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U.S. AIR FORCES, AIR WEATHER SERVICE, WASH., D.C. (AIR WEATHER SERVICE TECHNICAL REPORT NO. 105-43)

REPORT ON THE TYPHOON POST ANALYSIS PROGRAM (1948-1949) OF THE NORTH PACIFIC TYPHOON WARNING SERVICE - AND APPENDIXES I AND II

AUG '51 62PP DIAGRS, GRAPHS, MAPS

WEATHER - FORECASTING
TYPHOONS
METEOROLOGIC DATA - NORTH PACIFIC

METEOROLOGY (30)
PRACTICAL METEOROLOGY (1)

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AIR WEATHER SERVICE
TECHNICAL REPORT NO. 105-43

REPORT ON THE TYPHOON POST-ANALYSIS PROGRAM (1948 - 1949) OF THE NORTH PACIFIC TYPHOON WARNING SERVICE

AIR WEATHER
TECHNICAL RESEARCH
OCT 9 1951

AUGUST 1951

HEADQUARTERS
AIR WEATHER SERVICE
WASHINGTON 25, D.C.

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August 1951

Air Weather Service Technical Report No. 105-43, "Typhoon Post-Analysis Program, (1948 and 1949)," is published for the information and guidance of all concerned.

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P R E F A C E

This report has been prepared at Headquarters, Air Weather Service, on the basis of data submitted in the Annual Reports of the Typhoon Post-Analysis Board for 1948 and 1949. The report consists primarily of excerpts from the two unpublished manuscripts. Some editing, reorganization and condensation has been done in an attempt to present the technical findings of the board in as clear and simple a manner as possible.

The major deletion has been the removal of Part I ("Theoretical Aspects" of the 1949 report), which presented a method of forecasting typhoons by means of a modified version of the streamline-analysis technique of Palmer and others; it is available intact as AWS Technical Report No. 105-78.

Hq., AWS
August 1951

I. INTRODUCTION

1. Organization of Post Analysis Board. */

During 1948, great strides were made in the operational reorganization of the Typhoon Warning Center on Guam. Due to the rapidly increasing demands for warning service made upon the facilities of the Center, it had been determined late in 1947 that a complete overhaul of operational proceedures would be necessary to enable the Center to carry out its mission properly; however, a continuing shortage of qualified personnel delayed the realization of this objective until the early fall of 1948 when the Typhoon Warning Section of the Central came into being as a separate unit.

Until that time, warning operations had been superimposed upon an already over burdened Upper Air Analysis Section with a resultant drop in efficiency of both operations. A single forecaster had been assigned the duty of Post-analysis of all 1948 tropical cyclones and the writing of their individual histories. With the organization of the Typhoon Warning Section, however, the forecast, briefing, and post-analysis operations were separated completely from the Upper-Air Analysis Section and were combined into a single unit. Four forecasters were then assigned to permanent duty with the Section to carry on all typhoon-warning and post-analysis operations. Each function of the organization was then scrutinized closely for weaknesses, and procedures were streamlined at all points to obtain maximum efficiency and flexibility.

The mission of the Board is the post-analysis and detailed study of each North Pacific tropical cyclone in the light of all available data received from various sources both before and after the cyclone has dissipated. The results of this study are then incorporated into an individual history of each disturbance, which, in turn, is consolidated into a composite annual history and compilation of pertinent data. Although research and special projects are adjuncts of the Post-Analysis Board, no comprehensive attempt at research, beyond the scope of this Report, has yet been attempted due to the relatively short period of forecasting experience of the individual Board members and the lack of specialized meteorologists with the required research background.

The eyes of the Typhoon Warning Service are the reconnaissance aircraft of the 514th Weather Reconnaissance Squadron (VLR) based on Guam. Without the services of this organization to draw upon, the problem of accurately forecasting the movement of tropical cyclones over vast areas of open ocean, with the attendant lack of data, would be virtually impossible. Although no method has yet been devised to dissipate the destructive forces of tropical cyclones, with the aid of long-range

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*/ For background on the post-analysis program see AWS Technical Reports 105-37 and 105-42.

aerial reconnaissance, adequate early warning can now be given to minimize the loss of life and property.

A most important phase of 1948 Typhoon Warning Operations was establishment of much closer coordination of efforts between Harmon and Fleet Weather Centrals. All information that could conceivably improve typhoon forecasts, such as late ship data or reconnaissance reports, and bulletin forecasts were jointly coordinated prior to release. This degree of cooperation tended, in large measure, to allay natural fears and add to a sense of greater security among the various local commands and the native population of Guam when a tropical cyclone was approaching the Marianas. Joint forecasts wereissued every few hours over the local Armed Forces Network radio station during such periods.

Similarly, during 1948, a greater appreciation of mutual operational problems was effected between the Weather Central and the 514th Weather Reconnaissance Squadron. It is felt that the addition of rated Weather Officers to the Central's staff during the year was an important factor in effecting this change since they were better qualified to evaluate the operational limitations of the B-29's with which the 514th Squadron was equipped. Conversely, an earnest effort was made on the part of both organizations to familiarize 514th Squadron personnel with the problems affecting the Central. The success of these efforts is readily apparent in the fine degree of coordination now existing.

On 1 February 1949, the Weather Central, including the Typhoon Warning Section, was moved from Harmon Air Force Base to North Guam Air Force Base. There is little reason to doubt that this move resulted in even greater Typhoon Warning efficiency during 1949 than was possible during 1948, due primarily to the closer contact of Weather Central personnel with those of the 514th Squadron and allied facilities. The elimination of several serious communications difficulties encountered while the Central was at Harmon Air Force Base also served to improve the Warning Service.

2. <u>North Pacific Typhoon Warning Service</u>.

The North Pacific Typhoon Warning Service has responsibility for the proper dissemination of typhoon warnings to all agencies designated to receive them in the North Pacific area. The Warning Service is composed of weather units of the 2143rd Weather Wing, Tokyo, Japan. It is divided into three component parts:

(1) The Typhoon Warning Network,

(2) The Typhoon Post-Analysis Board and

(3) The 514th Weather Reconnaissance Squadron.

The network is a closely integrated group of six weather stations of which North Guam Weather Central is the Typhoon Warning Center. Radiating out from it, like spokes of a wheel, are the radio and teletype lines of communications to the five Sub-Centers, each of which is, in itself, the focal point of a minor network of reporting units known as the Field Stations. The Sub-Centers are located in an arc around Guam at the following strategic points:

(1) Clark Air Force Base, Luzon, Philippine Islands;

(2) Kadena Air Force Base, Okinawa;

(3) Lunghwa Weather Detachment, Shanghai, China;

(4) Haneda Air Force Base, Tokyo, Japan; and

(5) Hickam Air Force Base, Oahu, Territory of Hawaii.

In order to appreciate fully the tremendous area over which the B-29 aircraft of the 514th Squadron operate during typhoon tracking operations and for which the Typhoon Warning Service has forecast responsibility, reference should be made to the chart on the following page. If an outline map of the United States, drawn to scale, were superimposed on a map of the North Pacific with Guam placed in the geographical center of the United States, Clark Air Force Base (Manila) would lie about 200 miles west of San Francisco while Okinawa would fall over Vancouver. To the east, Kwajalein Atoll would lie near Bermuda, Wake Island would lie over Portland, Maine, and Hickam Air Force Base, Hawaii, would be in the vicinity of the Azores. To the north, Iwo Jima would be near Winnepeg, Canada, and Haneda Air Force Base, Tokyo, would be located still farther north, in the Canadian Northwest.

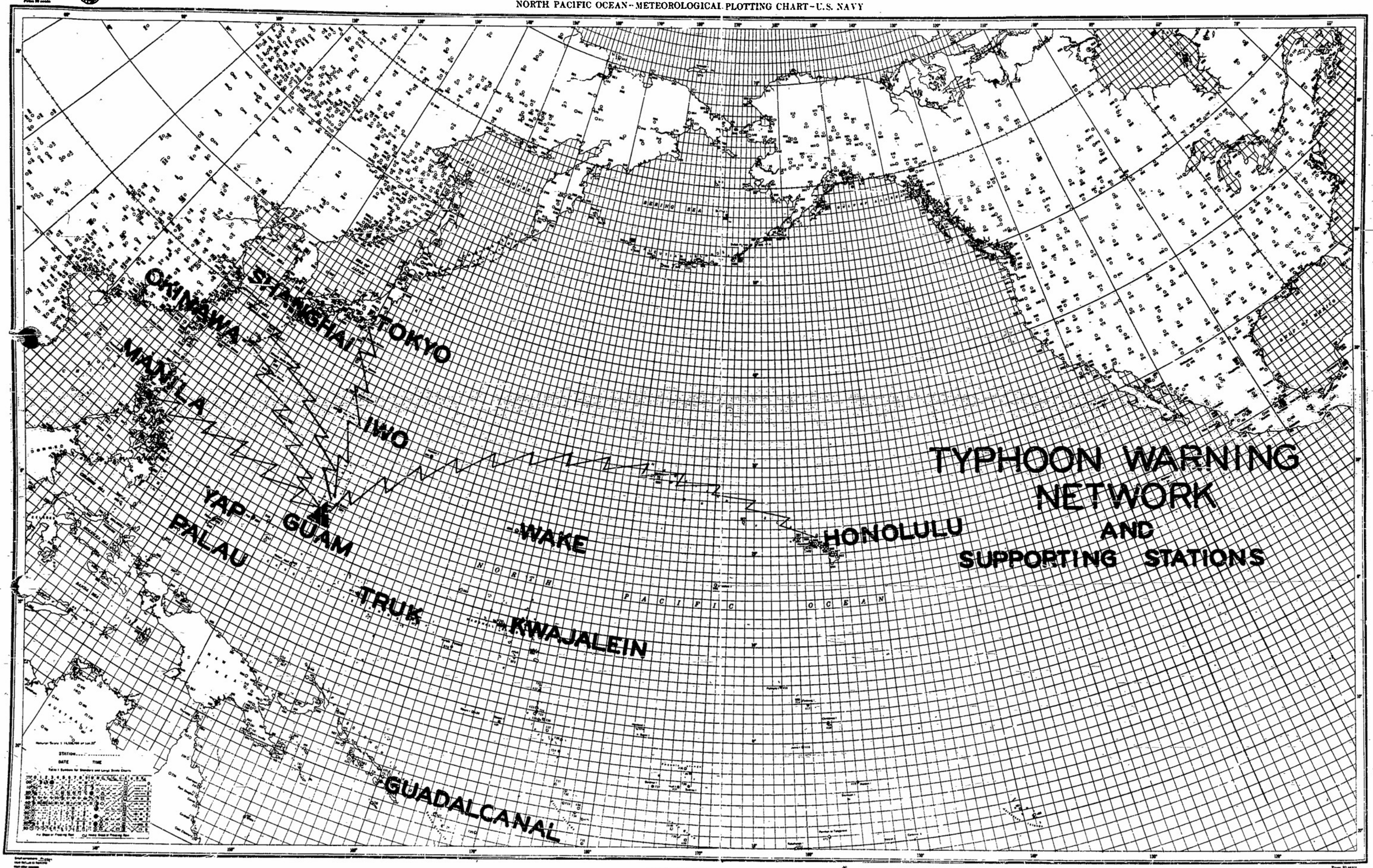
II. SUMMARY OF DATA.

3. Sources of Data.

Numerous books and articles have been written on the subject of typhoons and hurricanes, the majority of which have been based on information gained from regions provided with a rather close-knit weather reporting network. Forecasting of hurricanes in the Caribbean area, where the number of reporting stations is relatively large, has shown that present day forecasting rules and techniques, applicable to tropical cyclones, leave much to be desired. This is especially true in the Pacific where reporting stations are thousands of miles apart. The Western North Pacific encompasses an area of great magnitude.

No. 5556

NORTH PACIFIC OCEAN—METEOROLOGICAL PLOTTING CHART—U.S. NAVY



No 5556

With this vast domain, the breeding ground of typhoons, are located eight island stations from which the Center regularly receives surface and rawinsonde reports. These few reports are supplemented by ship reports and aircraft in-flight data, the accuracy of which is often somewhat questionable.

One of the primary purposes of this Report is to place on record the knowledge gained during 1948 and 1949 typhoon warning operations in the Western North Pacific and to emphasize the need for additional reporting stations at strategic points throughout the Western North Pacific. Points brought out in the following discussion are the results of empirical observations rather than theoretical applications. A higher level of experience and the anticipated addition of personnel with research backgrounds promises to make subsequent annual Reports far more comprehensive.

4. Classification of Tropical Cyclones.

There are only two areas in the world where intense tropical cyclones are known as typhoons. Those areas are the Western North Pacific and the South China Sea. Since tropical cyclones occur in varying degrees of intensity, it is necessary to classify them accordingly. In the following descriptive classifications, it is not to be construed that every tropical cyclone will fall unerringly into one of the three patterns. Rather, it should be kept in mind that the pictures presented are idealized ones and bear the most often observed characteristics of the storms in each category.

a. Tropical Depression.

A tropical depression is, in reality, a tropical storm or typhoon in its early stages. It is defined as a tropical cyclonic circulation of winds with maximum velocity of 27 knots or less. On a surface chart it appears as one or more closed isobars. It is most often characterized by a large, loose, often ill-defined, center surrounded by considerable cumulus and cumulonimbus activity interspersed with varying decks of moderately thick altostratus and capped with a sheet of cirrostratus clouds which extend out some distance from the center. Sea conditions are light to moderate associated with general squalliness throughout the area except near the center where light continuous rain is found. Except in the vicinity of cumulonimbus activity, flying conditions will be characterized by only light turbulence with visibility reduced by cloud decks.

b. Tropical Storm.

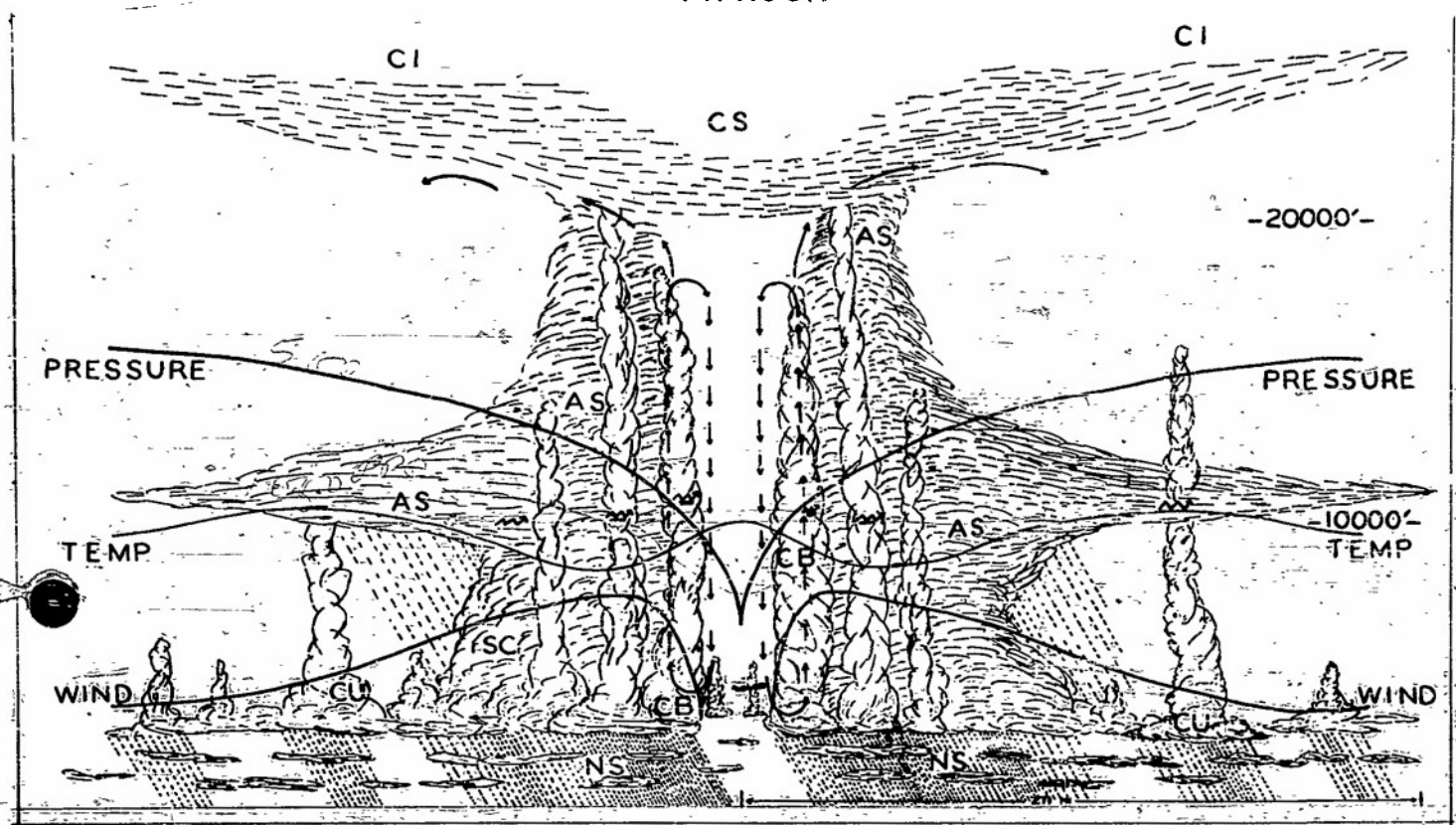
A tropical storm is best defined as a tropical cyclonic circulation of winds with maximum velocity randing between 28 and 64

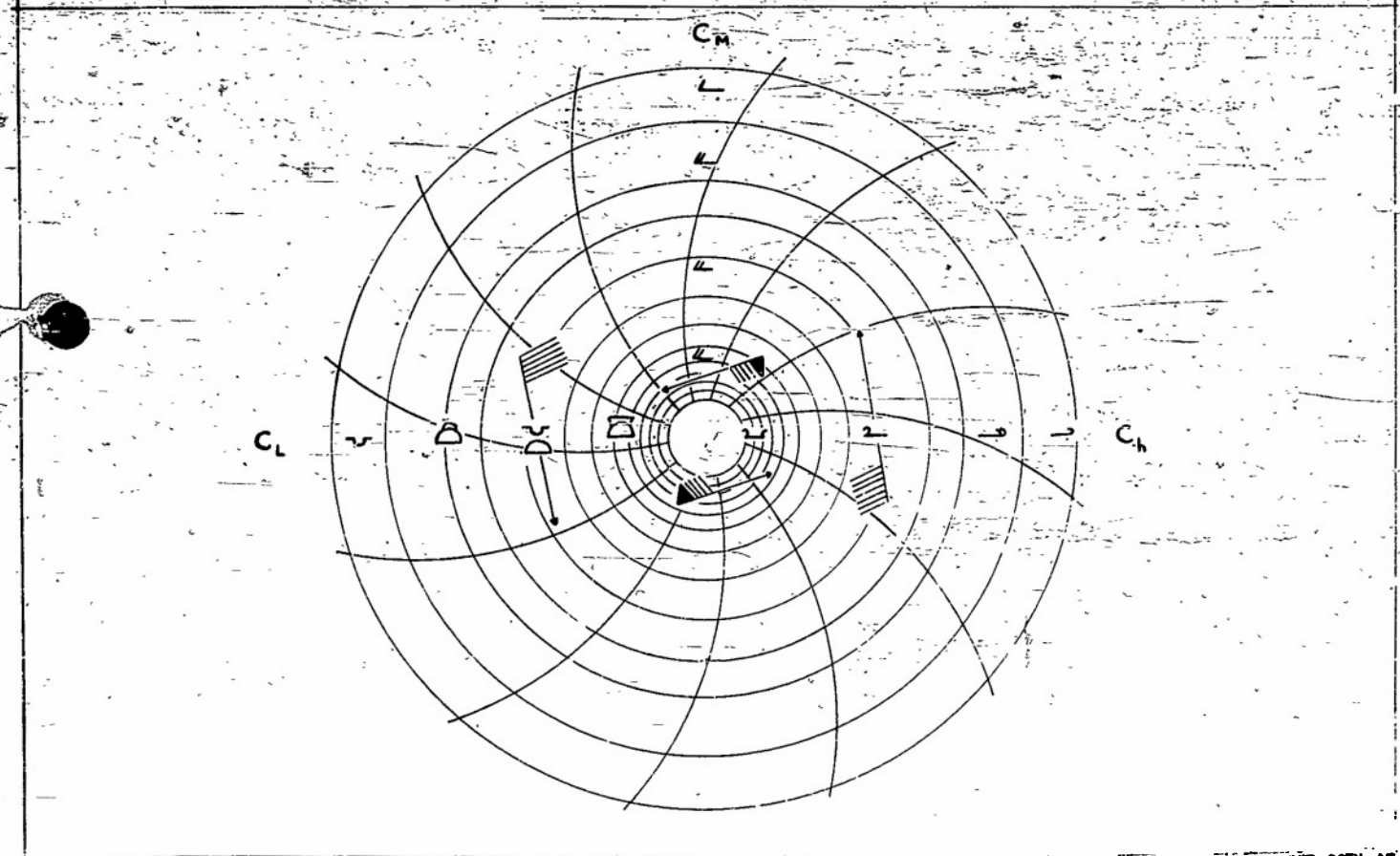
knots. It is characterized by two or more closed isobars with greater symmetry than those of the tropical depression. It has a fairly well defined center surrounded by decreasing heavy cumulus and cumulonimbus activity imbedded in decks of thick altostratus capped with cirrostratus. There are moderate to heavy bands of precipitation around the outer portions of the storm. The areas between the bands are relatively free of rain and the visibility is better. The band of weather immediately surrounding the center is moderately turbulent depending upon the degree of cumulonimbus activity and heavy continuous rain is typical of the area. Flying conditions are not considered particularly hazardous, although turbulence is moderate in the bands of heavy rain oriented around the storm's circulation and visibility is mostly obscured by clouds except in fairly open areas between the rand bands and between decks of altostratus. The sea is characterized by moderate to heavy swells of greater than normal length. Much foam and spray give evidence of the effect of the strong winds on the surface.

c. Typhoon.

A typhoon is a tropical cyclonic circulation of winds with intensities of 64 knots or greater. It usually has a well-defined center, or "eye"; an area of light variable winds and generally either open to the sky or capped by a thin veil of cirrostratus. Surrounding the typhoon in a radius of 250 miles to as much as 500 miles, are cloud formations of varied descriptions. Starting from the outer edges, a thin overcast of high cirrostratus is encountered, and, as the center of the typhoon is approached, low scud is encountered under thickening layered decks of altostratus. Embedded in the altostratus are scattered cumulonimbus in varying degrees dependent upon horizontal wind shear and the energy present in the typhoon. Inside the comparatively open area of the eye, are found scattered scud clouds near the surface. On the following page, the chart depicting the idealized structure of a typhoon shows lines of weather radiating out from the center of the storm like the streamers from a pinwheel (see lower figure). It is thought that the bands of rain and turbulence about the typhoon are, in reality, lines of convergence, with built-up cumulus and cumulonimbus, very heavy rain, and moderate to severe turbulence along the length of the line. This conception appears to be borne out by the cloud configuration about a typhoon as photographed on a radar scope.

VERTICAL CROSS-SECTION TYPICAL TYPHOON





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The state of the sea in the typhoon area also indicates the tremendous forces in play there. The ocean is sometimes churned into giant waves 40 to 50 feet high, wave crests are blown off in flying sheets of foam to form long streamers over the heavy typhoon swell. These swells, of unusally long wave length, extend out from the center as far as 1,000 miles in a severe typhoon and are one of the most reliable indications of the presence of the storm.

5. The Danger Period.

There is no such thing as a "normal" typhoon season. Averages can be obtained for the characteristics of typhoons observed over a period of years, but any individual typhoon may vary greatly from such an average. For example, the typical life cycle of a tropical storm as described in the literature is well known: A depression forms somewhere in the easterlies, moves west-northwest while intensifying into a tropical storm or typhoon, encounters a westerly trough, decelerates, recurves and moves off to the northeast accelerating and losing intensity. This is the "average" or "typical" picture of a typhoon, and yet only two tropical cyclones, Patricia and Allyn out of the twenty occurring during the 1949 season behaved in such a fashion. All the others followed tracks with almost every variation possible, including inverse recurvature, double curvature, and loops. Still, some attempt should be made to define a central tendency in order to provide a basis for comparison. It should be remembered that averages must always be taken with a grain of salt, and this is particularly true where typhoons are concerned.

During the period that the Typhoon Warning Center is issuing bulletins on a tropical cyclone, the usual series of events is to issue warnings on all three stages of development, the length of time in each phase being dependent upon the rapidity with which the cyclone reaches typhoon proportions. All tropical cyclones that reach typhoon intensity begin as tropical depressions, develop to storm intensity, and eventually emerge as typhoons. Once the air in which the typhoon is imbedded loses its energy potential, dissipation, in the reverse order, takes place. The final stage is the acquisition of extratropical characteristics, or rapid and complete dissipation.

Because of the erratic nature of tropical cyclones, few adhere strictly to the systematic progression outlined above. The number of times that a tropical cyclone can vary between storm and typhoon intensity is apparently unlimited. This variation is practically impossible to detect over open ocean areas and can be determined definitely only by information gathered from frequent reconnaissance missions.

6. Typhoon Statistics.

During the period 11 January 1948 through 12 December 1949, the Typhoon Warning Center issued Bulletins on a total of 43 storms

(25 in 1948 and 18 in 1949). Thirty of these storms reached full typhoon intensity. The most destructive storms of the period were Libby in 1948, and Della, Gloria, Judith, Kitty, and Allyn in 1949. Consolidated summaries of meteorological data on these storms is presented in table form on the following pages. A more detailed analysis of the reasons for formation and recurvature is given in the next section. The Appendix to this report contains a series of maps by months showing the storm track and relative intensity of tropical cyclones during the period 1945 through 1949.

III. ANALYSIS OF DATA.

7. Seasonal Distribution.

The table on page 13 shows the average number of tropical cyclones occurring in the North Pacific Ocean each month. Two groups of data are shown: historical data for 1905-1937 and more current data for the years 1945-1949 inclusive. While there are certain differences, the two graphs have the same general features, in that both show the same seasonal fluctuation of cyclone activity, February being the month of minimum frequency and September the maximum. It also appears conclusive that the seasonal distribution of tropical cyclones is apparently governed, primarily, by the latitudinal shift of the Intertropical Front. During January, February, March and April, when the mean position of the Front is near, or south of the Equator, the frequency of tropical cyclones, in the North Pacific, is at a minimum, averaging less than one per month. During subsequent months, as the mean position of the Front moves northward, their frequency increases gradually until an average monthly maximum of 4.2 to 4.8 cyclones is reached during the month od September.

It is interesting to note that, while both graphs appear much the same in the overall picture, the respective monthly averages vary considerably. The 32-year average shows January, February, March, and April to have a greater frequency of cyclones than the corresponding months for the last four years. July and December also show a greater frequency but of lesser magnitude. Since the first four months just mentioned represent that time of year when mid-latitude storms occur farthest south, it is felt that this difference may be attributed to the fact that the lack of organized reconnaissance prior to 1945 may have resulted in warnings being issued on disturbances that were actually wave formations or shear lines, and not tropical cyclones as we know them today. Conversely, the recent four year average shows May, June, August, September, October, and November to have a greater frequency of cyclones than the corresponding months in the 32-year average. These increased frequencies during the months of the normal typhoon season are felt to be more reliable than previously used averages, as present-day reconnaissance makes possible the detection of a great number of storms which might have otherwise gone unnoticed.

	KAREN	LANA	MABEL	NADINE	OPHELIA	PEARL	ROSE	ANNABELL	BERTHA	CHRIS	DOLORES EUNICE	FLO	GERTRUDE	HAZEL	IONE	JACKIE	KIT	LIBBY	MARTHA	NORMA	OLGA	PAT	RITA	AGNES	BEVERLY
Date of initial detection	11 Jan	16 May	27 May	9 Jun	9 Jun	1 Jul	23 Jul	*	4 Aug	8 Aug	10 Aug	20 Aug	26 Aug	1 Sept	9 Sept.	10 Sept	20 Sept	27 Sept	2 Oct	11 Oct	11 Oct	25 Oct	2 Nov	11 Nov	1 Dec
Days duration as Tropical Cyclone	9	5	7	2	3	7	4		3	4	4	2	9	7	9	9	8	11	6	2	9	6	11	10	9
Days duration as Typhoon	6	4	3	0	0	5			1	0	0	0	3	4	4	6	0	7	4	0	0	0	3	5	6
Formation																									
Intensification of easterly wave on ITC caused by SW monsoon surge					X	X					X		X				X	X			X **			X	
Intensification of easterly wave on ITC caused by westerly trough				X										X											
Intensification of Easterly wave on ITC caused by a trough in the easterly flow induced by a westerly trough	X		X													X							X		X
Intensification of easterly wave on ITC caused by North Indian Westerlies							X					X													
Formation and intensification of low pressure area at base of westerly trough in vicinity of ITC		X							X	X					X				X	X		X			
Location of development	7.2 N 146.8 E	9.0 N 137.0 E	9.0 N 137.0 E	16.0 N 138.0 E	21.0 N 114.0 E	11.2 N 144.6 E	12.3 N 130.2 E		28.5 N 135.5 E	20.8 N 143.2 E	18.0 N 155.0 E	18.5 N 118.0 E	15.0 N 139.0 E	12.0 N 137.0 E	13.0 N 155.0 E	17.0 N 137.0 E	9.0 N 140.0 E	14.0 N 152.0 E	21.0 N 158.0 E	23.2 N 143.5 E	15.0 N 132.5 E	15.0 N 155.0 E	12.0 N 143.0 E	11.0 N 135.0 E	6.5 N 153.0 E
Maximum Winds (kts)	130	80	80	60	40	90	75		70	50	40	40	85	80	100	80	60	120	100	35	50	50	100	95	90
Maximum winds before recurvature (kts)	80		70			90				50	40	40	85	60	100	80	60	120	95	35	50	50	100	80	90
Maximum winds during recurvature (kts)	130		80			85								80	100			90	55	35		50		95	
Maximum winds after recurvature (kts)	100		60			75								60	100			75	100	35		50		60	
Point of recurvature	12.5 N 134.0 E		16.8 N 129.4 E			28.0 N 121.0 E								24.5 N 122.0 E	30.4 N 136.3 E			26.3 N 127.7 E	27.0 N 146.4 E	24.5 N 142.0 E		25.0 N 138.5 E		26.0 N 136.7 E	
Reason for recurvature																									
Recurved in advance of westerly trough	X													X				X				X		X	
Recurved into westerly trough			X			X														X					
Recurved because of circulation around another storm																			X						
Quadrant of strongest winds	unk	SE		unk	unk		NE		S	N	S	N	SE			NE	NW				NE		NE		E
Before recurvature	unk		E			SE								NE	N			SE	S & SE			E & SE		N & NW	
During recurvature	unk		SE & E			NE								E	NE			SW	E & SE	N		E		E & SE	
After recurvature	unk		SE			SE								NE	NE			NE	NE	N		S		NE	
Speed of movement (overall average) (kts)	10	11	15	12	7	16	12		6	7	14	13	9	11	17	8	14	10	13	7	8	16	9	16	11
Before recurvature	7		10			15								10	15			10	11	7		14		15	
During recurvature	6		11			19								11	15			8	12	6		13		14	
After recurvature	14		23			18								13	25			21	19	16		26		37	
Minimum pressure reported (millibars)	unk	986	992	1002	993	950	988		991			996	991	994	977	985	994	962	947		990	999	990	986	953
Radius of activity (force six winds or greater)	500 mi	250 mi	450 mi	225 mi	150 mi	450 mi	250 mi		75 mi	275 mi	60 mi	60 mi	250 mi	300 mi	500 mi	250 mi	300 mi	400 mi	200 mi	120 mi	240 mi	300 mi	300 mi	400 mi	400 mi
Point of dissipation	Ex Trop 19.5 N 146.5 E	Ex Trop 27.0 N 146.0 E	Ex Trop SE Japan 32.0 N	Decayed 18.5 N 134.4 E	China Coast 22.0 N	Ex Trop Korea 38.0 N	China Coast 22.8 N		Ex Trop E Tokyo 142.0 E	23.0 N 131.0 E	Dsptd Tokyo Area	20.4 N 100.3 E	China Coast 22 N	Ex Trop Yellow Sea	Ex Trop NE Japan	China C ast 26 N	China Coast 22 N	Ex Trop Tokyo 36 N	Ex Trop E Japan 35 N	Ex Trop 27 N 147 E	Dsptd 17.5 N 109.0 E	Ex Trop E Japan 33 N	Filled 21 N China Sea	Ex Trop E Japan 36 N	China Sea 18 N

* Bulletin issued and tropical cyclone named prematurely on trough activity

** Low developed at intersection of ITC and strong trough that extended southwest from Norma

1948

NAME OF TROPICAL CYCLONE	CARMEN	DELLA	ELAINE	FAYE	GLORIA	HESTER	IRMA	JUDITH	KITTY	LISE	MADELINE	NELLY	OMELIA	PATRICIA	RENA	ALLYN	BETTY	CAMILLA
DATE OF INITIAL DETECTION (FIRST BULLETIN ISSUED)	15 JAN	17 JUN	8 JUL	13 JUL	20 JUL	23 JUL	28 JUL	12 AUG	28 AUG	2 SEP	2 SEP	13 SEP	1 OCT	23 OCT	11 NOV	14 NOV	3 DEC	9 DEC
NUMBER OF DAYS DURATION (BULLETINS ISSUED)	5	4	2	5	4	6	2	5	4	5	3	2	3	5	2	10	3	4
NUMBER OF DAYS DURATION AS A TYPHOON	3	4	0	4	4	2	0	3	3	5	1	1	2	2	0	9	1	2
REASON FOR FORMATION I. INTENSIFICATION OF EASTERLY WAVE ON ITC CAUSED BY SW MONSOON SURGE. II INTENSIFICATION OF EASTERLY WAVE ON ITC CAUSED BY WESTERLY TROUGH. III INTENSIFICATION OF EASTERLY WAVE ON ITC CAUSED BY A TROUGH IN THE EASTERLY FLOW INDUCED BY WLY TROF IV INTENSIFICATION OF EASTERLY WAVE ON ITC CAUSED BY NORTH INDIAN WESTERLIES V. FORMATION AND INTENSIFICATION OF LOW PRESSURE AREA AT BASE OF WLY TROF IN VICINITY OF ITC. VI. INTENSIFICATION OF SURFACE LOW BY LOW ALOFT SURFACING. VII. UNKNOWN. VIII. MOVEMENT OF A VORTEX INTO A STAGNANT LOW PRESSURE AREA.	V	I	VII	VI	I	I?	VI	I?	II	VIII	VI	V	II	I?	I?	II	VII	VII
LOCATION OF DEVELOPMENT (FIRST BULLETIN)	10.9 N. 144 E.	15 3 N 128 0 E.	13.8N. 120.8 E.	20.7 N. 136.8 E.	15.1 N. 132.7 E.	16.3 N 143.9 E.	21.8 N 120.7 E.	18.5 N 125.8 E	23 3 N. 154.5 E	13 0 N 137 0 E	20.5 N. 181.5 E.	21 8 N. 127.7 E.	15 1 N. 131.2 E	17 0 N. 131.5 E.	08 3 N. 127.8 E.	09.3 N. 153.9 E.	07.4 N. 131.5 E.	09 0 N. 154.0 E.
MAXIMUM WINDS (KNOTS)	85	110	45	90	110/175	110	50	60	65	65	70	70	70	110	45/65	120	70	65
MAXIMUM WINDS BEFORE FIRST CURVATURE (KNOTS)	65	75	45	85	90	50	50	60	65	65	55	90	70	58	50	120	70	65
MAXIMUM WINDS DURING FIRST CURVATURE (KNOTS)	65	85	UNK	85	100	85	50	65	90	70	60	90	--	85	50	100	--	60
MAXIMUM WINDS AFTER FIRST CURVATURE (BEFORE SECOND CURVATURE, IF ANY) (KNOTS)	60	110	UNK	90	110	65	50	65	75	120	45	95	--	--	50	75	--	55
MAXIMUM WINDS DURING SECOND CURVATURE (KNOTS)	60	75	--	--	110	50	--	60	--	--	--	--	--	--	--	--	--	--
MAXIMUM WINDS AFTER SECOND CURVATURE (KNOTS)	85	70	--	--	110	20	--	45	--	--	--	--	--	--	--	--	--	--
POINT OF FIRST CURVATURE	11.1 0 N. 134.3 E.	17.5 N. 125.5 E	10.0 N. 117.7 E	24 0 N 131.5 E	16.0 N 132 0 E	16 0 N. 146.0 E	25 0 N 23.0 E	20 0 N 125.0 E.	31 1 N 141.1 E	18 5 N. 136.5 E	22 3 N. 150.2 E.	23 5 N 125.5 E	--	19 5 N. 127.5 E	13 9 N 117.5 E	18 2 N. 131.8 E	--	18 0 N 121.5 E.
POINT OF SECOND CURVATURE, IF ANY	13 2 N 136.1 E.	30 0 N. 130 0 E.	--	--	22.0 N 131 0 E	35 0 N. 136 5 E	--	30 0 N. 131 0 E	--	--	--	--	--	--	--	--	--	--
DIRECTION OF FIRST CURVATURE EXAMPLE: W-NNW	NW-NE	NW-NNE	NNW-WNW	NW-N	NW-N	SE-E-N-NW	NE-N	NW-N	NW-N	NW-NNE	NW-N	NW-W	--	NW-N-NE	NW-N	NW-N-NE	--	NW-NE
DIRECTION OF SECOND CURVATURE	SE-WSW	NNE-N	--	--	N-NW	NW-N-NE	--	NE-NNW	--	--	--	--	--	--	--	--	--	--
REASON FOR CURVATURE EXAMPLE: A. I. B. IV A FIRST CURVATURE B SECOND CURVATURE I. RECURVED IN ADVANCE OF WLY TROF II. RECURVED INTO WESTERLY TROUGH III. RECURVED IN TROUGH CAUSED BY ANOTHER STORM IV. CURVED BECAUSE OF MISSING TROUGH V. CURVED BECAUSE OF BLOCKING HIGH VI. CURVED BECAUSE OF CHINA LOW CIRCULATION VII RECURVED BECAUSE OF A SPLIT HIGH CELL	A I B IV	A I B V	IV	II	A I B V	V	VI	A I B V	I	VII	VIII	V	--	II	I	I	--	I
QUADRANT OF STRONGEST WINDS (WHEN CONSTANT DURING EXISTENCE OF CYCLONE)	--	--	UNK	--	--	UNK	UNK	--	UNK	--	SW	SE	SE	--	SW	--	S	--
QUADRANT OF STRONGEST WINDS BEFORE FIRST CURVATURE	S	NE	UNK	E	N	UNK	--	NE	S	W-SW	SW	SE	SE	SW	SW	S	S	N
QUADRANT OF STRONGEST WINDS DURING CURVATURE	SE	UNK	UNK	NE	NW	SW	--	UNK	UNK	W-S	UNK	UNK	--	SE	--	SW	--	UNK
QUADRANT OF STRONGEST WINDS AFTER FIRST CURVATURE	SE	E	UNK	NE	NE	UNK	--	UNK	UNK	W	UNK	UNK	--	S	--	W	--	UNK
QUADRANT OF STRONGEST WINDS DURING SECOND CURVATURE	UNK	UNK	--	--	N	UNK	--	NE-SE	--	--	--	--	--	--	--	--	--	--
QUADRANT OF STRONGEST WINDS AFTER SECOND CURVATURE	NW	UNK	--	--	N	UNK	--	UNK	--	--	--	--	--	--	--	--	--	--
SPEED OF MOVEMENT (OVERALL AVERAGE) (KNOTS)	7	14	11	8	10	12	15	10	15	7	15	12	12	15	15	13	11	13
SPEED BEFORE FIRST CURVATURE	10	9	13	9	7	UNK	13	10	10	10	15	10	12	8	15	8	11	11
SPEED DURING FIRST CURVATURE	7	8	10	9	8	7	14	14	13	5	13	10	--	8	15	7	--	10
SPEED AFTER FIRST CURVATURE	2	19	7	10	12	15	16	10	19	7	15	30	--	AVG. 30	15	26	--	24
SPEED DURING SECOND CURVATURE	3	34	--	--	9	15	--	9	--	--	--	--	--	--	--	--	--	--
SPEED AFTER SECOND CURVATURE	10	12	--	--	UNK	UNK	--	7	--	--	--	--	--	--	--	--	--	--
MINIMUM PRESSURE REPORTED	RECON 1001	KADENA 956 3	PRATAS 1002	NAZE 968.7	NAHA 946.9	SHIP 1949	FORMOSA 992	RECON 987	RECON 980	SHIP 957.9	RECON 984	FORMOSA 984	RECON 991	RECON 940	SFC CHART 964	RECON 932	RECON 999	SFC CHART 992
MAXIMUM RADIUS OF FORCE SIX WINDS OR GREATER IN NAUTICAL MILES	300	350	50	250	400	200	100	210	200	250	125	110	150	300	150	200	75	200
POINT OF DISSIPATION (LAST BULLETIN)	9 5 N 128.2 E	37.4 N 131.3 E.	21 3 N. 114.9 E.	33.8 N. 130.3 E.	29.5 N. 122.0 E.	35.0 N. 137.5 E.	32.0 N. 123.0 E.	33 8 N 129 7 E	44 2 N 141 0 E.	34.9 N 150 5 E.	35.4 N 150 5 E.	24 3 N. 117.1 E.	23 3 N. 117.5 E.	34.4 N 143.6 E	18.7 N 114.3 E.	32.0 N 142.2 E.	10.8 N. 120.7 E.	22.0 N. 123.0 E.
UNITED STATES INSTALLATIONS DAMAGED	NONE	OKINAWA KYUSHU	NONE	NONE	OKINAWA	NONE	NONE	KYUSHU	HONSHU	NONE	NONE	NONE	NONE	NONE	NONE	GUAM	NONE	NONE
MINIMUM 700 MB PRESSURE	9600	UNK	UNK	8250	9620	10050	UNK	9130	UNK	8900	UNK	UNK	9730	8400	UNK	RECON 6900	UNK	9400

A consideration of the charts depicting cyclone tracks for the past four years, contained in the appendix at the backend of this Report, will reveal that there were any number of cyclones, that, without the aid of reconnaissance and numerous aircraft in-flight data, would have gone undetected. An outstanding example of this is the month of November. Yvonne, Elnora, Nora and possibly Betty, if it had been a typhoon of narrow dimensions, could have conceivably gone unnoticed.

During 1949, the seasonal distribution of storms varied considerably from the mean. The maximum occurred in July rather than September, and the season did not actually begin until June, no storms have occurred in February, March, April, or May. Carmen, which occurred in January, is considered as part of the 1948 season. Also, August, September, and October had only 8 storms, as compared with an average of 11 for 1905-1937, and 13 for 1945-1949.

Such variations from the mean are quite common. The range of the number of storms for the month of February is 0-4, whereas the mean is 0.4. In July, the range is 0-7 with a mean of 3.4. These figures serve to illustrate the reliability of the mean.

Statistics gathered in the past four years, with the aid of excellent reconnaissance and experienced observers, tend to emphasize two important conclusions: that many more tropical cyclones occur annually in the Pacific than was previously thought, and, that a very limited number of them occur during the months of January, March, and April. These conclusions, however valid their accuracy, are still limited by their short period of observation and should be considered merely as a trend until further substantiated by data to be gathered subsequently.

8. Latitude of formation.

As was stated earlier in this discussion, tropical cyclones form at varying degrees of latitude, dependent upon the location of the Intertropical Front at the particular time. On the following page is a graph depicting the average latitude of tropical cyclone formation in the Pacific. Here again, data gathered from 1905 through 1936 is compared to that gathered from 1945 through 1948. Prior to World War II, when there was no aerial reconnaissance and only a limited number of aircraft in-flight reports, the majority of tropical cyclones were not detected until they had reached a point north of the 15th parallel and west of the 145th meridian, an area frequently traveled by surface vessels. It is thought, that for this reason, statistics presently in use relating to Pacific cyclones, show the average monthly latitude of formation to be abnormally far north. Again, increased reconnaissance and more in-flight reports have shown that, on the whole, tropical cyclones in this region form much farther south than was previously thought. A study of

MONTHLY DATA ON TROPICAL CYCLONES

IN SOUTHEAST PACIFIC

1949 COMPARED WITH HISTORICAL DATA[1]

MONTHS	JAN	FEB THRU MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
AVERAGE NO. PER YEAR	0.9	NO	1.4	3.4	3.6	4.1	3.2	1.9	1.2	22.3
NUMBER IN 1949	1	STORMS	1	(6)# 3	2	4*	2	(2)# 1	2	(20)#*$
MEAN LAT. OF FORMATION	8		15	15	16	14.5	11.5	10	8.5	
MEAN LAT. IN 1949	10.5	IN	15.5	17.5	21	20	15	9	8	
MEAN LAT. OF RECURVE	——	1949	22	29	30	25	15	19	17	
MEAN LAT. IN 1949	11		17.5	20	25.5	21.5	19.5	16	18	

$ Includes a tropical storm on which no bulletins were issued.
# Includes tropical storms.
* Includes typhoon on which no bulletins were issued.

[1] (1905-1937 Incl)
From US Air Forces, Weather Div, [illegible] Climate of China, 194[illegible],

the graph shows this to be the case in practically every instance, with the exception of August. The average latitudes of formation for February and March have been omitted as there were no storms occuring in February and only one occuring during March in the past four years. Since cyclones during these two months are so infrequent, their average latitude of formation, presumably around 6°N, is uncertain but significant in that they must be considered in any theory of typhoon formation.

9. Development and Intensification.

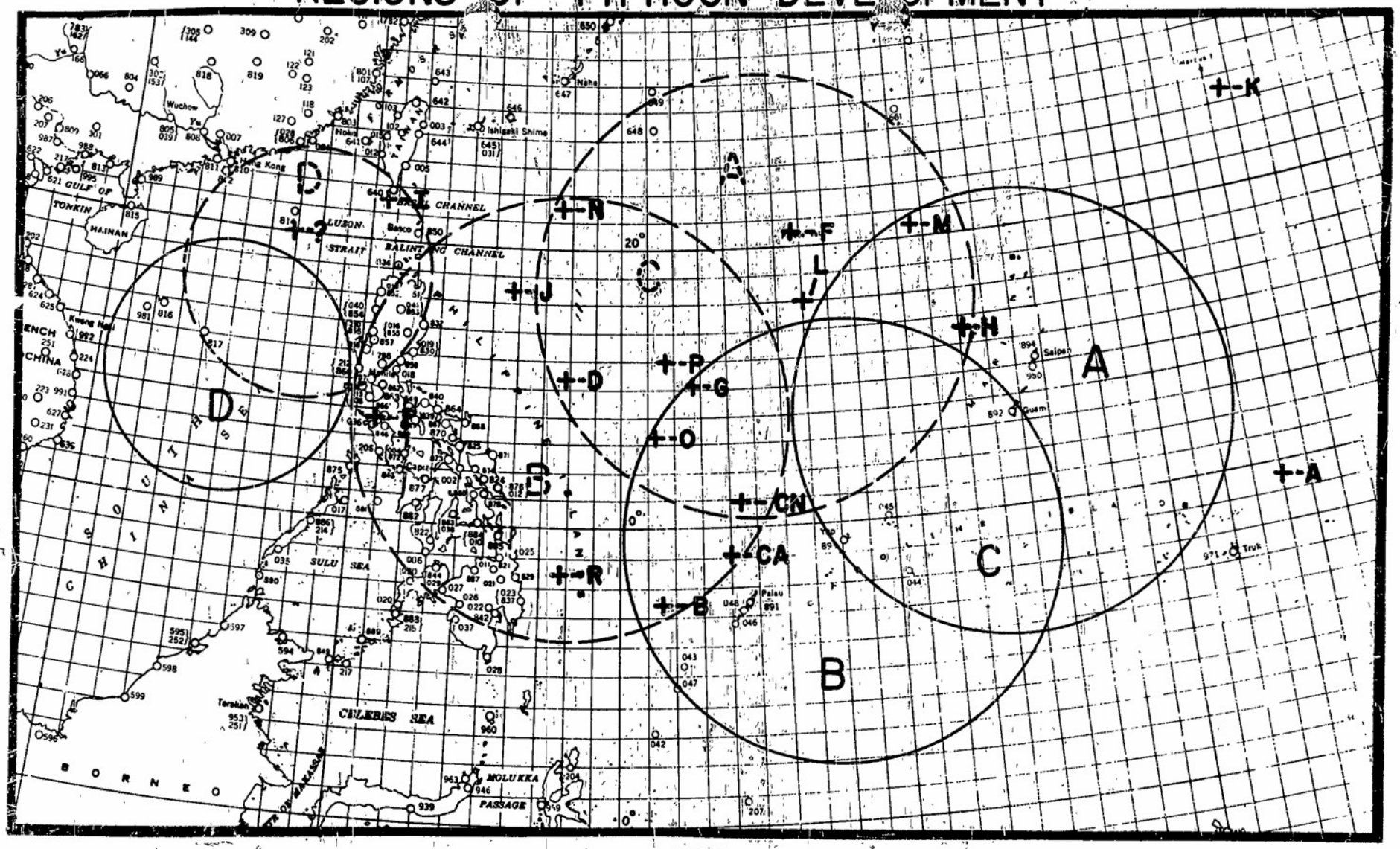
"Weather and Climate of China" shows three regions where storms originate in the North Pacific Ocean. A copy of this chart is shown on the next page. Studies by the typhoon Post Analysis Board have indicated that typhoons do not "originate" in any such defineable area, but develop from easterly waves that can in most cases be traced back to Kwajalein Atoll or farther to the east. It has been estimated that some 30 percent of the total number of easterly waves develop into tropical cyclones, following a fairly regular pattern of intensification from wave to tangent point to vortex to depression to tropical storm and finally to a typhoon.

Perhaps a better term than origination would be "intensification". An intensification area could then be defined as the area where the tropical cyclone intensified to a sufficient extent to be called a typhoon. "Weather and Climate of China" does not give any criteria for determining the areas depicted, so it is not known whether they are the areas in which a typhoon was first noticed, or where the depression had intensified into a tropical storm or typhoon.

If it is assumed that the pictured areas are areas of intensification, then they agree fairly well with the areas of intensification of 1949 storms. The criteria for establishing the point of intensification of the 1949 storms is the position given on the first bulletin. The areas that include most of these points do not coincide exactly with the so-called areas of origination, due possibly to the use of different criteria or to the fact that the data for 1949 is not entirely representative, but there is a great deal of similarity.

In the 1948 report of the Typhoon Post Analysis Board, the areas of origin were determined by the points at which tropical cyclones were first detected, regardless of the intensity at the time. Such a procedure naturally placed the supposed areas of origin farther to the east than those shown on the chart. The trouble with this method is that some storms may be detected when they are just beginning to intensify, while others may have reached full typhoon intensity before data indicates their presence.

REGIONS OF TYPHOON DEVELOPMENT



KEY

+- LOCATION OF FIRST BULLETIN, 1949 STORMS IDENTIFIED BY INITIAL.

HISTORICAL AREAS*

A = 6 STORMS, 23 %
B = 3 STORMS, 13 %
C = 7 STORMS, 30 %
D = 3 STORMS, 12 %
OTHERS = 5 STORMS, 22 %

*U.S. ARMY AIR FORCES, WEATHER DIVISION WEATHER AND CLIMATE OF CHINA, 1945, P. 26

1949 AREAS

A = 4 STORMS, 21 %
B = 5 STORMS, 26 %
C = 6 STORMS, 32 %
D = 2 STORMS, 11 %
OTHERS = 2 STORMS, 10 %

From 1949 data it appears that the area of most probable intensification is the Philippine Sea; that part of the Pacific Ocean bounded by the Philippines on the west, the Marianas on the east, Palau on the south, and approximately the 23rd parallel on the north. In this region 14 or 70 per cent of the tropical storms and typhoons of 1949 intensified. It is hardly necessary to state that easterly waves or tropical cyclones of less than tropical storm intensity should be carefully watched in this area for signs of intensification.

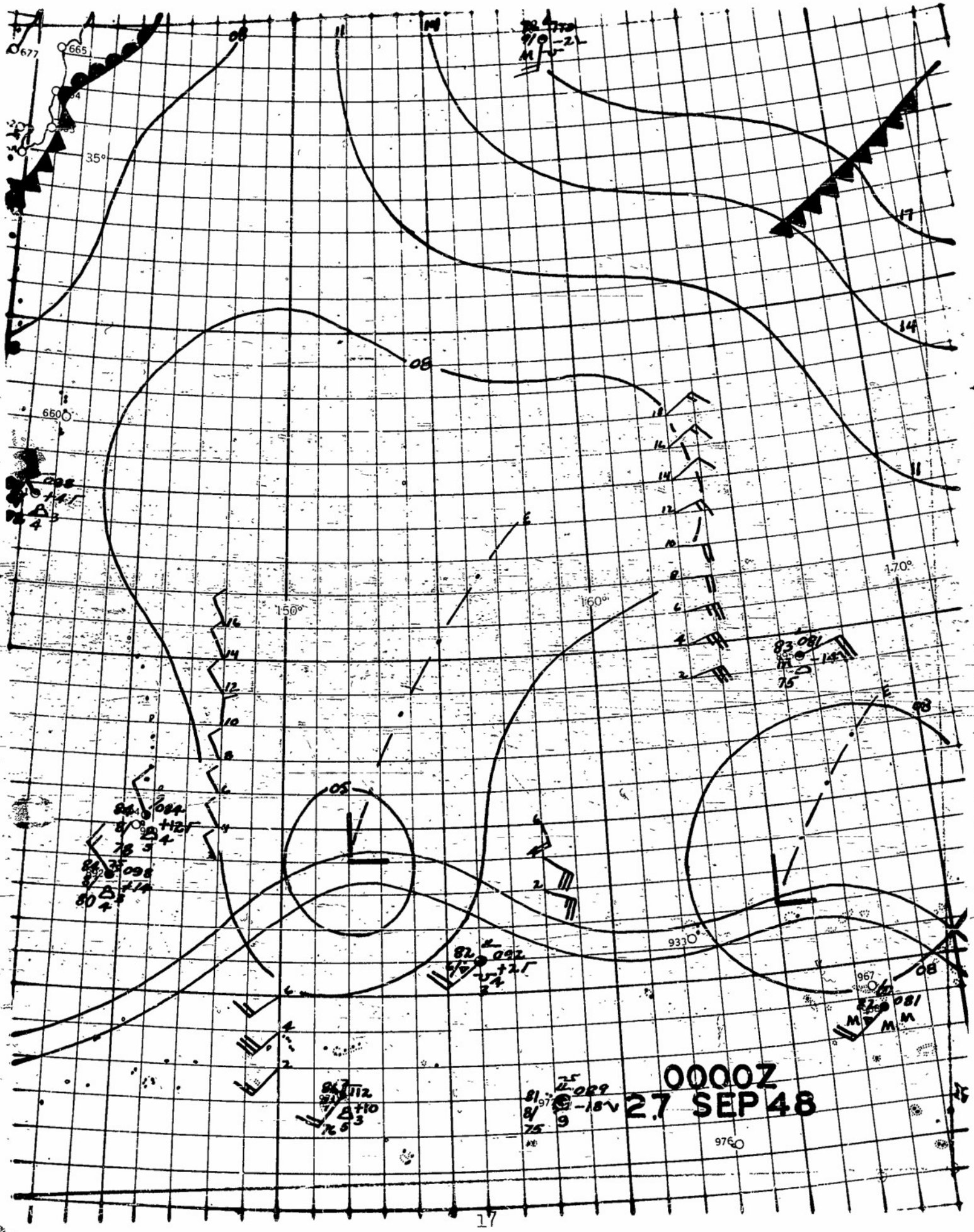
10. Reasons for Formation.

At the present time, little can be written on the development of Pacific typhoons other than to point out apparent causes according to the synoptic patterns in which they originate. The inadequacy of weather data in the open ocean areas of the Western North Pacific precludes the accuracy of analysis necessary to detect typhoon development with any degree of efficiency. Even when a tropical cyclone has reached typhoon intensity and is the dominant feature of the weather map, the analyst is frequently at a loss as the exact location of the typhoon, and certainly is handicapped by lack of information with which he is expected to forecast the movement.

The volume, "Handbook of Meteorology," by Berry, Bollay, and Beers, classifies tropical cyclones into four types of depressions depending upon which one of the following four synoptic models was instrumental in their formation: The Intertropical Front, strong polar trough, the easterly wave, or the induced trough. It is thought that this classification was determined, primarily, from data obtained in the Caribbean area and does not, necessarily, apply to tropical cyclones in the Western North Pacific. From present indications, none of the above four types, in themselves, result in cyclone formation in this region. Rather, it is felt that a combination of two or more of the patterns listed must be present in the formation of each cyclone. An example of this would be the presence of an easterly wave associated with the Intertropical Front and the combination of systems being intensified by a southwest monsoon surge.

a. Intensification of an Easterly Wave on the Intertropical Front caused by a Sounthwest Monsoon Surge.

On the following page is a section of the surface map at the time typhoon Libby, one of the more intense 1948 typhoons began its development. The two parallel lines drawn through the two low pressure centers near the bottom of the map represent the Intertropical Front. The dash-dot lines extending northeastward from the lows indicate the positions of the easterly waves. On the map prior to the one illustrated, the lower two-thirds of the area shown comprised a flat 1008 millibar pressure field with the base of the two easterly waves imbedded in a


0000Z
27 SEP 48
35°
150°
160°
170°
677
665
660
933
967
976

1005 millibar cell of low pressure along the Intertropical Front. Subsequent developments were such, that the low pressure cell split, forming the two separate lows as indicated. The southwest monsoon surge to the south of the Intertropical Front, as indicated by the 2000, 4000, and 6000 foot winds at Truk (97ϕ), was sufficient reason to request a reconnaissance flight to the suspected area midway between Saipan (894) and the weather ship "Birddog 4" stationed at 11.0 degrees north latitude and 156.0 east longitude. The reconnaissance mission flown to this area reported a weak, closed circulation at 14.0 degrees north latitude and 152.0 degrees east longitude. This depression at the base of the easterly, imbedded in the Intertropical Front, intensified as the result of the southwest monsoon surge, and resulted in an extremely intense typhoon.

The pressure field, accompanying Libby's development, was not the typical pressure distribution normally associated with the intensification of an easterly wave in this manner. The more usual picture is that of a well developed easterly imbedded in a deep easterly flow to the north of the Intertropical Front with the western lobe of the Pacific High Cell well to the west of the perturbation. The Intertropical Front and the easterly wave form what is commonly known as the "triple point." At this stage, however, the circulation is not complete. To the north of the Intertropical Front, there is a fairly strong, open, cyclonic wind flow, while to the south there are but light, variable winds. The picture thus presented is capable of producing wide-spread squalliness to the north of the Front.

All that is now needed to produce a tropical cyclone, is a southwest surge of air. In the case of Libby, it is felt that the surface surge, as represented by the winds at Truk (971), was produced by a previous, or possibly simultaneous, intrusion from the south of relatively cold air aloft into the potential storm area. This advection of cold air produced an increased tilt to the axis of the easterly wave, resulting in decreased surface pressures. It is believed that the surface surge was the result of the decreased pressure at the base of the easterly. Storm development was rapid once the surge was established.

Tropical cyclones that develop in the manner described above are variable in their intensities. This variability is determined, for the most part, by the moisture content of the air masses involved. The higher the moisture content, the more intense the storm. This type of storm usually occurs most frequently during the summer months when the Pacific High cell has reached its most westerly point of migration.

b. Intensification of an Easterly Wave on the Intertropical Front caused by a Westerly Trough.

Of the five synoptic patterns listed on the composite data sheet, it is felt that this one is least probable of causing cyclone

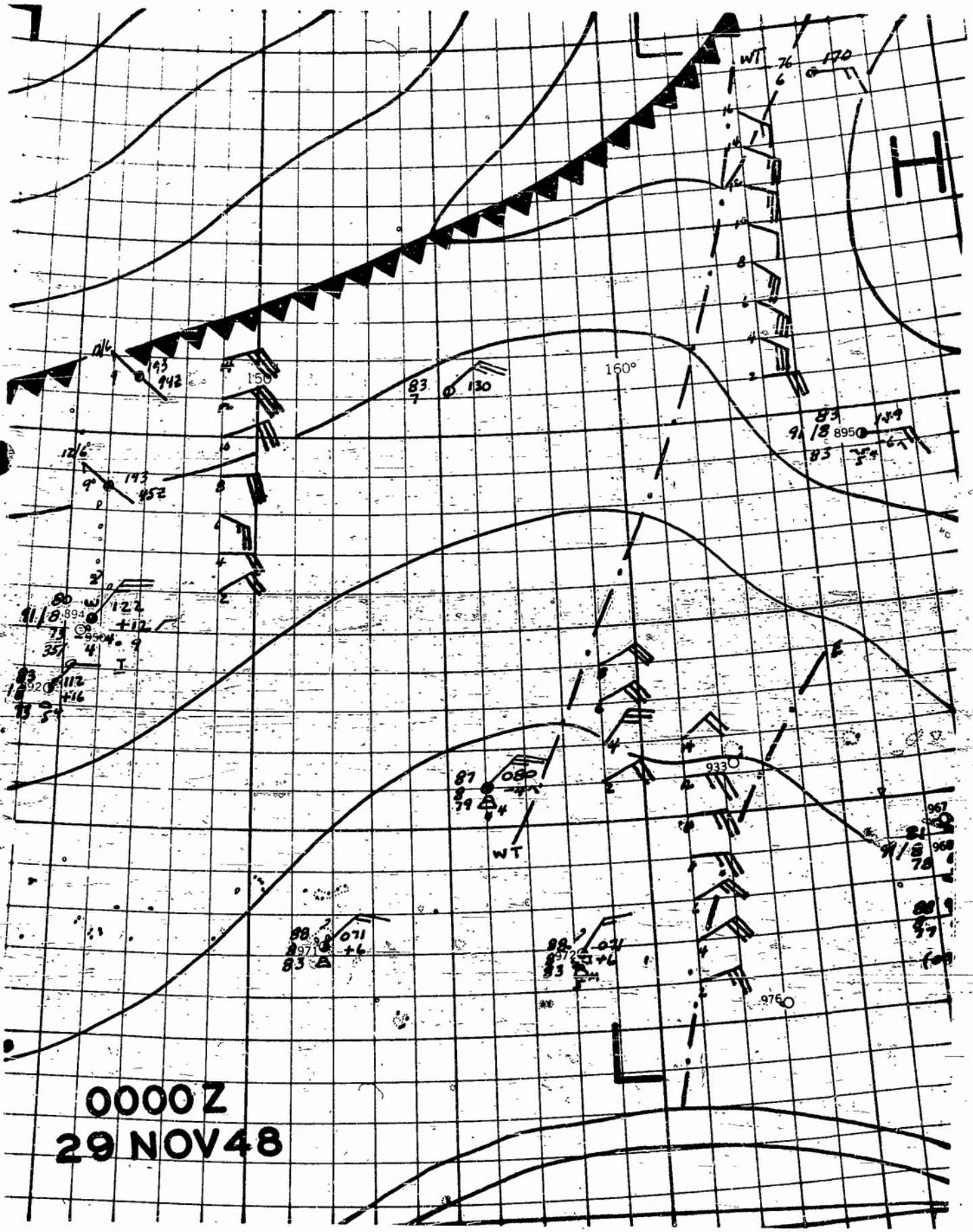
development. At the time the two cyclones, Nadine and Hazel, formed, the only apparent reason for the intensification of the easterly wave on which they developed was that of a fairly weak westerly trough some distance to the north. At the time, it was believed that the Southern end of the trough, at some unknown height above the easterly, caused its intensification. However, it is reasonable to assume that, if a westerly trough is not sufficiently strong to induce a surface trough in the easterly flow, neither is it sufficiently strong to intensify an easterly wave, unless, of course, the vertical activity of the easterly extends to unusual heights. Consequently, no further discussion of this synoptic type will be made in this Report. It is felt that further study is necessary to explore possibilities and justify the validity of its classification as a cause of tropical cyclone development.

c. Intensification of an Easterly Wave on the Intertropical Front caused by a Trough in the Easterly Flow Induced by a Westerly Trough.

On the following page is a section of a chart showing the synoptic models that led to the development of Typhoon Beverly, the last tropical cyclone of the 1948 season.

During the winter, when the temperate latitude frontal systems move into the tropics, there are a number of troughs, in the easterly flow, induced by westerly troughs associated with temperate latitude systems. During this time of year, the Pacific High Cell is displaced well to the east and south of its summer position. This southward displacement of the systems, however, does not preclude the possibility of easterly wave intensification, providing the necessary factors for intensification are encountered before the easterlies reach 150 degrees east longitude, near which point they usually dissipate. This being the case, the majority of cyclones resulting from synoptic patterns of this type usually form in source region "A".

The map referred to above, shows a westerly trough just to the west of weather ship "Birddog 4", and an easterly wave approaching the island of Ponape (972). Both systems were rather intense, as determined by the weather experienced as they passed Guam (892) and Kwajalein Atoll (968) respectively. As the easterly came under the influence of the area of mass divergence associated with the westerly aloft, the surface pressures fell, and, in effect, induced the Intertropical Front into the potential storm area. This, in turn, provided an influx of air from the south. A short time later, the series of events just described were completed and a definite closed circulation existed at 6.5 degrees north latitude and 153.0 degrees east longitude. In general, the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29 NOV48
160°
150
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933
967
976

tropical cyclones produced in this manner reach typhoon intensity shortly after a definite closed circulation has been established.

d. Intensification of an Easterly Wave on the Intertropical Front caused by the North Indian Westerlies.

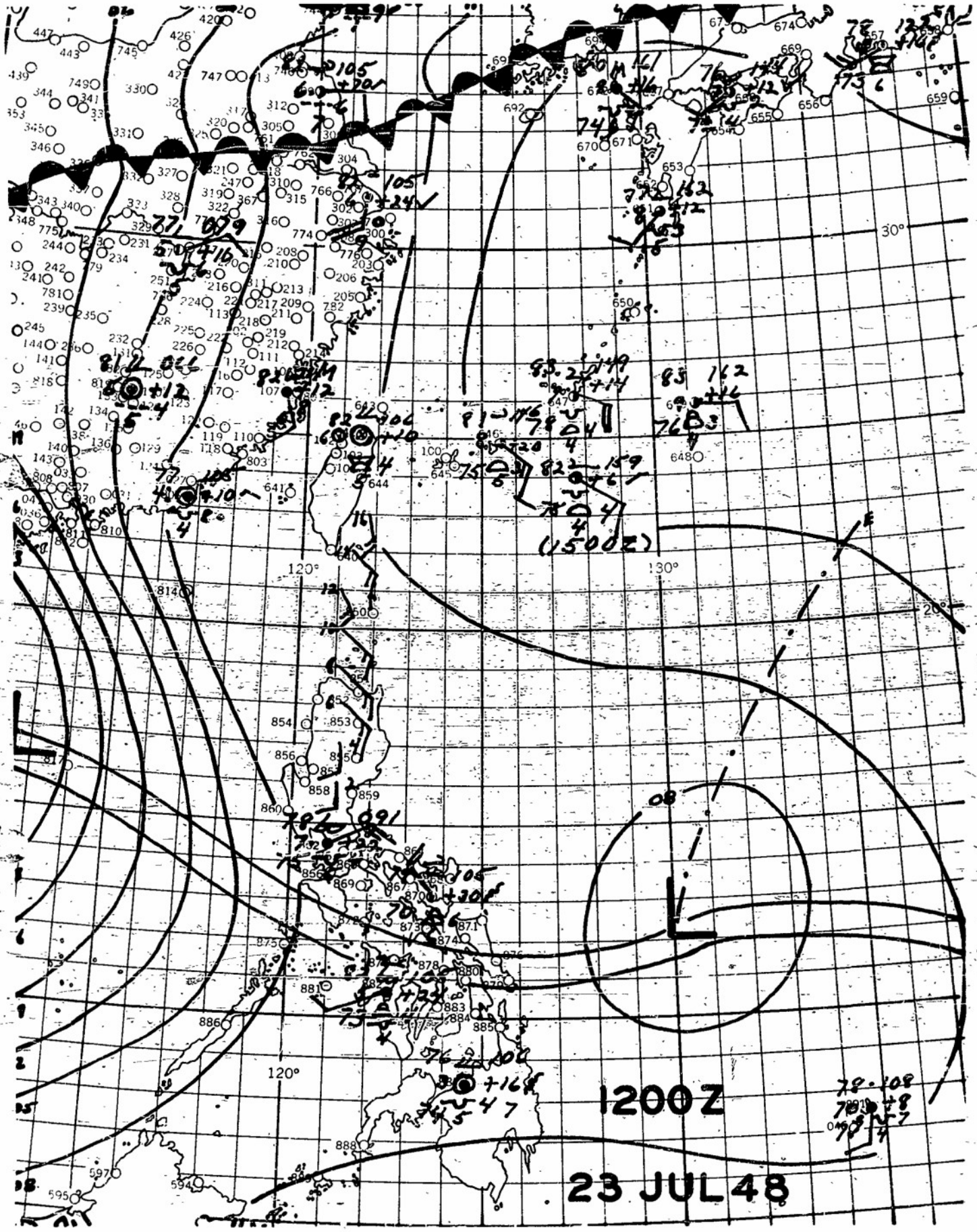
The synoptic pattern represented by the chart on the following page is distinctive, in that the only place in which it is responsible for the development of tropical cyclones is in, or near, source region "C". Involved in this case, as in the three previous cases, are the seemingly inseparable easterly wave and Intertropical Front, the third necessary factor being a strong westerly flow of air across the southern Philippines, comparable in all respects to the North Indian Westerlies referred to by Deppermann. (See American Meteorological Society Bulletin for December, 1947). The chart referred to above shows the synoptic pattern that was instrumental in the formation of tropical cyclone Rose.

During the months of July and August, the mean position of the Intertropical Front, in the Philippine and South China Sea region, is, in general, an east-west line over southern China then dipping southeastward through Formosa to Guam. This peculiar orientation of the Front produces a southwest monsoon flow over the entire South China Sea and as far east as the 130th meridian. The normal path of easterly waves to the west of Guam, during these two months, is northwestward along the line of convergence between the southwest monsoon and the northeasterly trades. The simultaneous existence of a low pressure area in the South China Sea and an active easterly wave to the east of the Philippines, is a situation favoring the formation of a tropical cyclone in source region "C". The westerly flow of the warm, moist air across Mindanao, as is indicated on the chart, provides the required potential for cyclone development at the base of the easterly. Cyclones forming in this manner are usually small, the winds of typhoon intensity being confined to a relatively small area near the center.

e. Formation and Intensification of a Low Pressure Area at the Base of a Westerly Trough in the Vicinity of the Intertropical Front.

A consideration of the chart on the following page will probably raise a question as to the difference in this situation and that brought forth in Example C p. 18. The main differences to be pointed out are the absence of an easterly wave in this example and the differences in the structure and intensity of the respective westerly troughs involved.

The westerly trough discussed here, as contrasted to the


1200Z
23 JUL 48
30°
20°
120°
130°
(1500Z)

one associated with the easterly wave in Example C, was well developed, slow moving, and, at times, quasi-stationary. The intensity and southern extent of the trough was substantiated by the winds aloft over Guam. This well developed westerly, induced a surface trough of the magnitude required for the northward displacement of the Intertropical Front. Here again, as in Example C, the Front was induced far enough northward to provide a surge of warm air from the south completing the circulation. It is doubtful if an easterly wave, in addition to not being necessary for this type of cyclone development, could exist in a synoptic pattern of this type. A westerly trough of great intensity disrupts the deep easterly flow to the east of it and results in the dissipation of any easterly wave that may be present. Since the base of the polar westerlies is usually low over a cyclone that develops as a result of this synoptic pattern, the cyclone, of necessity, is comparatively shallow. The majority of them appear to form north of the 15th parallel during the months of August, September, and October, and are usually of short duration.

f. Other Causes.

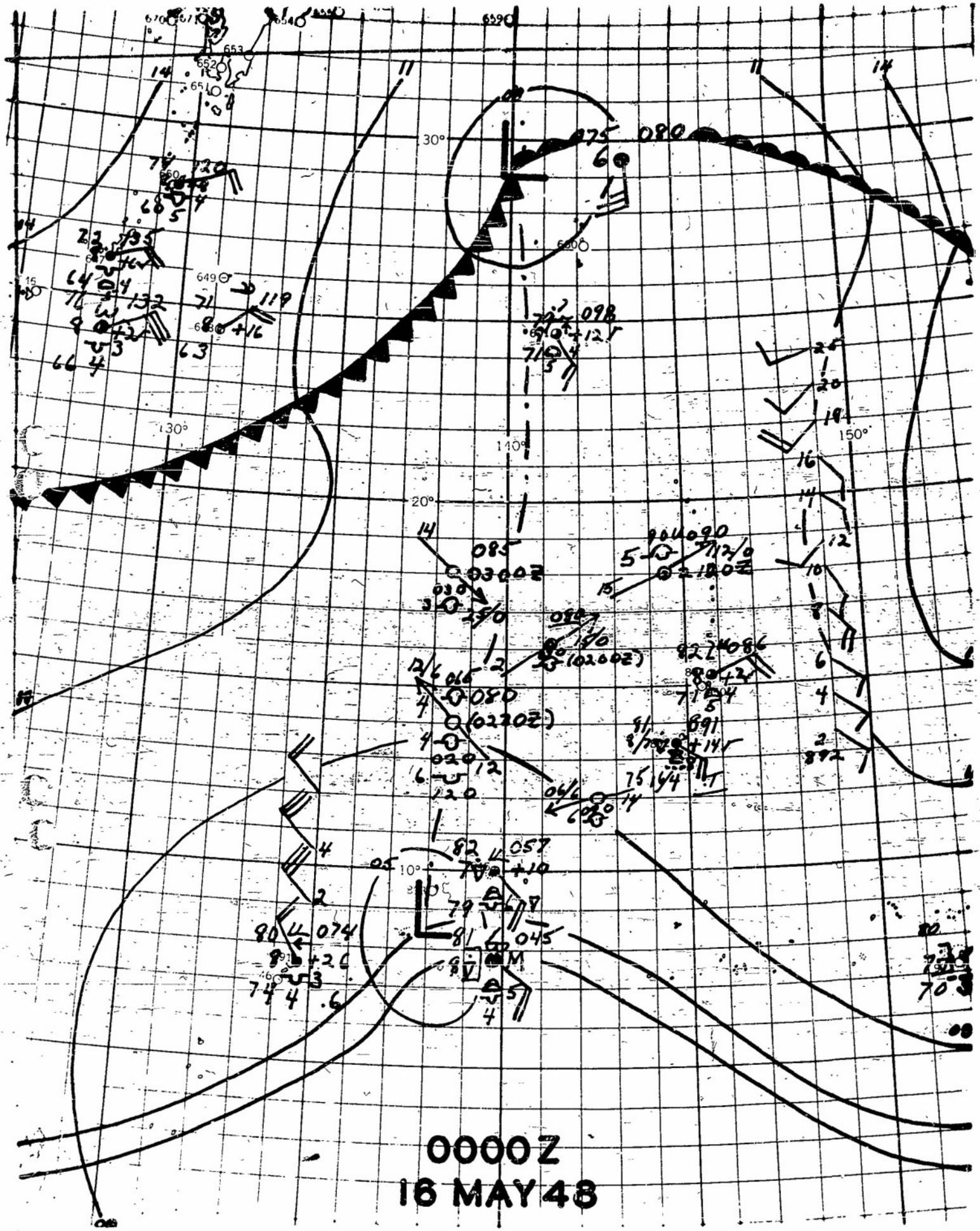
In addition to the five types of patterns discussed on pp. 15, 17, 18, and 20, there is one additional situation that leads, not infrequently, to storm development. This invloves the case of a tropical cyclone which develops in the trough induced by another cyclone. The exact reason for this action is obscure. However, any trough with a circulation such that air from a mature storm is being fed into it deserves the closest scrutiny.

Although the synoptic patterns for development as explained in this section are all apparent and based, for the most part, on a single year's observations, it is hoped that they may be of value to all concerned in determining the approximate time and place of the development of tropical cyclones.

11. Direction of Movement.

In 1948 and 1949, tropical storms moved in every conceivable direction. A glance at the post analysis tracks in The Appendix show examples of typical recurvature, inverse recurvature, loops, and many other types of movement. From this can be seen how seldom the so-called typical typhoon occurs.

Determining the direction of movement is probably the most important phase of tropical cyclone forecasting. Although there are apparently no definite forecasting rules or techniques resulting in a high degree of accuracy that can be applied, it is felt that a close correlation between the surface and 700 millibar synoptic patterns,


30°
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16 MAY 48

adequate reconnaissance, and the application of practical, common sense concepts of meteorology can reduce forecasting errors to a minimum.

Because most Pacific tropical cyclones develop between 8 degrees north latitude and southern periphery of the semi-permanent Pacific High cell, their first tendency is to move westward in the strong easterly trade flow. There appears to be a direct relationship between the synoptic pattern resulting in their formation and their initial direction of movement. Generally speaking, the cyclones that form at the base of easterly waves, with the exception of those that form just to the east of the Philippines, will move west northwestward. This initial direction of movement is apparently necessitated by the deep easterly flow to the north of the storm area and the fact that the disturbance is still associated with the Intertropical Front.

A cyclone that forms just to the east of the Philippines has a tendency to move northwestward, since it follows the circulation around the low in the South China Sea that was initially instrumental in its formation. A cyclone that forms at the base of a quasi-stationary westerly trough can move in either of two directions, depending upon developments subsequent to intensification. Generally, if the trough to the north remains stationary, the storm will move northward in the trough. If, however, the trough fills or moves rapidly to the east, the storm will move northward until it comes under the influence of the strong northerly winds to the west of the trough, at which time it will move toward the west or west southwest.

12. Speed of Movement.

Speed of movement of the various Pacific storms of 1948 and 1949 varied as greatly as did their paths. Many of the large, intense storms moved quite rapidly considering their areas of activity and over-all average movement. This view-point, however, must be tempered by the fact that they also moved much faster than the average storm AFTER recurvature, causing their over-all speed of movement to appear unduly rapid. It seems reasonable to assume that their persistence in mid-latitudes after recurvature was, in large measure, a direct reflection of their energy, and, in consequence, allowed a longer period of time for acceleration before dissipation occurred.

The table on the next page gives the average speeds for different positions along the tracks of 1949 tropical cyclones as compared with historical data (1905-1937). In most cases these agree fairly well, considering the comparatively small sample used in obtaining the 1949 data.

COMPARISON

RATES OF MOVEMENT

1949 TROPICAL CYCLONES AND HISTORICAL MEANS

LATITUDE	YEAR	BEFORE RECURVING		WHILE RECURVING		AFTER RECURVING	
		MEAN	ORDINARY LIMITS	MEAN	ORDINARY LIMITS	MEAN	ORDINARY LIMITS
5°-10°N	1905-1937	14	7-22	13	5-21	—	—
	1949	11	5-16	5	—	10	—
10°-15°N	1905-1937	13	9-17	13	5-21	—	—
	1949	13	9-17	16	16-17	—	—
15°-20°N	1905-1937	12	8-17	13	5-21	10	5-16
	1949	9	7-11	8	5-12	11	—
20°-25°N	1905-1937	12	8-16	13	5-21	15	9-22
	1949	13	10-15	11	8-12	19	14-29
25°-30°N	1905-1937	13	7-20	13	5-21	18	9-31
	1949	12	—	10	8-15	18	8-32
30°-35°N	1905-1937	17	9-26	13	5-21	22	12-33
	1949	—	—	9	4-15	23	11-36
35°-40°N	1905-1937	—	—	—	—	28	15-38
	1949	—	—	—	—	31	11-47

The average speeds for all 1949 tropical cyclones were:

Before recurvature	$10\frac{1}{2}$ knots.
During recurvature	$9\frac{1}{2}$ knots.
After recurvature	$15\frac{1}{2}$ knots.
Over-all average	12 knots.

13. Recurvature.

Once a tropical cyclone is fully developed and has moved out of its source region or become disassociated from the Intertropical convergence zone, the problem arises as to whether it will continue its present direction or recurve in a different direction. The problem of forecasting recurvature in the Pacific is one that will not be satisfactorily solved until data at several strategic points becomes more readily available, and data now available, more reliable.

The terms, "recurvature" and "point of recurvature", as applied to cyclone tracks, do not mean the same thing to all people. For the purpose of clarification, the following definitions apply in this discussion: "recurvature" refers to that part of the storm track that curves in an opposite or unusual direction from its previous heading. The term, "point of recurvature," is applied to that point on the track where the storm loses its westerly component and acquires an easterly component.

Once a tropical storm breaks away from any influence of the Intertropical Front and becomes merely an intense circulation in the general flow surrounding it, it becomes subject to many variables in that flow which tend to steer the storm according to the flow patterns in its vicinity. Once the location and intensity of the surrounding high pressure cells and their associated troughs and ridges have been firmly established, the flow patterns, as represented by the five figures on the following page, have been observed to produce the types of tracks indicated by the broken lines. A brief discussion of the effects and the degrees of variability of each of the typical flow patterns follows. Although the statements are worded in a positive manner for the sake of brevity, they are very general assumptions based on the observation of 1948 Pacific storms and their actions under these conditions as outlined:

a. If the base of the westerlies, to the west of a storm, as represented by Figure 1, lowers appreciably and remains low, the storm will recurve to the northward. The point ahead of a trough where the storm will begin recurvature is dependent upon a number of variables t that are always present, although their degree of effectiveness is often

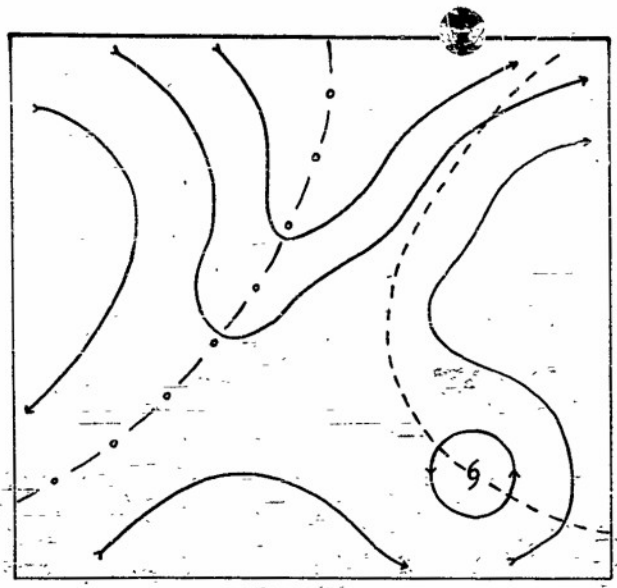


FIGURE 1

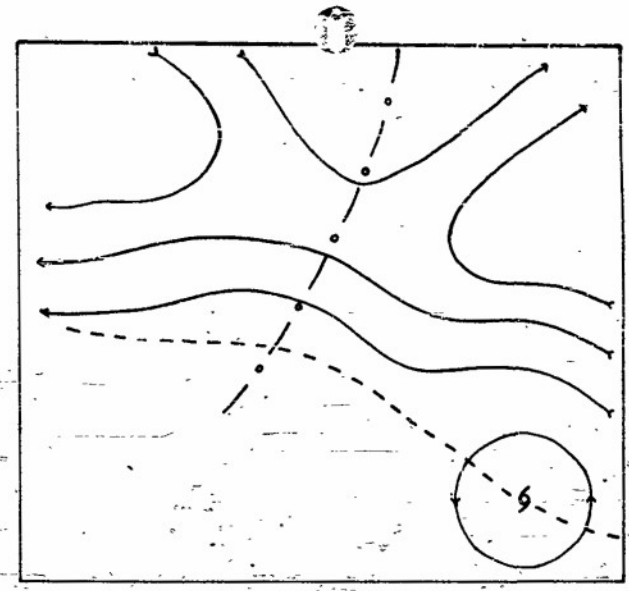


FIGURE 2

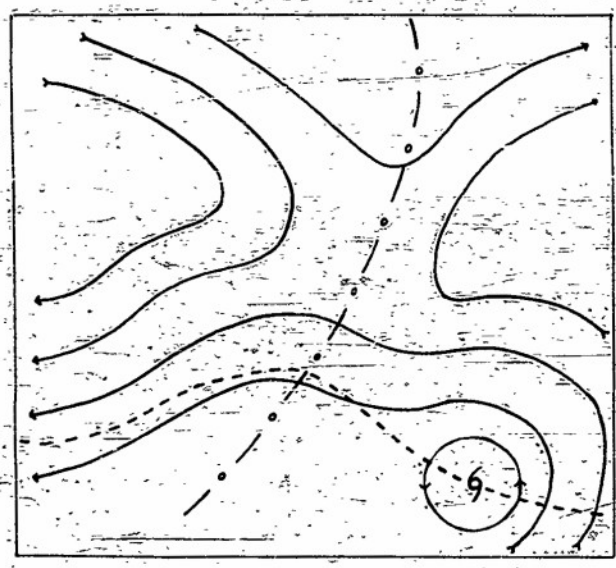


FIGURE 3

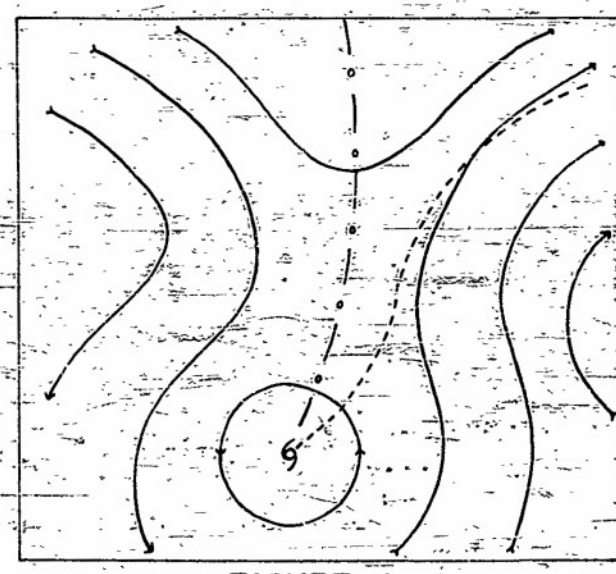
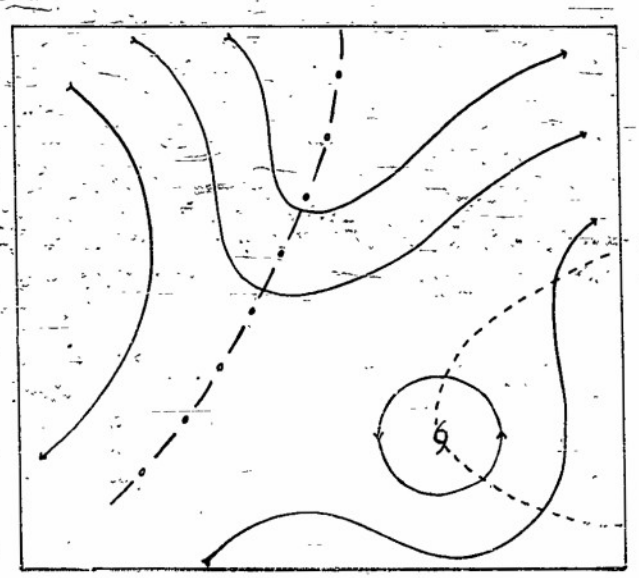


FIGURE 4



difficult to determine. The slower and more intense the trough, the farther in advance will the storm recurve. On the other hand, if the storm is well developed and moving rapidly, it will move closer to the trough before recurvature. In general, it can be said that, under certain circumstances, the storm will begin to recurve as far as 500 miles in advance of the trough, but the usual distance is in the vicinity of 300 miles.

b. In Figure 2, the base of the westerlies to the west of the storm are at some unknown height above the level of the storm but low enough to induce a surface trough in the easterly flow. It has been observed that the usual sequence of events, in this case, is the recurvature of the storm northward into the surface trough; then, since the base of the westerlies is not low enough to effect its movement for any great length of time, the storm veers back to the west around the periphery of the high cell to the rear of the trough. The degree to which the storm will recurve northward is dependent upon the intensity of the surface trough and the speed of the westerly trough aloft that induces it. The degree of recurvature appears to diminish as the speed of the trough increases.

The type of recurvature just described occurs for the most part south of the 20th parallel. If the storm is north of this point and encounters a weak trough as illustrated in Figure 2, it has been noted that it often becomes a part of the trough, thereby changing the circulation and movement of the storm to a pattern resembling that shown in Figure 4. This usually occurs, however, only if the trough is stationary or quasi-stationary.

c. Figure 3 depicts a situation similar to that represented in Figure 2, with the exception that, the high cell to the rear of the trough has built southward to such an extent, it tends to block the storm's westward movement. Here, as in Figure 2, the storm recurves northward into the surface trough instead of moving westward after having failed to catch the westerly trough, moves southwestward around the blocking high cell to the rear of the trough. Once the storm begins moving southwestward, it has been observed to decrease rapidly in intensity, and, at times, to dissipate entirely.

d. The circulation and track of the storm represented in Figure 4 is characteristic of a storm that develops at the base of a westerly trough and/or a storm that, subsequent to development, has become part of a westerly trough as explained under Figure 2 above.

e. The circulation illustrated in Figure 5 is that of a tropical cyclone approaching a strong, deep, westerly trough which extends well

into tropical latitudes. This circulation seems most conducive to sharp recurvature of cyclones, due apparently to the strong southwesterly flow to the east of the trough. This situation was seen many times in the area immediately east of the Ryukyus and the Japanese Empire where strong troughs from the west are most common.

14. Dissipation.

Since tropical cyclones persist only so long as the necessary supply of moisture in large quantities is present, it follows, therefore, that when the supply is eliminated, the cyclone will begin to dissipate. It is thought that the energy necessary to form and maintain a tropical storm is derived from the latent heat of condensation contained in the warm moist air of the tropics. It is plain that when this source of energy is not present, the storm loses its identity and decays.

The elimination of the energy source is accomplished in several different ways. First, when a tropical cyclone moves over a large land mass such as the Philippine Islands or China where the air being introduced into the cyclone is relatively much drier than that of the tropical sea, the cyclone will begin to dissipate. In reference to the Philippines, however, overland storm trajectories over those islands is comparatively short and most storms tend to regenerate upon entering the South China Sea.

Frictional forces derived from rugged terrain features also combine to dissipate tropical cyclones in that area. Over China, the terrain effect is also felt in large degree although the lack of a moisture source seems to be indicated as the primary reason for storm dissipation in that region.

As typhoons move from tropical latitudes to more temperate latitudes over the ocean, there has been a tendency in the past on the part of some typhoon forecasters to refer to the typhoon as being extratropical when it reached the vicinity of 35 degrees north latitude or moved into the proximity of a mid-latitude frontal system. This is a dangerous assumption and should not be made without sound basis in fact. As has been previously pointed out by Palmer and others, the process of dissipation is a gradual one and does not occur over a period of hours, but usually of days. The structure of the typhoon differs markedly from that of the extratropical storm and evolution from one to the other takes place only after the gradual induction of colder, drier air into the typhoon circulation.

Only two tropical cyclones during 1949 dissipated while over tropical ocean waters, and both of these occurred during the winter when the advection of cool dry air into their circulation was quite likely. The other cyclones dissipated upon crossing over a large land mass such China, or upon reaching latitudes above 30 degrees north. The more intense of the tropical cyclones reaching higher latitudes (Patricia and

Allyn for example) did not dissipate, but assumed extratropical characteristics and moved off to the northeast as deep mid-latitude cyclones.

15. Damages.

During 1948, as in past years, death and destruction followed in the wake of the Pacific storms. The known damage and loss of life staggers the imagination. The unknown damage was also undoubtedly tremendous among the countless coral atolls and volcanic islands that dot the Pacific and throughout the land areas of the Philippines and South China where news travels slowly.

Typhoon Libby was, perhaps the most destructive storm of the year. Developing rapidly east of Iwo Jima, it pounded that tiny volcanic spit with winds of 120 miles per hour and gusts estimated at 175 miles per hour. Roaring west, it presently reached Okinawa where it stagnated directly over the station for seven hours. Then, as abruptly as it had arrived, it headed northeast, leaving behind an estimated $10,000,000 property damage and a dazed and battered populace.

Of the eighteen named Tropical Cyclones that pursued their various paths across the Western North Pacific, only a few caused serious damage to military installations. They were: Della, Gloria, Judith, Kitty and Allyn. The greatest damage to military installations has been credited to Typhoons Gloria and Allyn; these are the only storms on which authoritative damage reports are available. Although no breakdown of the destruction incurred by Okinawa as Gloria passed, was received by the Weather Central, total losses were estimated to be in excess of twenty (20) million dollars.

Allyn was somewhat less destructive to Guam, as may be seen from the following breakdown:

Air Forces	$ 11,000,000
Navy	3,811,158
Non-Military	2,503,700
Army	1,750,000
Total	$ 19,064,858

Included in the above was the loss of crops suffered by the native Guamanians which has been a continuing problem affecting their livelihood.

The afore-mentioned Tropical Cyclones, plus several others, inflicted severe damage to civilian population throughout the Philippines, China, Formosa, Okinawa, Japan and Guam. A breakdown of the civilian damages reported in Japan is shown on page 31.

DAMAGES BY STORMS	KITTY	HESTER	DELLA	JUDITH
Dead	98	3*	127*	134
Injured	392	0	194	127
Missing	44	5	1,000	93
Houses completely or half destroyed	11,822	41	1,600	1,698
Houses lost	1,270	0	0	1,102
Houses flooded over floor	116,133		3,327	15,569
Paddy fields lost	18,086	2,679	3,824	2,734
Paddy fields flooded	11,532		0	55,045
Bridges lost	310	57	199	181
Banks destroyed	242	0	0	406
Ships sunk	15	0	0	14
Ships lost	109	0	0	76
Ships damaged	87	0	0	36

* No Americans

Although much non-military damage results from high winds, the greatest destruction is a result of heavy rainfall associated with typhoon activity. This was especially true in Japan, as shown by the breakdown on page 31, and in the Philippine Islands. In the Philippines, extensive damage was caused by storms in which no winds in excess of forty(40) knots were recorded. Actual accounts of such instances are not available to the Typhoon Post Analysis Board.

In general, much military and civilian damage is prevented each year by adequate storm warning; however, this only applies to wind destruction as very little may be done to combat the heavy rainfall that accompanies these disturbances.

16. Error Analyses.

Since the primary function of the Typhoon Warning Network is to prepare accurate forecasts of tropical cyclones in the Northern West Pacific Ocean, it is necessary that some sort of verification program be instituted to check on the success of the forecasts.

At the Typhoon Warning Center the errors for bulletin locations, 12 hours forecasts, and 24-hour forecasts made on all bulletins issued have been computed. The method used for determining the error consists of measuring the distance in nautical miles from the questioned position to the position as determined by post analysis for the same time.

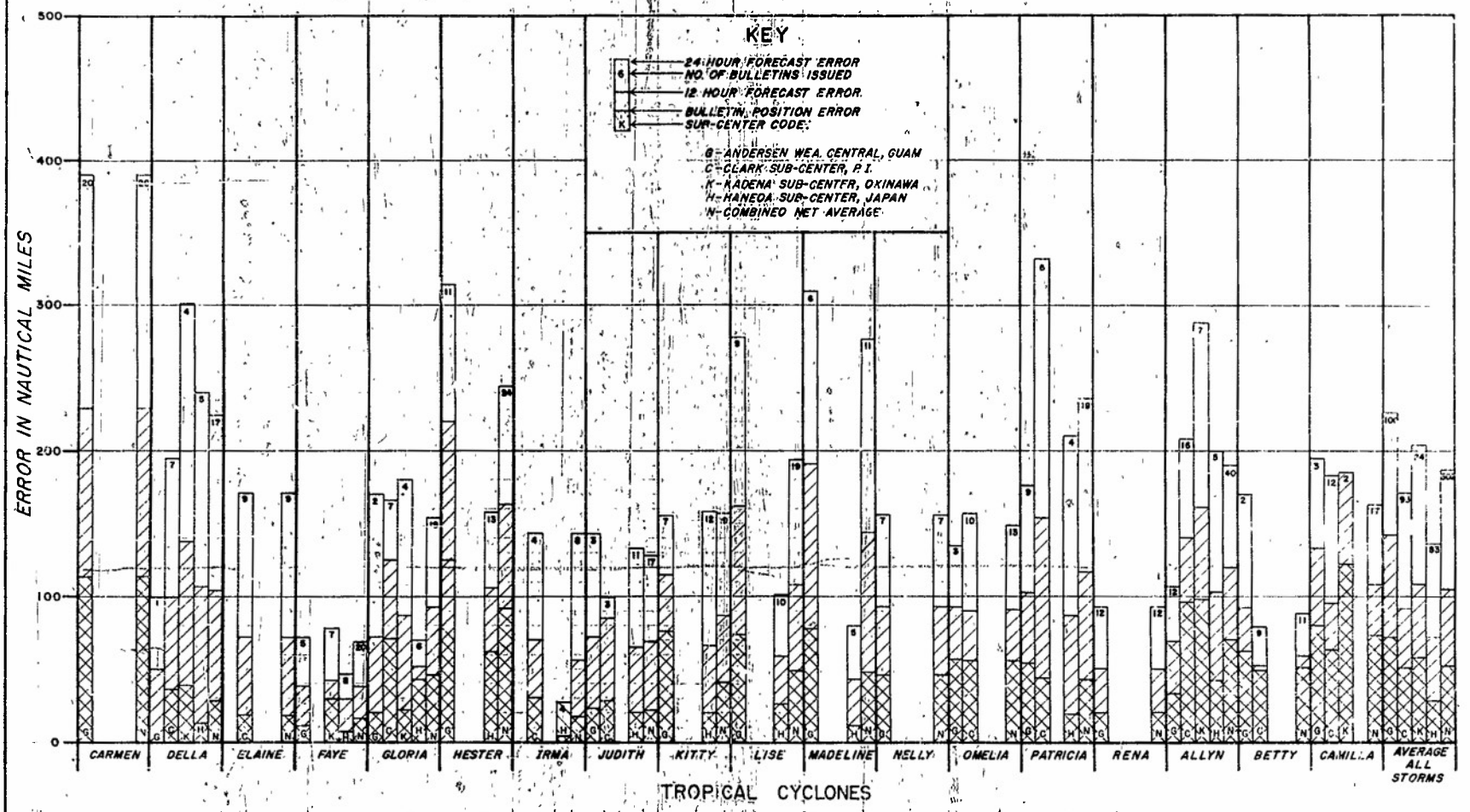
A chart showing the various average errors made by each sub-center for each tropical cyclone that occurred during 1949, is presented on the following page. This chart shows no noticeable trend, further emphasizing the fact that each individual cyclone is a problem by itself. The part of the graph showing the combined averages for all storms for each sub-center and the Net is of particular interest. It would appear that the forecaster's abilities at each sub-center are indicated by the heights of these bars. This is not the case, however, as many other factors enter into the consideration.

From the graph, it appears that the forecasters at Andersen Weather Central are less proficient than those at other stations. It must be remembered, however, that the forecasts made at Guam were usually made at the beginning of the life cycle of the storm when it was ill-defined and subject to changes in speed and direction. In addition, the data available in Guam's area of responsibility is extremely scarce, often being limited to reports from Guam, Saipan, Iwo Jima, a few islands to the south of Guam, and whatever ships might happen to be in the area.

Clark was hampered somewhat by lack of data and also by the fact that many storms recurved in their area. Kadena, being out of

ERROR GRAPH

1949 TROPICAL CYCLONES



operation for a long period due to damage caused by Typhoon Gloria, issued only 24 bulletins, rendering their errors non-representative. Haneda Sub-Center had the advantages of a comparative wealth of data and relatively straight tracks which were usually established before reaching their area. Cooperation of the Japanese Central Meteorological Observatory was also of great aid. This is not meant to infer that the forecaster at Haneda are less proficient than those at other sub-centers, only that if all forecasters had the same tools to work with, the average errors would be much closer together.

Much of the error in forecasting is due to the erroneous location of the center of the storm at the time the forecast is being prepared. In an effort to eliminate this error and obtain a figure more representative of the forecaster's ability, the forecast errors were recomputed using the same forecast direction and velocity, but using the post analysis position as a basis rather than the erroneous bulletin position.

It is beyond the scope of this report to discuss the forecast errors individually, but explanation of the large errors made on certain storms should be attempted. Detailed explanation has usually been covered in the individual Tropical Cyclone Reports.

The largest average errors of 1949 were made by Guam in forecasting the movement of Typhoon Carmen. A glance at the post analysis path of this cyclone on page - will show the reason for this; Carmen had a very unusal path, to say the least. Also reconnaissance was inadequate and data from the area very meager. Typhoon Hester, another unusal storm, had large forecast errors for the same reasons. The large errors on Lise and Madeline were due mostly to the fact that unknown to the forecasters, both were in the process of recurvature at the time they were first detected.

Other large errors were made by Kadena in forecasting Della and Allyn, and by Clark in forecasting Patricia, the latter two cases being due to unanticipated recurvature. Haneda had average 24-hour forecast errors or more than 200 miles on only three storms during the season; Della, Patricia, and Allyn. The large errors on Della were due to the rather unusual northward movement, the errors on the other two storms being due to acceleration of the storm after recurvature.

On the credit side of the ledger are the numerous accurate forecasts made by each member of the Net. In almost every case, these small errors are attributable to the smooth track of the cyclone and the availability of data.

Unfortunately, no verification of tropical cyclone forecasts was attempted in previous years either in the Pacific or the Caribbean; at least none appears in the available literature. Thus there is no basis for comparing the success of the forecasters of the 1949 season with that attained in previous years. It would seem, however, that a 24-hour forecast error of 187 miles leaves much to be desired. This average error means that the storm could be located anywhere within an area of 110,000 square miles, which is quite a large area even in the Pacific Ocean. Similarly the 12 hour forecast error of 105 miles means an error area of 35,000 square miles. In locating the bulletin position of the storm the average error amounted to 52 nautical miles, an error area of 8,500 square miles.

IV. TYPHOON AERIAL RECONNAISSANCE

17. 1948 Operations.

Discussion and debate of the relative merits of high and low level typhoon reconnaissance is as old as reconnaissance itself. Each method has its advocates since both types of reconnaissance have their place in the never ending search for tropical cyclone data. The goal of the search is, of course, possession of all possible knowledge pertaining to tropical-cyclone phenomena. While attainment of this goal is not feasible with present methods and equipment, nevertheless, the search will go on and both types of aerial reconnaissance mentioned above will continue to play a large part in the eventual realization of the goal.

Weather reconnaissance in the Pacific during 1948, as performed by the 514th Weather Reconnaissance Squadron, was a combination of the two methods, usually dependent upon the type of information desired by the using agencies. The standard typhoon reconnaissance procedure not in use and developed late in the year, is such a combination and employs the boxing method of circumnavigating the storm.

Following the take-off on a typhoon mission, the aircraft climbs on course to the storm area until the 700-mb level is attained. Upon reaching the storm, a penetration is made directly into the eye by flying perpendicular to the wind toward the center until the eye is reached, keeping the wind off the left wing. Within the relative calm of the eye, a descent is made to 1,500 feet, at the discretion of the aircraft commander. The weather observer aboard determines the pressure of the storm at the center, gathers other information normally required, and sends his report. Circumnavigation must now be accomplished. A climb back to the 700-mb level is made, and departure from the eye is made through the weakest quadrant of the storm as determined by radar-scope returns. When the point is reached where the circulation of winds about the storm has dropped to 40 knots, another descent is made to 1,500 feet and the bracketing procedure begins. This consists of flying four legs

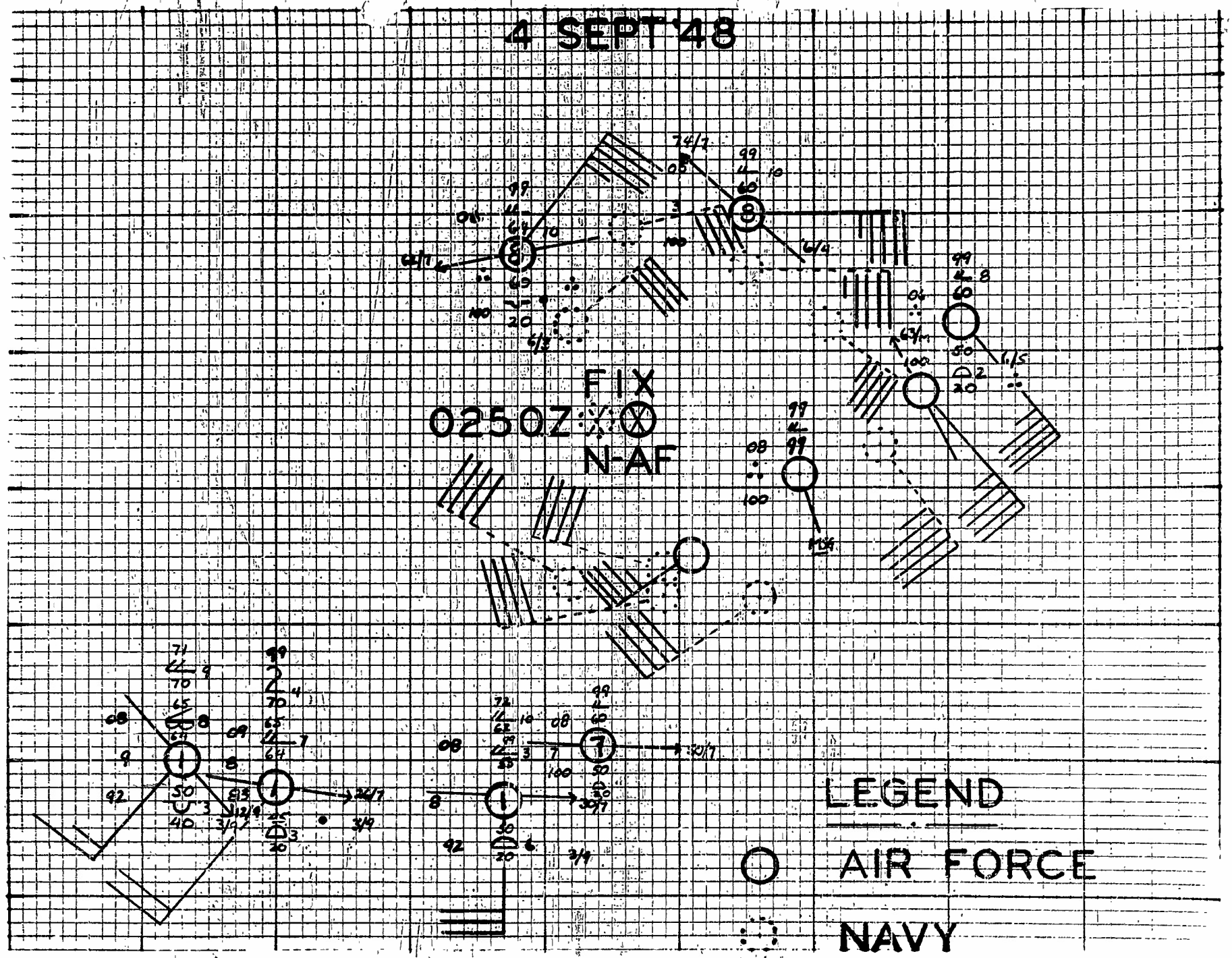
counterclockwise about the storm, each leg approximately 70 to 80 miles in length, depending upon the configuration of the 40-knot winds. The legs are oriented respectively on the cardinal headings of south, east, north, and west, and the movement of the storm taken into consideration while the bracketing is being accomplished.

The advantages of this method appear to be obvious in that both surface and upper-air data is gathered. The surface data is obtained at a fixed distance from the storm center in all quadrants. The eye is definitly fixed at both levels. The minimum 700-mb height and surface pressure, together with the maximum temperature within the eye, are secured. Although more time is consumed in the climbs and descents required than would be the case if the entire mission were flown at one level, it is felt that the information gained warrants it and is of greater importance. Also, to be seriously considered is the factor of crew fatigue, which in bypassing the areas of severest turbulence, is lessened considerably. In like manner, the danger of damage to the aircraft is reduced to a minimum.

18. Reconnaissance on Typhoon Hazel.

During the period of Typhoon Hazel, September 2-7, 1948, a noteworthy opportunity arose to consider both high and low-level reconnaissance at close hand. On the morning of 4 September 1948, a B-29 of the 514th Reconnaissance Squadron, staging out of Clark Field, Manila, toom off to reconnoiter Typhoon Hazel, centered 250 miles off the east coast of Luzon. At that time, single-level missions at the 700-mb level was standard procedure. Consequently, the aircraft climbed on course to the 700-mb level and, in due time, arrived in the storm area where circumnavigation was begun in the southwest quadrant. Flying counterclockwise with the circulation around the center, the aircraft secured readings in all four quadrants then took up a heading to establish the center of the typhoon and presently broke out into the eye. Flying below them at 600 feet over the water, the crew saw a Navy Privateer aircraft which had been dispatched from Sangley Point Naval Air Station, Manila, also to reconnoiter the storm. Although the flights had not been planned to coincide intentionally, it, nevertheless, afforded an unprecedented opportunity to study the two methods of reconnaissance whose combined reports resulted in the plot shown on the following page.

A close examination of the plot will reveal a remarkable similarity of data obtained. To simplify the chart so that it would have greater wind field clarity, only a very small porportion of the data reported is plotted. The Air Force reports are indicated by solid figures and the Navy reports by dashed figures. Both crews reported the area of maximum winds and heaviest rain to be in the northeast quadrant. The Navy observer reported surface winds as "gusts to 75 knots in squalls" while the 514th Squadron observor obtained 700-mb level winds of 74 knots determined by double drifts. Both crews reported the eye as


4 SEPT 48
0250Z
FIX
N-AF
LEGEND
AIR FORCE
NAVY

The outlook on typhoon reconnaissance for the 1950 season is considerably brighter. The 512th Reconnaissance Squadron (VLR) Weather is to become operational very soon at Yokota Air Force Base, Japan, and should be an immeasurable aid during the next season. At the present time, a forecaster from that organization is on TDY with the 514th Reconnaissance Squadron and is working with the Typhoon Post Analysis Board to familiarize himself with its procedures, problems and needs. It is felt that this training will be of valuable assistance to the 512th Reconnaissance Squadron when they begin flying typhoon reconnaissance

One of the faults of reconnaissance during 1949 was the scarcity of fixes on typhoons and the inaccuracy of some of the fixes obtained. During the reconnaissance of Typhoon Allyn the 514th Reconnaissance Squadron inaugurated the procedure of sending two navigators on each flight. The results were far beyond the most optomistic expectations. It was found that two navigators could fly two consecutive missions with less fatigue than one navigator would fly one mission alone. On these missions where two navigators work together, one man does all dead reckoning taking responsibility for position reports and directing the aircraft while the second navigator concerns himself primarily with obtaining fixes for the other navigator by means of Loran, radio, celestial or any other method available. This procedure provided more fixes which were more accurate than by any previous method. It is therefore recommended that whenever possible two navigators should be sent on each typhoon reconnaissance mission.

Another common fault found with typhoon reconnaissance in 1949 was a lack of coordination between the Typhoon Center and the 514th Reconnaissance Squadron. In accordance with a directive from 2143rd Air Weather Wing a forecaster from the 514th Reconnaissance Squadron has been assigned to full time additional duty with the Typhoon Post Analysis Board. He is to concern himself with collecting reconnaissance data from his squadron, prepare reconnaissance or operational, portions of individual tropical cyclone reports and the yearly summary, act as monitor for the Typhoon Post Analysis Board during tropical storms and maintain liaison between the 514th Reconnaissance Squadron and the Typhoon Post Analysis Board. This should eliminate the delays experienced in the past in securing reconnaissance; also, it should provide more complete information from the reconnaissance organization, thus preventing the loss of much valuable data as experienced during the 1949 season.

In several instances during 1949 the reconnaissance missions failed to circumnavigate the storm being reconnoitered. In most cases the reason for this was because of late take-off due to aircraft not being in commission, or long distances prevented circumnavigation because of darkness. With two squadrons flying typhoons in the 1950 season it is reasonable to expect that every storm will be circumnavigated. It is

strongly recommended that an earnest attempt be made to do so as the data obtained by such reconnaissance is invaluable.

Only nine soundings were made in typhoon centers. The reasons for not taking soundings were: insufficient time in the typhoon's eye, shortage of fuel supply, and in many cases due to cloud coverage in the eye. Eighteen dropsondes were released; six of them were successful.

Radar scope photographs and aerial cloud photographs were not always taken. Radar operators and Weather observors seem to need more instruction in the use of the K-20 aerial camera.

It is the opinion of the Typhoon Post Analysis Board that very high altitude reconnaissance on Typhoons would be of great value for research purposes. It is recommended that, if at all practical, this be carried out during the 1950 typhoon season.

OPERATIONAL SUMMARY

514th RECONNAISSANCE SQUADRON (VLR) WEATHER

(1949 TYPHOON SEASON)

Aircraft and crews available	
1. Average number aircraft available.	0.5
2. Average number crews available.	5.0
Missions required	
1. Actual typhoon monitoring (75 mph winds)	46
2. Search, research or synoptic weather reconnaissance missions of primary concern to typhoon forecasting.	54
	Total 100
Missions accomplished	
1. Actual typhoon missions flown.	40
2. Search, research or synoptic missions.	10
	Total 50

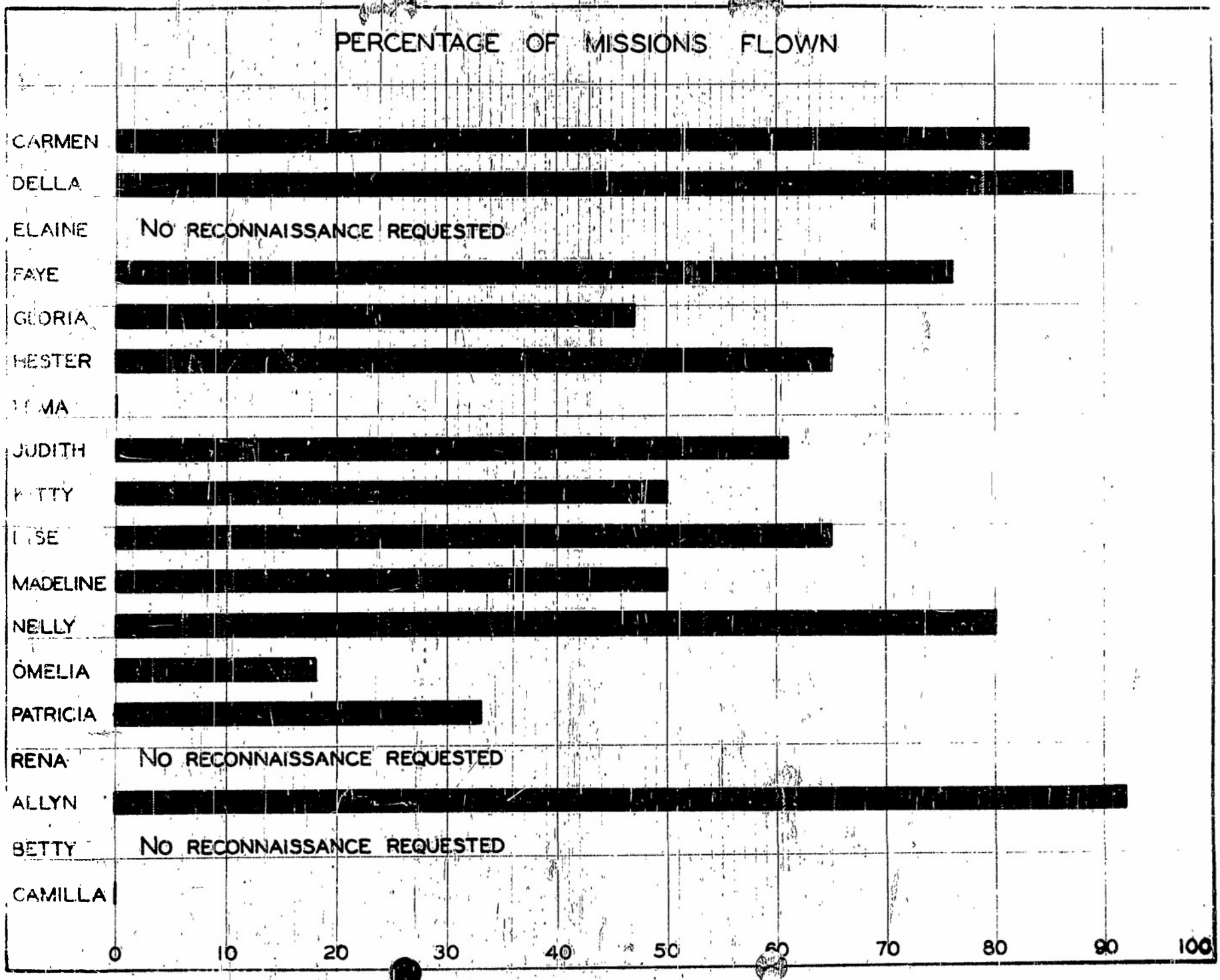
being open to the northwest and estimates of surface winds made by the 514th Squadron observer agreed within five knots with those reported by the Navy observor in all quadrants. The only discrepancy noted in the two reports, was a difference of 15 miles in the position of the typhoon center, which was conceivably an instrument or navigational error, or the combination of any number of factors. An error so small in determining the center of a typhoon of the magnitude of Hazel is of little consequence, as an allowable error of 25 miles is the normal limit. Although no concrete conclusions as to the relative merits of high or low-level reconnaissance can be drawn from this single mission, it can be stated definitely that a need for both methods exists. The type to be used must be determined by the information desired and the intensity of the storm to be reconnoitered.

19. 1949 Operations.

The Typhoon Warning Center at Andersen AFB (formerly North Guam AFB) made 100 requests for typhoon reconnaissance during the 1949 typhoon season. Of the requests made, only half could be fulfilled by the 514th Reconnaissance Squadron (VLR) Weather. The 50 missions flown actually covered 54 requests as there were four cases where two separate storms were reconnoitered by one flight. There were four cases where the 514th Reconnaissance Squadron used aircraft furnished by the 19th Bombardment Wing (Medium).

In every instance where reconnaissance was requested and the 514th Reconnaissance Squadron was unable to furnish the mission, the reason was the same - no aircraft available. The tropical climate and aged equipment began to hamper the squadron's operations more and more as the season progressed. On the first five typhoons of the year the 514th flew 70.92 percent of the missions requested, but on the last five typhoons only 44.38 percent of the missions were flown and this percentage is high only because of typhoon Allyn on which eleven missions of twelve requested (91.66 percent) were flown. These percentage figures show very well how reconnaissance declined as the 1949 season progressed (See page 36).

Communication of reconnaissance data showed an almost reversed trend to the missions flown. At the beginning of the season reports sometimes required several hours to reach the Typhoon Center. In a few cases they were never received by the Center at all. Toward the end of the season conditions were very much improved and it was usually only a matter of minutes until this information reached the Center. Only in cases where communications equipment was damaged by storms were there any long delays in the receipt of reconnaissance messages. It is regrettable that accurate logs were not maintained on reconnaissance messages by the Typhoon Post-Analysis Board so that communications statistics could be included in this report. However, such a program has been initiated and a detailed report on this subject will be included in the 1950 Operational Report.


PERCENTAGE OF MISSIONS FLOWN
CARMEN
DELLA
ELAINE
NO RECONNAISSANCE REQUESTED
FAYE
GLORIA
HESTER
JUDITH
KITTY
LISE
MADELINE
NELLY
OMELIA
PATRICIA
RENA
NO RECONNAISSANCE REQUESTED
ALLYN
BETTY
NO RECONNAISSANCE REQUESTED
CAMILLA
0
10
20
30
40
50
60
70
80
90
100

Hours flown	DAY	NIGHT	TOTAL
1. Actual typhoon missions.	319.40	110.45	430.25
2. Search missions.	71.40	27.30	99.10
Total	391.20	138.15	529.35

Observations transmitted

1. Primary addressee NGAFB Typhoon Center — 880
2. Secondary addressee - Net — Unknown

Observations received by Typhoon Center

North Guam AFB (Andersen AFB) — 875*

Average delay in receipt of message

Record not kept.

Soundings

1. Aircraft — 9
2. Dropsonde — 18 (6 Good)

* Approximate

APPENDICES

TROPICAL CYCLONES OF 1949

TYPHOON CARMEN
January 15-20

Carmen, the last storm of the 1948 season, was post-analyzed as having moved in an anti-cyclonic arc. Its origin can be traced to the southeast of Yap, at the junction of the base of a westerly trough and a secondary line of convergence associated with the Inter-tropical trough. Its track can be followed south of Yap and northwest between Yap and Palau. Much speculation was afforded when three reconnaissance fixes indicated a loop in Carmen's path. Indications were that Carmen was a very small storm in the respect that high winds and weather extended only a short distance from its center. An allowance for navigational error along with a 48 hour stagnation would have discounted the unusual recurvature. The final leg pursued a southwest course into Mindanao, the result of the Siberian high cell's intrusion into the Philippine Sea. Sporadic surface and upper air data throughout the storm's duration was of insufficient value to present a true picture; the result -- confusion and inaccurate forecasting.

TYPHOON DELLA
June 17-21

Although Della was the second tropical cyclone of the year, she was the first of the 1949 typhoon season. Della began as an easterly wave and can be traced as far east as Truk with consistence. Kwajalein shows the passage also, but its track to Truk is indistinct. The eventual track was substantiated by data at Guam and Yap with intensification evident near 15 N and 127 E, seven days after the easterly passage at Truk. A surge of moist unstable air from the southwest was the primary factor in intensification. A parobolic path was followed, with the eye passing over Okinawa. Contrary to climatological data, Della pursued a path across Kyushu rather than the conventional movement up the polar trough to the south of the Japanese Empire. Della moved into the Japanese Sea and became extratropical four days after it was detected as a Typhoon.

TROPICAL STORM ELAINE
July 8-10

Elaine, a tropical storm throughout her life, developed from an ill-defined easterly wave that passed south of Guam. Lack of sufficient data prevented accurate detection of the easterly east of Guam. As Elaine passed Yap, a surge of the monsoon winds to the south of the Inter-tropical trough intensified the wave and a weak

circulation developed at its base. A 290 degree movement at 12 knots was followed until it passed over the northern tip of Mindanao; from this point a gradual recurvature toward the northwest was taken. A southerly flow in the South China Sea aided in intensification but there was no evidence of winds more than 45 knots throughout the storm. The storm tracked within 60 miles of Manila and dissipated rapidly as it entered the China coast west-southwest of Hong Kong.

TYPHOON FAYE
July 13-18

Faye was one of two storms that had its origin in the upper air, between 25 and 40 thousand feet, and gradually descended to the surface over the western edge of the Pacific high cell. (Indications of Kwajalein's upper winds verified the presence of an upper air low, and five days later it's nearness to Iwo Jima was reflected on the surface) Faye, a moderate storm moved near and to the south of Iwo Jima and recurved around the Pacific high cell, 500 miles to the west of Iwo Jima. Faye followed a northerly path upon recurvature and passed over the western edge of Kyushu into the Japanese Sea.

TYPHOON GLORIA
July 20-24

Gloria, one of the most intense and destructive typhoon's of the 1949 season, formed from a vortex associated with an easterly wave which was intensified by a southwesterly monsoon surge after passing south of Guam. Gloria was first detected as a typhoon near 15 N and 132 E. Her future track was north for 450 miles with inverse recurvature to the northwest passing over Okinawa and entering the China coast near Shanghai. Maximum winds were estimated in excess of 110 knots.

TYPHOON HESTER
July 23-28

Hester, one of the season's most confusing storms, resulted from the intensification of an easterly wave near Guam. Post analysis indicates that a convergent westerly and southwesterly flow in the vicinity of Saipan was the factor in intensification. Reconnaissance revealed a loop in Hester's track near Saipan. After a north-northwesterly movement to the east of Iwo Jima, the storm finally entered the Japanese mainland to the south of Tokyo.

Hester was strongest at the time she was first detected and weakened thereafter, becoming negligible when it struck the Japanese islands.

TROPICAL STORM IRMA
July 28-30

Irma originated in the South China Sea and intensified into a weak storm for reasons that are only supposition due to a lack of data in that area. Her path was northeast and finally north. Throughout her life, reconnaissance could find no evidence of a defined center, but reported 50 knot winds.

TYPHOON JUDITH
August 12-16

Judith, began as a vortex associated with an easterly wave and can be identified as having passed Kwajalein 20 days prior to its dissipation. Intensification into a typhoon was near 14 N and 126 E, but the cause is uncertain. Soon after detection of the typhoon, normal recurvature began, but two days later inverse curvature was evident. At the time it was thought that Judith split into two cells; one cell moving east-northeast and the other north-northwest. Post analysis indicates that only one cell was present and its path was slightly to the east of Okinawa with inverse recurvature over western Kyushu. Judith was a weak typhoon, attaining maximum winds of 65 knots.

TYPHOON KITTY
August 28-1 September

Kitty originated from an easterly wave that passed Kwajalein and intensified near 23 N and 154 E. It is believed that intensification was the result of a westerly trough that moved to the north of the storm prior to its detection. Further, the northwest movement into the nose of the Pacific high cell assisted in maintaining the gradient. Kitty began recurvature near 32 N and 140 E, but normal recurvature was never completed as the storm maintained a northerly movement across Honshu and dissipated near Hokkaido. Reconnaissance reported a maximum wind of 65 knots. Kitty inflicted more damage on the Tokyo area than any storm during the season. Gusts to 75 knots were reported with torrential rains.

TYPHOON LISE
September 2-6

Tropical Cyclone Lise was first detected as a weak tropical low passing north of Guam and Saipan on 31 August. Navy Reconnaissance two days later established that this low had increased to typhoon intensity. Intensification is attributed to the low moving into a stagnant low pressure area in the Philippine Sea. Lise began a sharp recurvature on 2 September and passed 70 miles southeast of Iwo Jima as an intense typhoon on 4 September. Maximum winds of 85 knots were experienced at Iwo Jima for a short period.

TYPHOON MADELINE
September 2-4

Madeline was the second of two storms during the season that originated in the upper air and surfaced over the western edge of the Pacific high cell. A surface ship on 1 September gave first indications of a relatively weak storm in the vicinity of 21 N and 151 E. The storm was discovered while in the process of recurvature; the track thereafter moving northward, missing Iwo Jima by 450 miles. Madeline never reached typhoon intensity and disappeared into the polar trough five days after it was detected.

TYPHOON NELLY
September 13-15

Nelly was the result of an easterly wave that intensified into a typhoon eight days after its passage at Truk. The factor in intensification was a weak but persistent westerly trough that extended south-southwest to a point just northwest of the storm. Reconnaissance established Nelly as a typhoon 250 miles south of Okinawa, after three previous missions over a period of five days had failed to indicate winds in excess of 45 knots. The storm passed south of Okinawa and struck central Formosa. Nelly disappeared into the China coast north of Hong Kong.

TYPHOON OMELIA
October 1-4

Omelia was first noticed in the latter days of September, in the Yap-Palau area. This storm can be traced to Kwajalein, nine days prior to its intensification to a tropical storm. Data is insufficient to determine the cause of intensification, and reconnaissance fixes failed to reveal its intensity. Moving northwestward, Omelia passed between Luzon and Formosa, striking the China

coast on 4 October 180 miles northeast of Hong Kong. Omelia's distinguishing feature was the reported fact that no closed circulation could be found near the center by reconnaissance.

TYPHOON PATRICIA
October 24-28

On 17 October, surface ship reports from the Truk area gave the first indication of the tropical disturbance later named Patricia. As it moved slowly northwestward it began to intensify such that a definite closed circulation was apparent with the passage southwest of Guam on 20 October. At this time, the storm was in the process of recurvature and continued thereafter on a northeasterly track which skirted all U.S. Military installations. Patricia traversed over 3,000 miles in the eleven days it was under surveillance by the Network.

TROPICAL STORM RENA
November 11-14

Tropical Storm Rena was an example of the early winter storms which intensify in the Palau area, then move across the Southern Philippines to die in the China Sea. Rena passed through the islands bringing heavy rains but no excessive winds. It is thought that damage was slight since the maximum winds reported by a land station was 45 knots. Recurving slightly upon leaving the Philippines, Rena took up a course for Hong Kong, but dissipation had already begun, and in crossing the China Sea the storm soon lost its identity.

TYPHOON ALLYN
November 11-24

On 10 November, Kwajalein experienced the first affects of the storm which later developed into Typhoon Allyn. The torrential rains and a wind shift indicative of a vortex induced the Kwajalein forecaster to release a tropad alerting the Typhoon Warning Network. As the storm continued westward it rapidly intensified. The first reconnaissance flight established the center of the storm north of Truk with maximum winds of 60 knots. Three days later when the storm approached Guam, the winds had increased to 120 knots. On 17 November, Typhoon Allyn struck Guam with a ferocity unequalled since 1900. Passing within 35 miles of the southern end of the island, the storm created havoc on a grand scale. No lives were lost even among the natives, who, lacking typhoon shelters, endured the storm in their houses, hundreds of which were completely destroyed. By early morning on the 18th, the populace was able to leave their shelter to survey the destruction which amounted to millions of dollars. Allyn continued along a west northwesterly track apparently

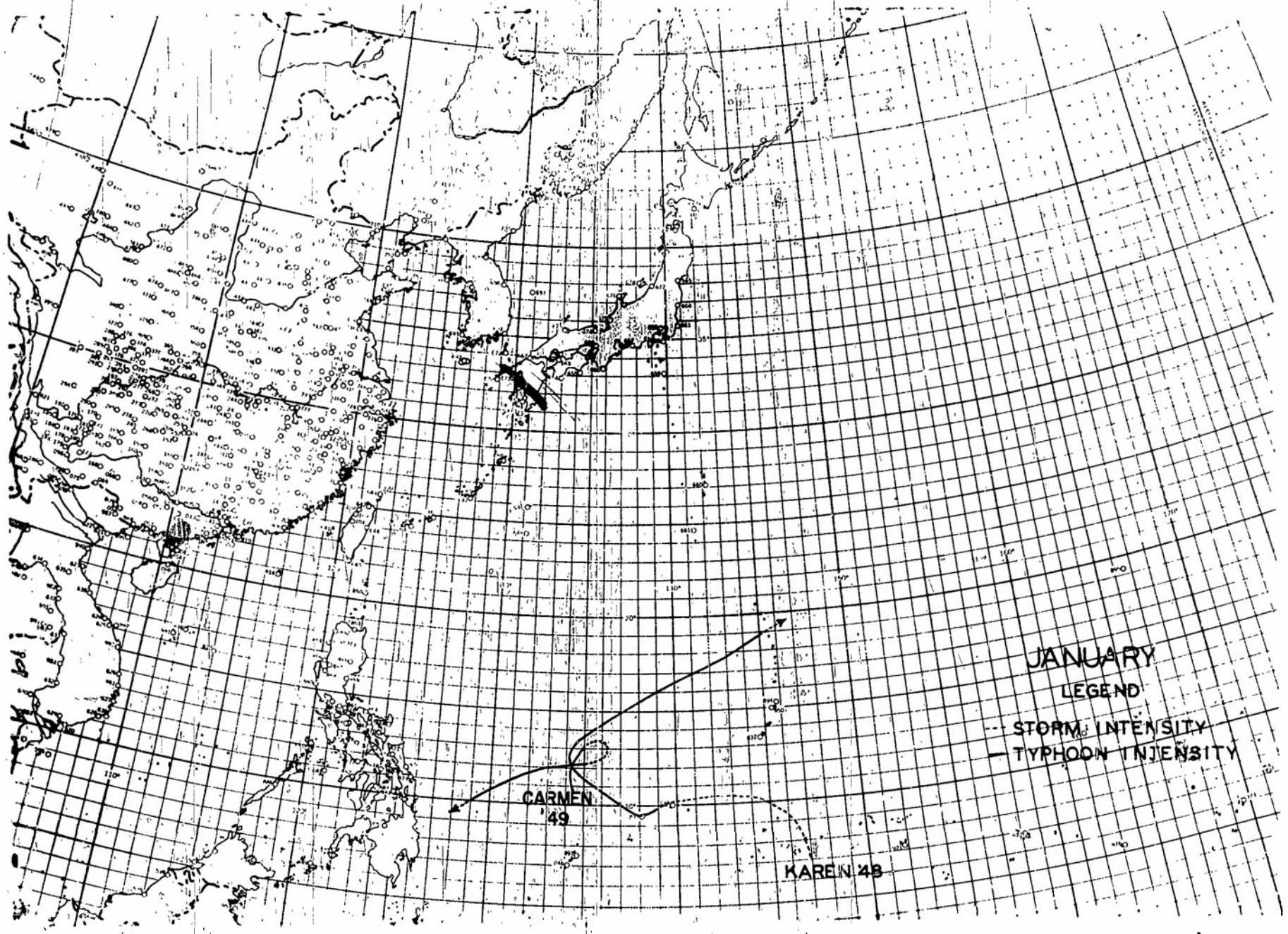
headed for Okinawa; however, recurvature occurred, and the typhoon passed south of Japan, lashing Torishima with 80 knot winds before setting course for the Aleutian low.

TYPHOON BETTY
December 3-5

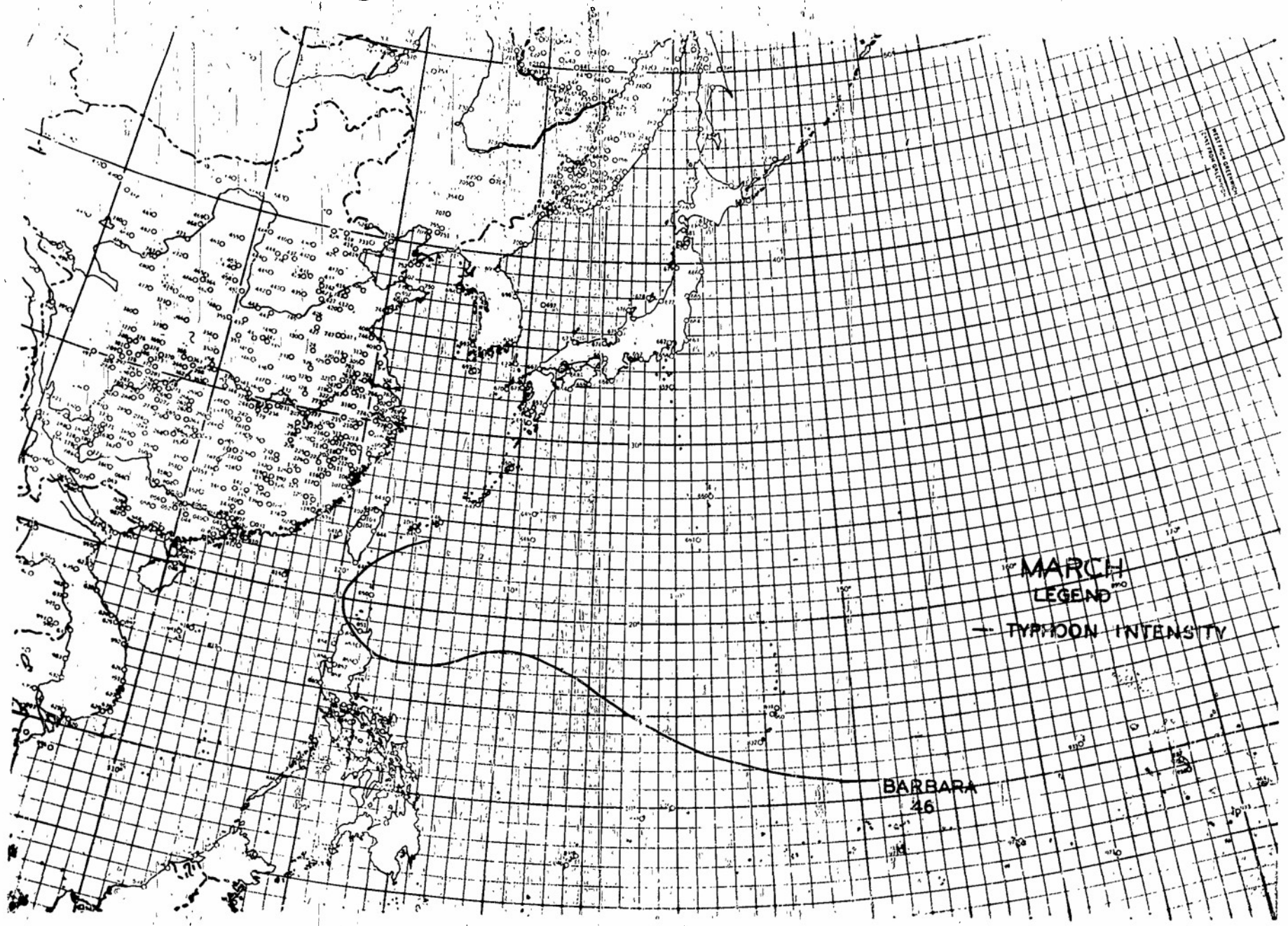
Tropical Cyclone Betty, a small but reportedly intense storm developed in the Yap-Palau area December 2nd and 3rd then moved west northwestward through the South Central Philippine Islands at an average speed of 12 knots. Although the first reconnaissance fix on December 3rd estimated the winds at 80 knots, the light surface winds reported as the storm moved through the Philippines indicate that Betty probably never exceeded 50 knots intensity. Thus ended one of the weaker and more obscure storms of the season.

TYPHOON CAMILLA
December 9-13

Camilla, the final significant storm of the typhoon season, was the ninth tropical cyclone to intensify in the Yap-Palau area. Similar to other late season storms, Camilla moved west northwestward across the Philippines at an average speed of 12 knots. Here, Camilla departed from the climatological tracks and curved northward across northern Luzon, dissipating while crossing the mountainous area. Camilla then moved northeastward up the polar trough, accelerating rapidly and becoming extratropical just east of Okinawa.


JANUARY
LEGEND
STORM INTENSITY
TYPHOON INTENSITY
CARMEN
49
KAREN 48

L-32-70



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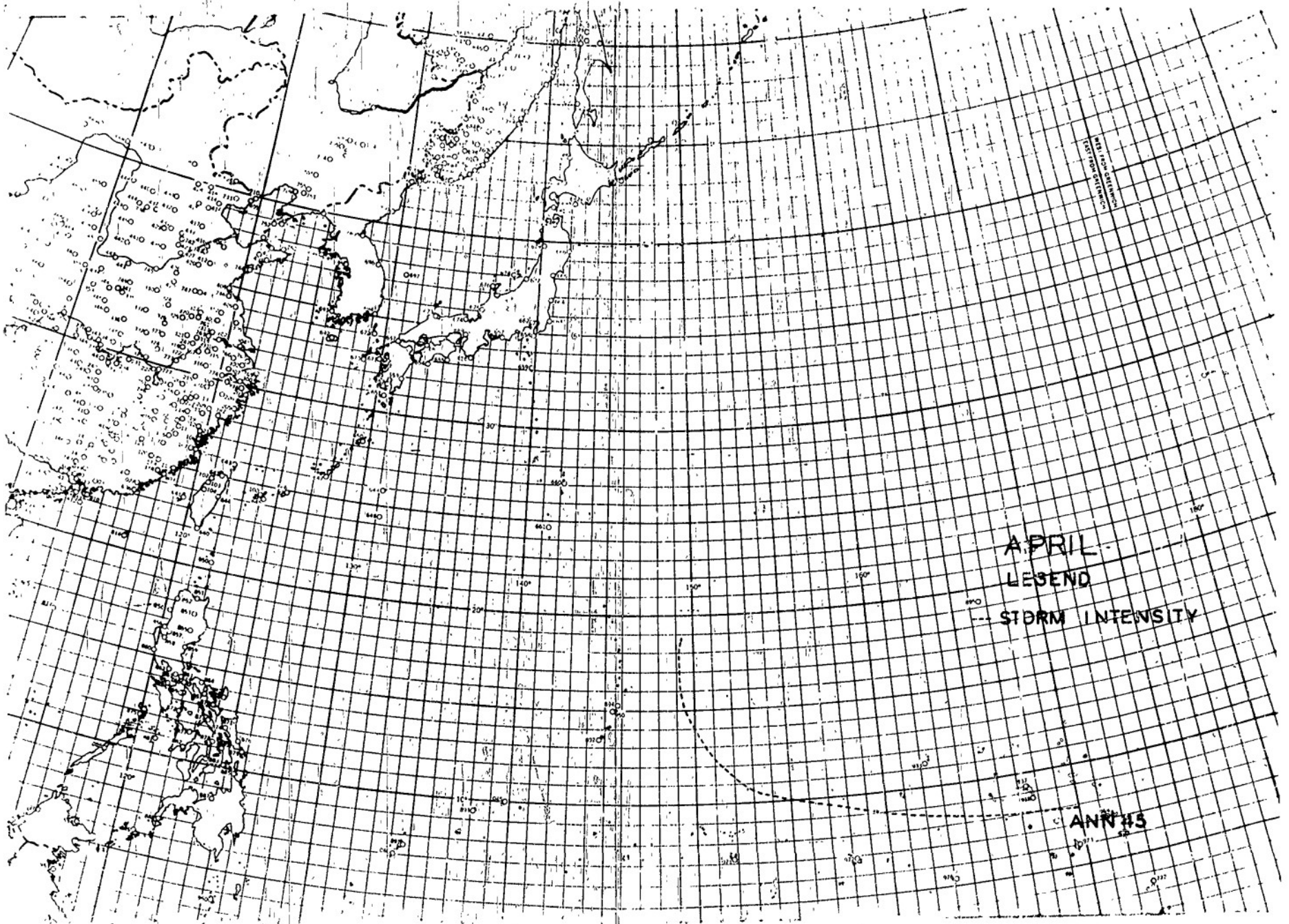

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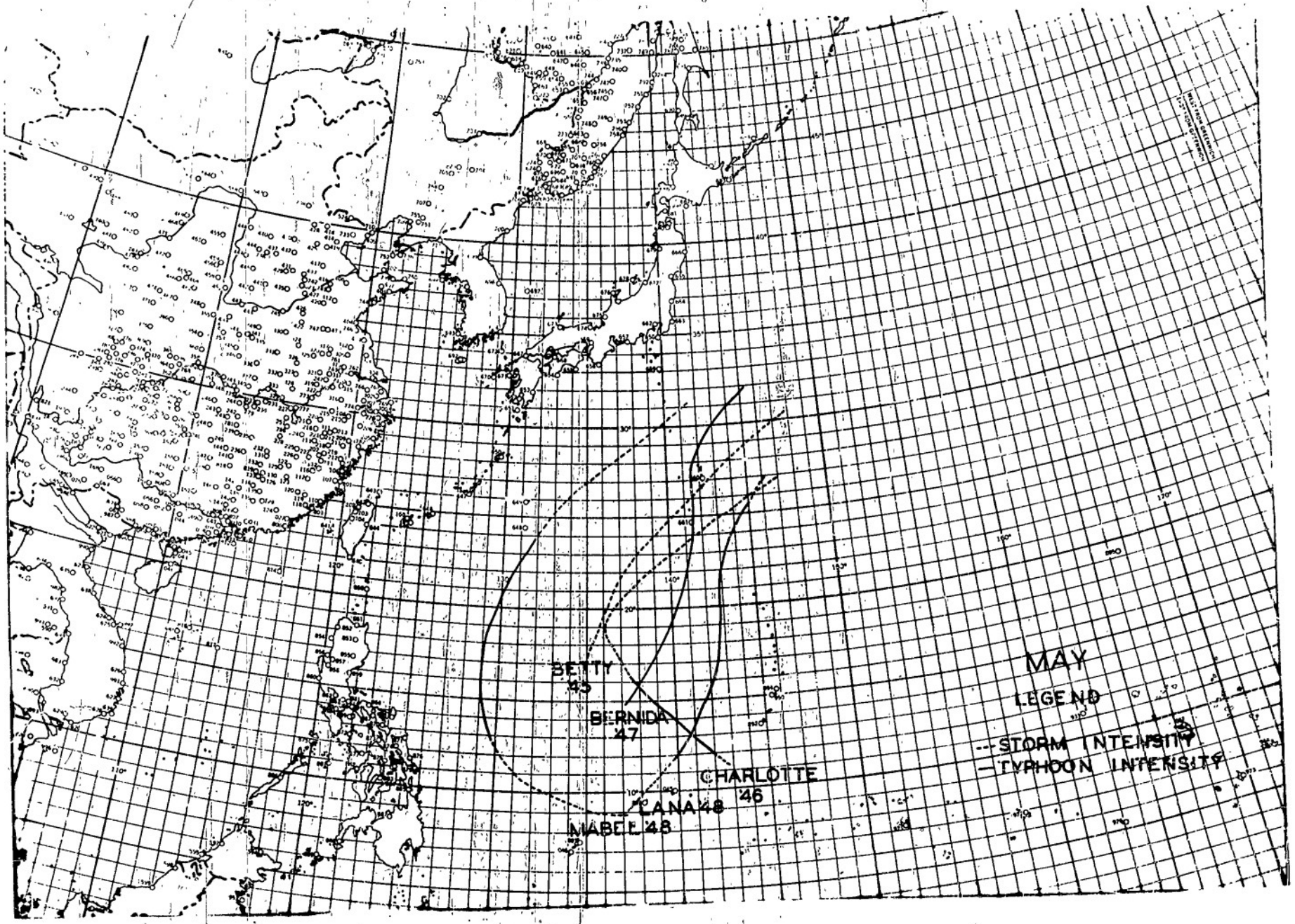
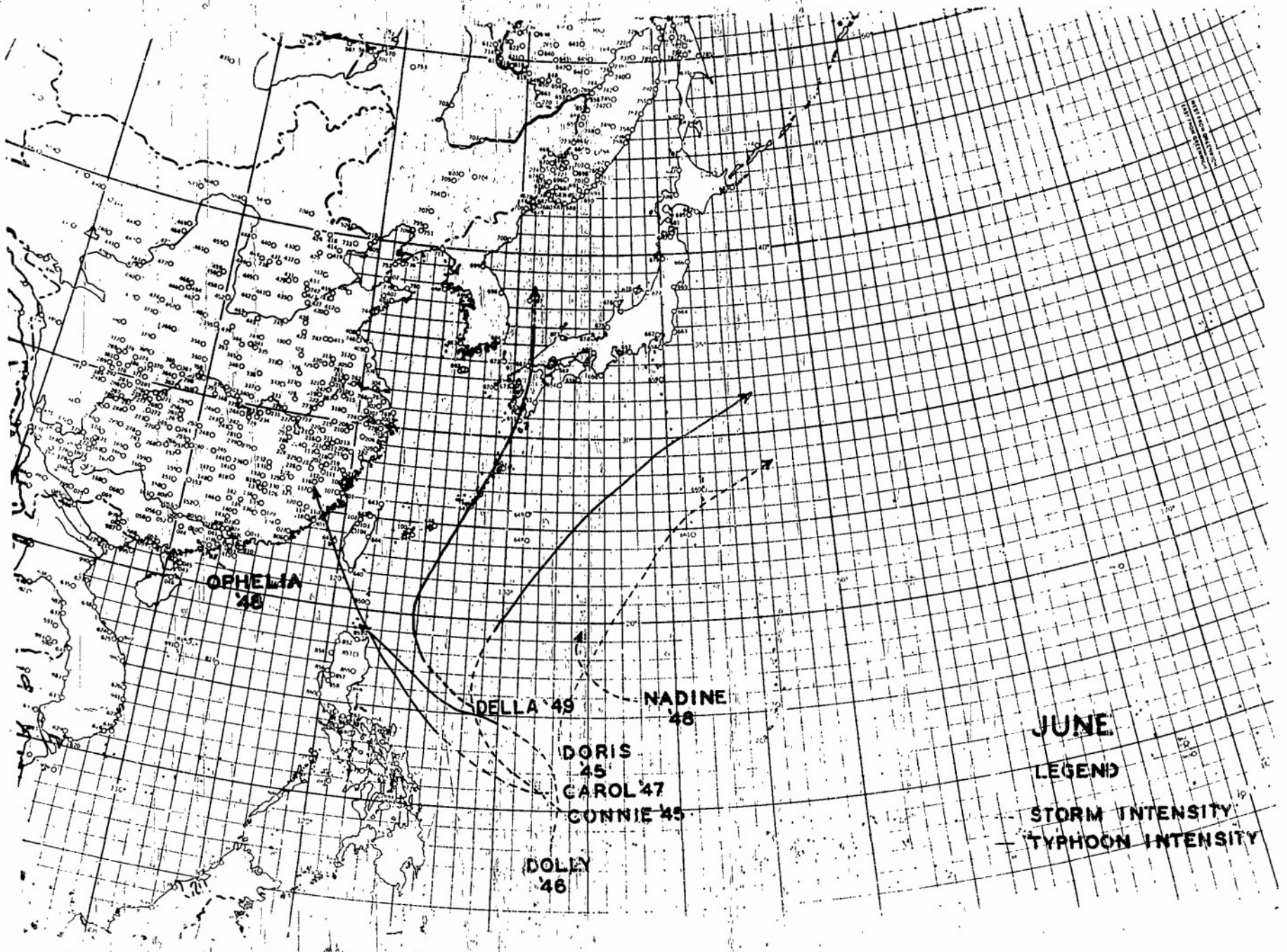

MAY
LEGEND
--STORM INTENSITY
—TYPHOON INTENSITY
BETTY
45
BERNIDA
47
CHARLOTTE
46
LANA 48
MABEL 48

L 55-50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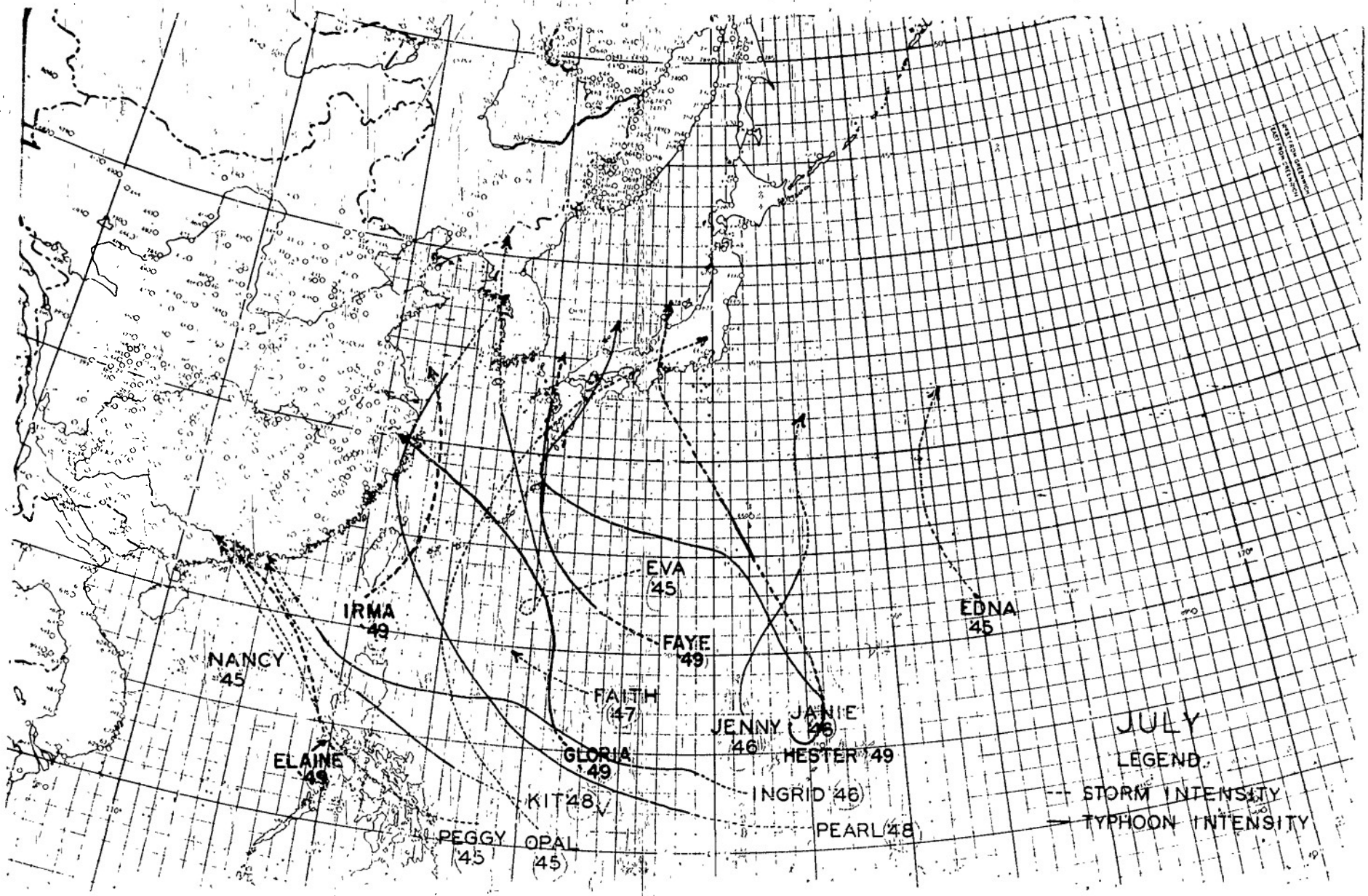
DELLA '49
NADINE '48
DORIS '45
CAROL '47
CONNIE '45
DOLLY '46
JUNE
LEGEND
STORM INTENSITY
TYPHOON INTENSITY

L-36-50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NANCY
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FAYE
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FAITH
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JANIE
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JENNY
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HESTER 49
GLORIA
49
ELAINE
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KIT 48
INGRID 46
PEARL 48
PEGGY
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OPAL
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EDNA
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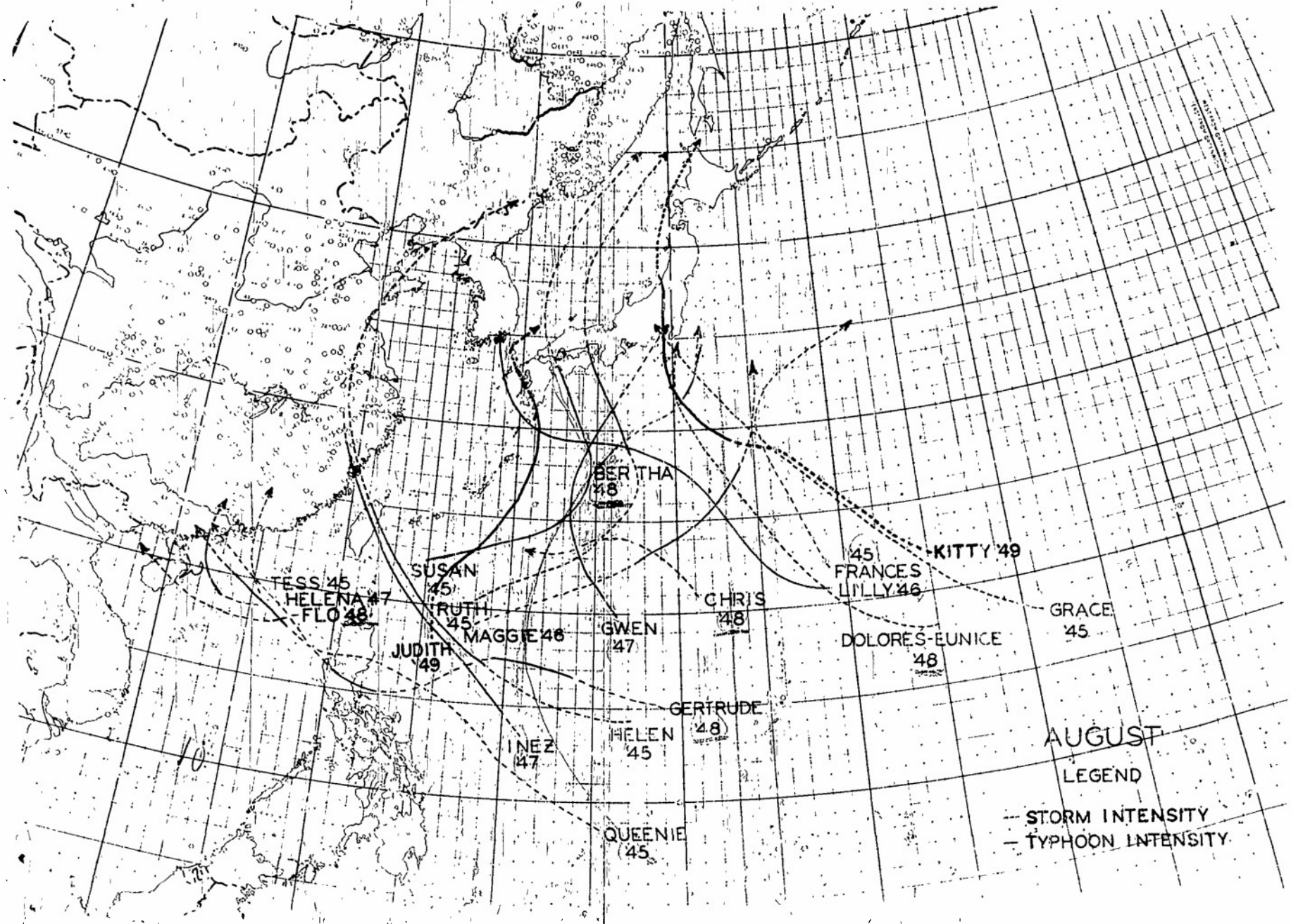
JULY
LEGEND
STORM INTENSITY
TYPHOON INTENSITY

L-37-50


BERTHA
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TESS 45
HELENA 47
FLO 48
RUTH
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MAGGIE 46
JUDITH
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GWEN
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CHRIS
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FRANCES
LILLY 46
KITTY 49
GRACE
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DOLORES-EUNICE
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GERTRUDE
48
HELEN
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INEZ
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QUEENIE
45
AUGUST
LEGEND
-- STORM INTENSITY
— TYPHOON INTENSITY

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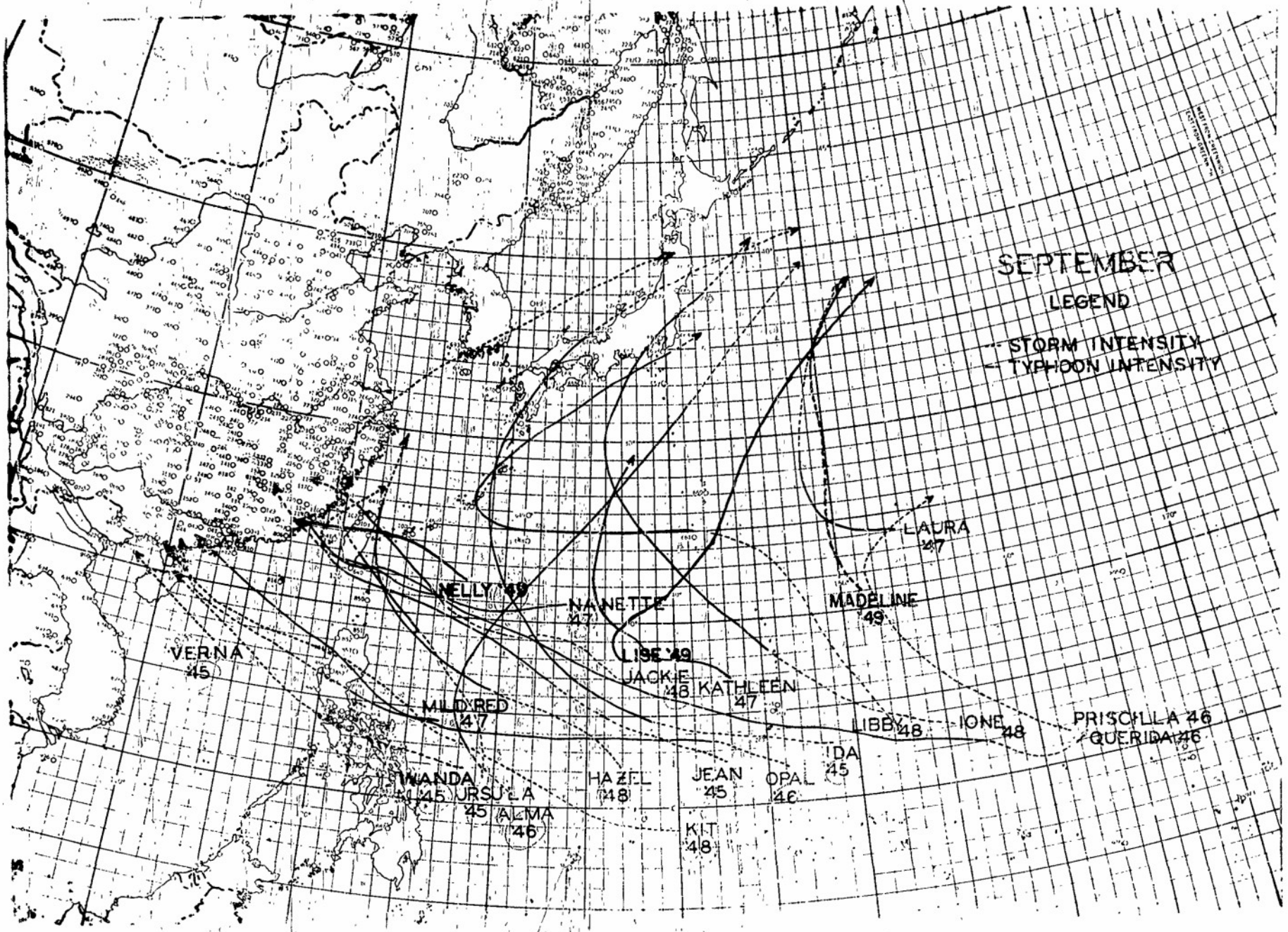
SEPTEMBER
LEGEND
STORM INTENSITY
TYPHOON INTENSITY
LAURA 47
MADELINE 49
NELLY 49
NANETTE 47
LISE 49
JACKIE 48
KATHLEEN 47
VERNA 45
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LIBBY 48
IONE 48
PRISCILLA 46
QUERIDA 46
IDA 45
IWANDA 45
URSULA 45
ALMA 46
HAZEL 48
JEAN 45
OPAL 46
KIT 48

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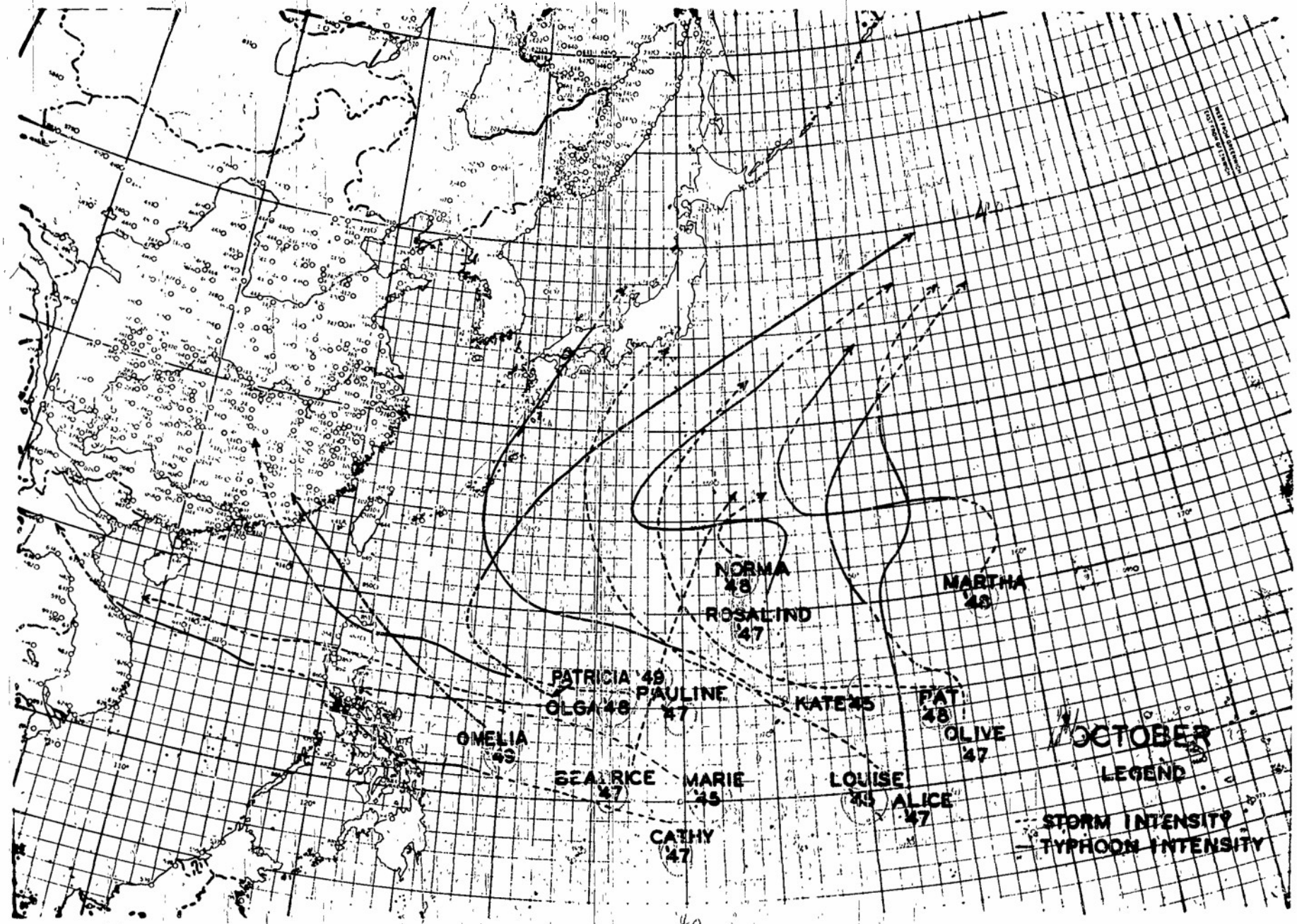
NORMA
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ROSALIND
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MARTHA
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PATRICIA 49
OLGA 48
PAULINE
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KATE 45
PAT
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OLIVE
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OMELIA
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BEATRICE
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MARIE
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LOUISE
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ALICE
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CATHY
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OCTOBER
LEGEND
STORM INTENSITY
TYPHOON INTENSITY

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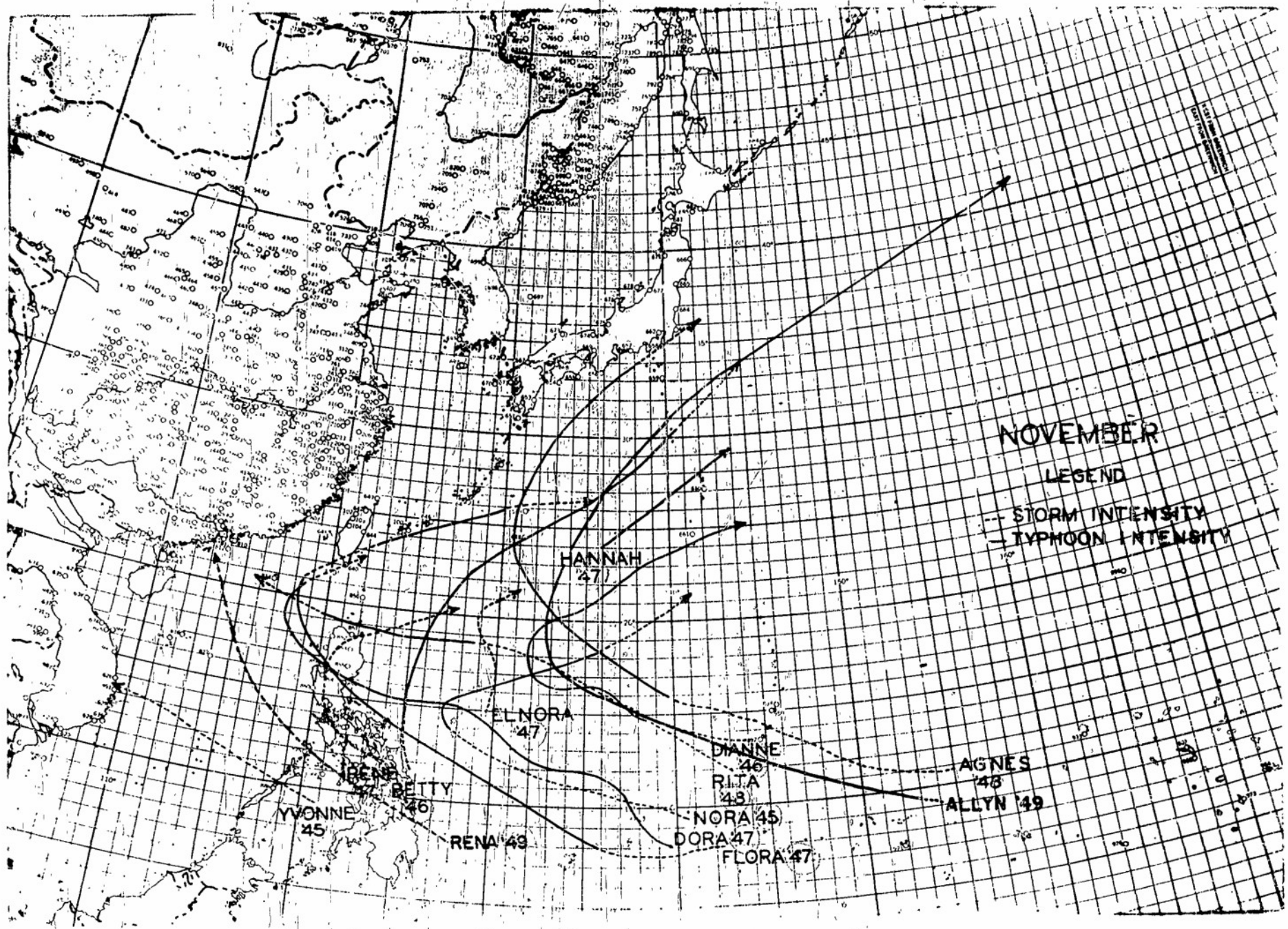
NOVEMBER
LEGEND
STORM INTENSITY
TYPHOON INTENSITY
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ELNORA 47
DIANNE 46
RITA 48
AGNES 48
ALLYN 49
NORA 45
DORA 47
FLORA 47
IRENE 47
BETTY 46
YVONNE 45
RENA 49

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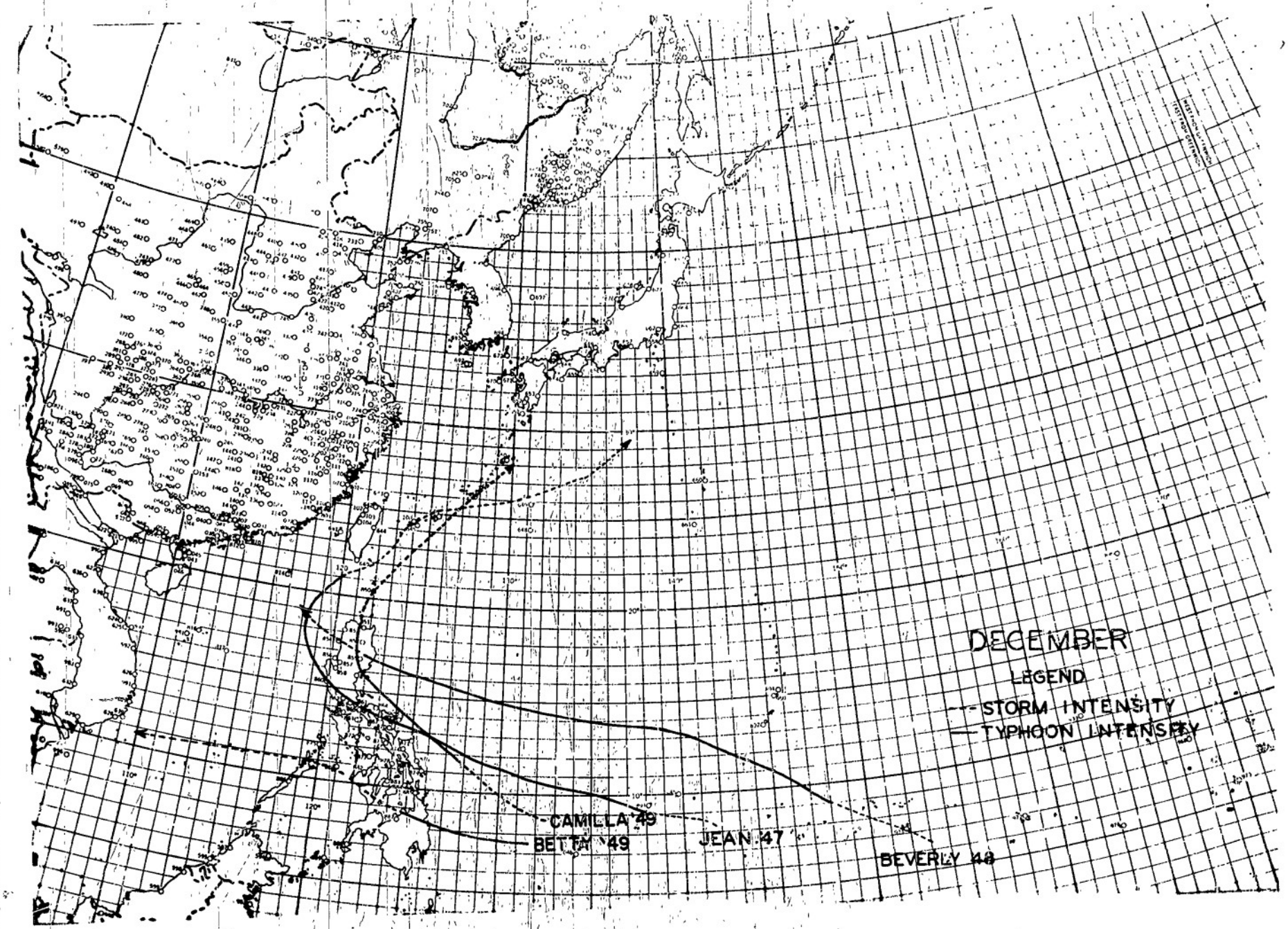
DECEMBER
LEGEND
STORM INTENSITY
TYPHOON INTENSITY
CAMILLA '49
BETTY '49
JEAN '47
BEVERLY '48

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