	30	284	30	168
NINA	28	83	28	198	28	299	25	182	28	286	28	242
ORA	13	90	13	164	13	269	10	195	13	171	13	265
TOTAL	105	95	105	267	105	317	93	184	105	265	105	217

TABLE 3-4

D. CLIMATOLOGY

1. Climatology of Fix Requirements

For the purpose of developing a monthly climatology of tropical cyclones related to operational fix requirements, a study of tropical cyclones since 1960 was made. For each cyclone, the fix requirements used in 1968 were applied to produce a statistical fix requirement based on the 1968 operational policy of four fixes per day per cyclone (tropical depression, tropical storm or typhoon). Allowances for cyclones beginning or ending during the day were made, but no allowance was made for storms not picked up in their early stages of development. The climatology developed will be conservative for this reason in years prior to 1965 when satellite data first came into operational use. No allowance was made for fixes scheduled on cloud masses that failed to develop. This problem has been greatly reduced by improved satellite coverage. Figure 3-1 shows the average monthly figures for the 9 year period as well as the figures for 1968. Also shown is the extreme number of fixes required for each month and the year in which this extreme occurred.

2. Climatology of Days with Multiple Storms

In addition to the number of fixes in each month the distribution of these fixes within the month is of importance. A given number of fixes occurring in a short span of time during a period of multiple storms will usually require more aircraft than an equal number of fixes distributed over a longer period without multiple storms. Figure 3-2 shows the average number of days in each month during which warnings were being issued on two or more cyclones. The number by month for the 1968 season is shown as well as the extreme number of multiple storm days that has occurred in each month during the 9 year period.

3. Typhoon Climatology

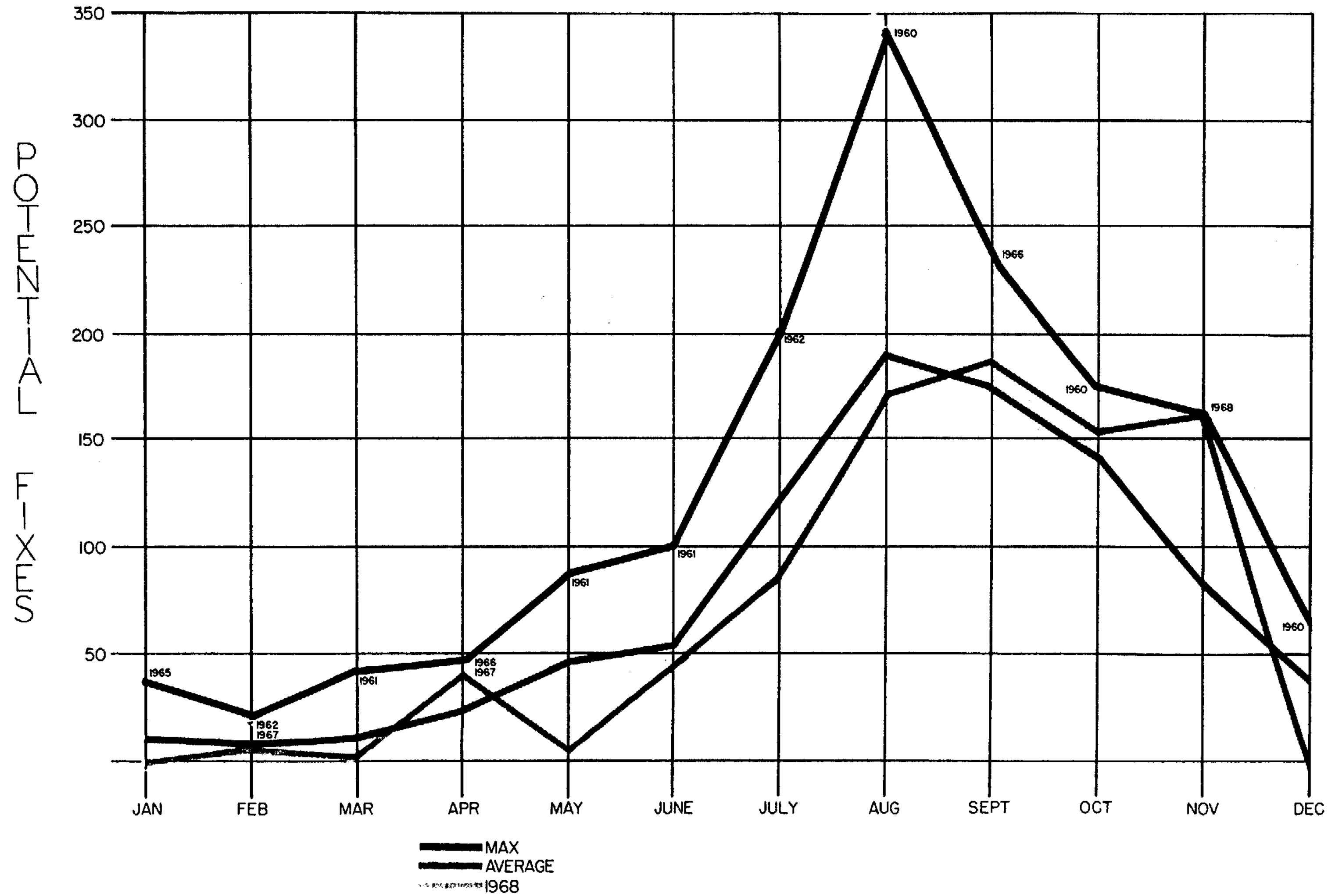
Direction and speed of movement of typhoons in the Western North Pacific by month from June through November.

Isotachs of model speed are analyzed as dashed lines and streamlines of model direction are drawn as solid lines. Both analyses are based on values contained in Charts LXIII to LXXIX in Royal Observatory Technical Memo No. 7 which includes 70 years of data. See Figures 3-3 through 3-8.

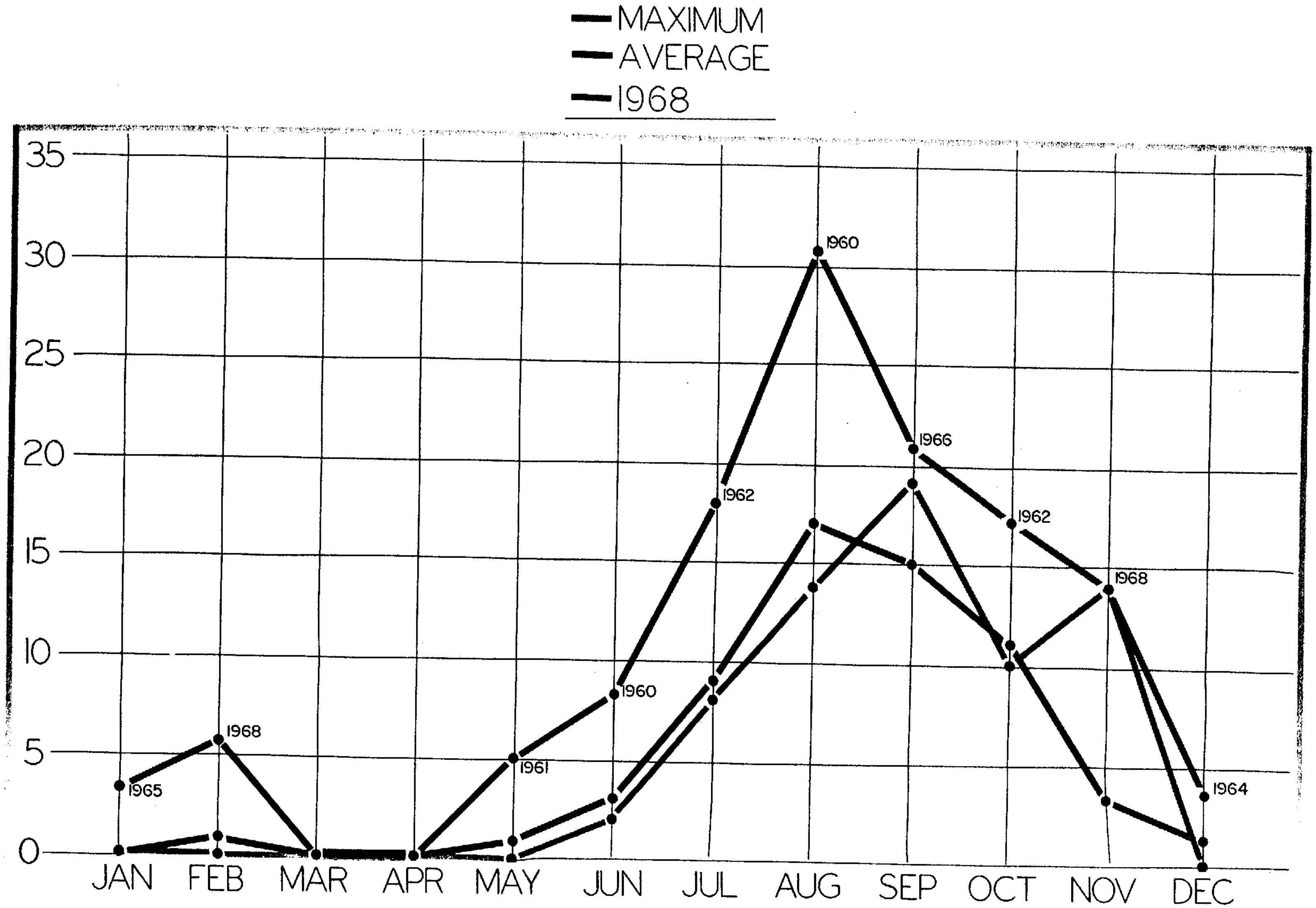
4. Figure 3-9 presents the actual distribution by months of 334 Western North Pacific typhoons in the 17 years from 1952 through 1968.

5. Figure 3-10 presents the revised 10 year frequency of typhoons by month.

MONTHLY CLIMATOLOGY OF FIX REQUIREMENTS



MONTHLY CLIMATOLOGY OF DAYS WITH MULTIPLE STORMS



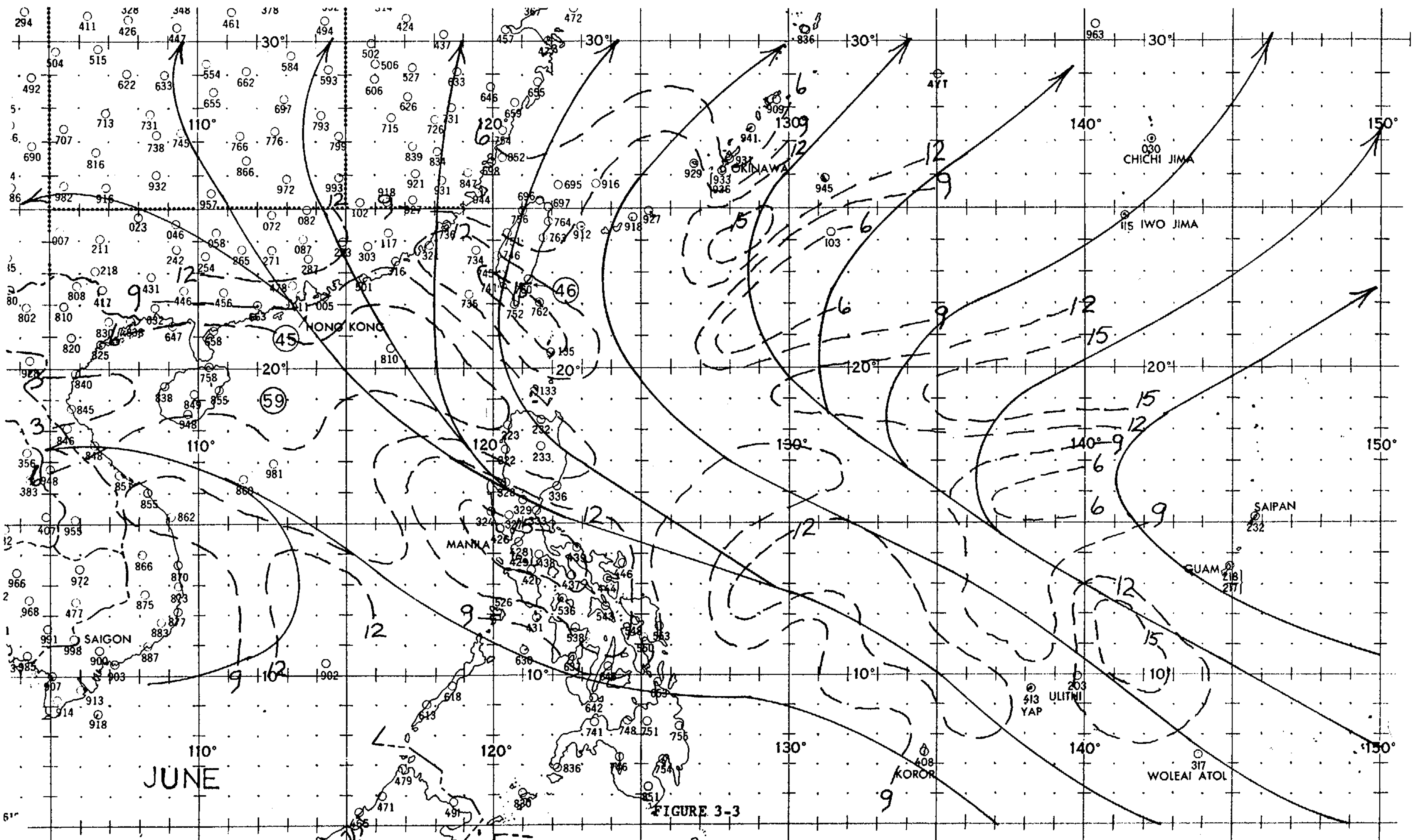

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FIGURE 3-3

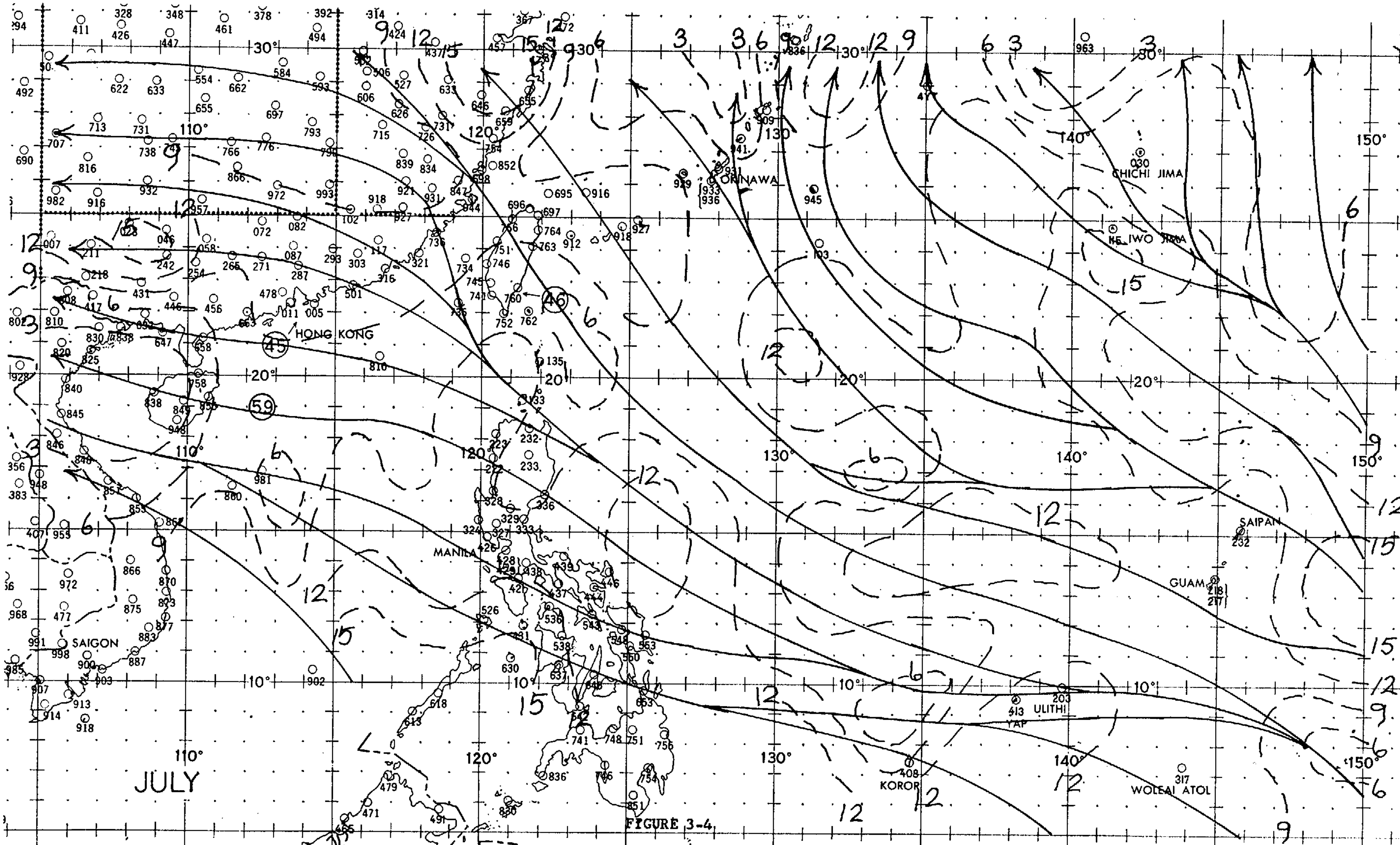
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FIGURE 3-4

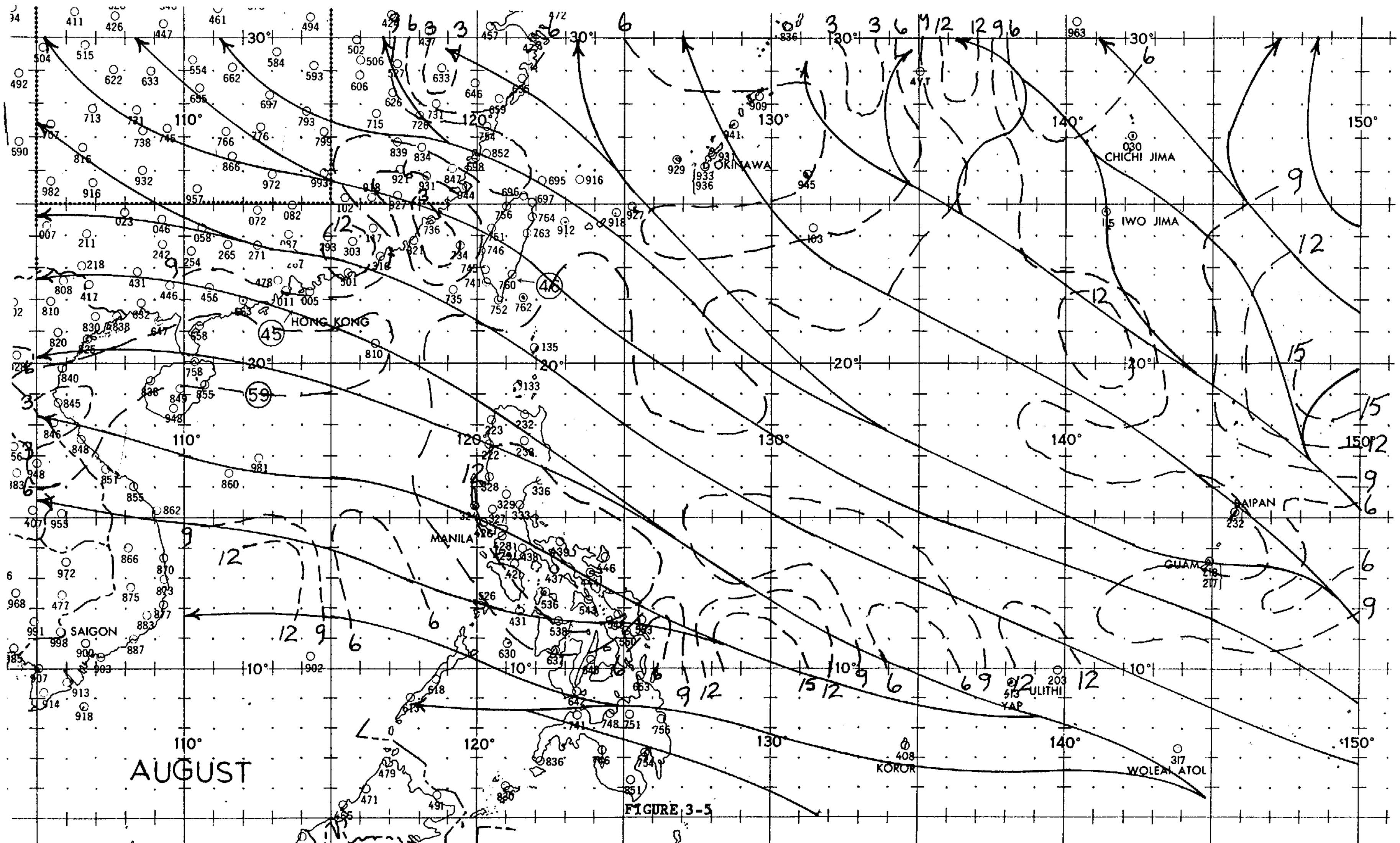
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FIGURE 3-5

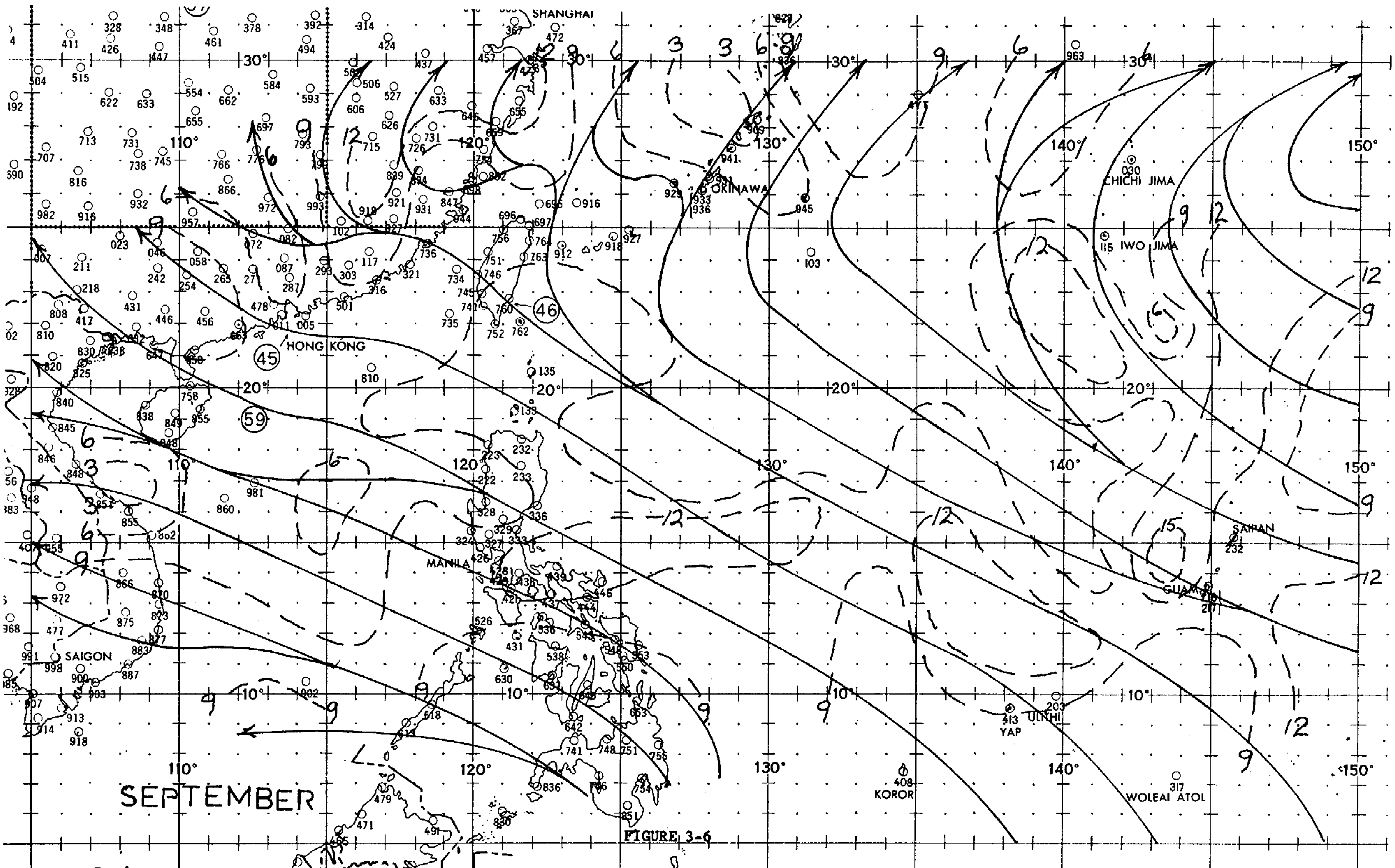
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FIGURE 3-6

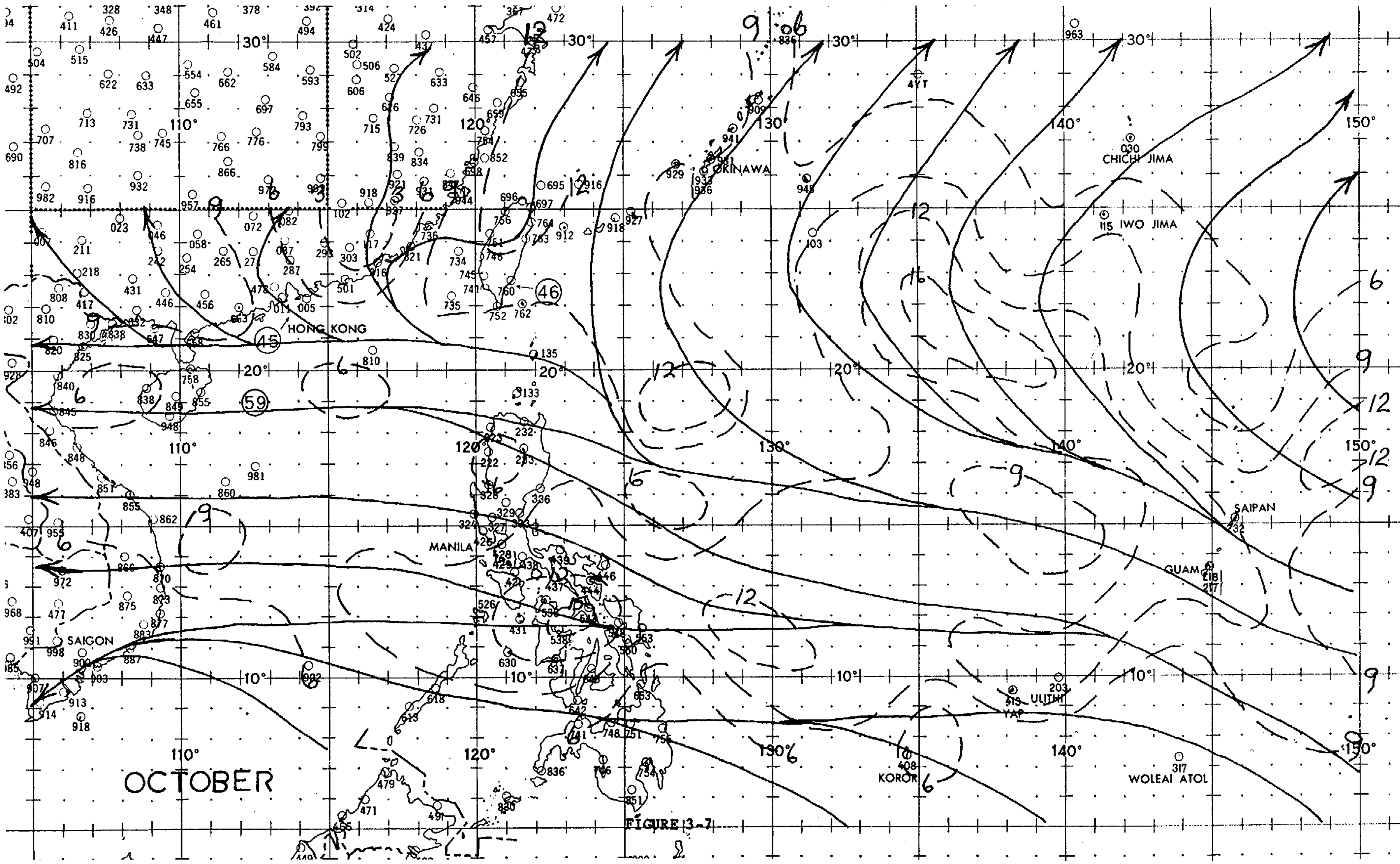
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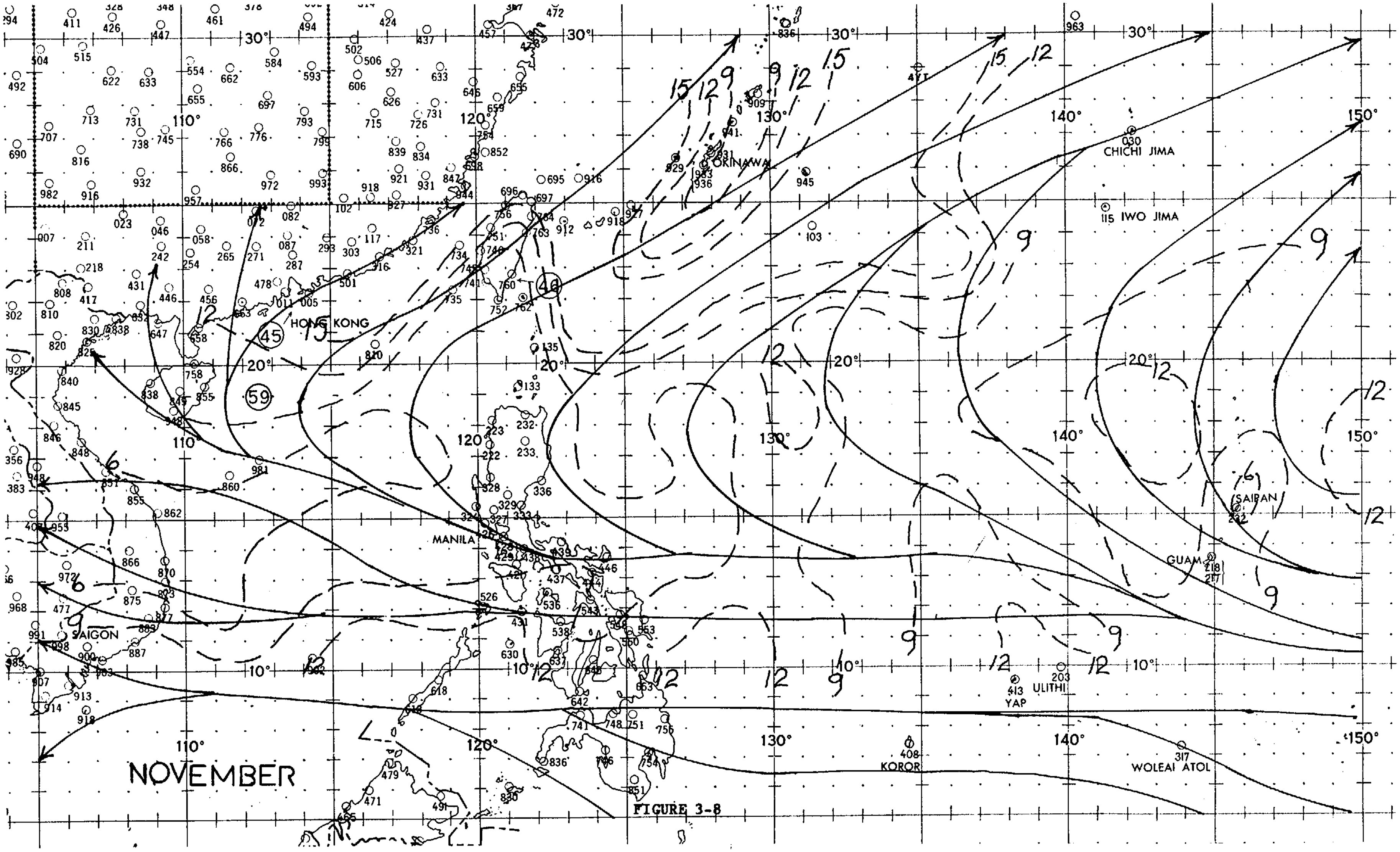
FIGURE 3-7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WOLEAI ATOL

FIGURE 3-8

17 YEAR TYPHOON DISTRIBUTION OF 334 WESTERN PACIFIC TYPHOONS

1952 - 1968

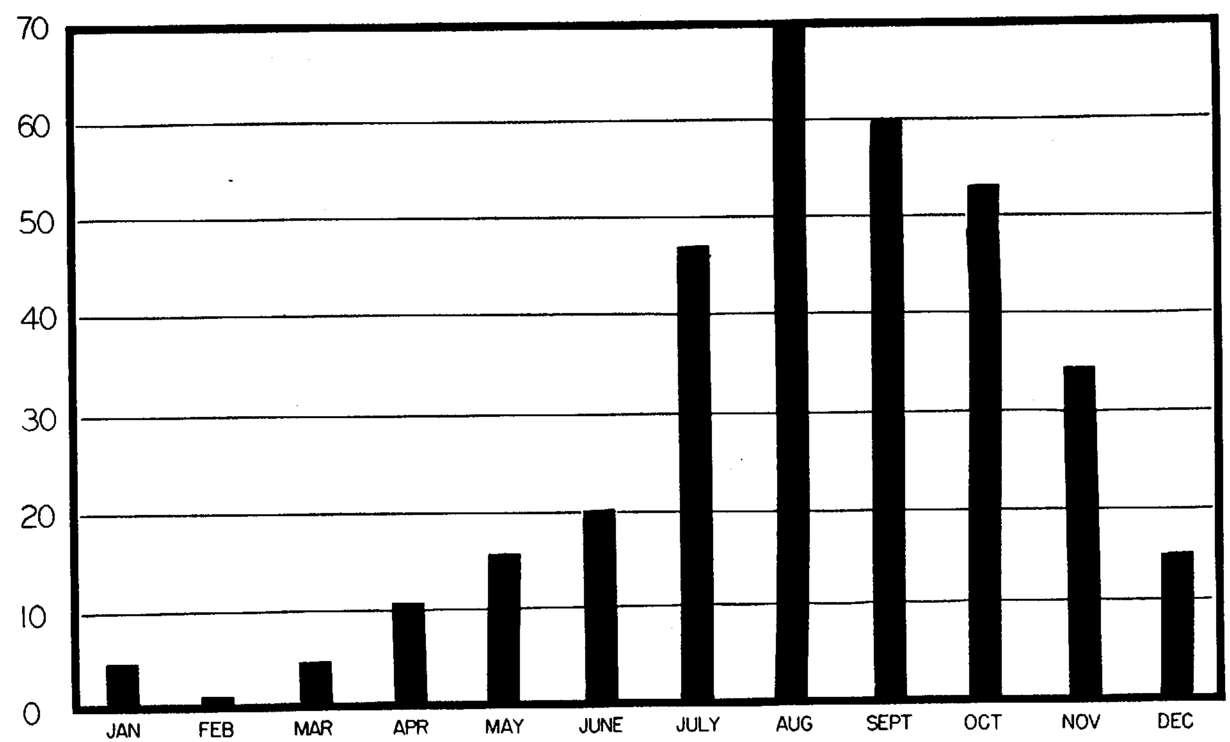


FIGURE 3-9

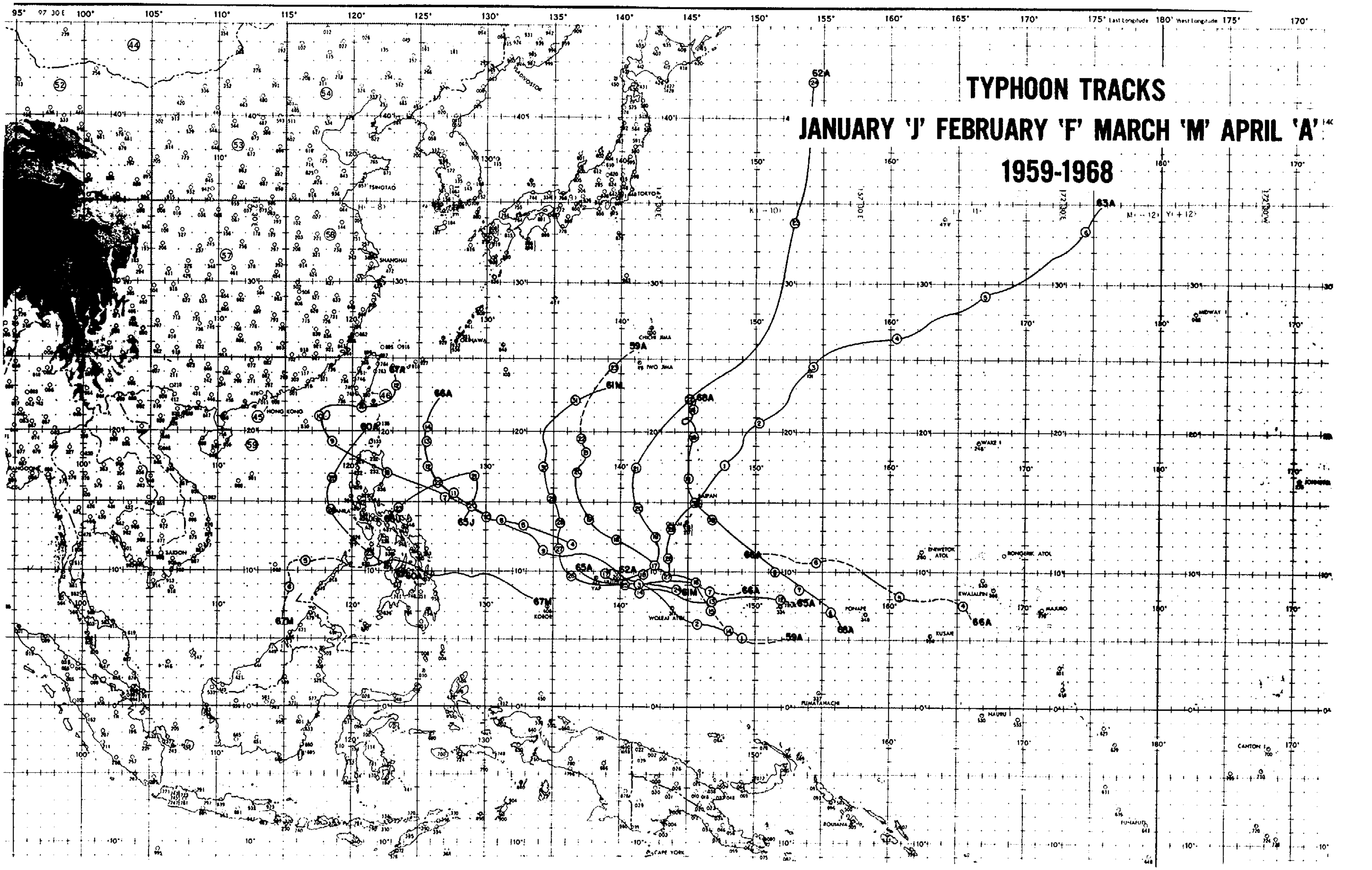
TYPHOON FREQUENCY
10 YEAR PERIOD

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL TOTAL
1959	0	0	0	1	0	0	1	5	3	3	2	2	17
1960	0	0	0	1	0	2	2	8	0	4	1	1	19
1961	0	0	1	0	2	1	3	3	5	3	1	1	20
1962	0	0	0	1	2	0	5	7	2	4	3	0	24
1963	0	0	0	1	1	2	3	3	3	4	0	2	19
1964	0	0	0	0	2	2	6	3	5	3	4	1	26
1965	1	0	0	1	2	2	4	3	5	2	1	0	21
1966	0	0	0	1	2	1	3	6	4	2	0	1	20
1967	0	0	1	1	0	1	3	4	4	3	3	0	20
1968	0	0	0	1	1	1	1	4	3	5	4	0	20
AVG	.1	0	.2	.8	1.2	1.2	3.1	4.6	3.4	3.3	1.9	.8	20.6

FIGURE 3-10

CLIMATOLOGY OF TYPHOON TRACKS

1959 - 1968


TYPHOON TRACKS
JANUARY 'J' FEBRUARY 'F' MARCH 'M' APRIL 'A'
1959-1968
SHANGHAI
HONG KONG
TOKYO
OKINAWA
SAIGON
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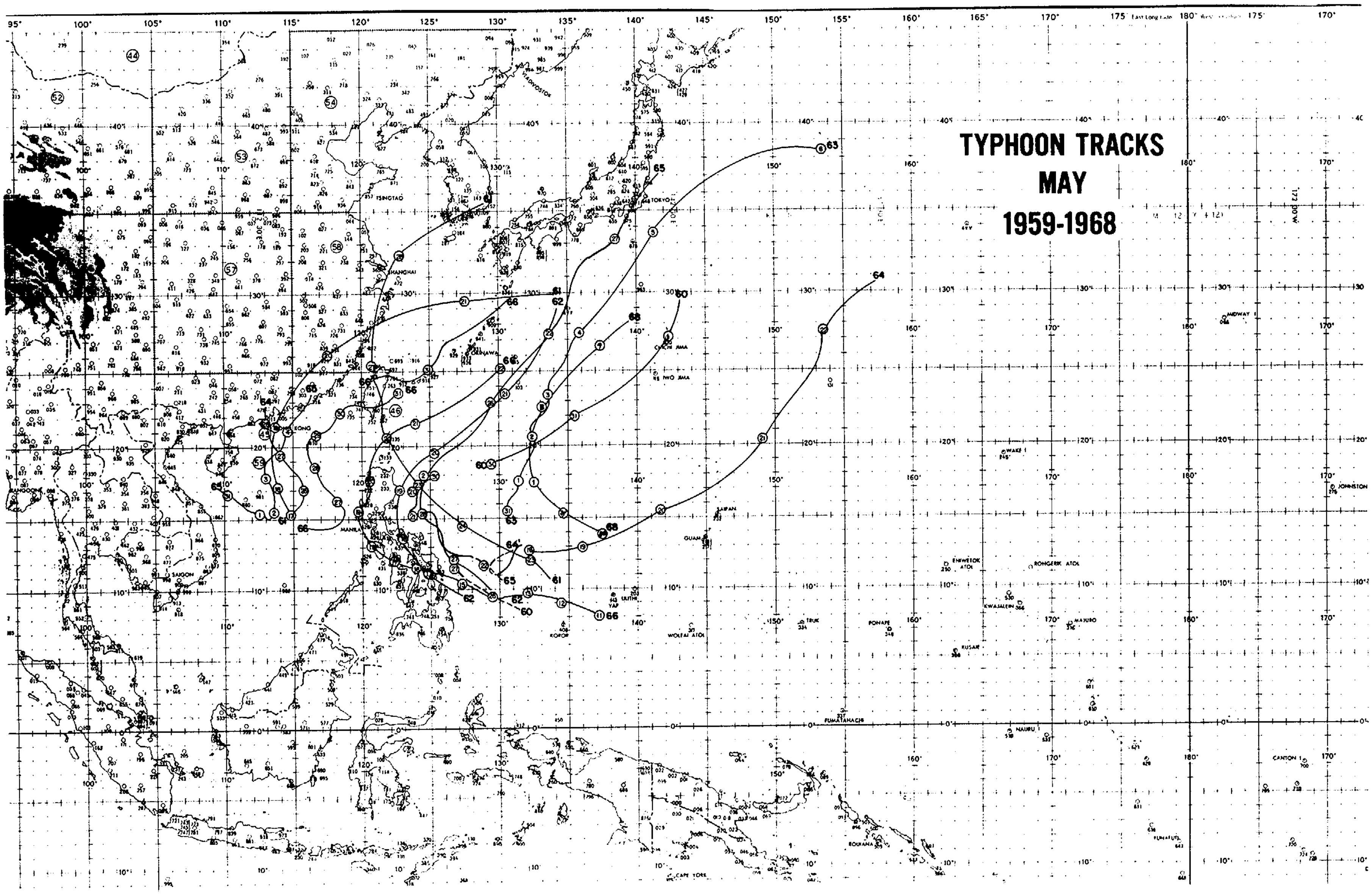
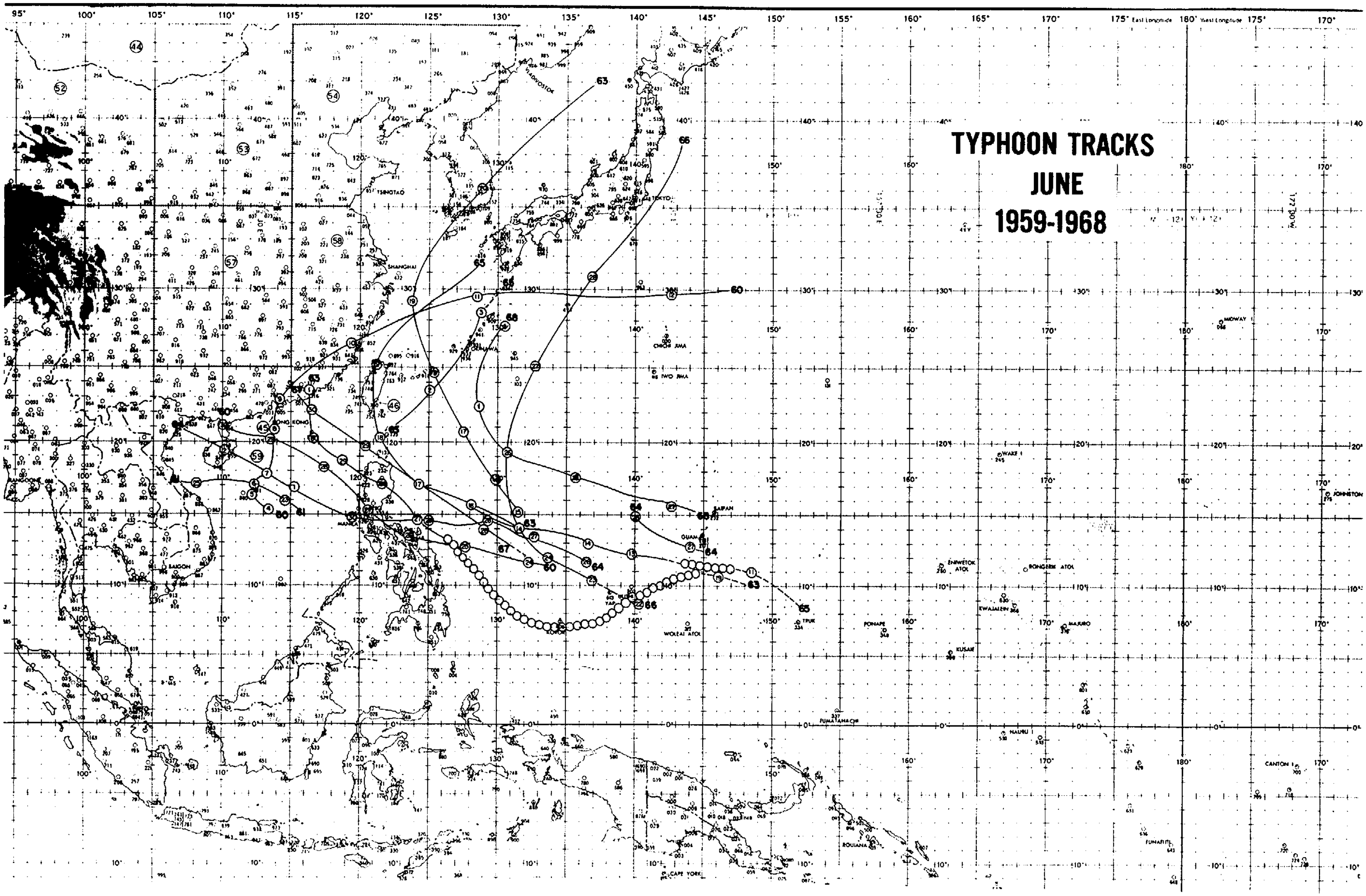

TYPHOON TRACKS
MAY
1959-1968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JUNE
1959-1968
TOKYO
SHANGHAI
HONG KONG
MANILA
SAIGON
GUAM
SAIPAN
IWO JIMA
WAKE I
MIDWAY I
JOHNSTON
KUSAIE
PONAPE
TRUK
YAP
NAURU I
CANTON I
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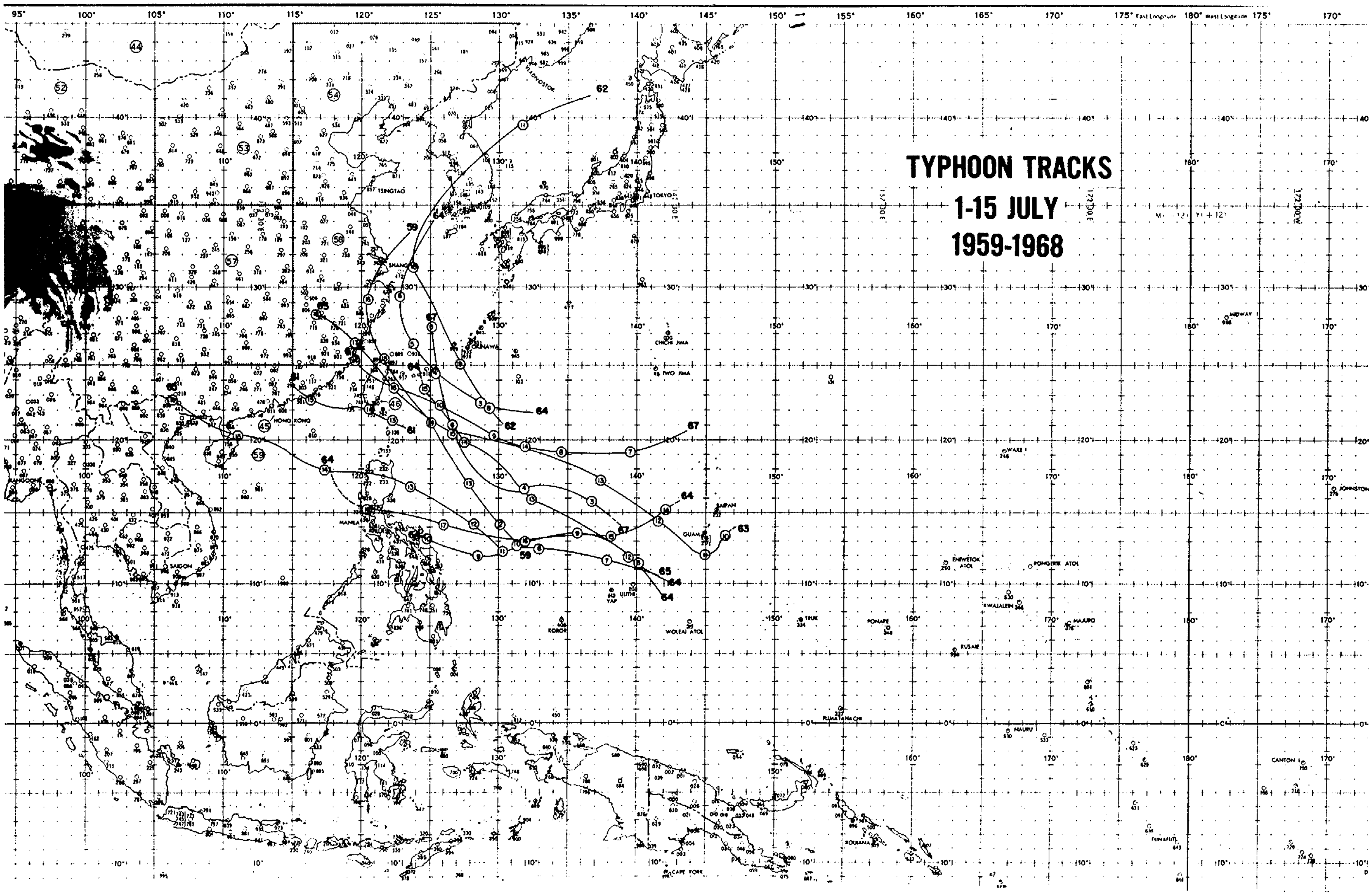
KWAJALEIN
MAJURO
WOLEAI ATOL
CAPE YORK
TSINGTAO
VLADIVOSTOK
FUNAFUTI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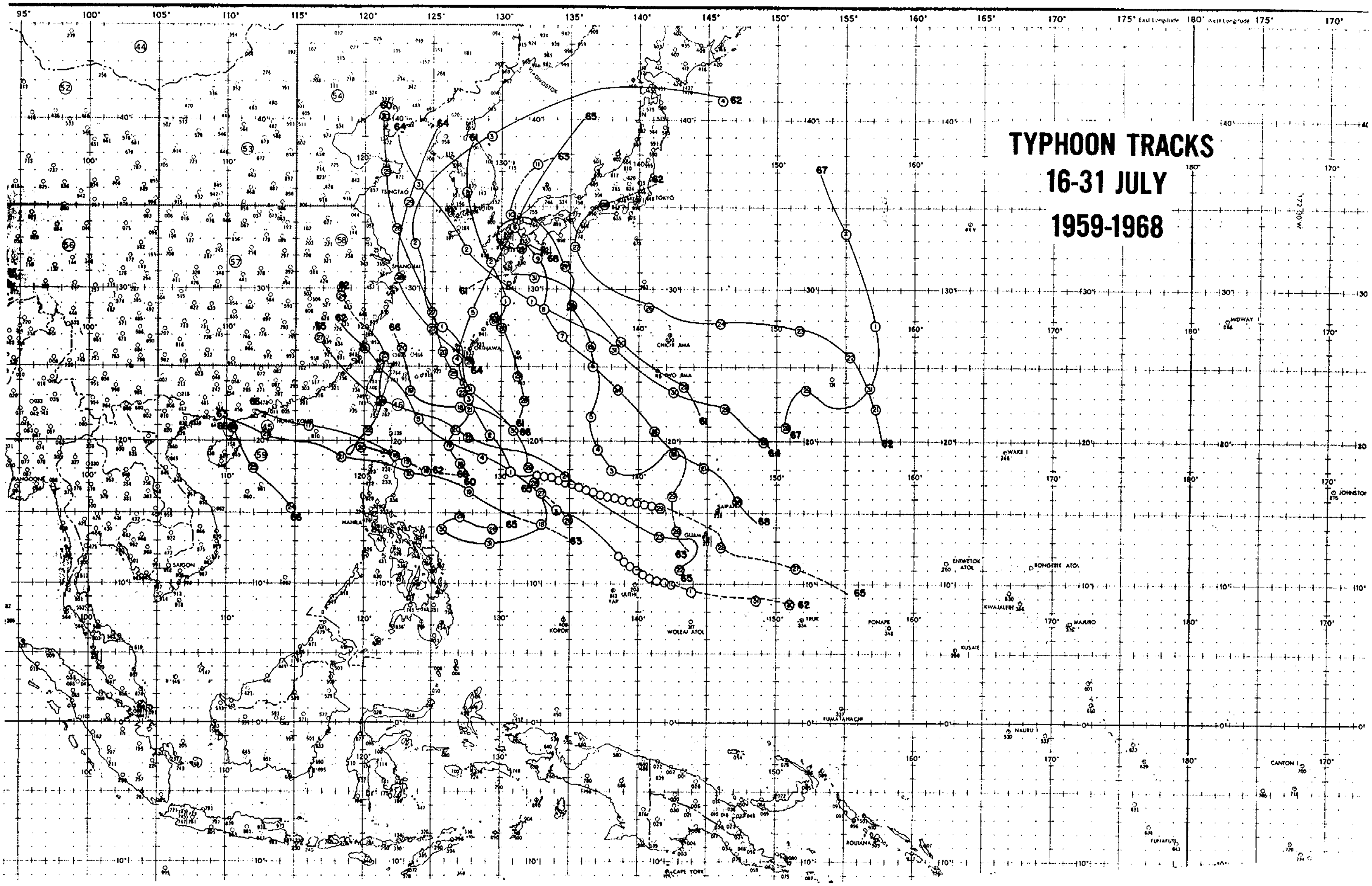
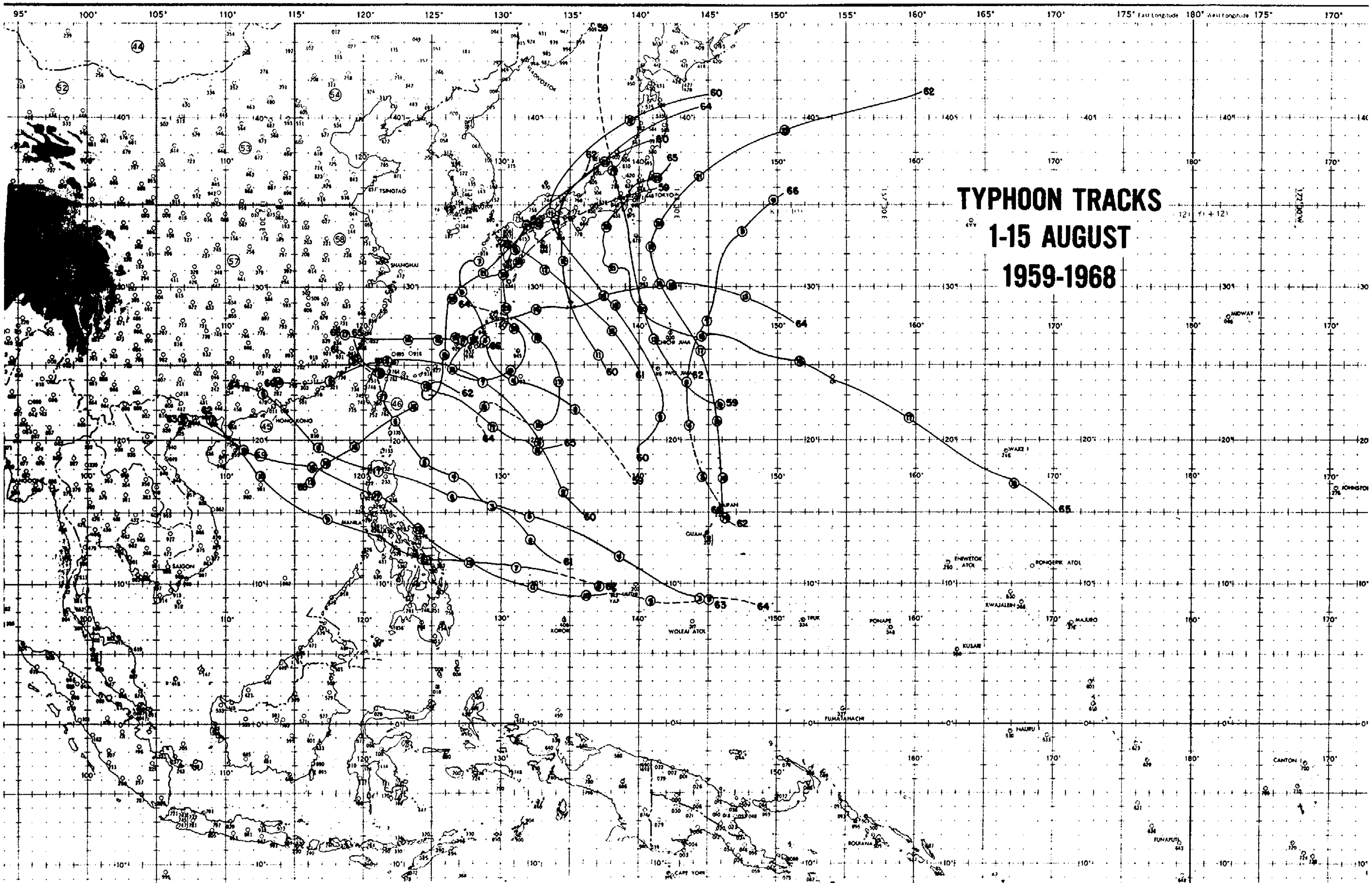
1-15 JULY
1959-1968

TYPHOON TRACKS 16-31 JULY 1959-1968

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1-15 AUGUST
1959-1968
SHANGHAI
HONG KONG
MANILA
SAIGON
TOKYO
GUAM
YAP
KOROR
WOLEAI ATOL
TRUK
PONAPE
KUSAIE
MAJURO
KWAJALEIN
ENIWETOK ATOL
RONGERIK ATOL
WAKE I
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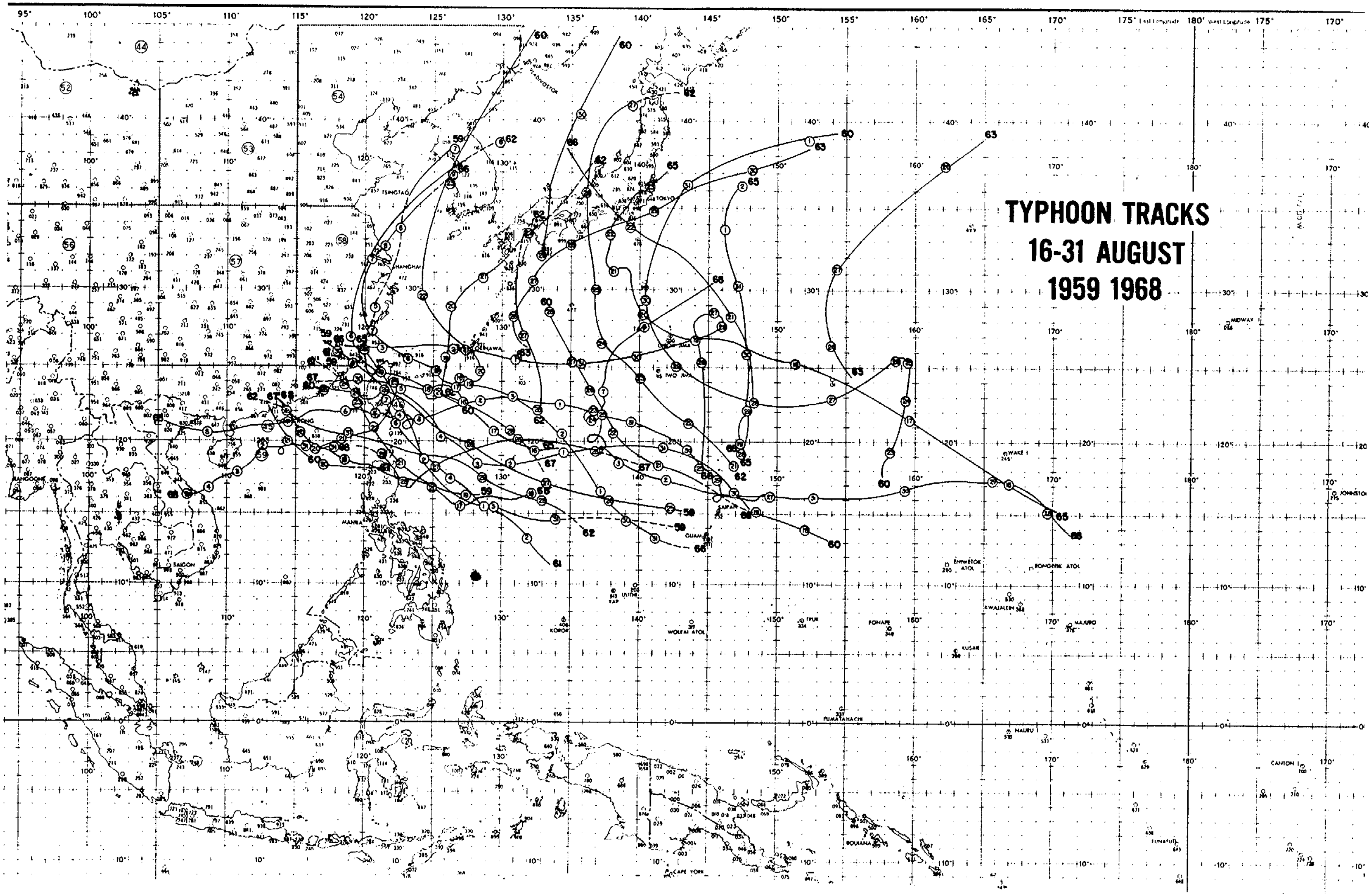
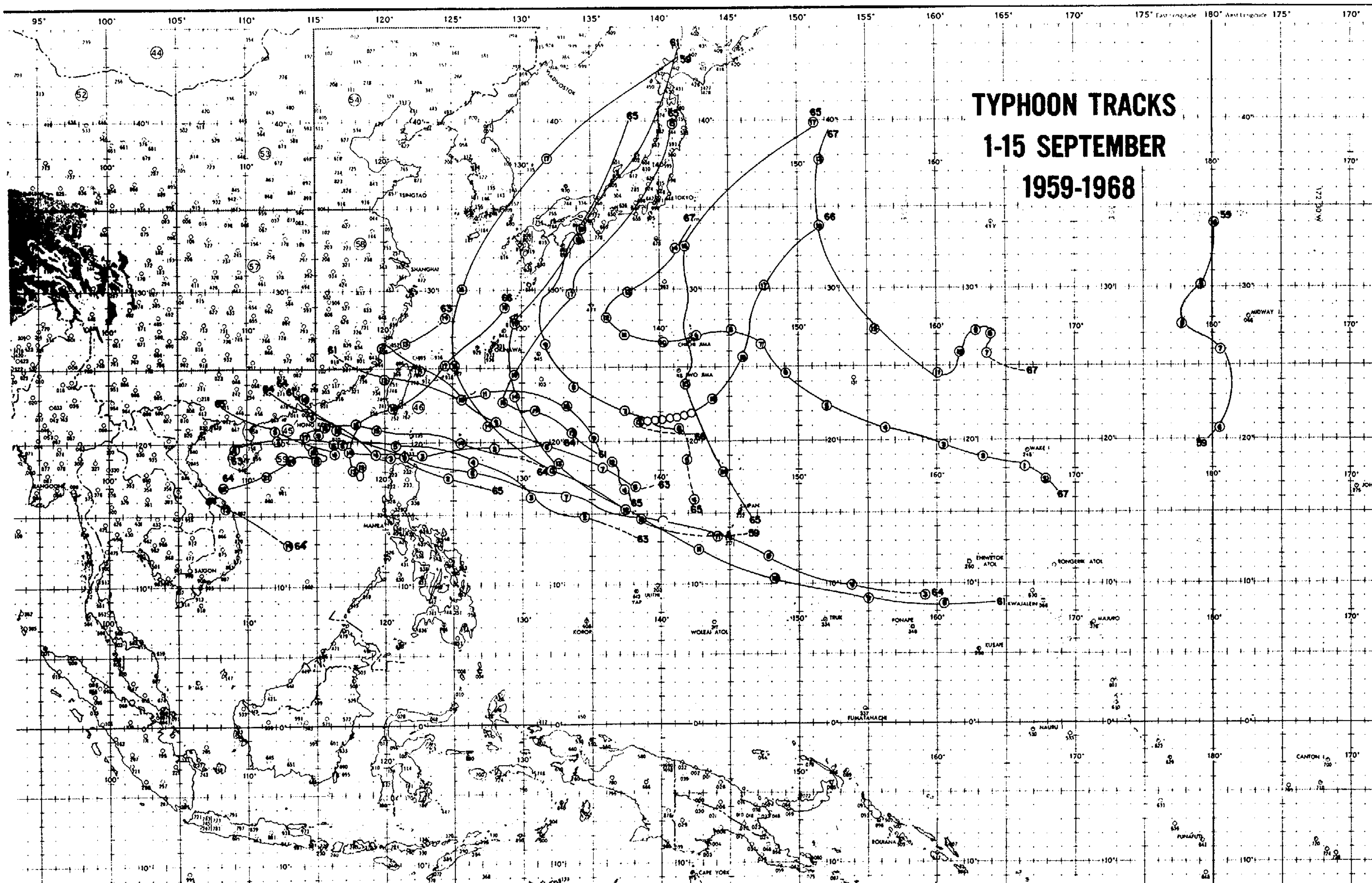
NAURU
CANTON I
FUNAFUTI
FUMATANACHI
CAPE YORK
VLADIVOSTOK
TSINGTAO



TYPHOON TRACKS
16-31 AUGUST
1959 1968



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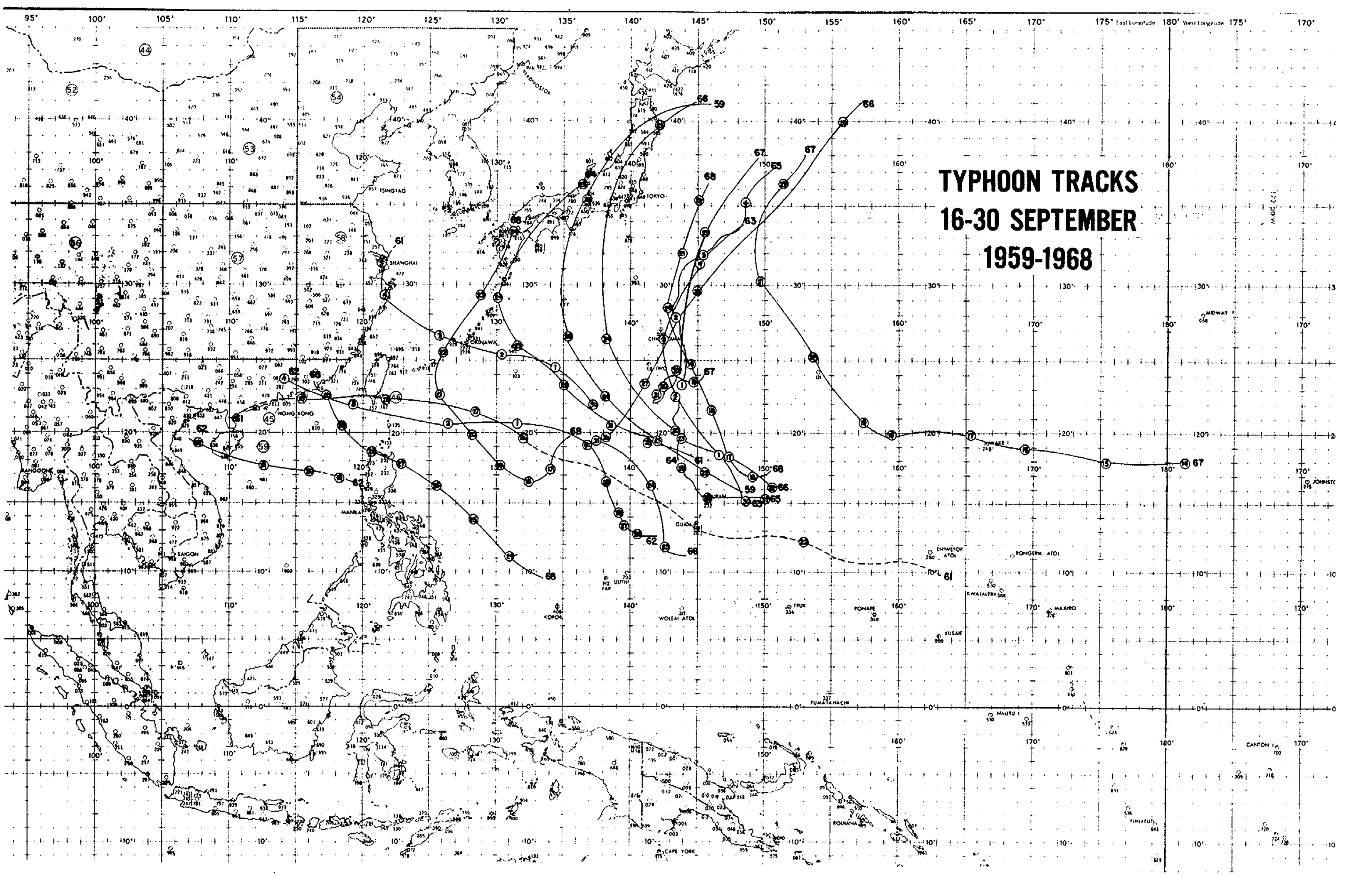
1-15 SEPTEMBER
1959-1968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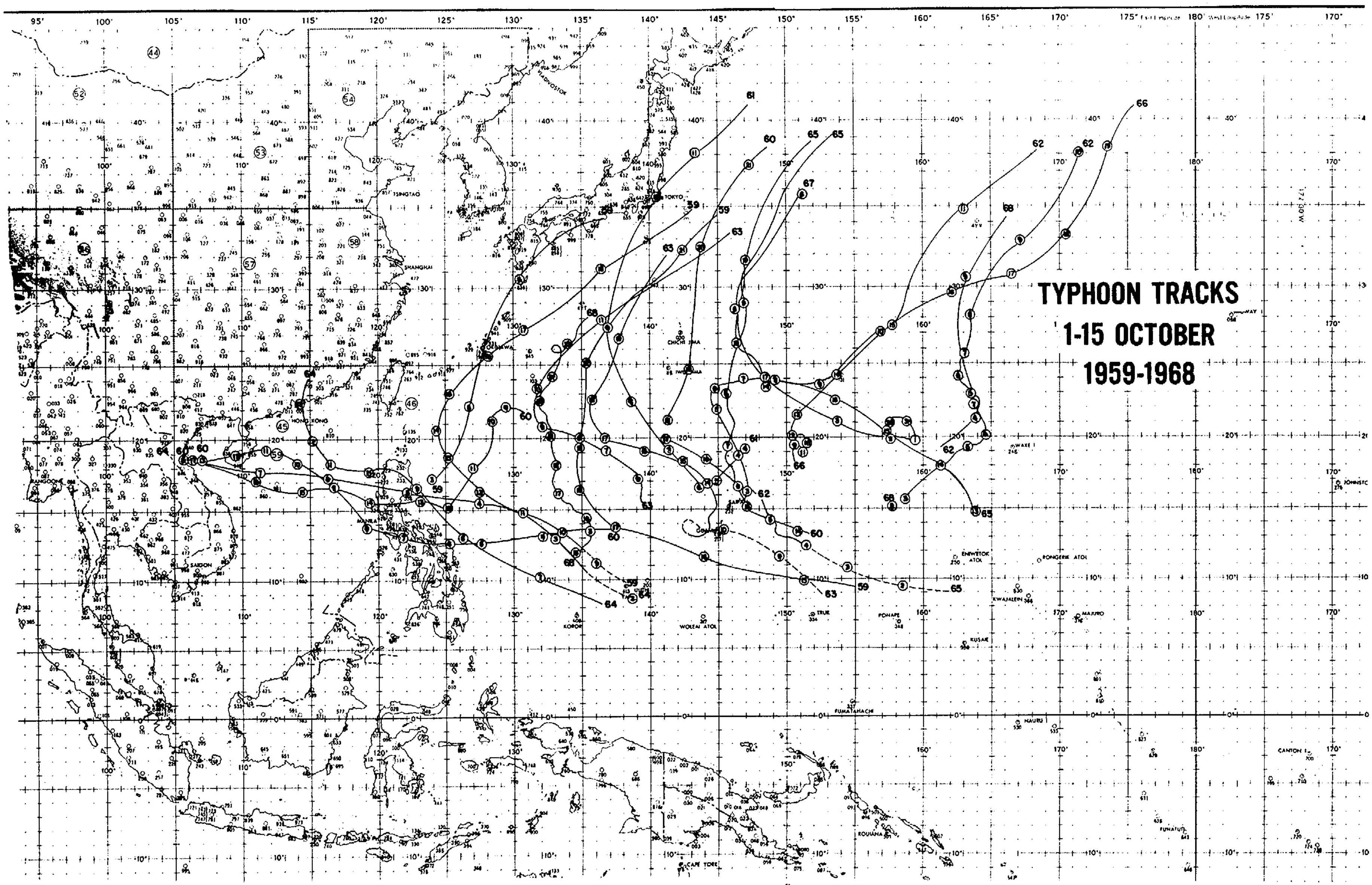
16-30 SEPTEMBER
1959-1968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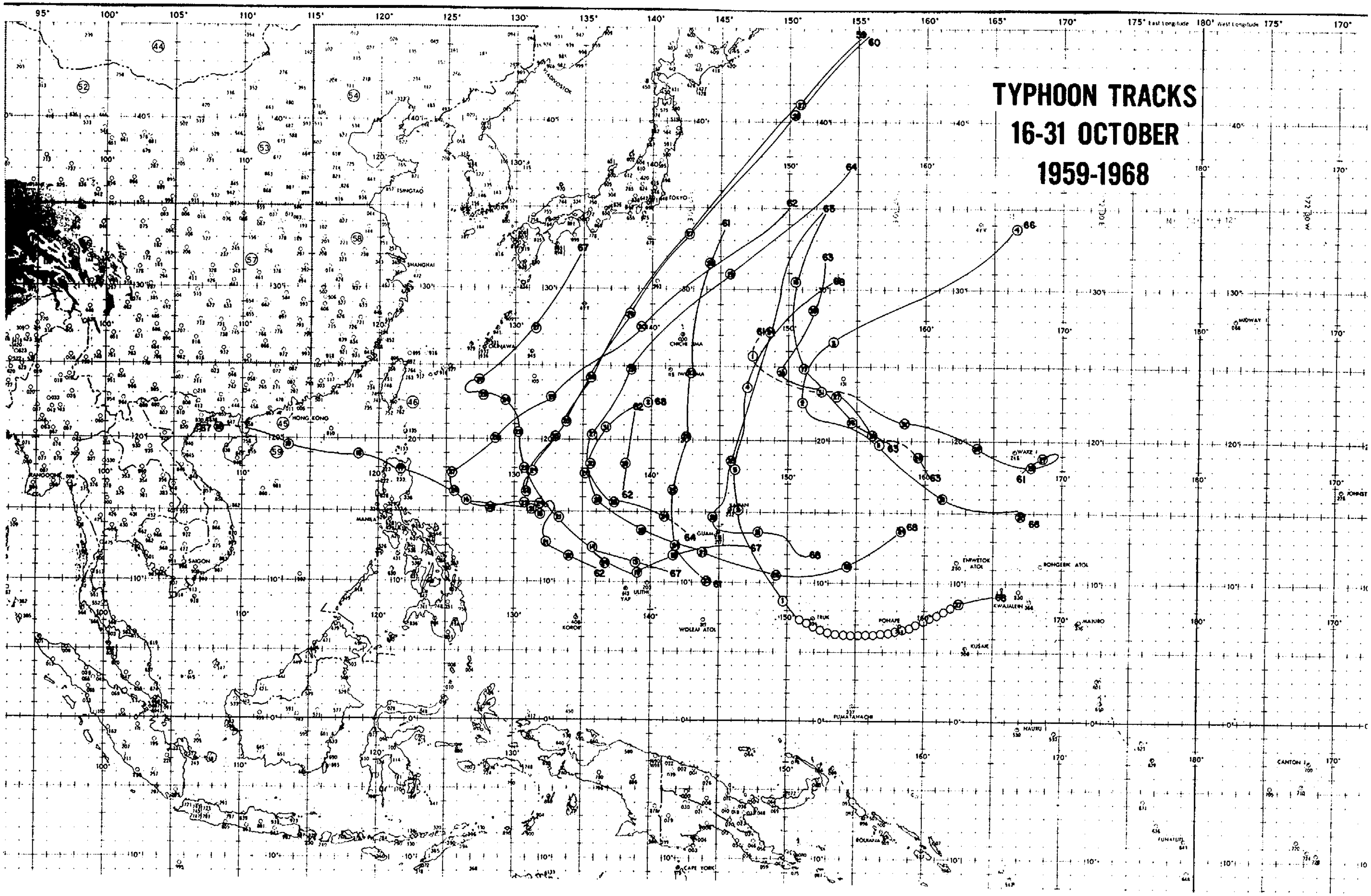
1-15 OCTOBER
1959-1968
TOKYO
SHANGHAI
HONG KONG
MANILA
SAIGON
TSINGTAO
VLADIVOSTOK
TRUK
PONAPE
KWAJALEIN
CANTON I.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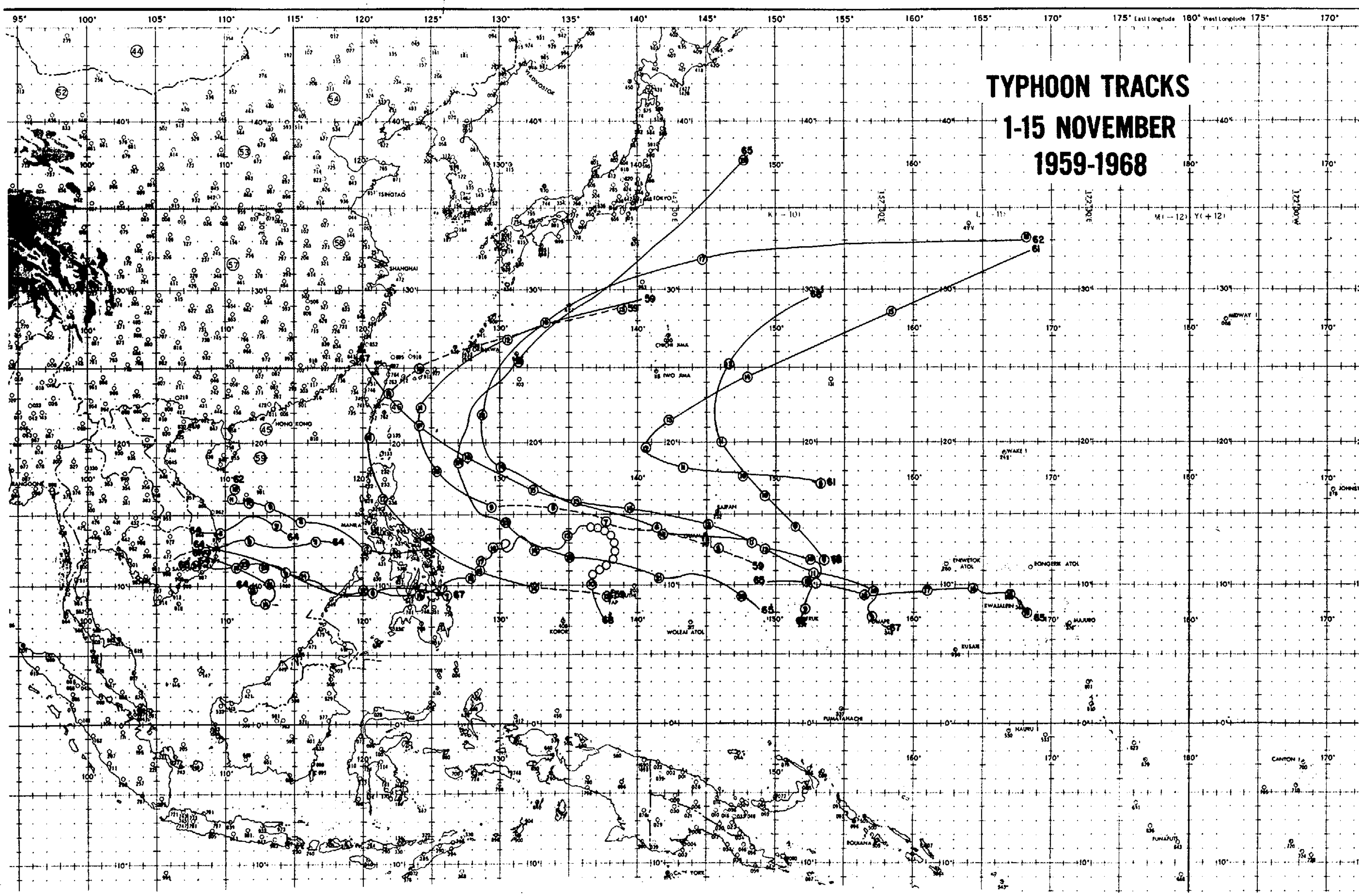
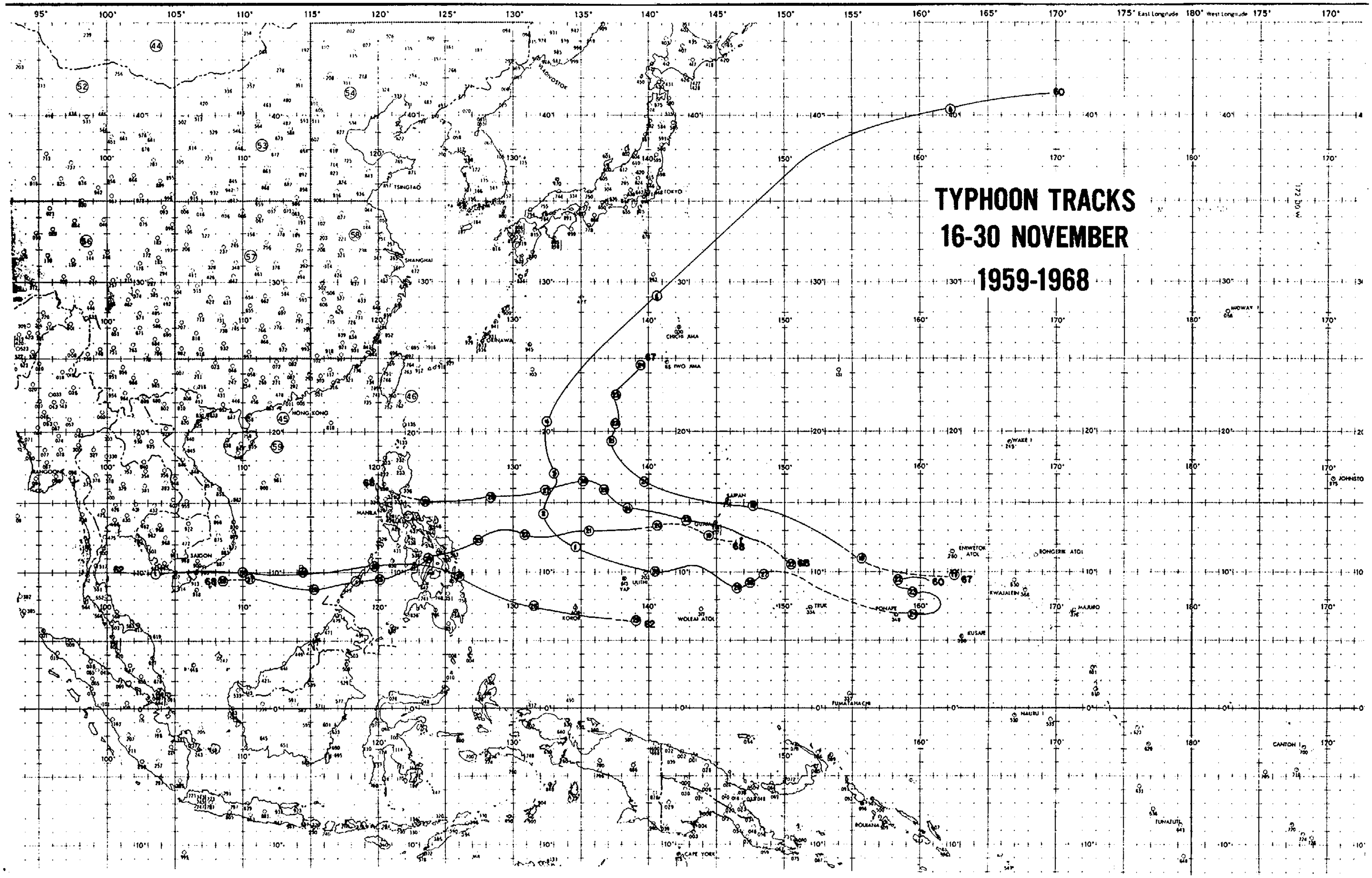
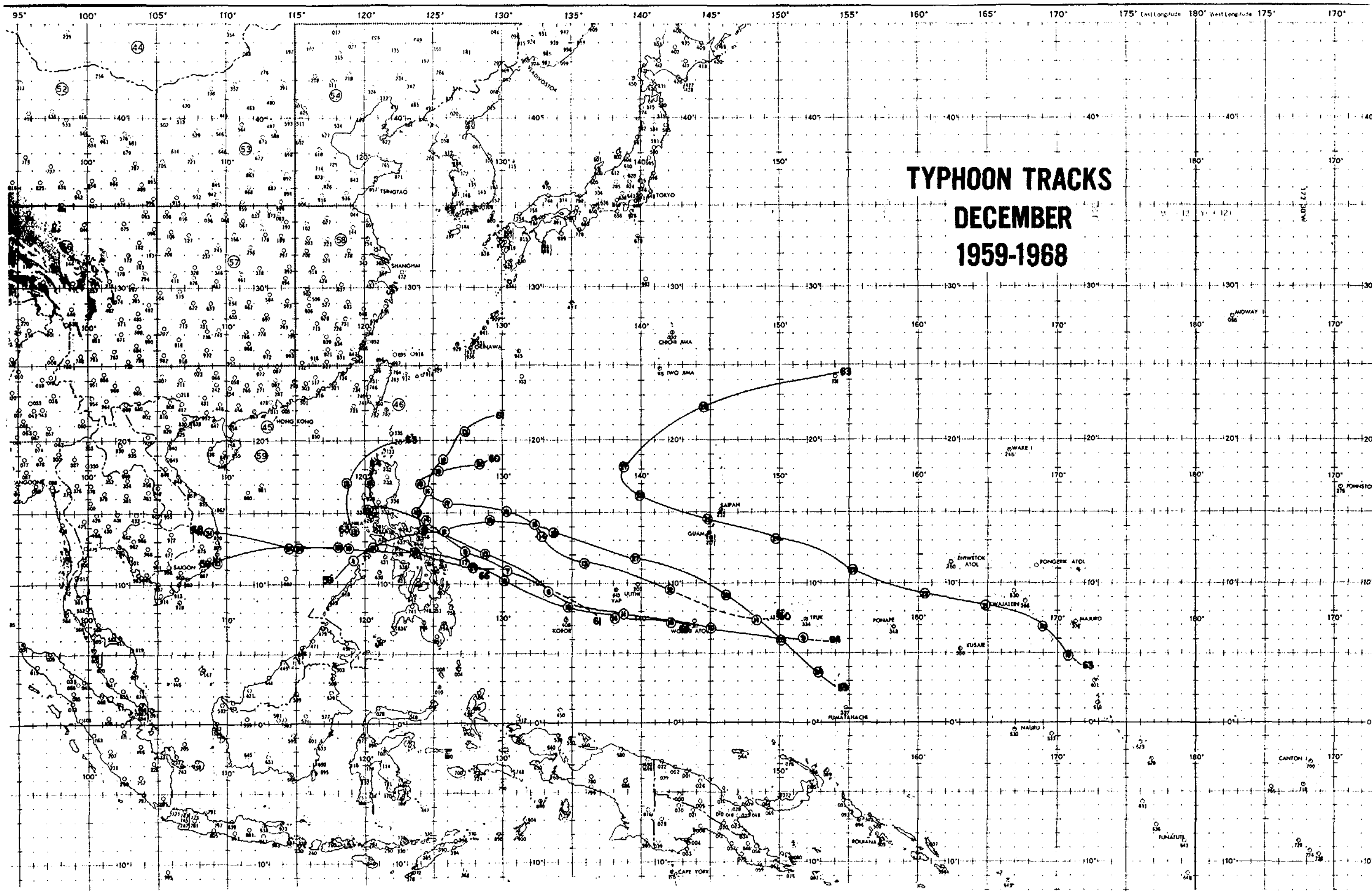
16-31 OCTOBER
1959-1968
HONG KONG
SHANGHAI
MANILA
SAIGON
TOKYO
GUAM
OKINAWA
TRUK
PONAPE
KWAJALEIN
WAKE I.
MIDWAY I.
YAP
ULITHI
CAPE YORK


TYPHOON TRACKS
1-15 NOVEMBER
1959-1968
SHANGHAI
HONG KONG
TOKYO
SAIPAN
WAKE I
MIDWAY I
IWO JIMA
ENIWETOK ATOL
KWAJALEIN
MAJURO
JOHNSTON
CANTON I
95°
100°
105°
110°
115°
120°
125°
130°
135°
140°
145°
150°
155°
160°
165°
170°
175° East Longitude
180° West Longitude
175°
170°


TYPHOON TRACKS
16-30 NOVEMBER
1959-1968
VLADIVOSTOK
TSINGTAO
SHANGHAI
TOKYO
HONG KONG
MANILA
SAIGON
RANGOON
SAIPAN
GUAM
IWO JIMA
ULITHI
YAP
KOROR
WOLEAI ATOL
TRUK
PONAPE
KUSAIE
ENIWETOK ATOL
RONGERIK ATOL
KWAJALEIN
MAJURO
WAKE I
MIDWAY I
JOHNSTON
NAURU I
CANTON I
CAPE YORK
FUNAFUTI


TYPHOON TRACKS
DECEMBER
1959-1968
SHANGHAI
HONG KONG
TSINGTAO
TOKYO
SAIGON
OKINAWA
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
WAKE I
MIDWAY I
ENIWETOK ATOL
KWAJALEIN
MAJURO
PONAPE
KUSAIE
TRUK
ULITHI
YAP
KOROR
NAURU
CANTON I
CAPE YORK
FUNAFUTI

E. EVALUATION OF THE SEAY GRAPH AND DEVELOPMENT OF AN IMPROVED PRESSURE-WIND CORRELATION GRAPH FOR TROPICAL CYCLONES

The original Seay graph was compiled from reconnaissance data for 1957, 1958 and 1959 and is discussed in the 1960 Annual Typhoon Report. The graph was modified during the 1964 season using additional reconnaissance data from the years 1956 through 1962 and appears in the 1964 Annual Typhoon Report as the JTWC graph.

During 1968 results using this graph were compared with actual land station reports. Although it is realized that this graph was designed to be used with data collected from within the eye, it was felt that an evaluation using data frequently obtained from outside the boundary of the eye could, nevertheless be useful.

The evaluation utilized data taken from CPA reports and land station reports received at JTWC for 1963, 1964, 1967 and 1968. A composite list of these reports and associated data is given in Tables 3-5 through 3-10.

Using the appropriate latitude value and reported Minimum Sea Level Pressure of the station at the time of CPA a surface "Seay" wind was obtained from the Seay graph. The actual wind reported by each station was then subtracted from this computed "Seay" wind. A positive value signifies that the "Seay" wind is greater than the actual wind reported by the station and a negative value signifies that the "Seay" wind is less than the wind reported by the station.

The first attempt to segregate the data involved separating the reports into the following two groups: Group I - Those reports south of 22N; Group II - Those reports north of 22N. For Group I a comparison of the 55 station maximum sustained wind reports and the 41 station maximum gust reports with the "Seay" wind are shown in Table 3-11. For Group II a comparison of the 36 station maximum sustained wind reports and the 28 station maximum gust reports with the "Seay" wind are shown in Table 3-11.

The second attempt to segregate the data, without regard to geographic location, involved a comparison of the 91 station maximum sustained wind reports and the 69 station maximum gust reports with the "Seay" wind, with the results shown in Table 3-11.

The third attempt to segregate the data involved separating the CPA reports into arbitrary distances from the storm center based on the time of the report and best track position of the storm. For the purpose of this study 0 to 20 miles was considered to have been a good range for those stations in or near the eye or close enough to the center to give accurate values using the Seay graph. However, the largest difference between the "Seay" wind and station maximum sustained wind for Group I and II was the 0 to 20 miles range, with the difference decreasing as distance from the storm center increased.

Finally, in order to adhere to the prerequisites established for validity of the Seay graph, station data, especially the Minimum Sea Level Pressure, was compared with available reconnaissance data to determine whether or not a station had been inside the eye. Twenty-two stations were found which fell into this category. The average computed "Seay" wind was found to be 23.4 knots higher than the maximum sustained wind as reported by these stations, with values ranging between -14.9 knots to +51.0 knots. Due to the small sample size no attempt was made to group these reports according to latitude.

Conclusions inferred from this evaluation are: (1) No significant difference was noted between results obtained from stations in the southern range of latitude and results obtained from stations in a more northerly latitude. (2) The present Seay graph corresponds much better with maximum gusts than sustained winds. (3) The Seay graph appears to be about 20 knots too high.

Before modifying the Seay graph using the above results, an attempt was made to derive a new equation for computing maximum sustained surface winds from sea level pressure data. The following equation was found to be very accurate, when compared to actual land data for wind values less than 45 knots.

$$V_{max} = \left(12 - \frac{\theta}{8}\right) \sqrt{1007 - P_o} \qquad (1)$$

where V_{max} = Maximum sustained surface wind (knots)

θ = Latitude of tropical cyclone

P_o = Minimum observed sea level pressure (MB)

Equation (1) was used to compute wind values less than 45 knots and a modified Seay equation (2) was used to compute wind values greater than 45 knots. The resulting graph, Fig (3-11), is a smoothed product utilizing both equations.

$$V_{max} = \left[\left(19 - \frac{\theta}{5}\right) \sqrt{364 - \frac{H_7}{28}} \right] - 20 \qquad (2)$$

where V_{max} = Maximum sustained surface wind (knots)

θ = Latitude of tropical cyclone

H_7 = Minimum 700MB height in feet in tropical cyclone center.

This graph will give a better estimate of the maximum sustained surface wind associated with a tropical system of tropical storm intensity or greater than could previously be obtained from the present Seay graph. Evaluation of this graph will continue as additional wind reports are obtained.

STATION	CPA(NM)	DTG(Z)	MAX WIND (KTS)	PEAK GUST (KTS)	MIN SLP (MB)	ACFT EYE/SLP/ SFC WIND	SEAY WIND	SEAY LESS MAX WIND	STORM/MONTH/YEAR	BEST TRACK(KTS)
FWC/JTWC	35W	290645	54	87	976.5	932/110	86	+32	T. OLIVE/APR/63	125
ANDERSEN	57N	242359	37	61	992.0	942/120	60	+23	T. SUSAN/DEC/63	120
SANGLEY PT	80NE	132000	28	36	1000.5	990/75	36	+08	T. CARMEN/AUG/63	100
CATANDUANES	12SW	130100	68	95	973.0	898/125	91	+23	T. CARMEN/AUG/63	110
BATAN	40SE	132300	18	30	993.6	---/75	51	+33	T. PHYLLIS/DEC/63	45
USS MAURY	UNK	120310	70	83	988.0	---/---	67	-03	T. PHYLLIS/DEC/63	55
SANGLEY PT	10NE	291620	45	64	976.0	968/75	87	+42	T. WINNIE/JUN/64	65
CUBI PT	15S	292015	40	54	973.0	968/75	91	+51	T. WINNIE/JUN/64	65
CATANDUANES	190NE	060600	14	30	999.5	927/200+	41	+27	T. IDA/AUG/64	135
BATAN	190SW	060801	30	60	995.6	927/200+	47	+17	T. IDA/AUG/64	135
NAULO PT	190NE	071401	40	58	995.1	971/75	51	+11	T. IDA/AUG/64	100
DA NANG	15S	150132	28	48	993.0	---/---	54	+26	T. VIOLET/SEP/64	70
DA NANG	70NE	261700	26	32	999.9	---/---	38	+12	T.S. ANITA/SEP/64	--
CATANDUANES	45S	281401	20	35	1000.6	---/---	38	+18	T.S. BILLIE/SEP/64	--
CUBI PT	105N	042344	13	17	1001.9	999/60	33	+20	T. CLARA/OCT/64	80
CATANDUANES	10N	201801	20	28	1000.8	---/---	37	+17	T.S. GEORGIA/OCT/64	--
TAN SON NHUT	UNK	080400	50	70	1001.0	1000/55	36	-14	T. JOAN/NOV/64	65
CUBI PT	45N	141812	41	51	995.9	975/90	49	+08	T. OPAL/DEC/64	75

TABLE 3-5 --GROUP I REPORTS SOUTH OF 22N

STATION	CPA(NM)	DTG(Z)	MAX WIND (KTS)	PEAK GUST (KTS)	MIN SLP (MB)	ACFT EYE/SLP/ SFC WIND	SEAY WIND	SEAY LESS MAX WIND	STORM/MONTH/YEAR	BEST TRACK(KTS)
CATANDUANES	20NE	132200	100	140	963.0	956/200	104	+04	T. OPAL/DEC/64	170
BATAN	170SW	151530	40	66	999.3	992/30	39	-01	T. OPAL/DEC/64	40
ANDERSEN	82N	202135	22	34	1000.7	---/---	36	+14	T.S.THERESE/MAR/67	---
NAULO PT	15SW	041201	45	60	984.4	975/45	71	+26	T. EMMA/NOV/67	60
WAKE	10N	162300	85	116	937.4	946/80	125	+40	T. SARAH/SEP/67	120
ANDERSEN	35N	122330	40	58	980.5	943/75	80	+40	T. GILDA/NOV/67	120
ANDERSEN	91NE	110430	38	54	997.4	932/130	46	+08	T. JEAN/APR/68	110
SAIPAN	35SE	110500	50	--	977.7	932/140	84	+34	T. JEAN/APR/68	110
BATAN	35NW	250300	50	90+	972.3	966/45	86	+36	T.S.NADINE/JUL/68	60
LOANG	10S	191200	25	--	982.1	968/50	73	+48	T. SHIRLEY/AUG/68	45
TUNG SHA TAO	53SE	201700	60	--	978.4	972/60	74	+14	T. SHIRLEY/AUG/68	60
VIGAN	80E	190600	40	--	992.8	962/50	56	+16	T. SHIRLEY/AUG/68	50
VIGAN	35NNE	191200	35	--	989.5	967/50	62	+27	T. SHIRLEY/AUG/68	45
VIGAN	45NW	191500	40	--	991.4	967/50	59	+19	T. SHIRLEY/AUG/68	50
DA NANG	35NNW	051410	35	50	985.0	---/---	70	+35	T. BESS/SEP/68	50
BATAN	70N	042200	45	50	985.1	972/---	67	+22	T. WENDY/SEP/68	80
SAIPAN	76N	020100	25	--	994.0	965/70	53	+28	T. AGNESS/SEP/68	90
TUGUEGARAO	60E	280300	45	--	986.1	930/100	68	+23	T. ELAINE/SEP/68	120

TABLE 3-6-- Group I reports south of 22N

STATION	CPA(NM)	DTG(Z)	MAX WIND (KTS)	PEAK GUST (KTS)	MIN SLP (MB)	ACFT EYE/SLP/ SFC WIND	SEAY WIND	SEAY LESS MAX WIND	STORM/MONTH/YEAR	BEST TRACK(KTS)
APARRI	25S	280900	60	--	977.8	---/---	81	+21	T. ELAINE/SEP/68	95
VIGAN	60NE	281800	60	--	988.0	---/---	63	+03	T. ELAINE/SEP/68	75
SAIPAN	37NW	221600	62	85	990.3	977/50	61	-01	T. IRMA/OCT/68	60
ANDERSEN	30N	220825	45	66	989.4	985/40	64	+19	T. IRMA/OCT/68	55
ANDERSEN	103SE	270227	32	50	1005.5	935/130	30	-02	T. JUDY/OCT/68	110
SAIGON	35SE	192000	24	34	1002.3	---/---	30	+06	T.S. HESTER/OCT/68	30
ANDERSEN	07S	221640	45	77	988.3	---/---	66	+21	T. ORA/NOV/68	45
ANDERSEN	85E	012140	26	41	1001.0	984/40	32	+06	T. KIT/NOV/68	50
MACTAN	75N	232300	37	52	996.0	---/---	51	+14	T. NINA/NOV/68	50
MACTAN	20SSE	190200	44	60	1001.0	---/65	32	-12	T. MAMIE/NOV/68	55
TARUMPITAO	50N	201200	30	38	1004.5	972/50	30	00	T. MAMIE/NOV/68	60
PHAN RANG	10S	231650	21	36	1005.0	---/35	30	+09	T. MAMIE/NOV/68	35
CAM RAHN BAY	27S	231450	28	38	1007.1	---/35	30	+02	T. MAMIE/NOV/68	40
SAIPAN	28ENE	020000	45	60	993.4	984/40	54	+09	T. KIT/NOV/68	50
NANSHA	47NNE	210600	35	--	1001.4	976/85	31	-04	T. MAMIE/NOV/68	60
SURIGAO	10N	181800	45	--	1001.0	972/80	31	-14	T. MAMIE/NOV/68	55
CATBALOGAN	30SE	231500	50	--	983.9	---/---	77	+27	T. NINA/NOV/68	50
TACLOBAN	10N	231500	45	--	975.1	---/---	91	+46	T. NINA/NOV/68	50
TARUMPITAO	10E	251000	40	65	988.2	977/60	67	+27	T. NINA/NOV/68	50

TABLE 3-7--Group I reports south of 22N

STATION	CPA(NM)	DTG(Z)	MAX WIND (KTS)	PEAK GUST (KTS)	MIN SLP (MB)	ACFT EYE/SLP/ SFC WIND	SEAY WIND	SEAY LESS MAX WIND	STORM/MONTH/YEAR	BEST TRACK(KTS)
TAIPAI	40SW	160400	40	68	980.0	943/80	70	+30	T. WENDY/JUL/63	60
TAIPAI	40NE	102200	--	84	969.2	932/100	83	--	T. GLORIA/SEP/63	110
ITAZUKE	20NE	090328	25	39	984.5	964/80	56	+31	T. BESS/AUG/63	60
KADENA	160SW	180254	26	44	998.8	962/100	36	+10	T. SHIRLEY/JUN/63	100
KADENA	130W	180600	30	47	989.9	---/---	54	+24	T. SHIRLEY/JUN/63	100
NAHA	135SW	181345	30	49	998.1	---/80	38	+08	T. SHIRLEY/JUN/63	100
KUNSAN	20SE	182154	23	30	995.2	--/---	38	+15	T. SHIRLEY/JUN/63	---
NAHA	30SW	260000	36	52	999.9	988/40	34	-02	T. FLOSSIE/JUL/64	40
KADENA	60SW	260625	27	49	1001.6	983/55	30	+03	T. FLOSSIE/JUL/64	50
KUNSAN	85SW	021700	18	25	990.0	---/---	45	+27	T. HELEN/AUG/64	65
NAHA	35W	161200	26	40	986.7	985/80	59	+33	T. KATHY/AUG/64	70
ITAZUKE	20W	232049	27	41	986.0	973/65	54	+27	T. KATHY/AUG/64	65
KADENA	30W	172000	25	39	989.2	954/100	55	+30	T. KATHY/AUG/64	95
ITAZUKE	100SE	241355	28	41	994.3	---/75	42	+14	T. WILDA/SEP/64	95
NAHA	105SE	070600	23	30	1000.0	995/30	33	+10	T. BILLIE/JUL/67	40
HUALIEN	10S	110615	70	90	970.2	965/75	83	+13	T. CLARA/JUL/67	80
KADENA	128SE	070400	16	30	1000.4	995/30	32	+16	T. BILLIE/JUL/67	45
ILAN	45S	291800	45	47	989.6	982/50	56	+11	T. NORA/AUG/67	45

TABLE 3-8--Group II reports north of 22N

STATION	CPA(NM)	DTG(Z)	MAX WIND (KTS)	PEAK GUST (KTS	MIN SLP (MB)	ACFT EYE/SLP/ SFC WIND	SEAY WIND	SEAY LESS MAX WIND	STORM/MONTH/YEAR	BEST TRACK(KTS)
NAHA	75E	261325	42	58	991.4	965/60	51	+09	T. DINAH/OCT/67	80
KADENA	95E	261355	30	48	991.2	968/55	51	+21	T. DINAH/OCT/67	80
TAIPEI	35SW	180500	44	65	994.7	---/---	45	+01	T. GILDA/NOV/67	50
MUROTOMISAKI	32SW	280900	70	--	978.4	973/35	64	-06	T. MARY/JUL/68	30
SHIMIZU	40E	280900	10	--	978.0	973/35	64	+54	T. MARY/JUL/68	30
HENGCHUN	OVER	251100	--	45	976.7	971/70	78	--	T.S. NADINE/JUL/68	50
KADENA	72ESE	020000	30	--	1002.4	1000/35	30	00	T.LUCY/JUL/68	45
KUNGSHAN	10W	280900	40	60	988.3	985/45	59	+19	T.S. NADINE/JUL/68	40
AMAMIO SHIMA	40NW	121800	15	--	996.6	984/40	40	+25	T.S. POLLY/AUG/68	40
TSUSHIMA	14WNW	160600	40	--	977.2	971/75	63	+23	T.S. POLLY/AUG/68	50
HONG KONG	OVER	211200	--	--	970.9	964/80	86	--	T. SHIRLEY/AUG/68	60
AMAMIO SHIMA	14WSW	272000	25	--	984.3	978/35	61	+36	T.S. TRIX/AUG/68	55
KADENA	76E	271627	20	34	989.0	978/35	55	+35	T.S. TRIX/AUG/68	50
ITAZUKE	80NW	160600	28	46	999.1	971/75	30	+02	T.S. POLLY/AUG/68	50
MARCUS	32NNW	071800	35	--	993.1	982/45	50	+15	T.S. POLLY/AUG/68	45
KADENA	46NNW	230800	48	69	991.0	940/100	53	+05	T. DELLA/SEP/68	100
TAINAN	75SSE	060154	32	41	988.2	972/60	58	+26	T. WENDY/SEP/68	65
MIYAKO JIMA	15E	221600	110	150	945.8	---/---	108	-02	T. DELLA/SEP/68	110

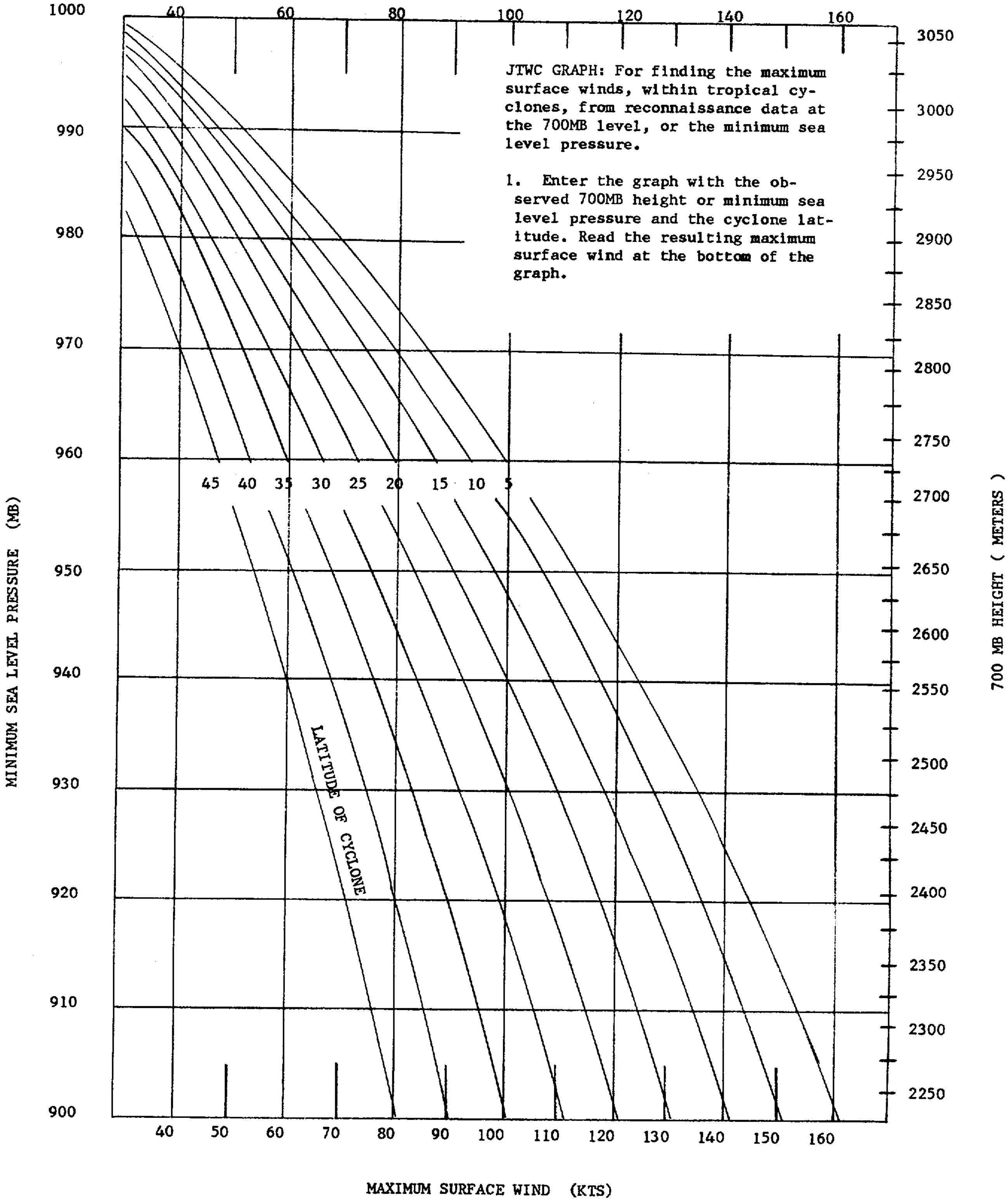
TABLE 3-9--Group II reports north of 22N

STATION	CPA(NM)	DTG(Z)	MAX WIND (KTS)	PEAK GUST (KTS)	MIN SLP (MB)	ACFT EYE/SLP/ SFC WIND	SEAY WIND	SEAY LESS MAX WIND	STORM/MONTH/YEAR	BEST TRACK(KTS)
HENGCHUN	35SE	051800	35	---	980.4	970/--	72	+37	T. WENDY/SEP/68	70
CHICHI JIMA	86NW	090100	30	---	980.4	976/45	68	+38	T. AGNES/SEP/68	55
KAGOSHIMA	10W	241300	45	---	989.3	---/---	51	+06	T. DELLA/SEP/68	60

TABLE 3-10--Group II reports north of 22N

	NUMBER OF STATION REPORTS	"SEAY" WIND LESS MAX SUSTAINED WIND (KNOTS	"SEAY" WIND LESS MAX GUST (KNOTS)
Group 1	91 69	+17.25	-1.13
Group II	55 41	+16.8	-1.6
Group III	36 28	+17.9	-0.5

TABLE 3-11 - - - Comparison of "Seay" wind with reported sustained wind and maximum gusts.


JTWC GRAPH: For finding the maximum surface winds, within tropical cyclones, from reconnaissance data at the 700MB level, or the minimum sea level pressure.
1. Enter the graph with the observed 700MB height or minimum sea level pressure and the cyclone latitude. Read the resulting maximum surface wind at the bottom of the graph.
MINIMUM SEA LEVEL PRESSURE (MB)
1000
990
980
970
960
950
940
930
920
910
900
700 MB HEIGHT (METERS)
3050
3000
2950
2900
2850
2800
2750
2700
2650
2600
2550
2500
2450
2400
2350
2300
2250
40
60
80
100
120
140
160
45 40 35 30 25 20 15 10 5
LATITUDE OF CYCLONE
40
50
60
70
80
90
100
110
120
130
140
150
160
MAXIMUM SURFACE WIND (KTS)

F. COMMENTS ON THE CHARACTERISTICS OF TROPICAL CYCLONES BECOMING EXTRATROPICAL

This study is intended to show, by use of satellite pictures and other synoptic data, characteristics of tropical cyclones that are becoming extratropical.

The term extratropical, as used in this study, is defined as that stage in the life of a tropical cyclone when the cyclone has moved to a position poleward of the belt of tropical easterlies (subtropical ridge) and the characteristic warm core center has become or is rapidly becoming indistinguishable.

Several tropical cyclones during 1968 displayed similar characteristics while becoming extratropical. Comparisons using reconnaissance, upper air and sea surface temperature data with corresponding satellite pictures are made for three tropical cyclones which became extratropical.

I. TYPHOON CARMEN

Tropical Cyclone Carmen (See Chapter V for best track) attained typhoon intensity at 171100Z SEP and reached its maximum intensity at 190500Z*. Table 3-12 lists sea level pressure (SLP), temperature difference at 700MB between inside the eye and outside the eye (Δ T), sea surface temperature (SST) and satellite classification for the corresponding date-time (DT). At the time of maximum intensity the subtropical ridge was located near 28N with a short wave trough located along 147E and another located over China. Both troughs were moving eastward at about 10 degrees of longitude per day.

Carmen passed thru the subtropical ridge and recurved near 28N at 202300Z*. The recurvature was a result of short wave troughs creating a weakness in the subtropical ridge through which Carmen could pass.

By 220000Z* Carmen was well north of the ridge and the 220006Z satellite picture (Fig. 3-12) shows a well defined circulation still present, with a polar front lying along a SW to NE line north of Carmen. Although Carmen was still a typhoon, the intensity was decreasing at a steady rate. Especially of interest is the decrease in the SST and Δ T from the time of recurvature. Much of the decrease in Δ T is probably due to

*See Table 3-12

the entrainment of the cold air associated with the polar front.

Twenty four hours later, at 230000Z*, Carmen had moved further northward into the westerly flow and cyclonic circulation at 300MB was no longer evident (Fig. 3-13). The 230059Z satellite picture (Fig. 3-13) still shows a well defined circulation with Carmen beginning to merge with the polar front. Carmen was now of tropical storm intensity and the SST and Δ T showed further decreases.

The final warning was issued at 231100Z* and by 240000Z* the upper level circulation (Fig. 3-14) had completely dissipated. The 232358Z satellite picture (Fig. 3-14) shows Carmen has merged with the polar front and the circulation has become appreciably disorganized.

II. TYPHOON DELLA

Tropical cyclone Della (See Chapter V for best track) attained typhoon intensity at 182300Z SEP and reached its maximum intensity at 220000Z**. Table 3-13 lists applicable data as defined in above discussion of Carmen. At the time of maximum intensity Della was located immediately south of the subtropical ridge and a short wave trough was located along 120E moving eastward at about 7 degrees longitude per day (Fig. 3-12). Shortly thereafter Della moved into the ridge and recurved near 24N at 220500Z. The 220201Z satellite picture (Fig. 3-12) shows a well organized circulation with a well defined eye visible.

During the following 48 hours Della moved slowly northeastward thru the weakness in the ridge created by the eastward moving trough (Figs 3-13 & 3-14) with the intensity decreasing slowly. The 230059Z satellite picture (Fig. 3-13) shows the same intensity as the 220201Z picture (Fig. 3-12) while the 240153Z satellite picture (Fig. 3-14) shows only a slight decrease in intensity. By 240000Z** Δ T had decreased 2 degrees C and the SST had decreased 4 degrees C.

Della moved over southern Kyushu at 241100Z and her intensity decreased so rapidly, due to the lack of a heat source from the ocean, that by 250500Z**, when the final warning was issued, Della contained maximum winds of only 25 knots. The 250053Z satellite picture (Fig. 3-15) shows only a cloud blob with very little circulation present and the great decrease in intensity which occurred over the preceding 24 hours.

* See Table 3-12

** See Table 3-13

III. TYPHOON GLORIA

Tropical cyclone Gloria (See Chapter V for best track) attained typhoon intensity at 172300Z OCT and reached its maximum intensity at 182300Z***. At the time of maximum intensity the subtropical ridge was located near 24N, a series of short wave troughs were moving eastward north of the ridge and the trailing edge of a polar front was located about 360 NM north of Gloria. Gloria continued moving slightly west of north until she recurved near 23N at 200500Z.

By 220000Z*** Gloria, which was now a tropical storm, was located north of the subtropical ridge and was moving northeastward along the upper level trough line (Fig. 3-15). The 220200Z satellite picture (Fig. 3-15) shows Gloria starting to merge with the trailing edge of the polar front. The SST was now 74 degrees F, a decrease of 8 degrees F since the time of maximum intensity. Twenty four hours later, at 230000Z***, Gloria showed no high level circulation but low level circulation was still present (Fig. 3-16). The 230058Z satellite picture (Fig. 3-16) shows Gloria has merged with the polar front and a decrease in the intensity of the cloud pattern. The SST decreased 1 degree F to 73 degrees F and Δ T decreased 3 degrees C to 2 degrees C in the 24 hours previous to 230000Z.

The final warning was issued at 232300Z***, with maximum winds of 35 knots, and the corresponding satellite picture showed Gloria to be greatly disorganized and rapidly dissipating.

IV. SUMMARY

The impetus for a tropical cyclone going extratropical is usually the eastward moving troughs north of the subtropical ridge creating a weakness in the ridge thru which the cyclone passes. After passing thru the ridge many cyclones maintain their tropical characteristics for as long as 48 hours (the warm core center is still present), although the intensity usually decreases at a very rapid rate.

In two of the cases discussed great decreases in intensity occurred as the cyclones merged with polar fronts (entrainment of cold air into the cyclone) and in the other case the intensity rapidly decreased after the

*** See Table 3-14

cyclone moved over land (loss of ocean heat source). In all three cases, after the cyclone had recurved, a steady decrease in the intensity was associated with a steady decrease in the temperature of the ocean surface over which the cyclone was moving.

DT	SLP (MB)	ΔT (°C)	SST (°F)	SATELLITE CLASSIFICATION**	MAX SFC WIND (KNOTS)
190500Z	936	4	82	STG X DIA 6 CAT 4	110
202300Z	952	4	81	STG X DIA 4 CAT 3	90
220000Z	962	2	78	STG X DIA 4 CAT 2	65
230000Z	974	1	74	STG X DIA 4 CAT 2	55
231100Z	980	0	72	NONE	45
240000Z	---	-	70	NONE	--

** See Project FAMOS Research Report (4-67) titled "GUIDE FOR INTERPRETATION OF SATELLITE PHOTOGRAPHY AND NEPHANALYSES".

TABLE 3-12 - TYPHOON CARMEN

DT	SLP (MB)	ΔT (°C)	SST (°F)	SATELLITE CLASSIFICATION**	MAX SFC WIND (KNOTS)
220000Z	930	8	83	STG X DIA 5 CAT 4	120
230000Z	939	7	81	STG X DIA 5 CAT 4	110
240000Z	950	6	79	STG X DIA 4 CAT 3	90
250500Z	1000+	-	--	NONE	25

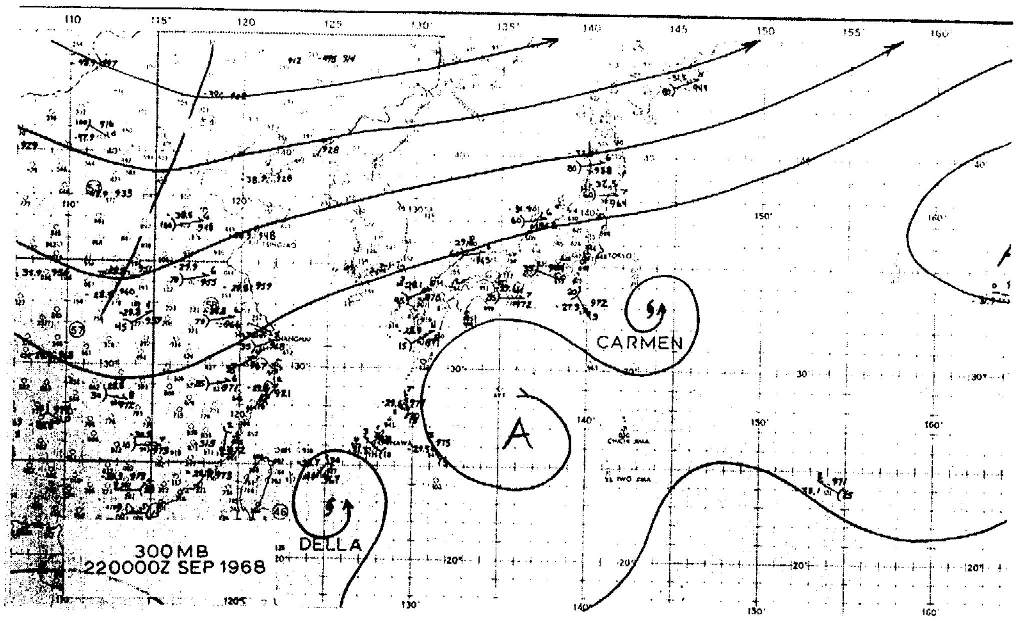
** See Project FAMOS Research Report (4-67)

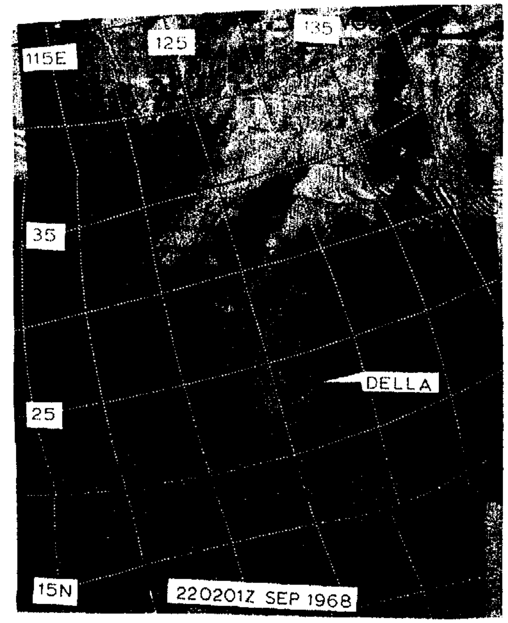
TABLE 3-13 - TYPHOON DELLA

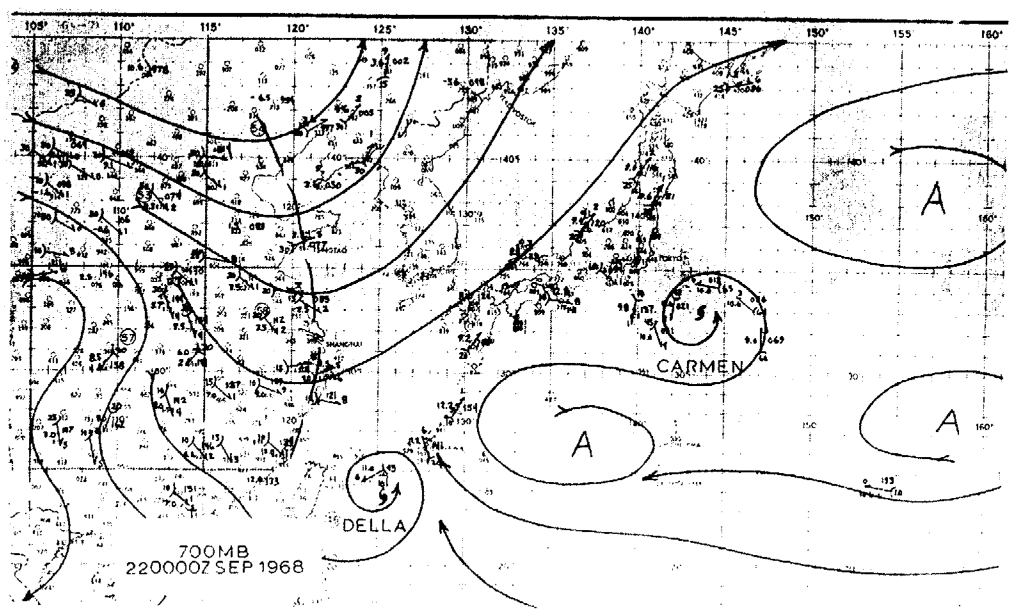
DT	SLP (MB)	Δ T (°C)	SST (°F)	SATELLITE CLASSIFICATION**	MAX SFC WIND (KNOTS)
182300Z	960	6	82	STG X DIA 5 CAT 3	90
220000Z	968	5	74	STG C	50
230000Z	977	2	73	STG C	45
232300Z	987	2	73	NONE	30

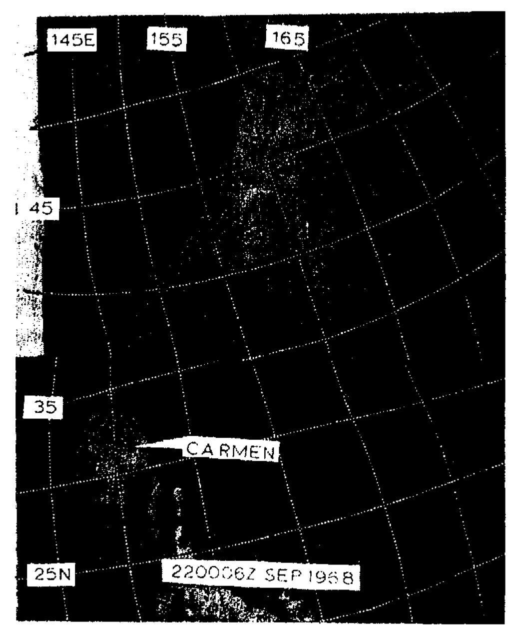
** See Project FAMOS Research Report (4-67)

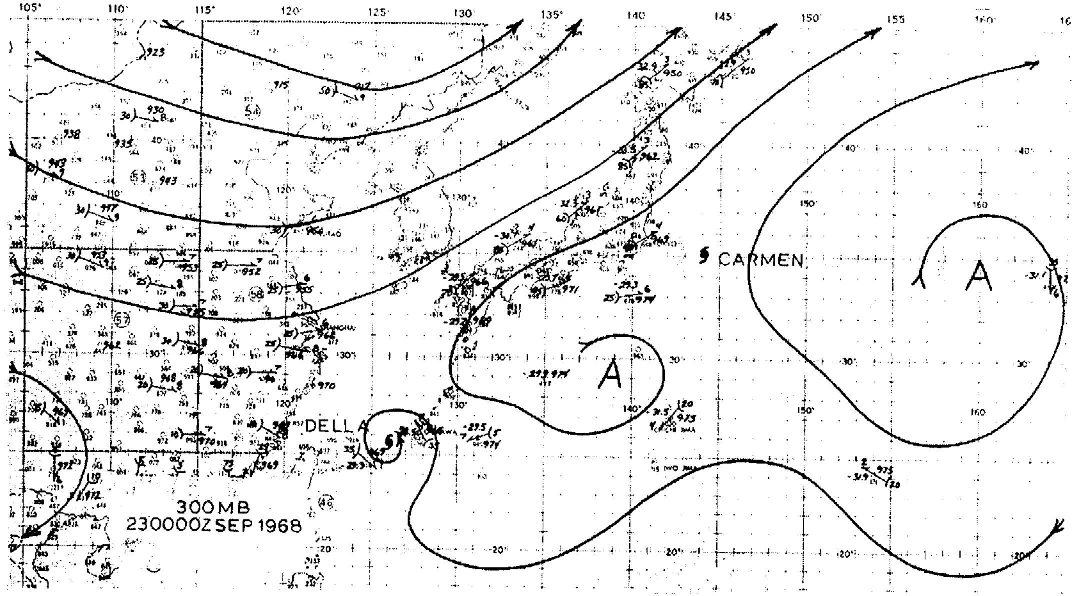
TABLE 3-14 - TYPHOON GLORIA

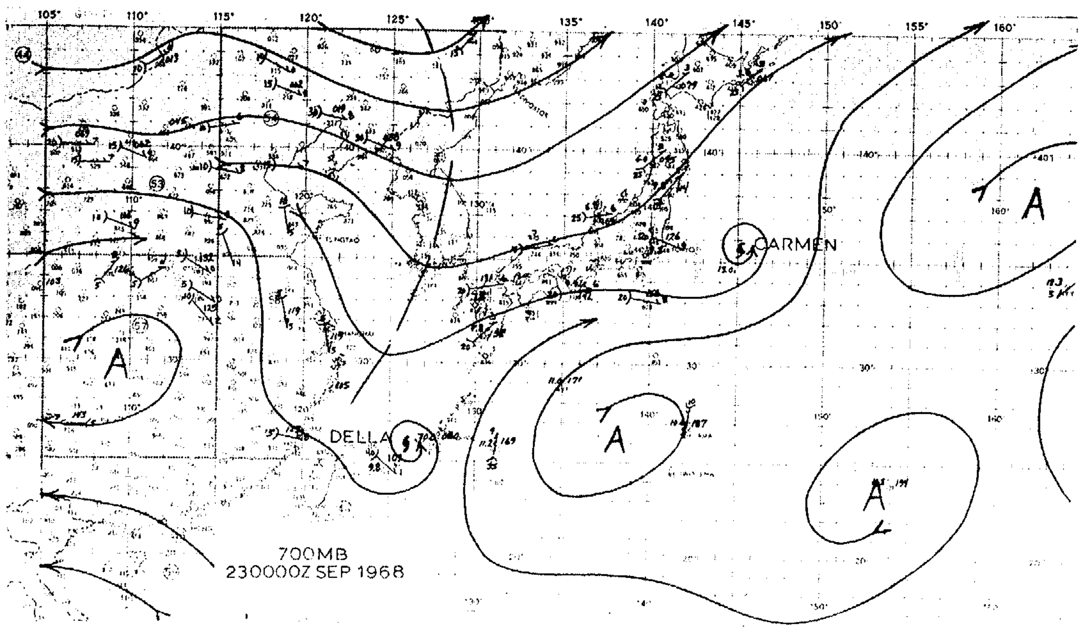

CARMEN
A
DELLA
300MB
220000Z SEP 1968

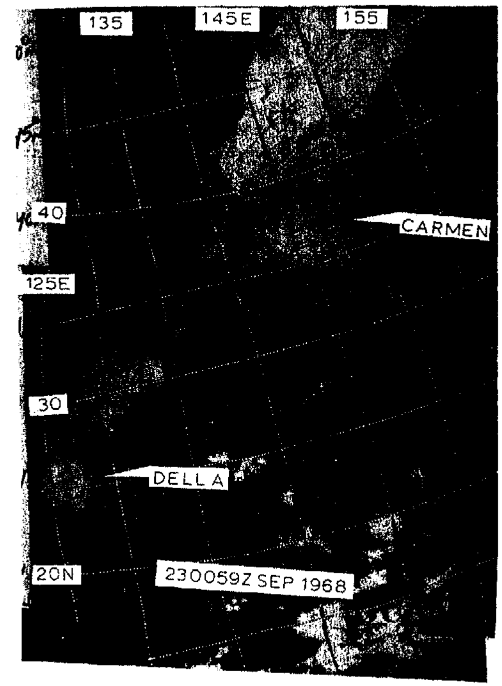

115E
125
135
35
25
15N
DELLA
220201Z SEP 1968

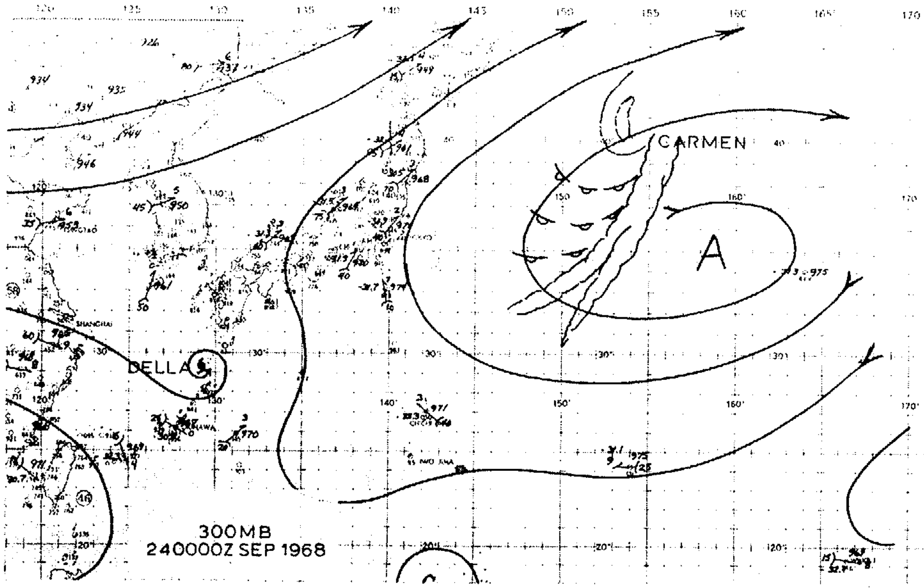

A
CARMEN
A
A
DELLA
700MB
220000Z SEP 1968

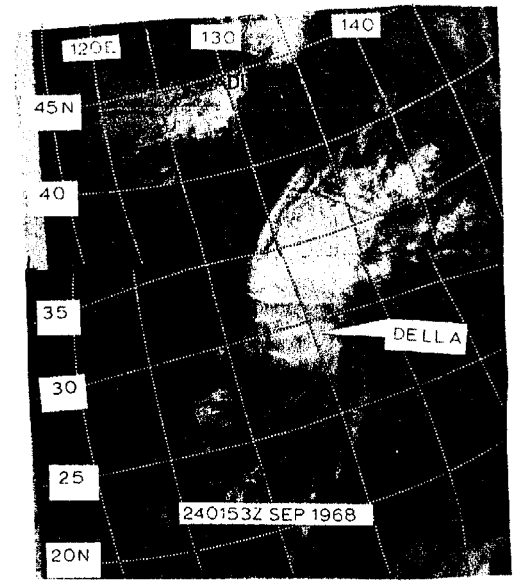

145E
155
165
45
35
CARMEN
25N

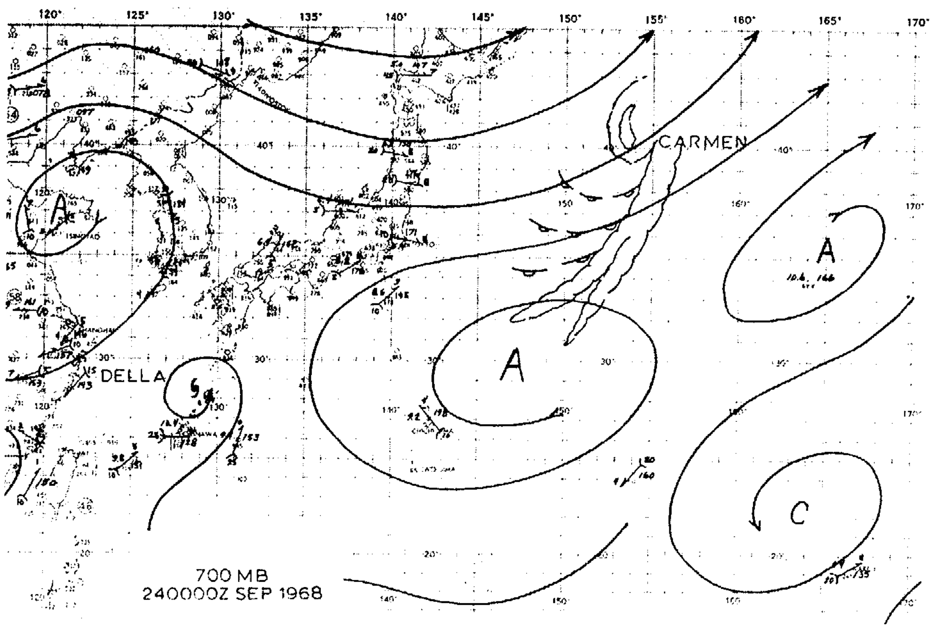

CARMEN
DELLA
300MB
230000Z SEP 1968

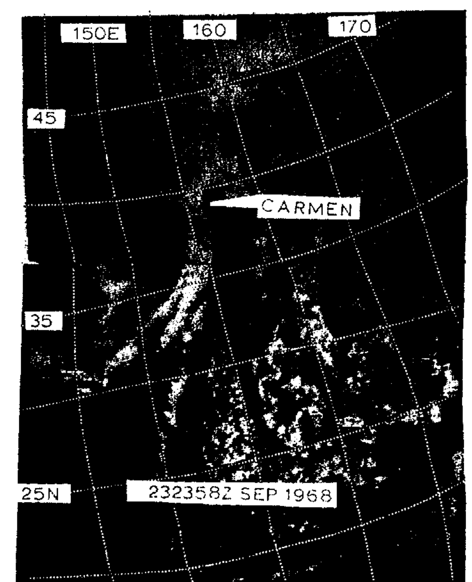

CARMEN
DELLA
700MB
230000Z SEP 1968

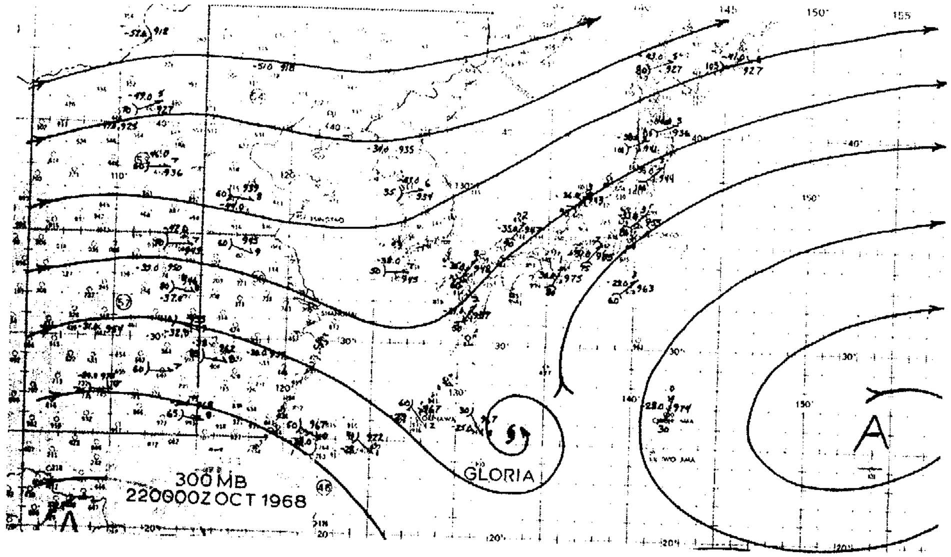

135
145E
155
40
CARMEN
125E
30
DELLA
20N
230059Z SEP 1968

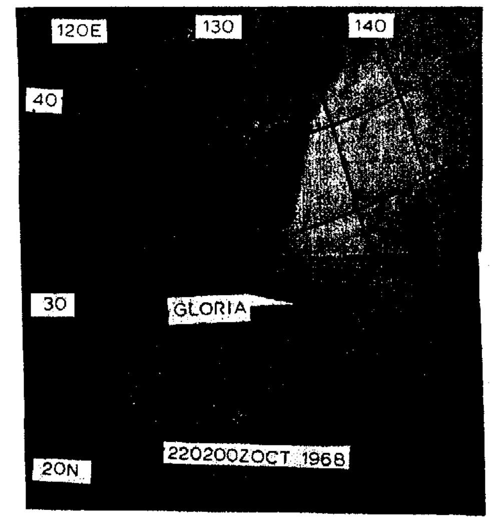

CARMEN
A
DELLA
300MB
240000Z SEP 1968

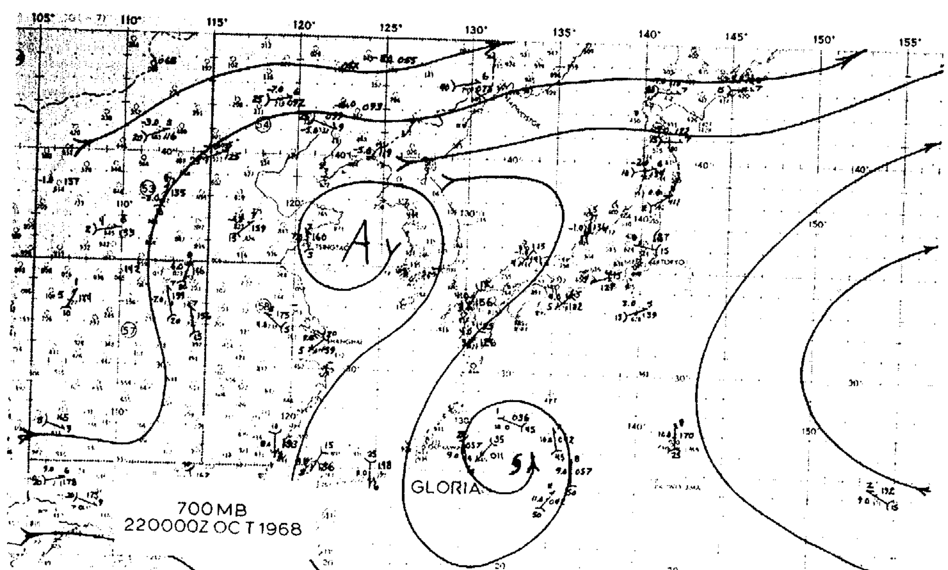

120E
130
140
45N
40
35
30
25
20N
DELLA
240153Z SEP 1968

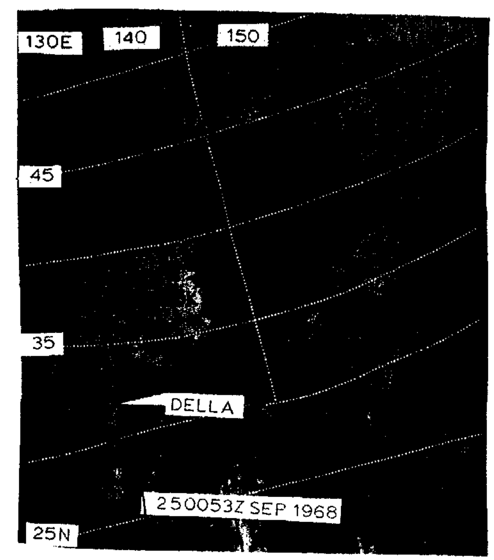

120°
125°
130°
135°
140°
145°
150°
155°
160°
165°
170°
CARMEN
A
A
A
C
DELLA
700 MB
240000Z SEP 1968

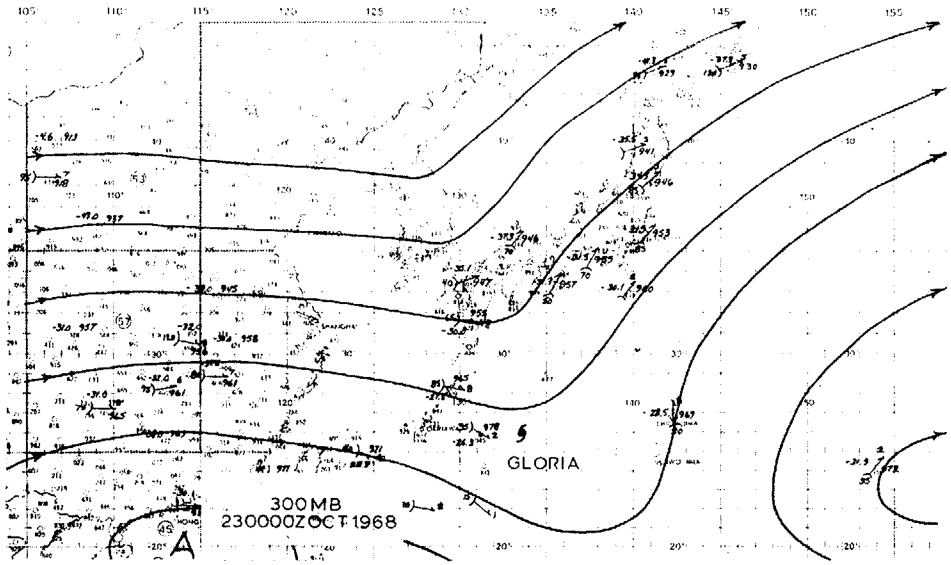

150E
160
170
45
35
25N
CARMEN
232358Z SEP 1968

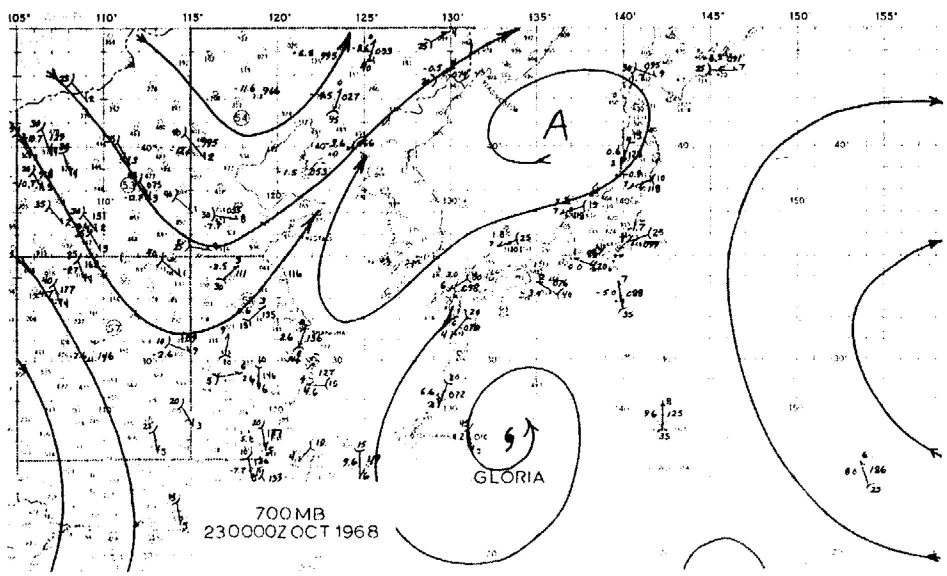

300 MB
220000Z OCT 1968
GLORIA
A

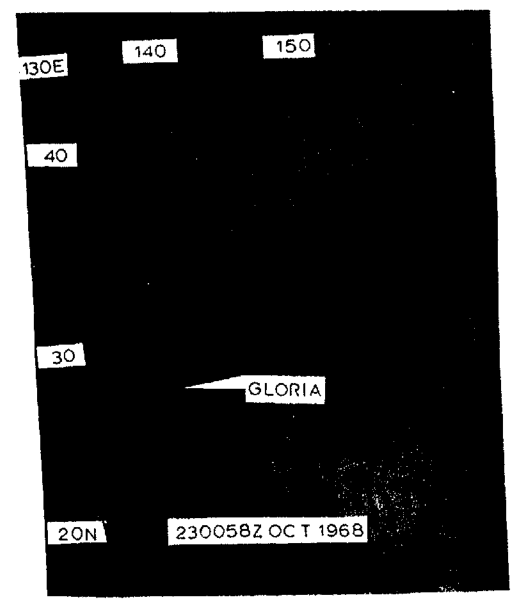

120E
130
140
40
30
GLORIA
20N
220200Z OCT 1968


700 MB
220000Z OCT 1968
GLORIA
A


130E
140
150
45
35
DELLA
25N
250053Z SEP 1968


GLORIA
300 MB
230000Z OCT 1968


105°
110°
115°
120°
125°
130°
135°
140°
145°
150°
155°
GLORIA
700 MB
230000Z OCT 1968


130E
140
150
40
30
GLORIA
20N
230058Z OCT 1968

G. Error Distribution in JTWC Official Forecasts

1. Background

The mean JTWC error is an overly simple description of error from an operational point of view. This study was made as a preliminary to making further improvements in individual and average forecasts and forms a basis for describing probable error in a statistical and graphical fashion.

2. Approach

Stratification of forecasts by time showed that the first two forecasts issued on the 20 typhoons of 1968 verified with an average error of 153NM compared with the overall average of 105NM. The initial forecasts thus contribute disproportionately to the mean error and must be accorded a lower level of confidence. Stratification by wind velocity at the time of verification shows increasing skill with higher wind velocities. Winds verifying 50 knots or under recorded an error of 143NM while those over 50 knots verified at 106NM. While it is difficult to separate the contribution of initial forecasts from that of lower wind velocities, it is evident that the motion of more intense storms is more predictable.

Stratification by direction of movement showed best accuracy (110NM) between directions of 260 and 360 degrees and a 20 to 25NM increase in error over the remainder of the compass. This indicates a lower ability to forecast unusual directions of motion. The largest error (139NM) was found in the northeast movers and the second largest in southwest movers.

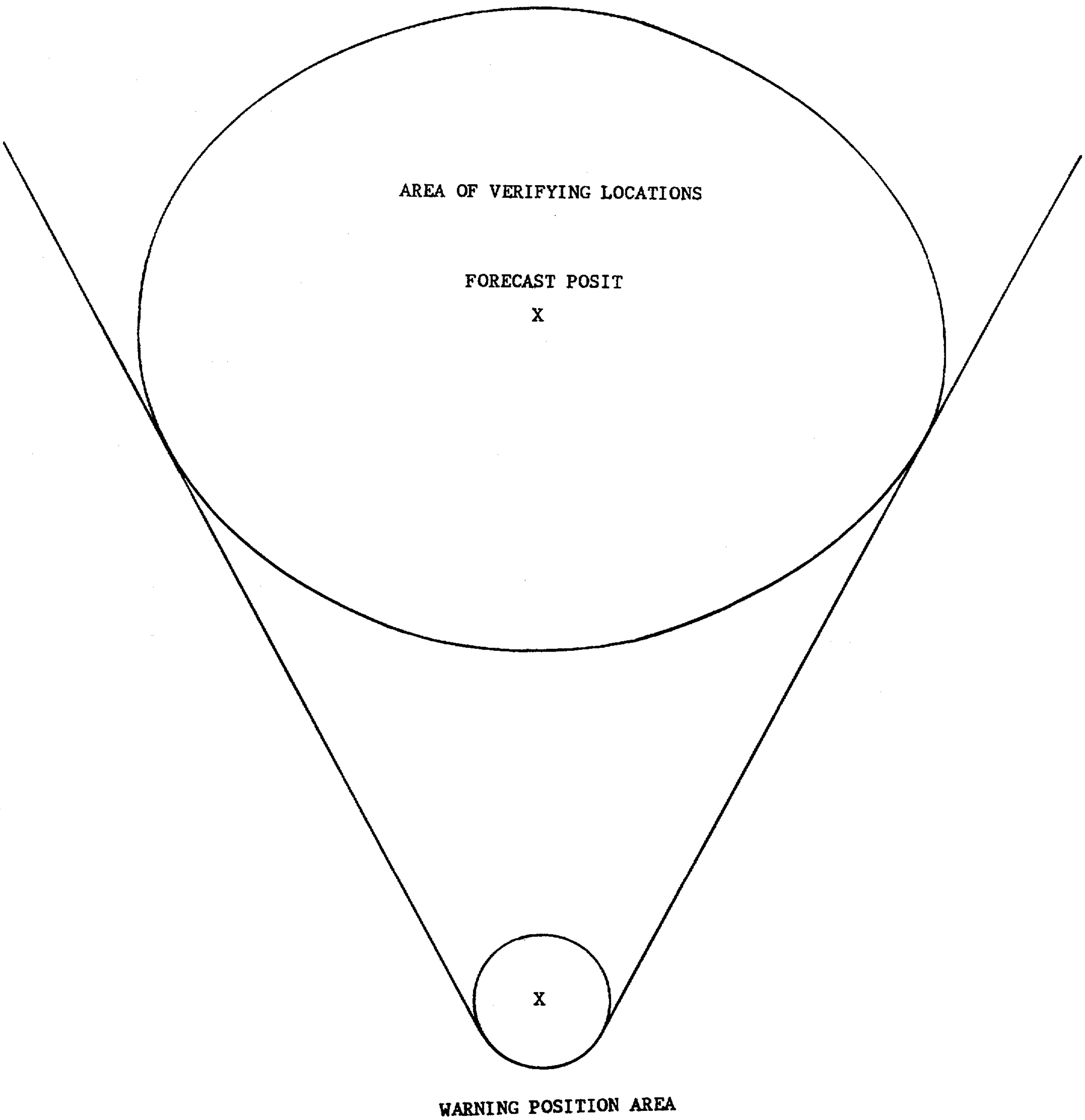
Stratification by intervals of the absolute verification error shows the modal error under 100NM for 24 hours. A relatively small number of forecasts verifying with large errors contribute a disproportionate amount of the mean error and probably have an adverse affect on user confidence in the system. One of the operational efforts in 1969 will be to anticipate and identify forecasts with large potential error. If this can be done successfully on the few difficult forecasts, the level of confidence on the remaining forecasts will be increased.

A graphic approach to official JTWC error was attempted by plotting the verified 24 hour error on a maneuvering board. It was observed that JTWC forecasts are slightly fast 62% of the time and the shape of the error distribution approximates an ellipse whose long axis is perpendicular to the typhoon track and has a ratio with the short axis of 4 to 3. The dimensions of the ellipse yielding an average error of 105NM are 94 X 118NM.

A study of right angle error shows that the ratio of error along the track to error at right angles to the track is 3 to 4 at 48 hours and 72 hours as well as at 24 hours over the last five year period. This indicates stability with time of the shape of the error pattern.

The rate of expansion of this pattern is a constant in relation to distance travelled. The mean track angle error in 1968 was 14 degrees. Over the past 5 years this error has been 18 degrees.

Use of these observations leads to construction of the probable area of verification (figure 3-17). It can be seen that this shape does not lend itself readily to description in terms of forecasting an area of probable storm location, nor does it include the extended area of storm or typhoon force winds extending outward from the center.


AREA OF VERIFYING LOCATIONS
FORECAST POSIT
X
X
WARNING POSITION AREA