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SOME CHARACTERISTICS OF THE FORMATIVE STAGE OF TYPHOON DEVELOPMENT: A SATELLITE STUDY[1]

by

Capt. Robert W. Fett
Air Weather Service Member
National Weather Satellite Center

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1964

[1]This paper is to be presented at the National Conference on the Physics and Dynamics of Clouds in Chicago, Illinois during the period March 24-26, 1964.

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SOME CHARACTERISTICS OF THE FORMATIVE STAGE OF TYPHOON DEVELOPMENT: A SATELLITE STUDY

Robert W. Fett
Air Weather Service Member
National Weather Satellite Center[1]

ABSTRACT

The Formative Stage of typhoon development is described as seen in the TIROS satellite photographs from the genesis of a tropical disturbance through progressive stages of intensification until tropical storm intensity is attained. These views suggest that unique appearances are characteristic of the tropical cyclone as maximum sustained surface wind speeds about the core of the storm increase to higher and higher values. A model of tropical cyclone development through the formative stage is proposed on the basis of this evidence which attempts to differentiate between the tropical disturbance and the tropical depression. Within the tropical depression category three distinct phases are frequently seen which appear closely related to surface wind speeds. The examples considered suggest unique appearances with wind speeds of (a) less than 20 knots, (b) 20-30 knots, and (c) 31-40 knots. Rapid intensification appears to result after surface wind speeds of 20-30 knots are attained and an anticyclone is established at the 200 mb level over the vortex. Establishment of the anticyclone aloft is very apparent in the satellite photographs as revealed by the cirrus striations diverging, parallel to the upper winds, in the outflow layer of the storm. These striations are most apparent during the period of rapid intensification.

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I. Introduction

One of the outstanding successes of the TIROS program has been the detection and tracking of tropical storms, hurricanes and typhoons. The unique appearance of these storms, having acquired extensive high cloud shields, marked organization of spiral rain bands, and frequently visible eyes and centers of circulation, has made identification from the satellite photos an easy task. Less success has been achieved, however, in the identification of the storms in their earlier stages of development as tropical disturbances and tropical depressions.[1] These stages might very logically be expected to be weaker and more poorly defined in general appearance. However, problems in identification are also related to more basic differences in structure. The formative stages of tropical cyclone development have been shown in many studies to be primarily cold core in nature wheras the mature storms have a warm core structure. Such basic differences might also be expected to be manifested in terms of appearance in the satellite photos. For example, with the establishment of a warm core outflow effects should certainly be more pronounced, and possibly revealed in the cirrus striations diverging at upper levels from the storm area. There are additional differences and requirements for attaining hurricane speeds, however, which have received considerable attention in recent years. The most important of these is the necessity for the formation of an eye before hurricane speeds can be attained. Malkus states that winds "cannot reach speeds greater than about 45 mph" until an eye has formed [2].

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1 The definitions of tropical cyclone terms adopted from Dunn and Miller [1] are used in this paper -

Tropical disturbance - Rotary circulation slight or absent on the surface but possibly better-developed aloft. There are no closed surface isobars and no strong winds. This type of disturbance is common throughout the tropics.

Tropical depression - One or more closed surface isobars. Wind force equal or less than Beaufort force 7(32-38 MPH or 28-33 knots).

Tropical storm - Closed isobars, wind force more than Beaufort force 7(39-73 MPH or 34-63 knots).

Hurricane or typhoon - Wind force Beaufort 12(74 MPH or more or 64 knots or more).

The reason for this is that the warmest temperatures prior to eye development have an upper limit determined by rain-bands in the circulation which have suffered little or no entrainment of cooler and dryer air. These temperatures prescribe the lowest pressures that can be obtained in the disturbed area. After the eye has formed much of the air converging under the wall cloud at lower levels rises undiluted to upper levels resulting in maximum warming as a result of the release of the latent heat of condensation. This heating is further accentuated near the center of the vortex through descent and dry adiabatic warming within the eye itself. Once this has been achieved according to Malkus, "velocities may wind up to hurricane fury in a few hours..." LaSeur and Hawkins in a detailed study of hurricane Cleo at maturity also emphasize the importance of eye development by concluding that "Only a small fraction of the total storm volume contains convective-scale vertical motions; the most significant area of this kind being the central eye structure, including the wall cloud [3]". Their detailed analysis supports the argument proposed above by Malkus.

Recognition of these significant differences between the hurricane and its precursor is very important in terms of understanding the characteristics of the formative stage. Through defining the characteristics of the hurricane we can also appreciate that these represent the upper limit toward which the more intense formative stages should tend and possibly resemble in appearance. An understanding of the importance and special function of the eye in the mature storm enables one to comprehend why mere "centers of circulation" frequently viewed in the formative stages are inadequate to produce pressures low enough to cause very intense winds.

This study shows examples of the formative stage of tropical cyclone development starting with the weakest disturbances and continuing to the most intense phase as tropical storm speeds of approximately 34 knots are attained. Available intensity estimates derived from reconnaissance reports and conventional analyses are discussed together with the TIROS photographs. On the basis of these estimates in combination with differences in appearance of the cloud systems viewed, an attempt is made to specify the relative maturity of the system. For the tropical disturbances, having no centers of circulation, judgments of relative intensity are most subjective. However, the very lack of a definite center, pronounced banding, outflow effects, and other characteristics of the mature storm, are themselves useful criteria to consider when debating the intensity of this earlier stage. At tropical depression intensities and above, for documentation of intensity, the maximum sustained surface winds that completely encircle the center of circulation are proposed as being the most diagnostic. This places the emphasis on the core of the storm which ultimately contains the eye and the wall cloud. It is true that in the formative stages higher wind speeds do not initially occur in this area, but typically in areas offset to the east and north. These latter winds, however, often exceed tropical storm velocity even prior to the establishment of a closed surface circulation and for that reason are not by themselves reliable indicators of intensity. Around the center of the storm, on the other hand, an increase in the maximum sustained winds is a necessary result of intensification as, step by step, the anttecedents to eye formation are completed. Certain ranges in these speeds appear to be typical of unique appearances in the tropical depressions to be described in this study.

II. PHASE I - The Tropical Cyclone as a Tropical Disturbance

In this phase of development the outstanding characteristic apparent from the satellite photographs, is that of enhanced convection throughout an overcast or nearly overcast area of irregular shape and dimensions. The cloud area is frequently elongated along the axis of the wave or perturbation with which it is associated. No closed circulation can be detected from surface reports, maximum surface wind speeds are less than 20 knots in the area of lowest pressure, and spiral banding present is normally not accentuated enough to determine a center of circulation from the satellite photographs. Figure 1 shows a tropical disturbance associated with a weak easterly wave just north of Hispaniola. The author was on a flight through this disturbance at the time of the satellite pictures in one of the DC-7 aircraft employed by the Weather Bureau Research Flight Facility. Cloudiness encountered was mainly dense cirrostratus and alto-stratus apparently formed from smaller convective areas of cumulonimbus, also viewed along the flight track. Winds at flight level (near 11,000 ft.) shifted from 080 degrees at 15 knots on the western side of the disturbance to 120 degrees at 15 knots on the eastern side, and in this manner defined the wave axis as can be seen in the 700 mb streamline analysis of figure 2. The major overcast area shown in the TIROS picture has been indicated by stippling on the 700 mb analysis. The disturbance was barely perceptible from surface analyses but quite well defined from wind shifts particularly in the layer from 700 to 300 mbs. Figure 3 is a time cross-section which shows effects of passage of the wave on the 17th of August at San Juan, Puerto Rico.

A more intense appearing tropical disturbance is shown in figure 4. This disturbance was located with geometric center approximately 300 miles north of Antigua, British West Indies. Cloudiness is elongated from north to south and the surface map (fig. 5) shows that a wave formation is readily defined from reports in the area of the disturbance. The form of the TIROS observed cloud mass has been superimposed on the surface analysis. Lowest pressure with rather weak winds appear on the southern extremity of the cloud system. To the north two ships indicate wind speeds of 25 knots, apparently the maximum attained in the area at that time. This perturbation was approaching maximum intensity as a tropical disturbance and by the next day became a tropical depression with closed surface isobars and a minimum pressure of 1012 mbs. Figure 6 is a time cross-section which shows effects of the passage of this disturbance at San Juan, Puerto Rico. Weak westerly winds at lower levels are indicative of the closed surface circulation on September 23rd.

III. PHASE II - The Tropical Cyclone as a Tropical Depression

a. Maximum sustained surface wind speed less than 20 knots.
At this stage of development weak low level spiral banding can be detected frequently defining a center of circulation unobscured by heavier adjoining cloud masses. A frequently appearing shape is that of a comma which broadens rather than narrows on the downward stroke. The center of circulation lies at the head of the comma. The broad portion of the comma consists of dense overcast cloudiness with embedded bands of cumulonimbus and generally is confined to the eastern quadrants of the cloud system. What has been described is, of course, the TIROS view of a segment of a vortex-neutral point combination embedded in easterly flow. The broad portion of the comma overlies the convergence asymptote.

Figure 7 is a TIROS mosaic of the formative stage of typhoon Bess as a tropical depression which portrays these characteristics. The circulation center is most apparent from banding visible in the inset frame of this figure. Maximum surface winds were reported by the Joint Typhoon Center as 10 knots on the preceding day (24 July 1963) and were not reported above 20 knots until 2210Z, on 29 July 1963 at which time winds of 25 knots were indicated. Time cross-sections showing passage of this depression at Ponape (7N, 158E) and Truk (7N, 152E) are shown in figures 8 and 9. The TIROS picture shows Bess midway between these stations.

Figure 10 shows the TIROS view identified by Fritz as the earliest satellite picture of the formative stage of hurricane Anna [4]. Note the comma-like shape of the cloud mass associated with this depression. The very sharply defined western boundary is distinctive. However, close inspection of the original film strip from which these pictures were made also suggests a circulation center weakly defined in the extreme northwestern sector of the depression. Maximum surface winds were not available in the depression area at the time of the TIROS pictures but a ship report near the center of the depression three days later (1200Z, 19 July 1962) indicated maximum surface winds of only 20 knots. Since the storm was rapidly intensifying at that latter time it seems unlikely that this sustained value had been exceeded earlier. Figure 11, in an area of more data, shows a fair quality view of a formative stage of typhoon Ruth. The comma-like appearance of the major cloudiness of this system and the cloud lines curving into its extreme northwestern quadrant suggest that it was of tropical depression intensity. This is verified by the analyses of the Joint Typhoon Warning Center which indicate that the system had been tropical depression for nearly 2 days commencing earlier on the 11th of August at 1200Z [5]. Figure 12 is a copy of the gradient wind analysis prepared by the Joint Typhoon Center and indicates that Ruth had a well defined low level circulation at the time of the TIROS pictures. Reconnaissance estimates of maximum surface winds were not available but ship reports in the depression area indicated speeds of 15 to 20 knots. It will be noted from the streamline analysis that the asymptote of convergence lies to the south of the vortex center and curves in from the south along the eastern quadrants. This, as previously suggested, relates well to the TIROS views of major cloudiness confined to the same areas and indicates that any speed divergence was more than compensated for by the confluence of streamlines along the convergence asymptote.

Figure 13 is the Typhoon Center's corresponding 200 mb analysis. Major cloudy areas from the TIROS mosaic have been superimposed upon this analysis. It can be seen that the cloud system of Ruth was located just west of the Mid-Pacific Trough and positioned under an area of diffluent streamlines which, in the absence of any compensating speed convergence, would be strongly favorable for intensification of the incipient typhoon. This happened so explosively in the case of Ruth that by the time the storm was viewed by TIROS on the next day it had already attained winds of 60 knots. For this reason other storms must be considered to define the intervening characteristics of more intense phases of the tropical depression.

b. The tropical depression with maximum sustained surface wind speed 20 to 30 knots.

At the low end of this speed range the tropical depression retains its "comma-like" character but the center of circulation becomes much more clearly defined, remaining, however, unobscured by middle and higher clouds. Figure 14 is a good example of this development and shows the TIROS view of what is believed to be a formative stage of hurricane Debra. The relatively weak appearance of this vortex belies the fact that effects of its circulation are apparent in cloud banding far to the north and to the south along the zone of intertropical convergence. There are no surface reports to verify whether or not Debra had indeed attained maximum winds of slightly over 20 knots at the time of the TIROS pictures. However, the change in appearance from the comma-like shape with an ill-defined circulation center to a similar shape with a well-defined circulation center appears to be a reasonable one resulting from slightly lower pressure at the vortex center with increased convergence. Figure 15 shows a more intense version of this stage of development. This picture of an early stage of hurricane Daisy, 1962, was taken when reconnaissance estimates of maximum surface winds ranged from 30 to 40 knots. These maximum speeds were confined primarily to the storm's northern quadrants. Maximum sustained winds around the circulation center were much weaker and in the range 20 to 30 knots. This picture and the one obtained of Daisy on the following day (fig. 16) throws much light on some puzzling aspects of hurricane development discussed in recent paper by Riehl [6]. In this paper he stated that an oddity of hurricane development was that "some storms develop from the inside out and others from the outside in". That is, some storms appear to develop maximum winds first at great distances from the storm while others develop them near the storm center right away. In both cases, however, the "ultimate hurricane wind profiles are very similar". It is interesting to speculate on how much this theory depends on the stage at which the storm was first entered and accurate documentation of the wind profile obtained. For example, if the first reconnaissance of Daisy, 1962, had been made on the 1st of October the storm would have been classified in the category "outside in". That is, winds were stronger in the convective cloudiness to the north and east than they were at the center of the storm. However, on the 2nd of October the spiral cloud band had wound about the center of the vortex (fig. 16) setting the stage for eye development. Maximum sustained winds increased to over 35 knots.

Initial reconnaissance on this day would have placed Daisy in the category of an "inside out" type storm with winds stronger at the center of the vortex and remaining stronger in that area throughout its further development. In Riehl's example of the "inside out" category, initial reconnaissance was made at a time when "the winds were just crossing the threshold of hurricane velocity in a small area east of the forming eye". This would appear to have been too late for a definitive type of documentation. At any rate the TIROS evidence suggests that sustained wind speeds of greater than 30 knots about the center of a circulation are not obtained in the "comma configuration" as exemplified by Debra and Daisy in figures 14 and 15. Such an increase in winds appears to be attendant upon the center of circulation itself becoming surrounded by convective cloudiness. At this stage maximum convergence must transfer from the banded areas of the comma-like cloud shield to the actual center of the storm. Only in this manner can the "warm core" become truly established. This transition out of the "comma configuration" appears to occur with maximum sustained surface winds approaching 30 knots. Figure 17 shows the TIROS view of Amy at this stage of development less than 6 hours prior to a reconnaissance penetration at which time maximum surface winds of 30 knots were reported. Figure 18 is the Joint Typhoon Center's 200-mb streamline analysis 40 minutes after the TIROS pictures were taken. The anticyclone above the storm at this time is quite impressive. The major overcast cloudy areas associated with Amy have been superimposed on this chart. Also indicated by black arrows are the directions of shear of the cumulonimbus anvils and the alignment of the cirrus striations in the high cloud shield. It will be noted that the agreement of these directions with the 200 mb streamlines is almost perfect. The shear line along the western sector of the storm is also a notable characteristic defining the radial limit of the outflow in this sector. The shear line has been found by the author in other studies [7] to overlie an area of marked subsidence and has important implications related to the general circulation of the storm. An especially cloud-free area can be seen in the mosaic of Amy directly under this shear line, which again suggests pronounced subsidence.

c. <u>The tropical depression with surface wind speeds 31 to 40 knots</u>.
In this stage of development outflow characteristics become exceedingly pronounced. The center of circulation remains obscured by middle and higher clouds as the warm core is established about the vortex. Because of the obscuration no eye or wall cloud can be seen in the TIROS pictures. Thick spiral bands appear which converge cyclonically to the apparent center of circulation. Marked cirrus striations superimposed upon the spiral bands define the direction of outflow in the highly developed anticyclone over the rapidly intensifying storm.

Figure 19 shows the TIROS view of the formative stage of Typhoon Wanda. The reconnaissance fix was not accurate enough to determine actual winds at the time of the TIROS photos. However, on the next penetration, at 0211Z on the 28th of August, an accurate fix was obtained and maximum surface winds of 40 knots were reported. The increased evidence of outflow is apparent in the TIROS photo, particularly in the storm's southeastern quadrant. Figure 20 is the 200 mb analysis prepared by the Typhoon Center upon which the major cloudiness and cirrus striations revealed in the TIROS photos have again been superimposed. A pronounced anticyclone over the storm is revealed in this analysis, which as in the other examples, was made without any recourse to the TIROS pictures. The excellent agreement of the 200 mb streamlines to the cirrus striations visible in the TIROS pictures is quite notable. The directions of some of these striations are again shown by black arrows on the 200 mb analysis. The shear line on the northern side of the storm through the neutral point relates very well to the cloud-free zone along the edge of the northern most spiral arm apparent in the mosaic, and denotes the zone of maximum subsidence.

Figure 21, the final TIROS example, shows the formative stage of typhoon Jean when it was intensifying very rapidly. An accurate reconnaissance fix was obtained on the preceding day and maximum winds of 25 knots were reported. An accurate fix was not obtained at the time of the TIROS pictures. However, slightly over 24 hours later another accurate fix was obtained and winds were determined to be 60 knots as Jean was upgraded to tropical storm status. The very noticeable appearance of the cirrus striations blowing off the spiral arms suggest the presence of an intensified anticyclone aloft. This is supported by the 200 mb analysis of figure 22. Note again the excellent agreement of the cirrus alignment, revealed in the TIROS photographs to the streamlines of the 200 mb analysis. The heightened effects of outflow revealed by the cirrus striations, in a storm which has its center obscured by a small but developing cloud shield, appears to be characteristic of this stage and the key to rapid intensification - this is the important point which, perhaps, should be emphasized.

IV. Summary and Conclusions

The TIROS photographs of tropical cyclones in the early stages as disturbances and depressions reveal cloud patterns closely related to the intensity of the cyclone as determined from the maximum sustained surface winds which completely encircle the vortex. A preliminary model of tropical cyclone development through the formative stage until tropical storm intensity is attained has been proposed. An important feature of this model envolves the shift in emphasis from the "comma configuration", when major cloudiness and maximum winds are found in the eastern semi-circle of the vortex, to the establishment of the area surrounding the storm's center as the primary active zone. It is at this time that the stage appears set for the most important development - the establishment of a "true" eye in which the wall cloud becomes the dominant convective area of the entire storm. The fascinating changes from tropical storm intensity to the most intense hurricane or typhoon revolve about this feature and remain to be adequately described.

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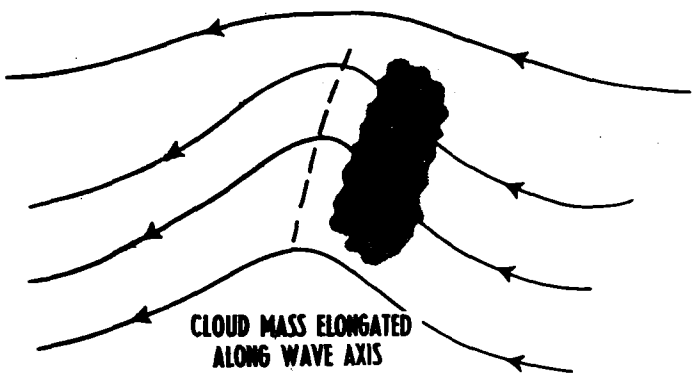
FORMATIVE STAGES OF TROPICAL CYCLONE DEVELOPMENT

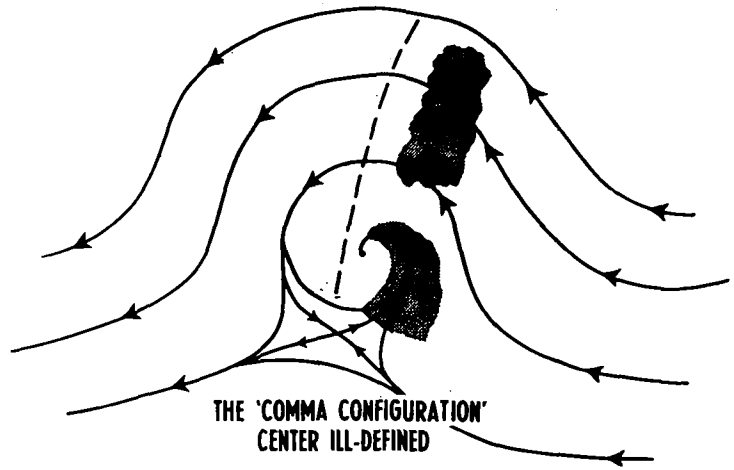
A.

THE TROPICAL DISTURBANCE
(NO CLOSED SURFACE ISOBARS)



B.

THE TROPICAL DEPRESSION I
MAX. CENTRAL ISOTACH LESS THAN 20 KTS



C.

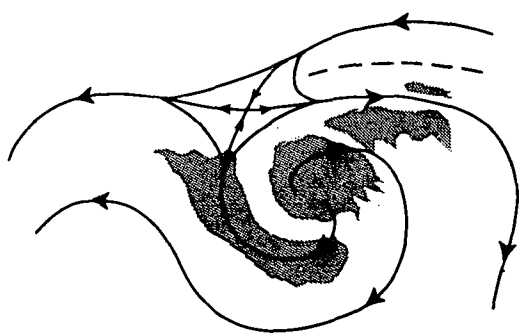
THE TROPICAL DEPRESSION II
MAX. CENTRAL ISOTACH 20–30 KTS

THE 'COMMA CONFIGURATION'
CENTER WELL-DEFINED

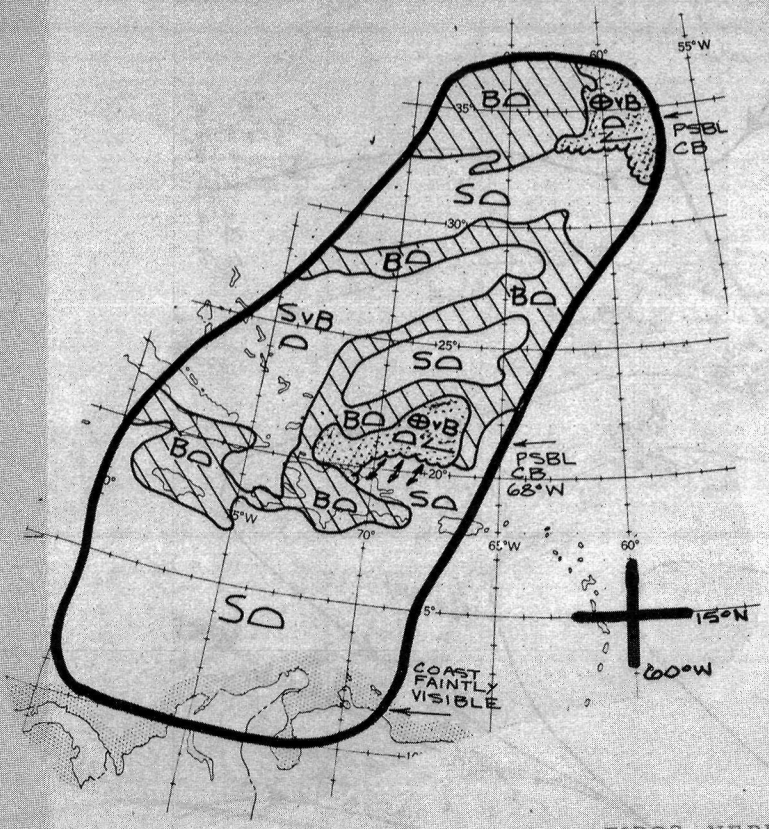
INITIAL OBSCURATION OF CENTER
SOME EVIDENCE OF OUTFLOW ALOFT

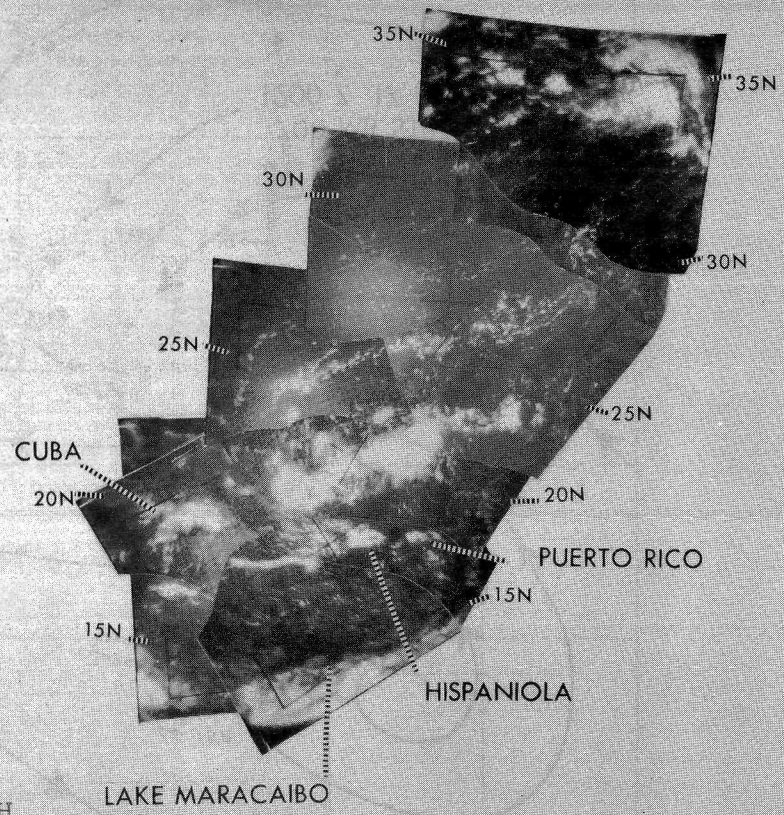
D.

THE TROPICAL DEPRESSION III — TROPICAL STORM I
MAX. CENTRAL ISOTACH 31–40 KTS



CENTER OBSCURED
OUTFLOW PRONOUNCED AT 200 MB





TIROS NEPH
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17 AUG 1962
ORBIT: 849 D
ACCURACY: ±3°

FIGURE 1

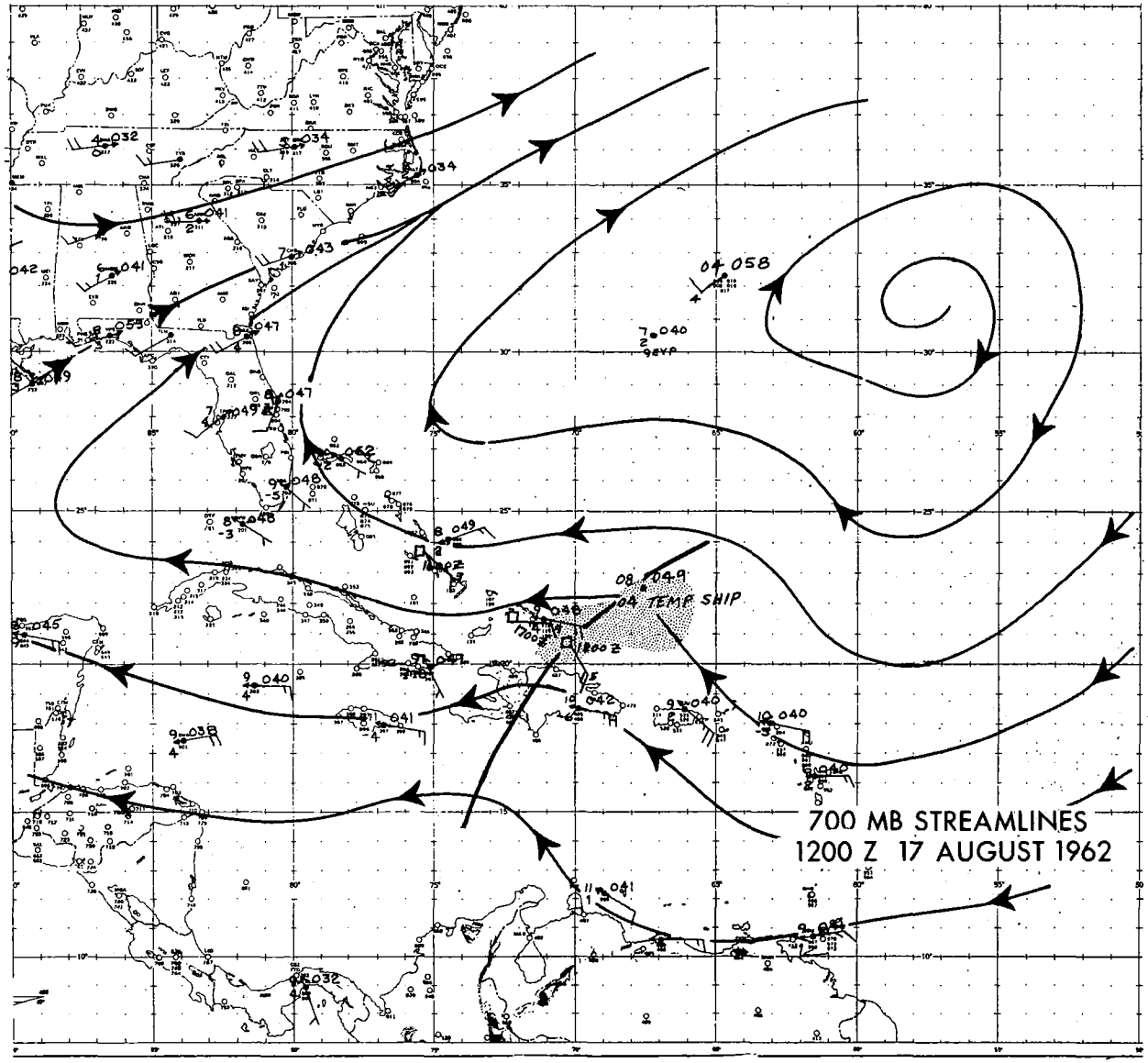
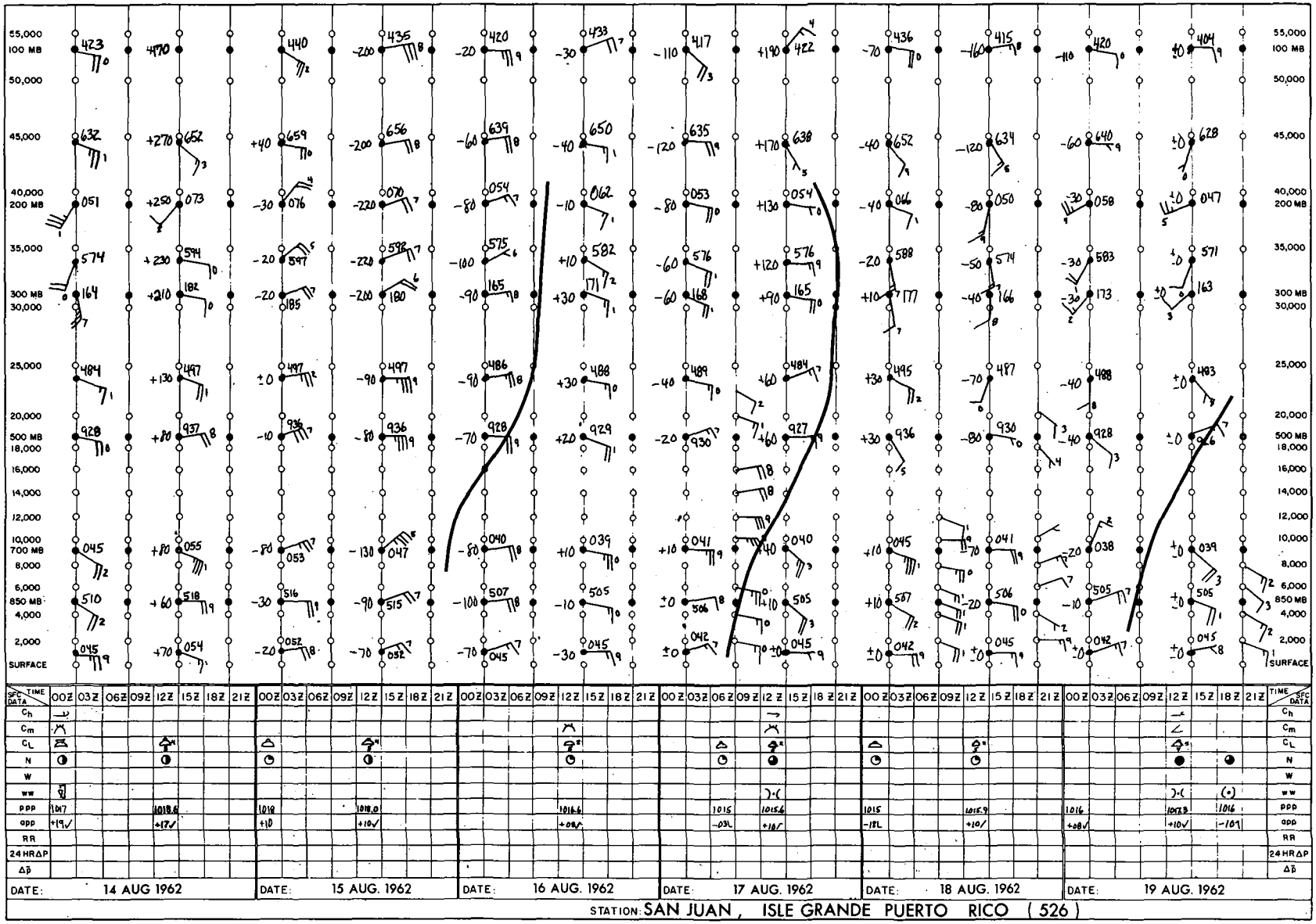


FIGURE 2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DATE: 14 AUG 1962
DATE: 15 AUG. 1962
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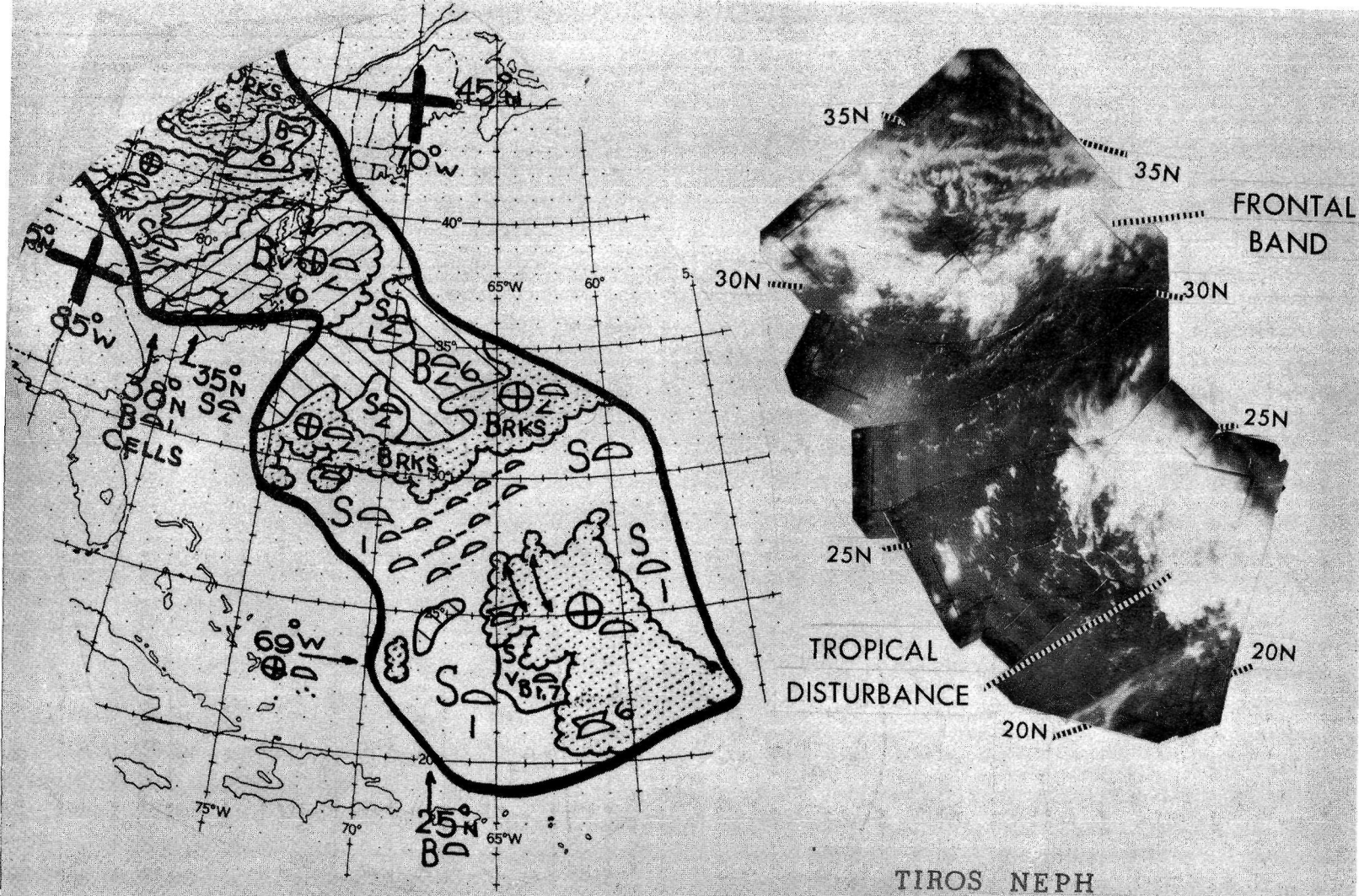
STATION: SAN JUAN, ISLE GRANDE PUERTO RICO (526)

FIGURE 3



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22 SEPT 1962
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ACCURACY: ±1°

FIGURE 4

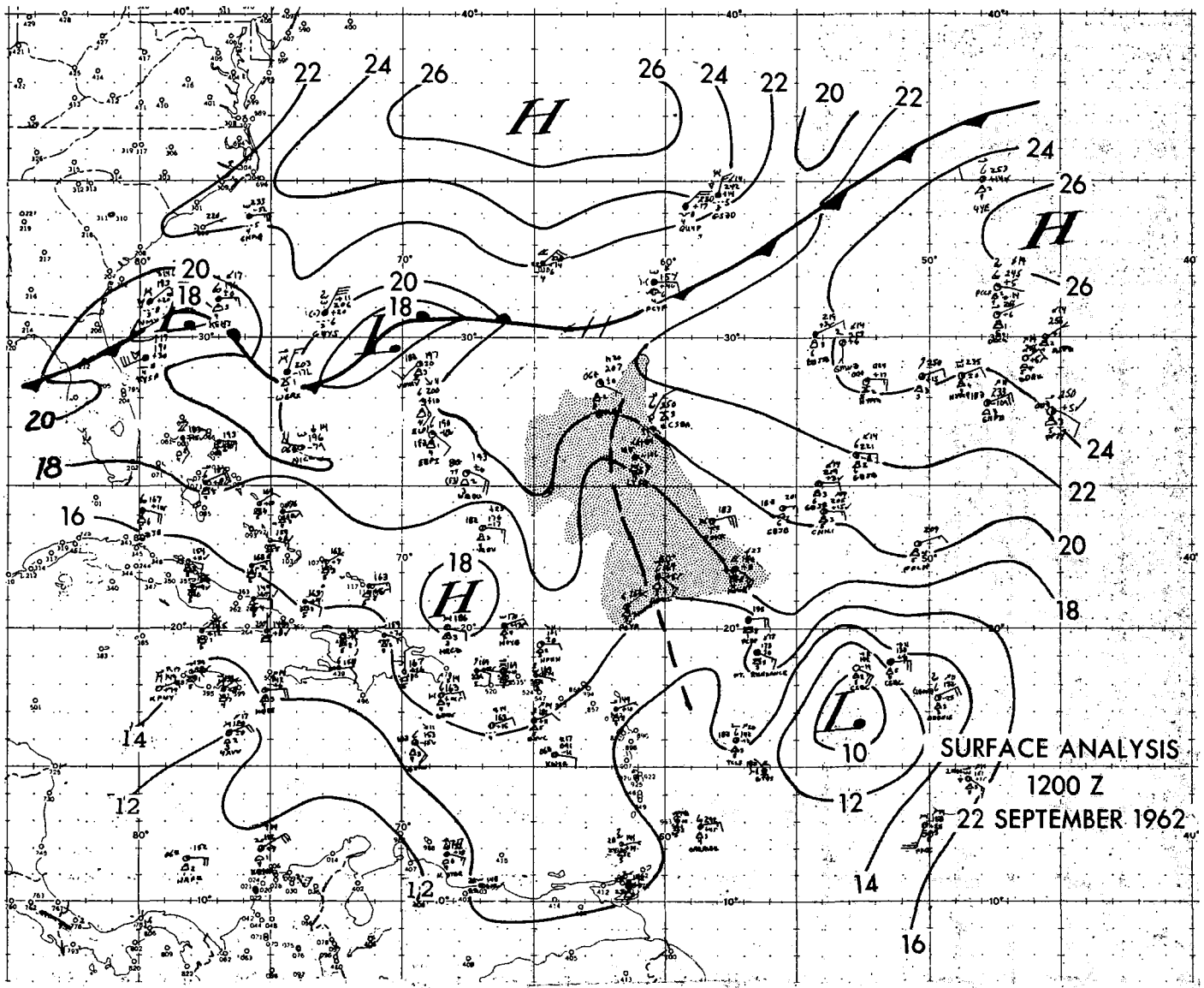
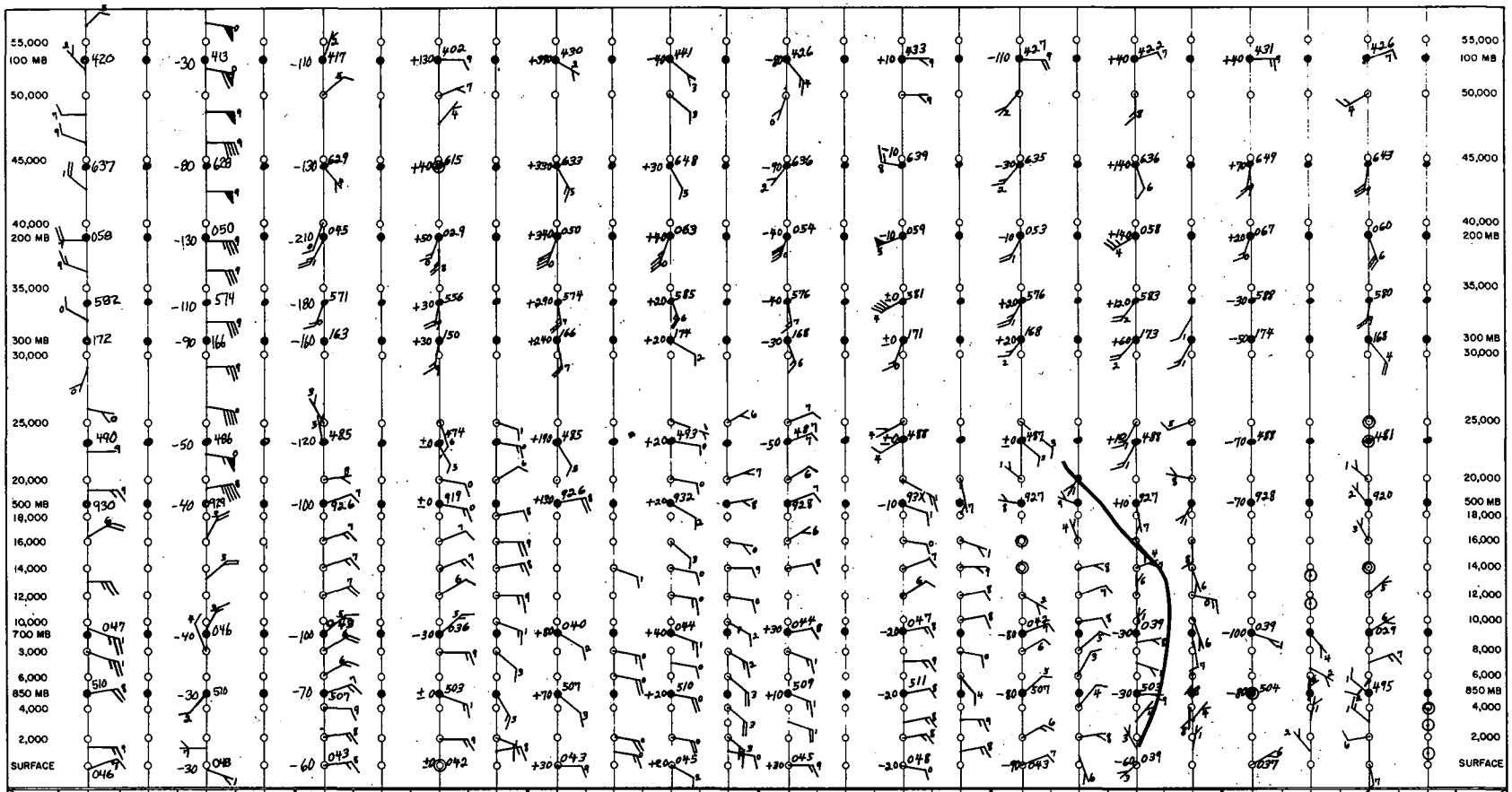


FIGURE 5



SFC DATA / TIME	00Z	03Z	06Z	09Z	12Z	15Z	18Z	21Z	00Z	03Z	06Z	09Z	12Z	15Z	18Z	21Z	00Z	03Z	06Z	09Z	12Z	15Z	18Z	21Z	00Z	03Z	06Z	09Z	12Z	15Z	18Z	21Z	00Z	03Z	06Z	09Z	12Z	15Z	18Z	21Z	00Z	03Z	06Z	09Z	12Z	15Z	18Z	21Z	TIME / SFC DATA
C_h																																																	C_h
C_m																																																	C_m
C_L																																																	C_L
N																																																	N
W																																																	W
ww																																																	ww
PPP	1016		1016		1017.3				1015.2		1014.6		1015.2		1014.2		1014.9		1015.6		1016.3		1015.6		1016.3		1016		1016.9		1014.9		1014.9		1014.2		1013.9		1012.2		1012.2		1011.5		1012.9		1011.5	PPP
ΔPP			-18		+10				+3		-14		+10		-20		+10		-7		+14		-14		+14		-18		+18		M		+X		-14		+7		-24		+10				+17		-14	ΔPP
RR																																																	RR
24 HR ΔP																																																	24 HR ΔP
$\Delta\bar{p}$																																																	$\Delta\bar{p}$
DATE:	19 SEPT. 1962								DATE: 20 SEPT. 1962								DATE: 21 SEPT. 1962								DATE: 22 SEPT. 1962								DATE: 23 SEPT. 1962								DATE: 24 SEPT. 1962								

STATION: SAN JUAN, ISLE GRANDE PUERTO RICO (526)

FIGURE 6

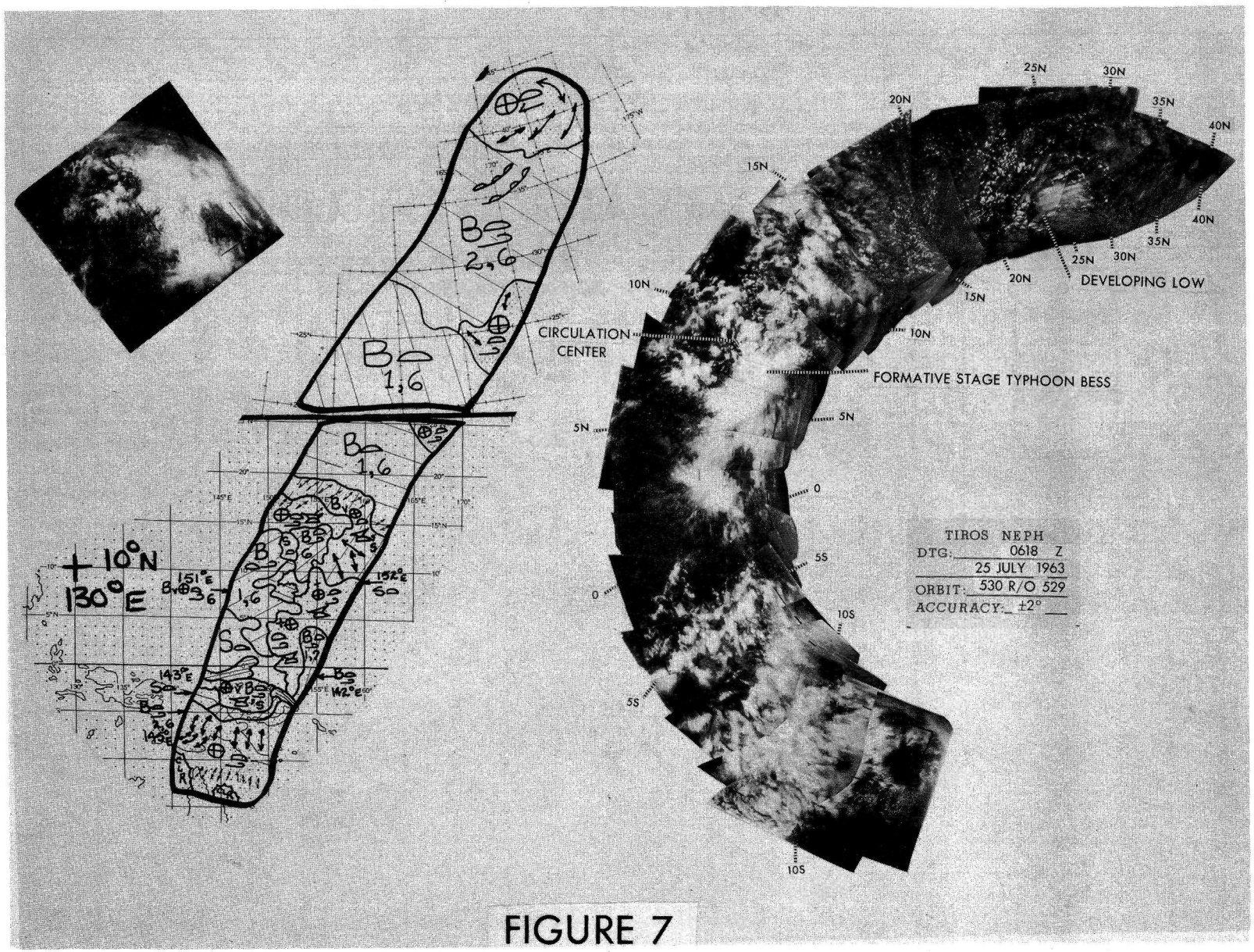
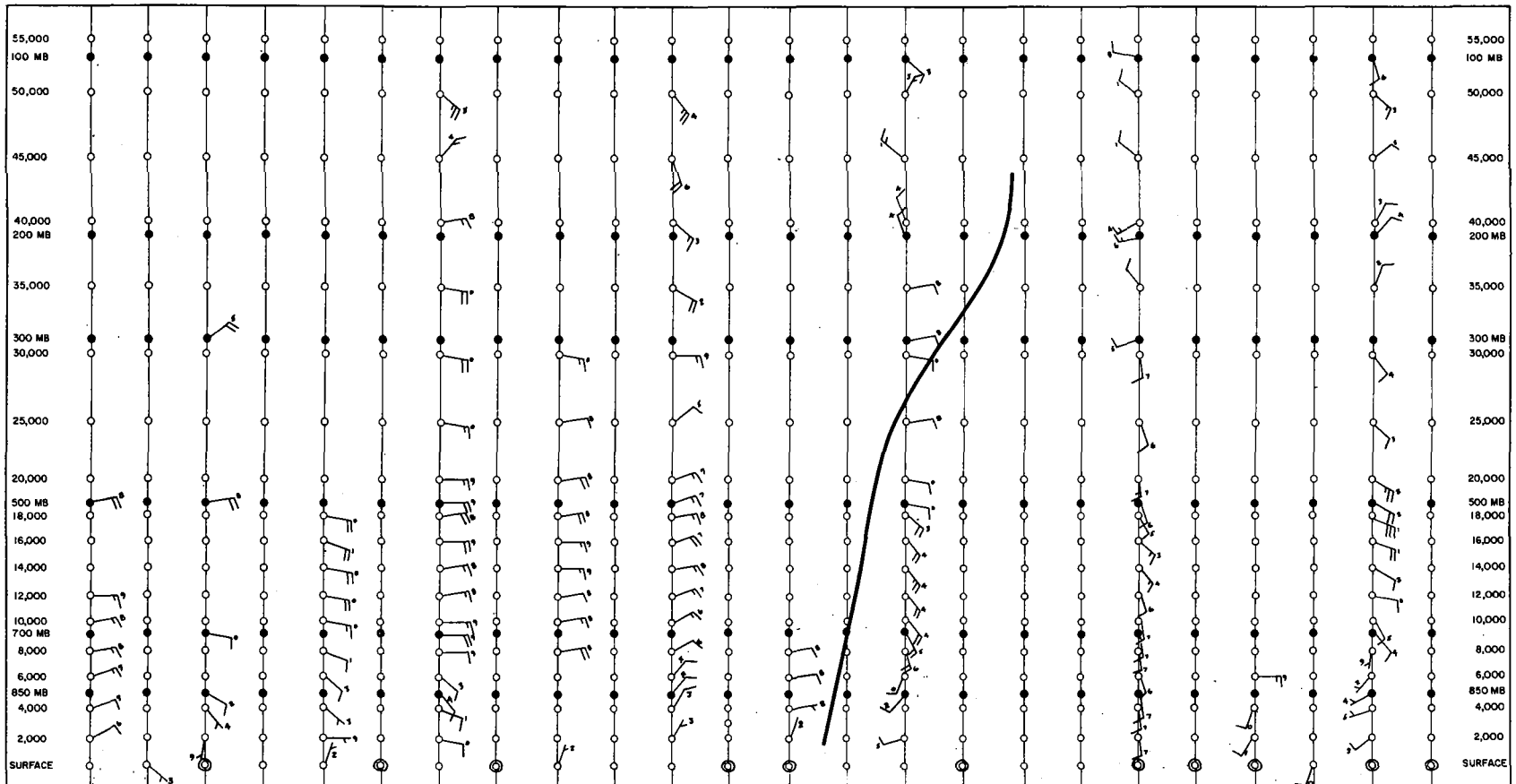

+ 10°N
130°E
CIRCULATION CENTER
FORMATIVE STAGE TYPHOON BESS
DEVELOPING LOW
TIROS NEPH
DTG: 0618 Z
25 JULY 1963
ORBIT: 530 R/O 529
ACCURACY: ±2°

FIGURE 7



SFC DATA / TIME	00Z	03Z	06Z	09Z	12Z	15Z	18Z	21Z
C_h								
C_m								
C_L	2/20	2/20	6/20	10/10	2/10	2/10		2/10
N	●	◔	◕	●	●	◔		◕
W								
ww								
ppp	1009.5	1008.1	1008.1	1009.1	1010.5	1008.5	1007.1	1008.5
app	+08/	-14\	-14\	+20/	+14/			+14/
RR								
24 HR ΔP		+0.3	+1.3	+0.6	+1.4	+0.4		
Δp̄								
DATE:	21 JUL. 1963							

SFC DATA / TIME	00Z	03Z	06Z	09Z	12Z	15Z	18Z	21Z
C_h								
C_m		M						
C_L	5/20	8/10	9/20	2/20	1/20	1/20	2/20	1/20
N	◕	◐	◕	◕	◔	◕	○	◐
W								
ww	⊕							
ppp	1009.1	1007.8	1006.8	1007.8	1009.5	1009.1	1008.5	1009.8
app	+07/	-15\	-00\	+12/	+27/	-05\	-05\	+14/
RR								
24 HR ΔP	-0.4	-0.3	-1.3	-1.3	-1.0	+0.6	+1.4	+1.3
Δp̄								
DATE:	22 JUL. 1963							

SFC DATA / TIME	00Z	03Z	06Z	09Z	12Z	15Z	18Z	21Z
C_h				2	2	2	2	
C_m								
C_L	6/20		4/10	2/20	4/20	2/20	4/10	2/20
N	◕	◕	◕	◕	●	●	●	●
W								
ww					⊕			
ppp	1010.2	1008.1	1007.9	1008.8	1009.8	1009.7	1008.5	1009.8
app	+02/	-20\	-06/	+12/	+10/	-05\	-07\	+14/
RR								
24 HR ΔP	+1.1	+0.3	+1.1	+1.0	+0.3	-0.6	±0.0	±0.0
Δp̄								
DATE:	23 JUL. 1963							

SFC DATA / TIME	00Z	03Z	06Z	09Z	12Z	15Z	18Z	21Z
C_h								
C_m						6		
C_L	3/10	6/10	1/10	6/10	2/10	2/10	1/20	10/20
N	●	●	●	●	●	●	◕	●
W								
ww	⊕							
ppp	1010.2	1009.1	1008.9	1009.1	1008.5	1007.5	1007.1	1008.1
app	+08/	-10\	-07\	+07/	-05\	-14\	-03\	+08/
RR								
24 HR ΔP	±0.0	+1.0	+0.9	+0.3	-1.3	-2.2	-1.4	-1.7
Δp̄								
DATE:	24 JUL. 1963							

SFC DATA / TIME	00Z	03Z	06Z	09Z	12Z	15Z	18Z	21Z
C_h					2	2		
C_m					6	6	6	6
C_L	4/06	2/06	1/10	2/10	2/20	6/20	6/10	2/20
N	●	●	●	●	●	●	●	●
W								
ww								⊕
ppp	1009.1	1008.1	1006.4	1007.8	1007.5	1007.5	1007.1	1008.8
app	+12/	-12\	-15\	+19/	+07/	-12\	-02\	+15/
RR								
24 HR ΔP	-1.1	-1.0	-2.5	-1.3	-1.0	±0.0	±0.0	+0.7
Δp̄								
DATE:	25 JUL. 1963							

SFC DATA / TIME	00Z	03Z	06Z	09Z	12Z	15Z	18Z	21Z
C_h								
C_m					6		6	
C_L	5/20	4/10	6/20	2/20	0/20	2/20	3/20	
N	◕	◑	◕	◑	◔	◑	●	●
W				▽	▽			
ww								⊕
ppp	1008.5	1006.0	1006.4	1008.1	1007.5	1008.8	1008.5	1010.8
app	-03\	-17\	-02\	+17/	+14/	-09\	-02\	+24/
RR								
24 HR ΔP	-0.6	-2.1	±0.0	+0.3	+2.0	+1.3	+1.4	+2.0
Δp̄								
DATE:	26 JUL. 1963							

STATION: PONAPE (348)

FIGURE 8

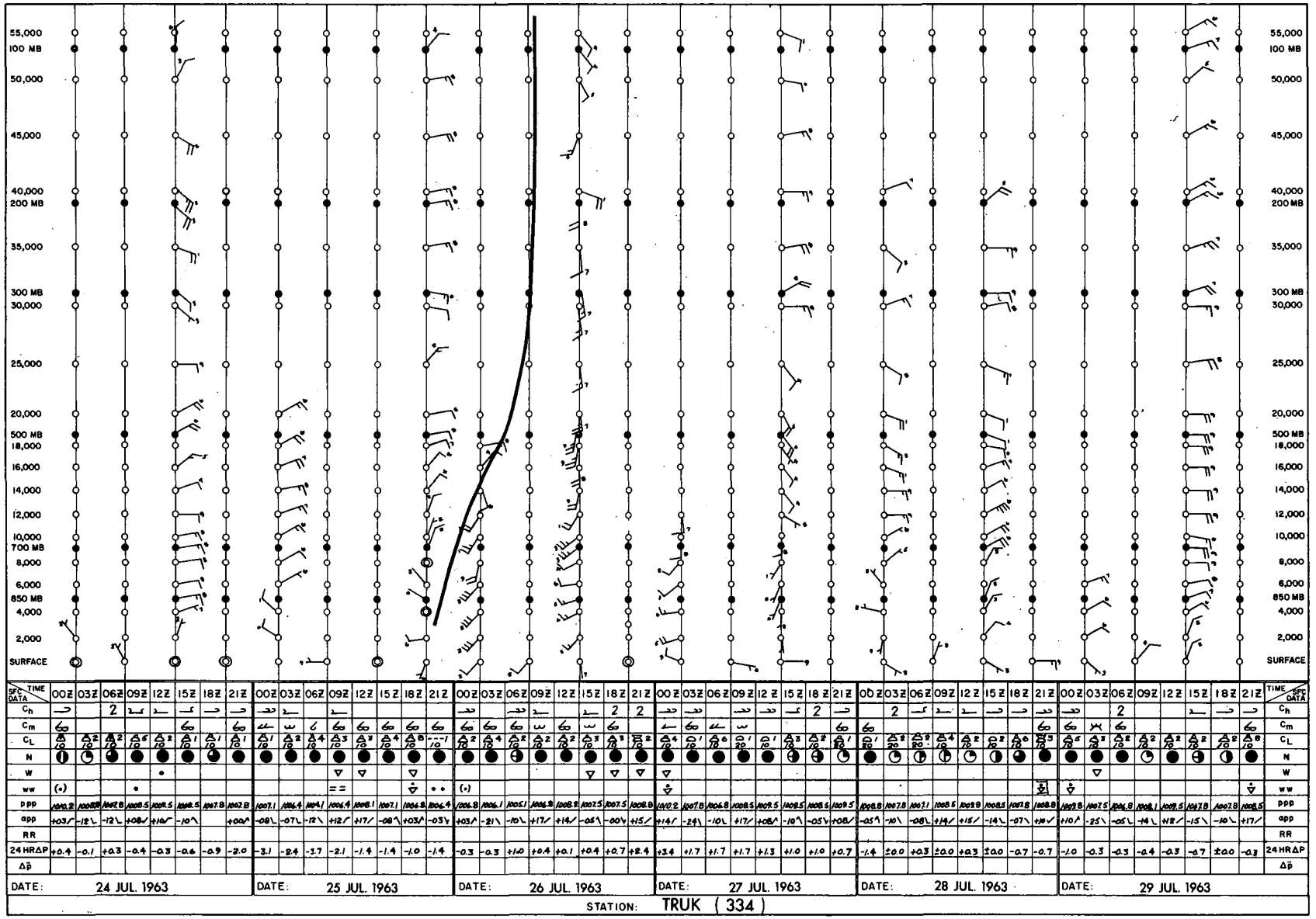

55,000
100 MB
50,000
45,000
40,000
200 MB
35,000
300 MB
30,000
25,000
20,000
500 MB
18,000
16,000
14,000
12,000
10,000
700 MB
8,000
6,000
850 MB
4,000
2,000
SURFACE
DATE: 24 JUL. 1963
DATE: 25 JUL. 1963
DATE: 26 JUL. 1963
DATE: 27 JUL. 1963
DATE: 28 JUL. 1963
DATE: 29 JUL. 1963
STATION: TRUK (334)

FIGURE 9

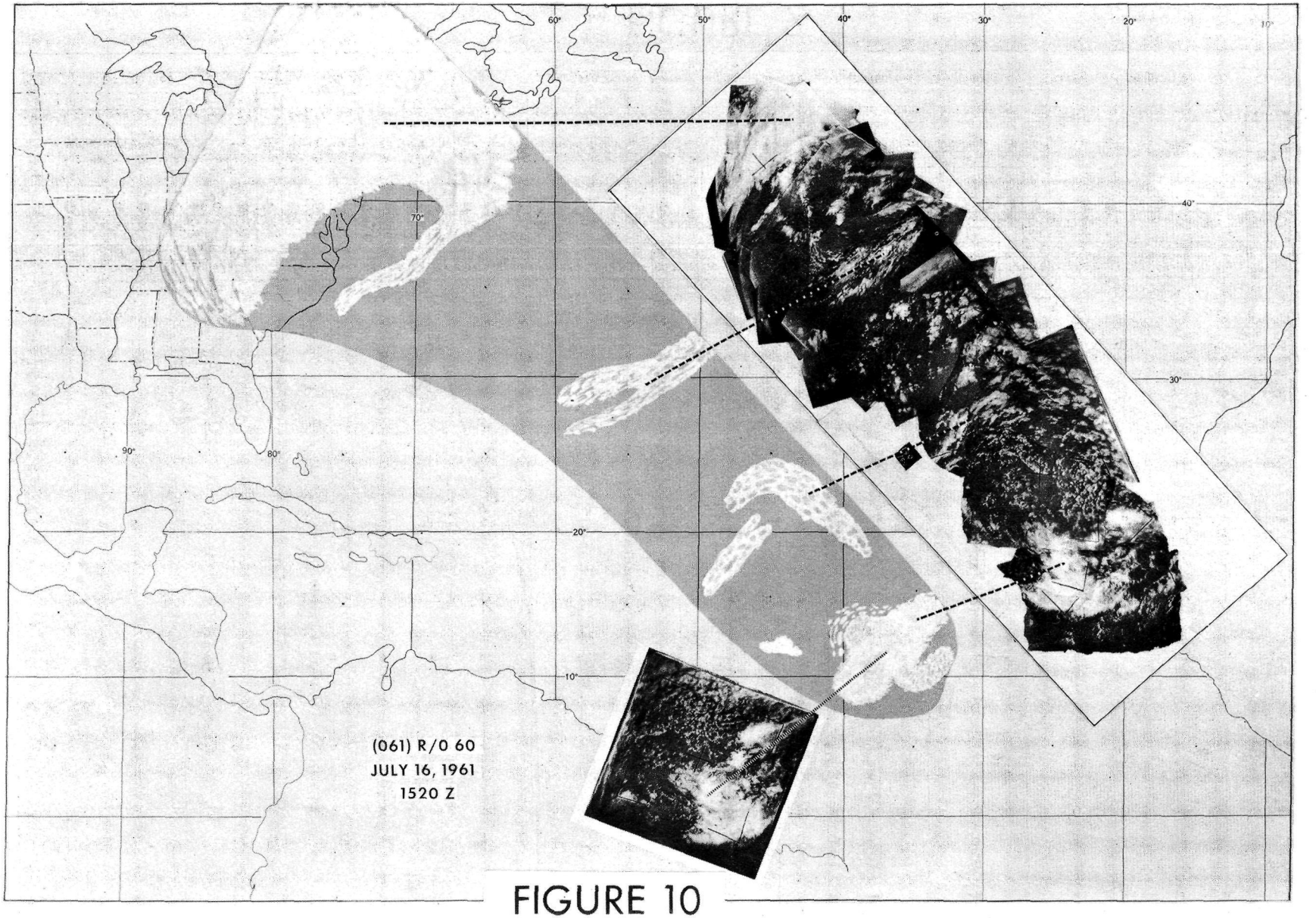
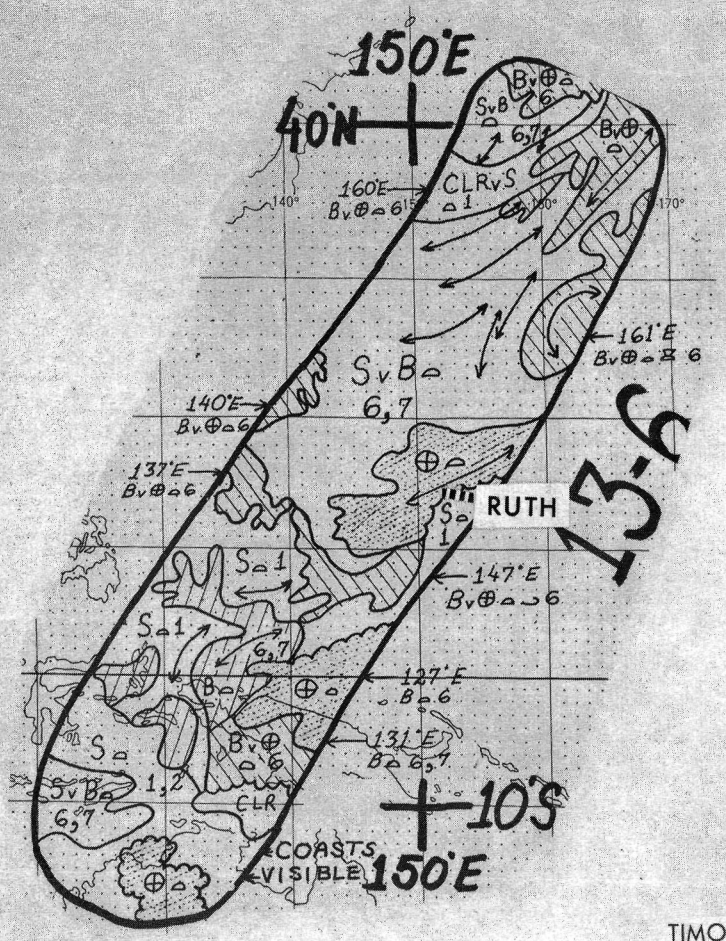


FIGURE 10


150°E
40°N
160°E
140°E
137°E
161°E
147°E
127°E
131°E
RUTH
13-6
10°S
COASTS VISIBLE
150°E

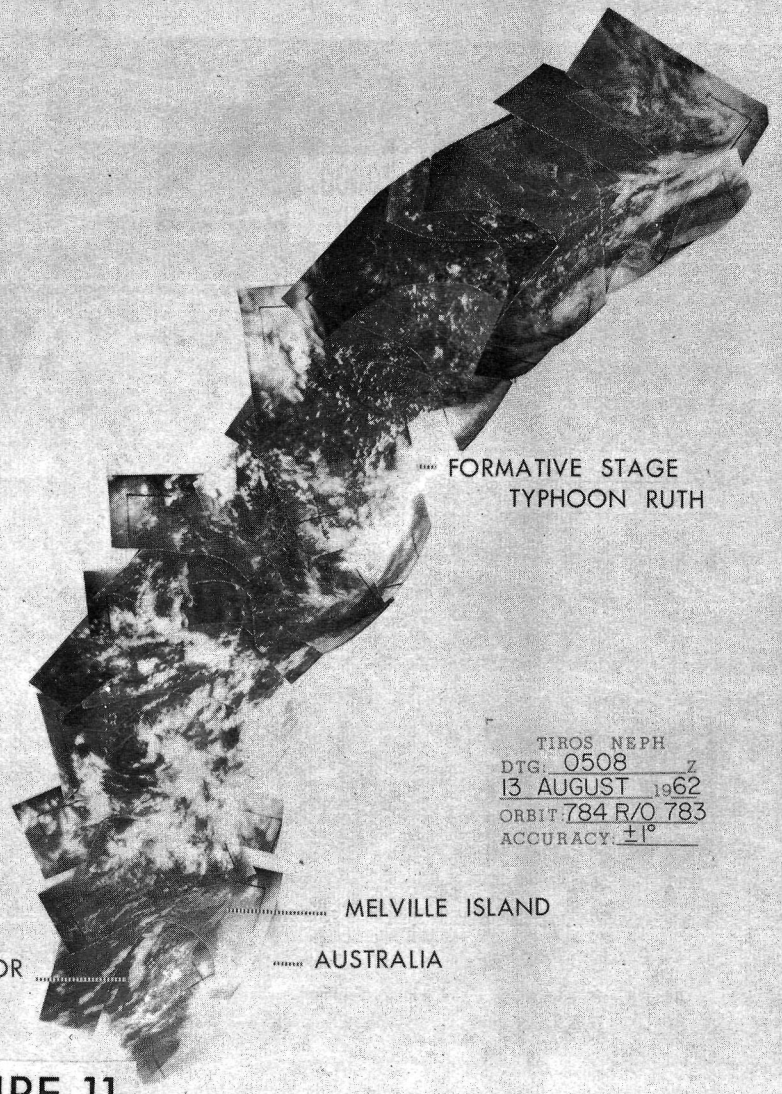

FORMATIVE STAGE
TYPHOON RUTH
TIROS NEPH
DTG: 0508 Z
13 AUGUST 1962
ORBIT: 784 R/O 783
ACCURACY: ±1°
MELVILLE ISLAND
TIMOR
AUSTRALIA

FIGURE 11

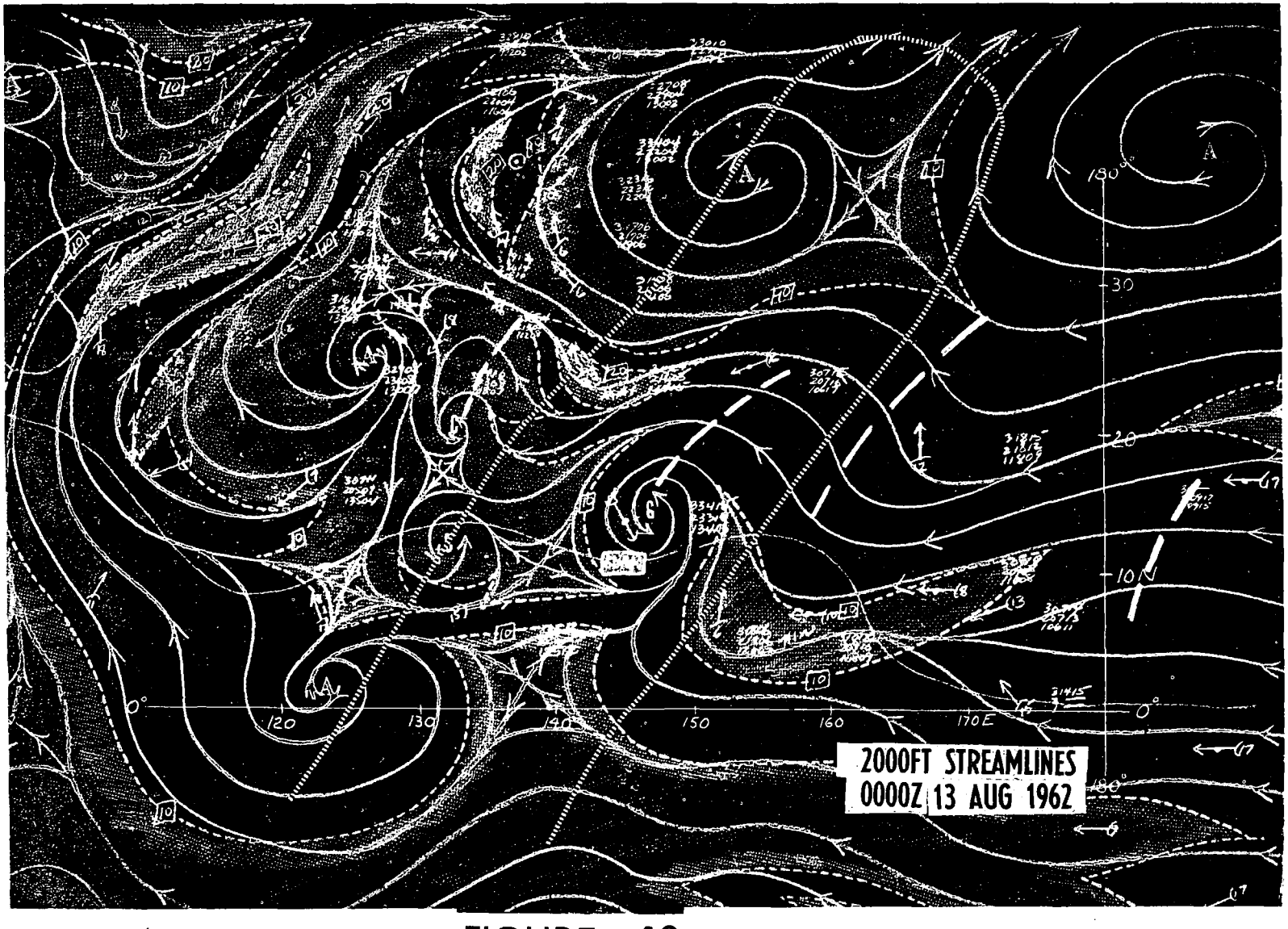

2000FT STREAMLINES
0000Z 13 AUG 1962
120
130
140
150
160
170E
180°
30
20
10N
0°

FIGURE 12

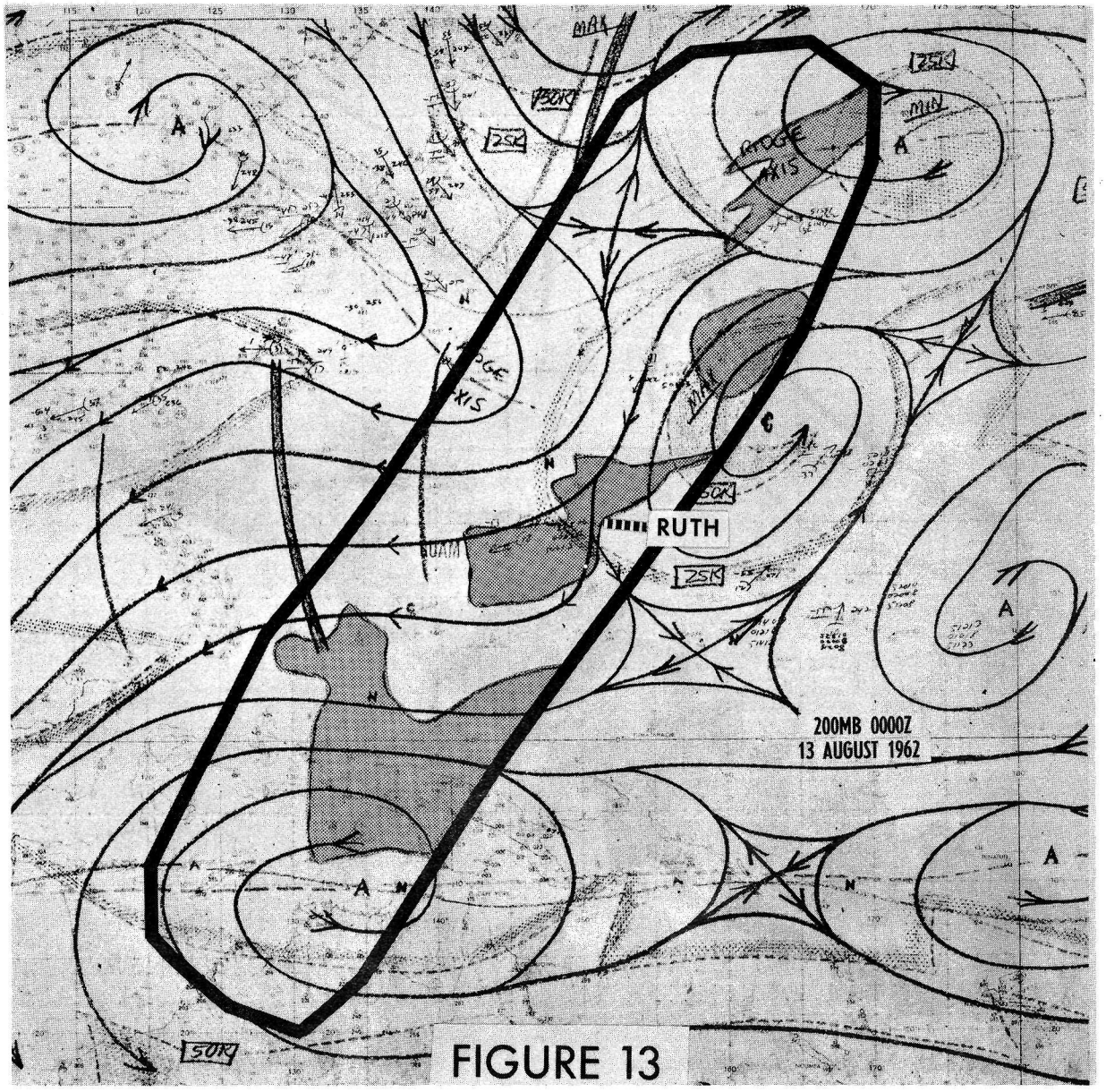


FIGURE 13

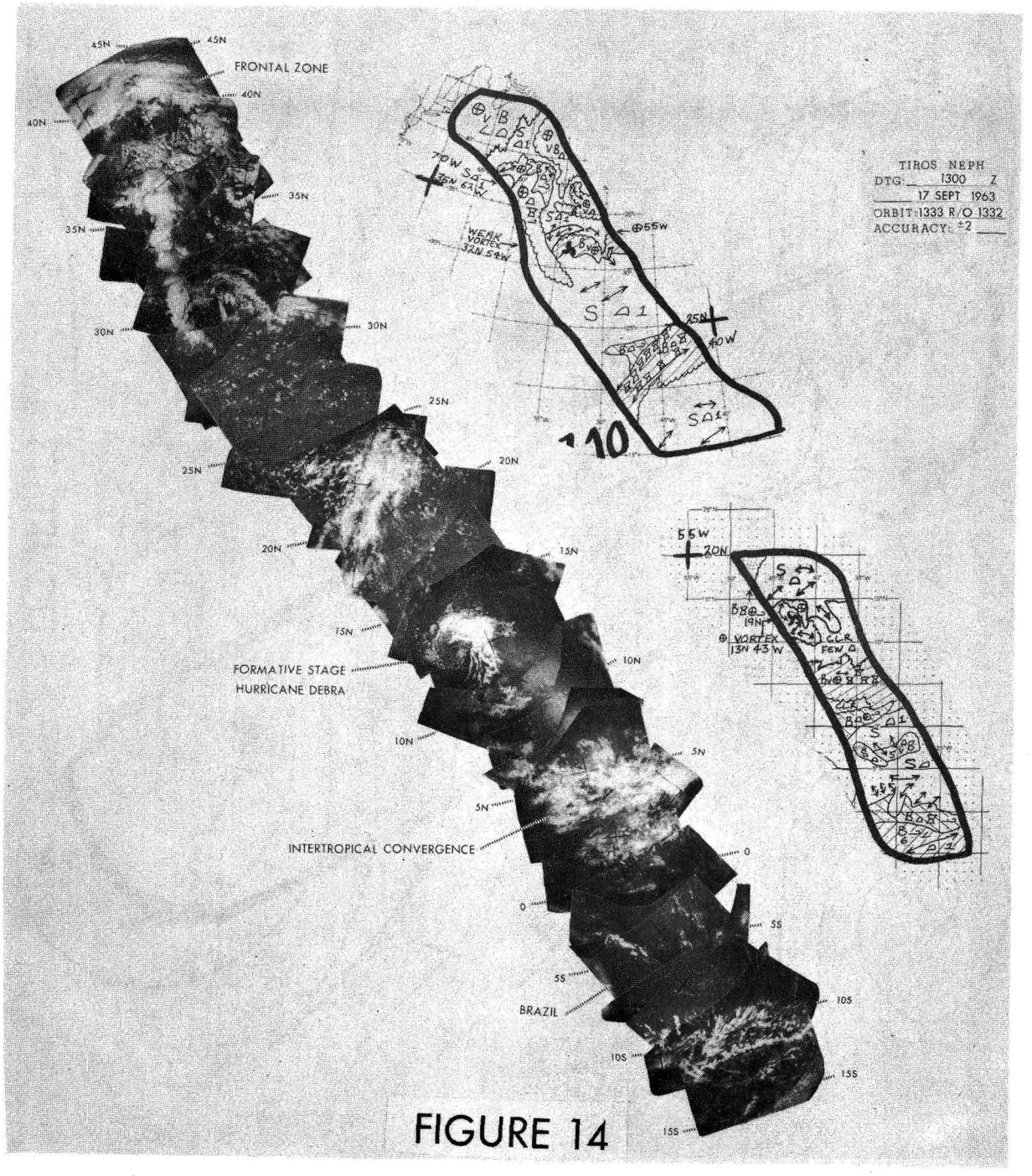
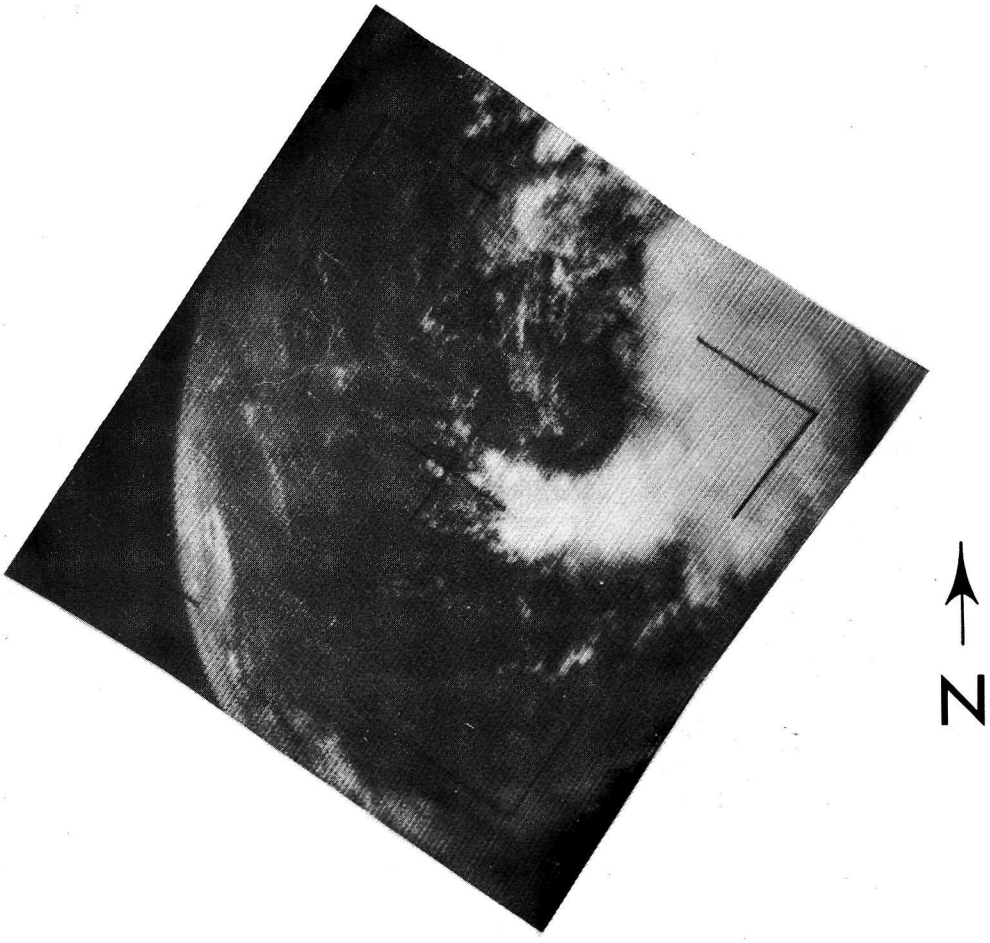
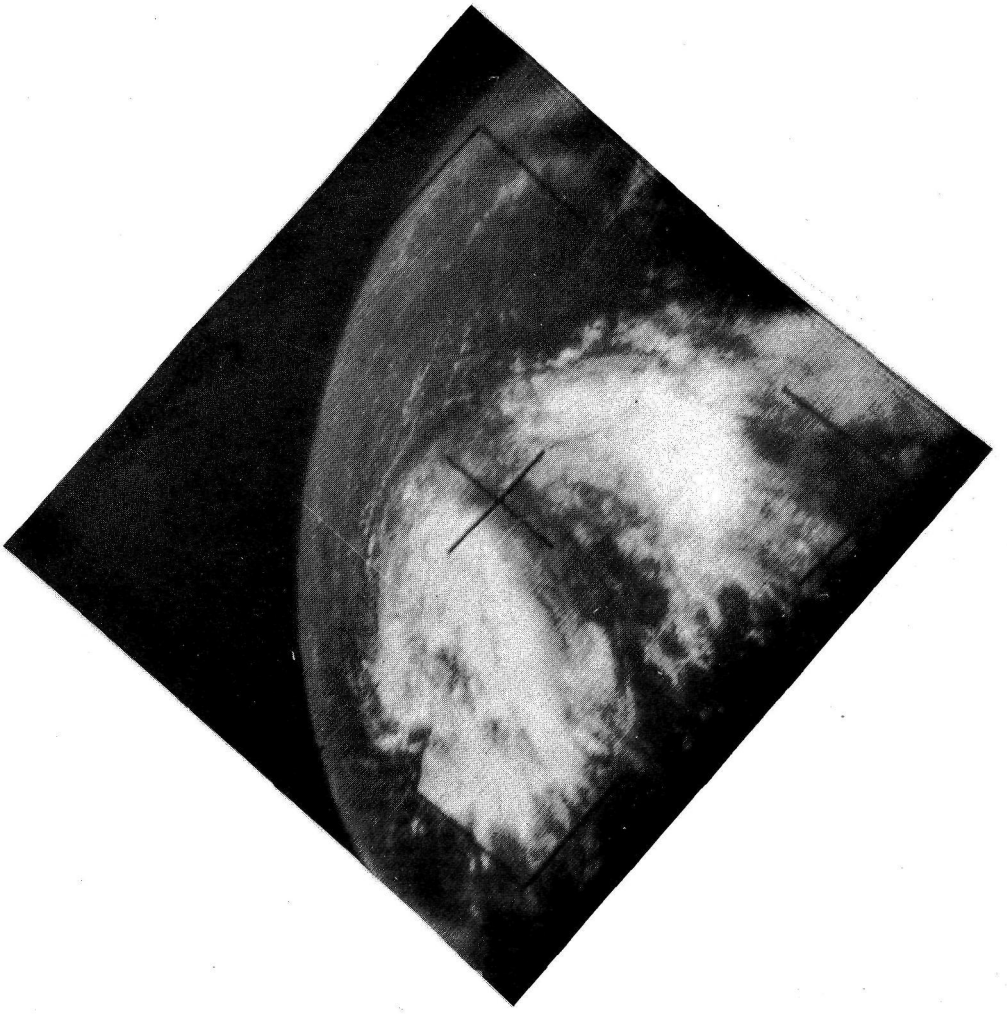

FRONTAL ZONE
FORMATIVE STAGE
HURRICANE DEBRA
INTERTROPICAL CONVERGENCE
BRAZIL
45N
40N
35N
30N
25N
20N
15N
10N
5N
0
5S
10S
15S
TIROS NEPH
DTG: 1300 Z
17 SEPT 1963
ORBIT: 1333 R/O 1332
ACCURACY: ±2
WEAK VORTEX 32N 54W
VORTEX 13N 43W
CLR FEW
55W
40W
70W
10

FIGURE 14



FORMATIVE STAGE HURRICANE DAISY
1330 Z 1 OCT 1962

FIGURE 15



N

TROPICAL STORM DAISY
1232 Z 2 OCT 1962

FIGURE 16

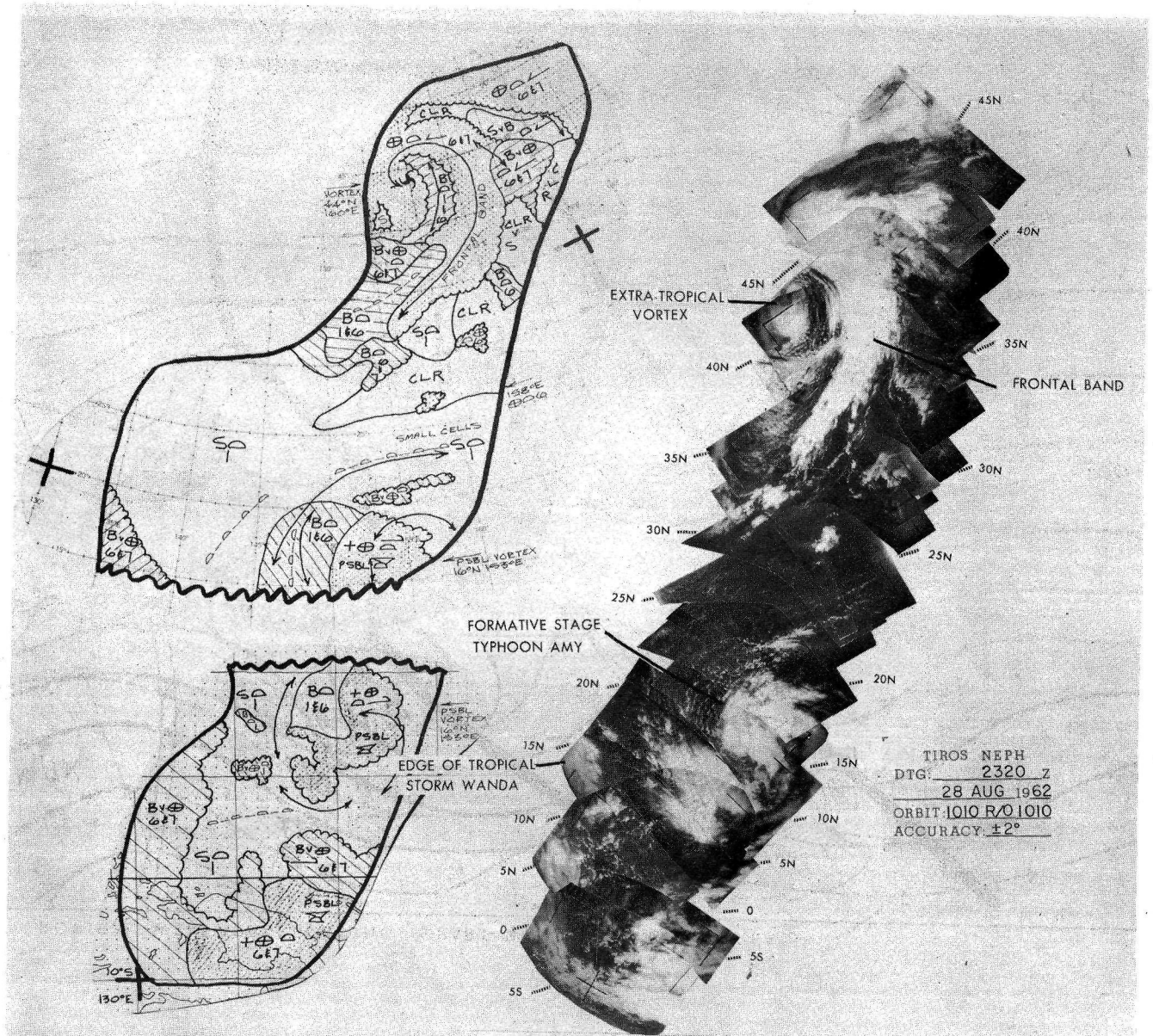

EXTRA-TROPICAL VORTEX
FRONTAL BAND
FORMATIVE STAGE TYPHOON AMY
EDGE OF TROPICAL STORM WANDA
TIROS NEPH
DTG: 2320 Z
28 AUG 1962
ORBIT 1010 R/O 1010
ACCURACY ±2°
45N
40N
35N
30N
25N
20N
15N
10N
5N
0
5S
CLR
SMALL CELLS
PSBL VORTEX
FRONTAL BAND
130°E

FIGURE 17

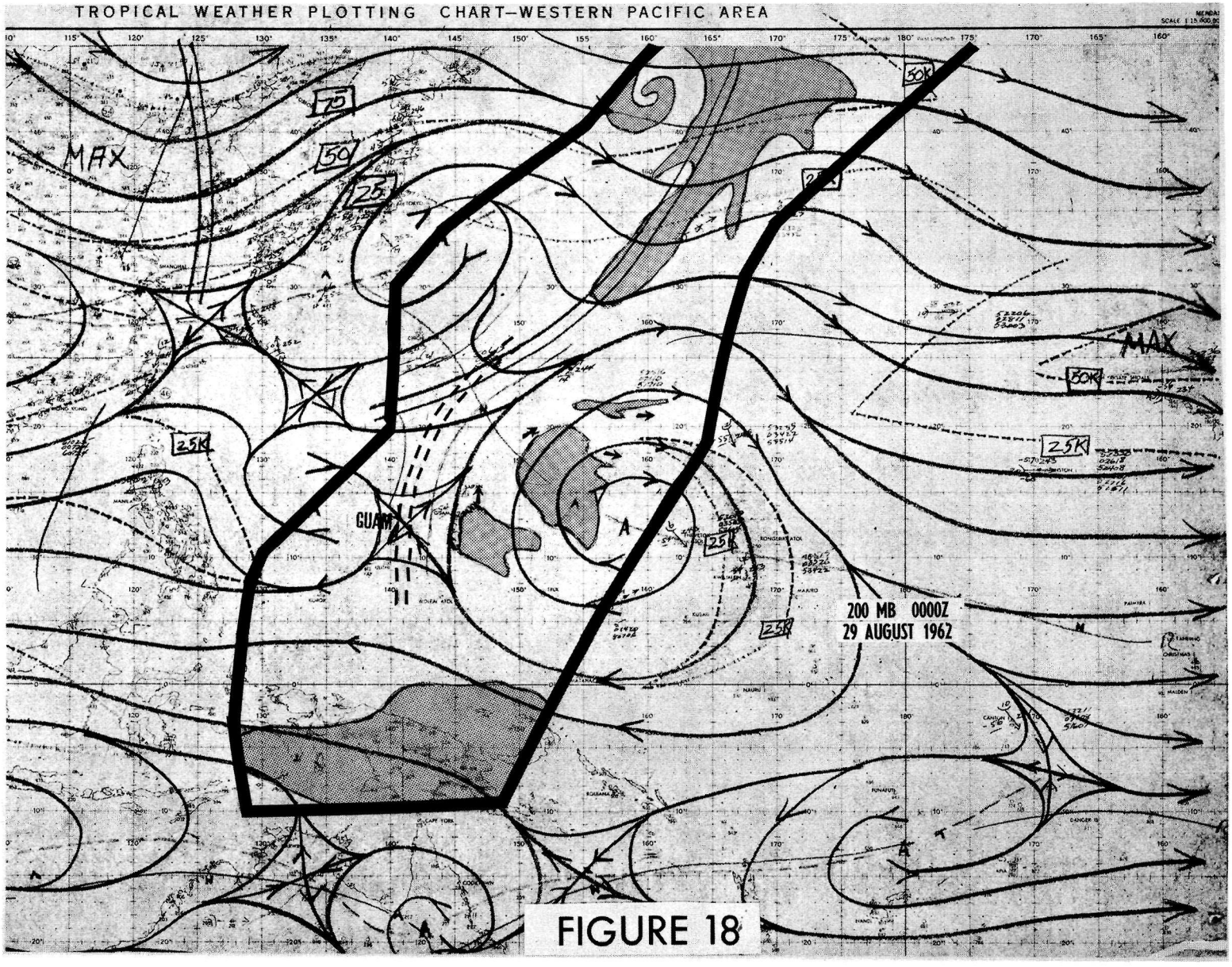

TROPICAL WEATHER PLOTTING CHART—WESTERN PACIFIC AREA
MAX
MAX
GUAM
200 MB 0000Z
29 AUGUST 1962

FIGURE 18

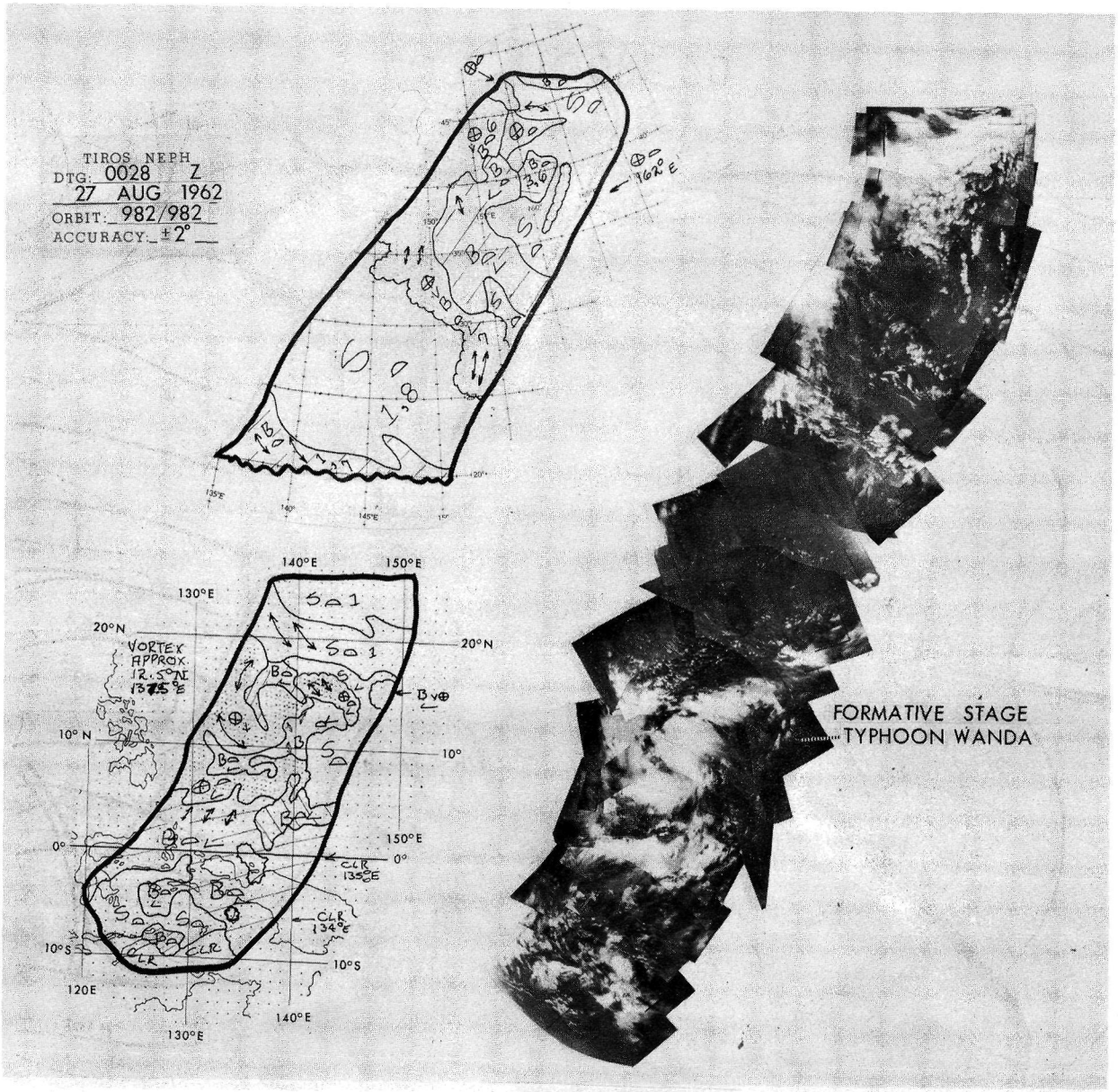

TIROS NEPH
DTG: 0028 Z
27 AUG 1962
ORBIT: 982/982
ACCURACY: ±2°
162° E
140°E
150°E
130°E
20°N
VORTEX
APPROX.
12.5°N
137.5°E
10° N
10°
0°
150°E
0°
CLR
135°E
CLR
134°E
10°S
10°S
120E
140°E
130°E
FORMATIVE STAGE
TYPHOON WANDA

FIGURE 19

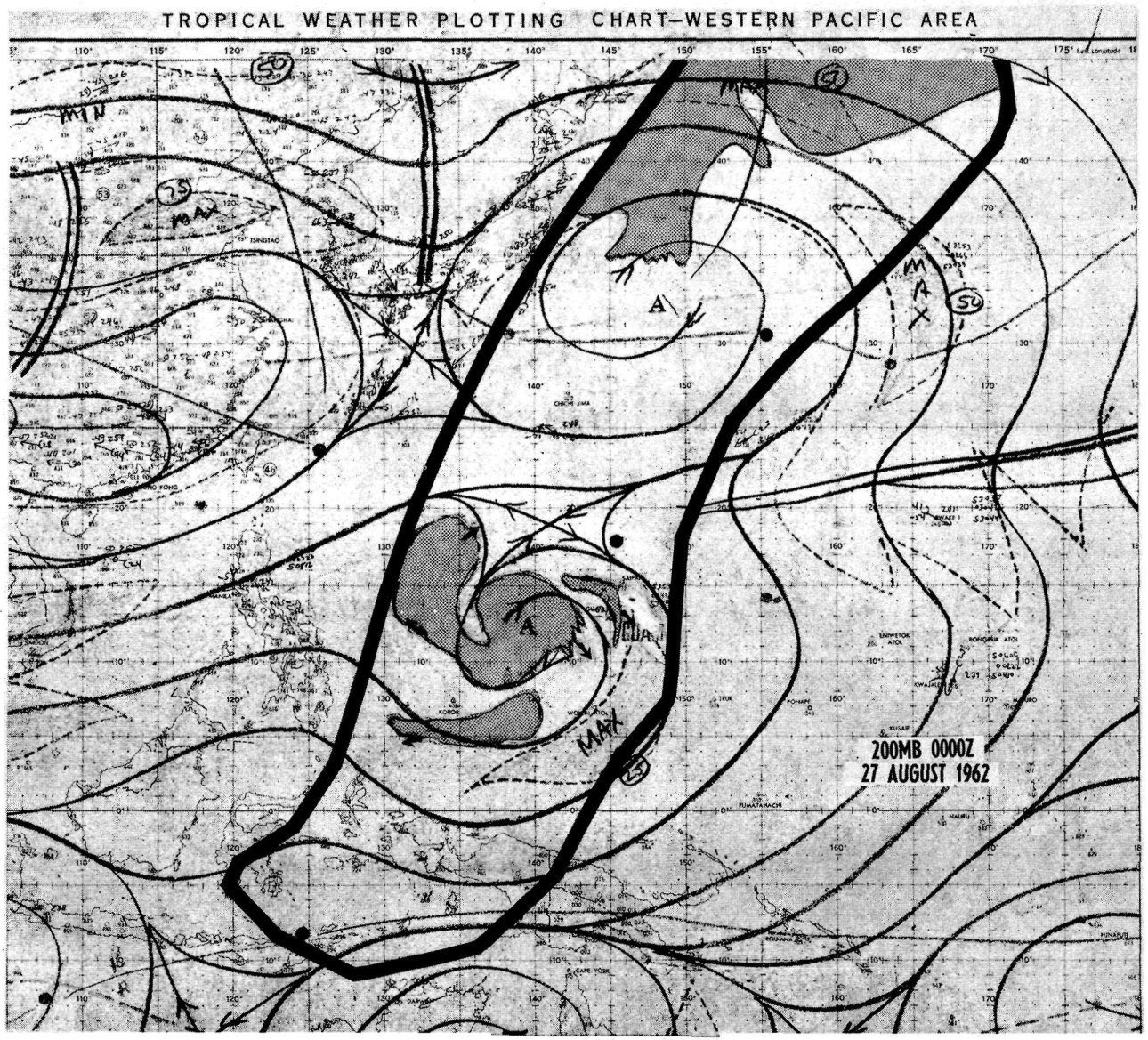

TROPICAL WEATHER PLOTTING CHART—WESTERN PACIFIC AREA
200MB 0000Z
27 AUGUST 1962

FIGURE 20

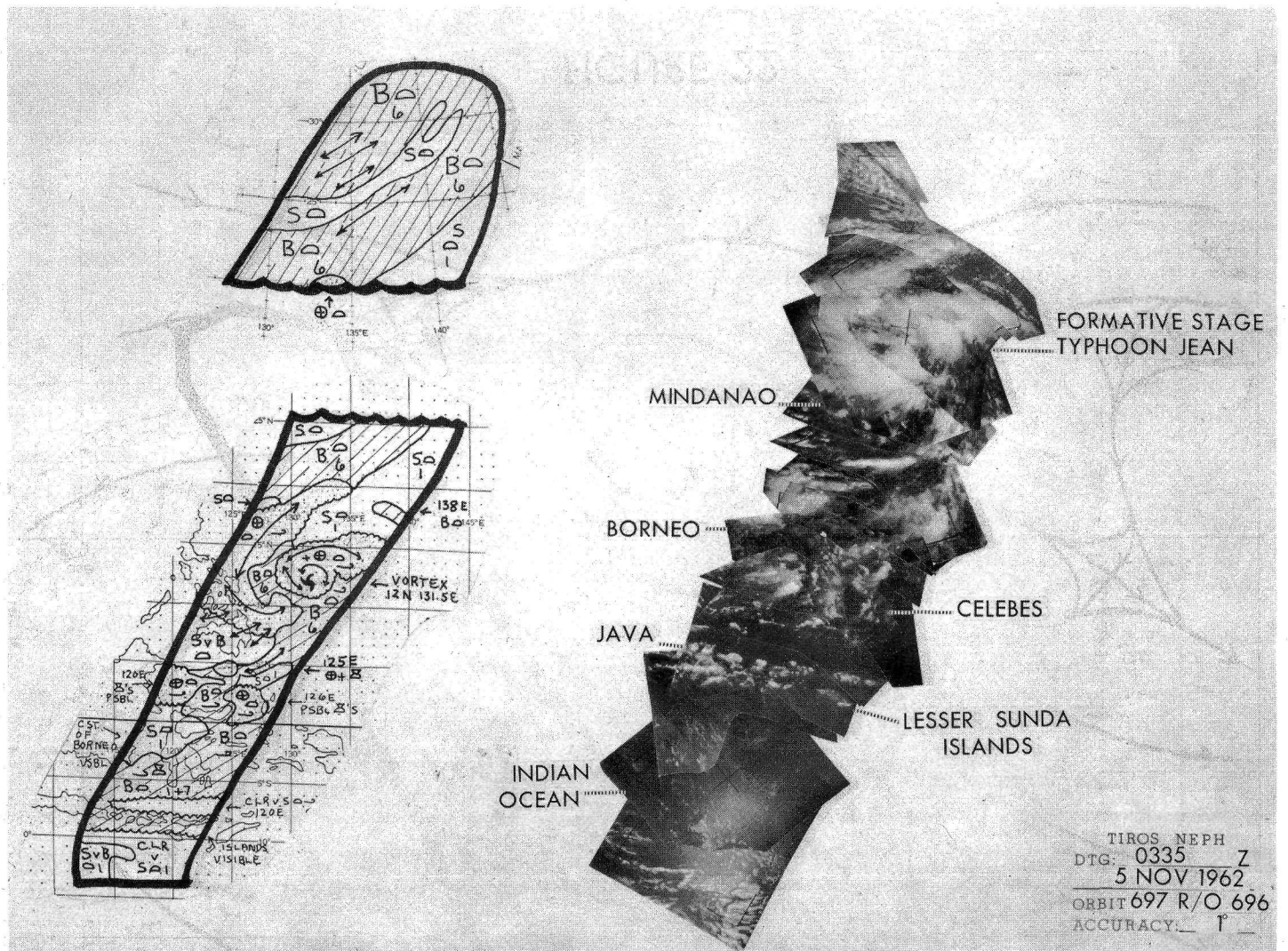

FORMATIVE STAGE
TYPHOON JEAN
MINDANAO
BORNEO
CELEBES
JAVA
LESSER SUNDA
ISLANDS
INDIAN
OCEAN
VORTEX
12N 131.5E
138E
125E
126E
120E
ISLANDS
VISIBLE
TIROS NEPH
DTG: 0335 Z
5 NOV 1962
ORBIT 697 R/O 696
ACCURACY: 1°

FIGURE 21

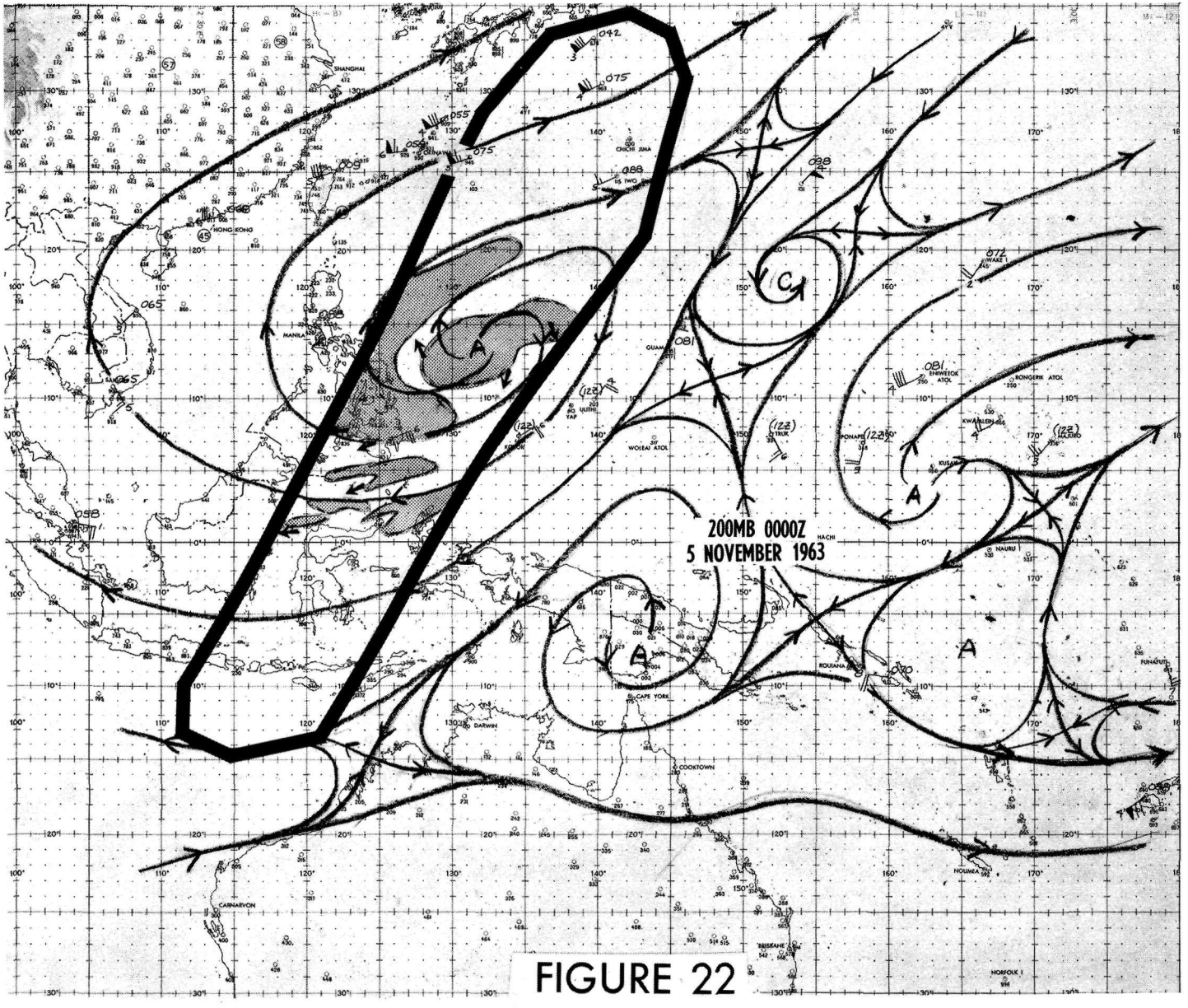

200MB 0000Z
5 NOVEMBER 1963
SHANGHAI
HONG KONG
MANILA
GUAM
IWO
CHICHI JIMA
EINIWETOK ATOL
RONGERIK ATOL
KWAJALEIN
WOLEAI ATOL
ULITHI
YAP
TRUK
PONAPE
KUSAIE
NAURU
FUNAFUTI
ROUSANA
CAPE YORK
DARWIN
COOKTOWN
NOUMEA
CARNARVON
BRISBANE
NORFOLK I
A
C

FIGURE 22

128 773