ROYAL OBSERVATORY, HONG KONG

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PERFORMANCE OF THE ECMWF MODEL IN PREDICTING THE MOVEMENT OF TYPHOON WAYNE (1986)

by

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1. INTRODUCTION

Typhoon Wayne (1986) was one of the most unusual tropical cyclones in the western North Pacific. Formed on the evening of 17 August, 1986, it roamed the northern part of the South China Sea and waters near Taiwan for the next 21 days. During its lifetime, it made four major directional reversals (Fig. 1) and presented forecasters with great problems in predicting its movement. Because of its ever-changing track, most of the objective forecast techniques also did poorly in predicting the movement of Wayne.

The Royal Observatory, Hong Kong routinely receives forecast products from the European Centre for Medium-range Weather Forecasting (ECMWF). The surface prognostic charts quite often show a low pressure centre near the position of a tropical cyclone. This centre can thus be interpreted as the forecast position of the cyclone. Similarly, on the 850 hPa wind forecast charts, a cyclonic circulation can usually be identified close to the tropical cyclone centre. Operationally, these centres of low pressure or cyclonic circulation are used as additional guidance in predicting the movement of a tropical cyclone.

This study is to investigate the performance of the ECMWF model in forecasting the positions of Wayne. This cyclone was chosen because of its unusual track. Each of its directional reversals resulted from a different type of synoptic-scale forcing. Therefore, such a study will provide a preliminary basis for designing some rules in using the ECMWF model for tropical cyclone track forecasting. These rules can further be tested on other tropical cyclones.

2. THE LIFE HISTORY OF WAYNE

As this study is focussed on the movement of Wayne, discussions on its intensity changes will be kept to a minimal. More details in this aspect can be found in the reports of the Royal Observatory (1986) and the Joint Typhoon Warning Center (1986).

After its formation on the evening of 17 August, 1986 over the northern part of the South China Sea, Wayne initially drifted northwestwards (Fig. 1). An upper-level vortex associated with the Tropical Upper Tropospheric Trough (TUTT) in its proximity (not shown) provided an outflow channel for Wayne which then intensified to a typhoon at around 1912 UTC[1]. With the subtropical ridge to its north and the westerlies over 10° latitude away from Wayne (Fig. 2a), one would not normally expect the latter to recurve. However, 12 hours later, the subtropical ridge split apart (Fig. 2b) and Wayne turned sharply towards the northeast at around 2000. This was the first major directional change of Wayne and resulted in large errors for forecasts based on the 1900 and 1912 data.

Wayne then turned east-northeastwards at around 2012 and headed for Taiwan. The absence of a TUTT-low resulted in Wayne weakening to a severe tropical storm. But at 2100, it was embedded in an upper-level anticyclone and reintensified to a typhoon (not shown). Continuing with its east-northeastward movement, Wayne swept across Taiwan on the morning of 22 August. Terrain interaction caused Wayne to weaken to a tropical storm.

Around 2212, Wayne began to slow down and turned southeastwards as the westerlies retreated northwards. A 500 hPa anticyclone developing over China (Fig. 3) then "steered" Wayne southwestwards at around 2306. This complete directional reversal was very unusual and again resulted in large forecast errors. Except for a brief turn towards the west, Wayne continued to move southwestwards until around 2606.

While Wayne was heading towards the southwest, another typhoon at around 140°E, Vera, was moving west-northwestwards (Fig. 4). With the circulation of Vera much larger than that of Wayne, the 'Fujiwhara' effect between the two cyclones was such that Wayne was under the influence of Vera from around 2400 to 2718 and this is indicated in Figure 5. During this period, Wayne moved cyclonically around Vera at radius of about 1 500 km with an average rotational speed of about 20° per day. As Vera recurved to the north over the East China Sea at 2612, Wayne also slowed down and began to turn eastwards. During this period, strong vertical shear continually weakened Wayne which finally became a tropical depression at 2606. The sharp turn towards the east at around 2618 as a result of the Fujiwhara interaction represents the third directional reversal in the life history of Wayne.

[1] Hereafter, the time will be referred to in 4-digit figures, the first two for the day and the last two the time in UTC (Universal Coordinated Time). Thus 12 UTC on the 19th is represented as 1912.

At around 2812, Wayne was steered northeastwards by a mid-tropospheric trough associated with Vera which was speeding across the Korean peninsula (Fig. 6). However, at 2912, the 500 hPa flow pattern shows that Wayne was surrounded by anticyclones on all sides (Fig. 7). As a result, Wayne became slow-moving over the waters just to the southeast of Taiwan. These conditions persisted for the next two days. During this period, Wayne reintensified to a severe tropical storm as the vertical shear decreased. Wayne further strengthened to a typhoon at around 3100 with the 200 hPa ridge axis directly over Wayne (not shown).

The last directional reversal of Wayne occurred at around 0100 when the 500 hPa anticyclone over south China became more dominant (Fig. 8). Wayne further veered west-southwestwards at 0200. By 3 September the 500 hPa subtropical ridge re-established to the north of Wayne (not shown). As a result, the latter took on a west-northwestward course and moved across the South China Sea. Wayne reached its maximum intensity at around 0406 with maximum sustained winds of 41 m s^{-1} near its centre and a minimum sea level pressure of 955 hPa. It then accelerated to a speed of around 30 km h^{-1} and passed through the Hainan Strait at around 0503. Wayne crossed the coast of Vietnam at 0518. Over land, it further weakened to a tropical depression and then an area of low pressure.

3. THE ECMWF MODEL PREDICTIONS

a. Locating the vortex centre

Operationally, the resolution of the ECMWF products is $2.5^{\circ} \times 2.5^{\circ}$ latitude. However, to provide a better definition of the centre of low pressure or cyclonic circulation, the high resolution ($1.125^{\circ} \times 1.125^{\circ}$ latitude) forecast products were used in the study. As the ECMWF model generates forecasts only at 12 UTC, only 24-, 48- and 72-h forecasts valid at this time each day were verified.

These forecast products include heights and winds on constant pressure surfaces. The 1000 hPa flow was therefore used to represent the vortex centre at the lowest level. In addition, the 850 hPa flow was also analyzed.

Three methods have been used to locate the centre of the vortex at 1000 or 850 hPa at a certain forecast time. In the first method, the heights at each level were analyzed to determine a relative minimum. This position was then taken as the centre. No attempt was made to interpolate the values between grid points. Therefore, the forecast positions always fell on a grid point unless two or more adjacent grid points had the same minimum value. In this case, the centre was taken as the point half way between these grid points. As more than one minimum could exist, the following criteria were established in choosing the forecast position:

(a) The minimum must occur within a specified box centred around the best-track position at the forecast time. This box has a dimension of 12° latitude for the 24-h, 16° for the 48-h and 20° for the 72-h forecast;

(b) If two or more minima occurred within the specified box, the one closest to the best-track position at the forecast time was chosen; and

(c) If two or more minima are equidistant, the one with the lowest heights was chosen.

Criterion (b) must be applied before (c).

The second method is to analyze the grid-point winds and locate a centre of cyclonic circulation. If two or more centres were present, the above criteria were used to determine the centre.

The last method computes the relative vorticity from the wind components based on centre-difference. The procedures and criteria used in locating the centre from the height fields were then applied except, in the case, the grid with maximum value was considered to be the cyclone centre.

Of the three methods, the second method (locating centre of cyclonic circulation) gave the most consistent and best result. Therefore, only these will be presented. However, a couple of problems were still present. The first one was that occasionally, no centre could be located at a certain forecast period. These cases were therefore ignored. The other problem that arose during the analysis was that quite often, the centre located using the 1000 flow did not coincide with that determined from the 850 hPa flow. Thus, these two sets of forecast positions were verified separately.

b. The forecasts

To make the verification easier, the track of Wayne was divided into five segments. Four of these centred around the time when each of the four directional reversals occurred. The fifth consists of the last few days of Wayne. The forecast tracks from ECMWF and those from the Royal Observatory (RO) are plotted on the same chart for comparison. As the RO does not routinely produce 72-h forecasts, the RO forecast tracks have only the 24- and 48-h positions.

(i) 1612-2012

The best track for this segment together with the forecast positions are shown in Fig. 9. Notice that while the RO forecasts had a strong persistence component, the ECMWF forecasts predicted recurvature at the critical time 1912. Even the 850 hPa forecast made at 1812 suggested a northward movement (Fig. 9b). After the recurvature, the ECMWF model also predicted that Wayne would return to the South China Sea by 2312. Although Wayne did not enter the South China Sea until 2500, the model predictions gave the correct trend.

(ii) 2112-2312

The largest errors made during the life of Wayne occurred during this period (see Table 1). The 48-h forecasts made by the RO and the Joint Typhoon Warning Center (JTWC) at 2212 and 2312 were over 1000 km. The RO forecast tracks again showed a strong persistence bias. The 72-h JTWC forecast made at 2212 was even close to 2000 km.

However, the ECMWF forecasts showed a directional reversal for both the 2112 and 2212 forecasts (Fig. 10). Thus, at the critical time 2212, the 72-h errors were only < 200 km. Further, the 2312 forecast suggested a continued southwestward movement. The ECMWF model therefore performed extremely well during this period.

(iii) 2412-2712

The ECMWF forecasts during this period were not as satisfactory as these in the last two (Fig. 11). The directional reversal that occurred at around 2612 was not predicted in the 1000 hPa flow. Although the flow at 850 hPa suggested, by 2812, a centre to the northeast of the position at 2612, a sharp turn in the forecast track occurred afterwards. These abrupt turns in the forecast track were also present in the 2712 predictions, giving rise to rather inaccurate forecasts. This result is quite discouraging as it was during this period that the 'Fujiwhara' effect between Wayne and Vera took place (see Section 2 and Fig. 5).

(iv) 2812-3112

The slowing-down of Wayne during this period was not well predicted by the ECMWF model. Forecast tracks derived from both the 1000 and 850 hPa (Fig. 12) were rather inaccurate for the 2812 and 2912 forecast. Although the forecasts using the 3012 and 3112 data suggested an eventual southwestward displacement, the short-term forecasts showed a westward movement. As the flow around Wayne was quite weak between 2912 and 3112, these results are not particularly encouraging.

The RO forecasts made at 2712 were quite good and the turning southwestwards on 3112 was also well predicted.

(v) 0112-0412

For this last segment of the track of Wayne in which no significant directional changes occurred, the RO forecasts were quite satisfactory (Fig. 13). Other than some fluctuations in the forecasts made on 0212, the ECMWF predictions during this period were quite satisfactory at least in terms of the direction.

c. Evaluation of the forecasts

To quantify the ECMWF forecasts, their errors can be compared with those made by the RO and the JTWC (Table 1). Only the 48- and 72-h forecasts were evaluated as the 24-h ECMWF forecasts were in general larger than those from the two other centres. The forecast errors of the JTWC were extracted from their annual report (JTWC, 1986). Unfortunately, for some forecast periods, the errors were not available. Note also that for those times in which no ECMWF forecast positions could be located (see Section 3a), no comparison is made.

A comparison between the forecasts made using the 1000 hPa and the 850 hPa flow shows that they are comparable. Some of the forecast errors are rather small. The mean errors at both the 48- and 72-h are much lower than those from operational centres. To compare the ECMWF forecast errors with those of the RO and the JTWC, a homogeneous sample is necessary. This reduces the number of cases by about half. At the 48-h interval, the ECMWF forecasts are better than the RO or JTWC forecasts by almost 30%. The 72-h ECMWF forecasts are even better, with errors only about 50% of those from the JTWC. Furthermore, notice that the ECMWF forecasts at both the 48- and 72-h intervals have much smaller standard deviations. This result suggests that the ECMWF model predictions are more consistent and do not fluctuate widely in most cases.

Note, however, that although the ECMWF forecast errors are much smaller than those of the operational centres, situations did arise in which the ECMWF model did not perform well at all, as have been discussed in the previous sub-section. A further examination of the forecast positions suggests that these were usually cases in which the forecast track showed rather sharp turns, i.e. not very physical. This must be taken into consideration when using the results from this study.

4. SUMMARY AND DISCUSSION

A general conclusion that can be drawn from this study is that the ECMWF forecast products can be useful at times in providing a guidance for tropical cyclone track forecasting. Both the 48- and 72-h forecasts seem to be much better than those from the operational centres. The 1000 hPa or 850 hPa wind fields give essentially the same results.

However, it is discouraging to find that the ECMWF model failed to predict two of the directional reversals. One case involves the Fujiwhara interaction between Wayne and Vera. DeMaria and Chan (1984) have shown that the radial vorticity distribution is critical in determining the interaction between two tropical cyclones. Therefore, the incorrect ECMWF forecasts during the period of Fujiwhara interaction could be due to an incorrect representation of the vorticity fields of the two cyclones. This result also points out that caution must be exercised in using the ECMWF forecasts as guidance when two tropical cyclones are in the proximity of each other.

The other group of inaccurate forecasts occurred during the period when the environmental flow was weak. In this case, the beta-effect should dominate. The magnitude of this effect depends on the vorticity distribution of the cyclone (e.g., Chan and Williams, 1987). Therefore, this result again suggests that the vortex representation in the ECMWF model is inaccurate.

As discussed in the last section, the model-predicted tracks tended to show sharp turns during these periods. This suggests that the model was not giving a very physically meaningful movement of the vortex, probably as a result of a wrong representation of the latter.

The two other correctly-predicted directional reversals involved changes in the synoptic-scale flow. This implies that in situations in which the environmental flow is quite well-defined, the ECMWF model can provide a rather good forecast of the flow and hence the movement of the cyclone.

Two main conclusions can therefore be drawn from this study :

(a) The ECMWF model is capable of forecasting the movement of a tropical cyclone. Its accuracy depends on the environmental flow conditions. Use of the model forecasts as guidance should be restricted to situations when the environmental flow is well-defined or when no other tropical cyclone is in the vicinity.

(b) Strong emphasis must be placed in the representation of the tropical cyclone in numerical predictions of tropical cyclone movement. The sensitivity of vortex structure to its movement has been documented in barotropic studies (e.g., DeMaria, 1983, 1985; Chan and Williams, 1987). The results from this study suggest that this sensitivity is also true in fully baroclinic models.

In this study, only one tropical cyclone was analyzed. A systematic evaluation of the ECMWF forecasts of tropical cyclone movement will be made to substantiate these conclusions. An analysis similar to that used by Chan _et al_. (1987) will even provide more meaningful results and may also lead to the development of some rules for using these forecasts.

5. ACKNOWLEDGEMENTS

The authors would like to thank Mr. Y.K. Chan for his help in acquiring the ECMWF data for this study. The programming efforts of Mrs. P.C. Yu Leung and contributions from M.Y. Chan, K.P. Wong, W.H. Lui and L.H. Lit in data analyses are much appreciated.

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TABLE 1. COMPARISON OF 48- AND 72-H FORECAST ERRORS (km) FOR TYPHOON WAYNE MADE BY THE ECMWF PRODUCTS, THE RO AND THE JTWC. S.D. = STANDARD DEVIATION, N = NO. OF CASES

		48-h Forecast			72-h Forecast		
		ECMWF			ECMWF		
Time	RO	1000	850	JTWC	1000	850	JTWC
1612	-	78	-	-	125	325	-
1712	-	352	502	-	665	-	-
1812	416	207	145	315	-	-	782
1912	826	256	432	669	196	237	-
2012	304	259	275	-	616	724	-
2112	180	317	347	389	522	499	1026
2212	1193	258	289	1245	196	212	1980
2312	1205	222	239	-	-	-	-
2412	677	395	-	-	-	-	-
2512	802	-	-	-	-	-	-
2612	1040	-	652	-	750	193	-
2712	84	430	386	-	-	665	-
2812	556	622	627	391	289	269	676
2912	270	591	697	213	428	472	670
3012	540	581	463	613	582	506	920
3112	185	378	71	574	287	181	920
0112	405	184	164	243	320	350	448
0212	551	332	365	435	725	[illegible]02	815
0312	-	572	488	498	-	-	-
Mean	577	355	383	508	438	410	915
S.D.	344	155	178	272	209	190	410
N	16	17	16	11	13	13	9

Comparison with RO and JTWC forecasts (for 1000 hPa flow)

	RO	1000	850	JTWC	1000	850	JTWC
Mean	512	373		509	419		932
S.D.	294	157		285	168		432
N	10	10		10	8		8

Comparison with RO and JTWC forecasts (for 850 hPa flow)

	RO	1000	850	JTWC	1000	850	JTWC
Mean	512		360	509		399	932
S.D.	294		193	285		166	432
N	10		10	10		8	8

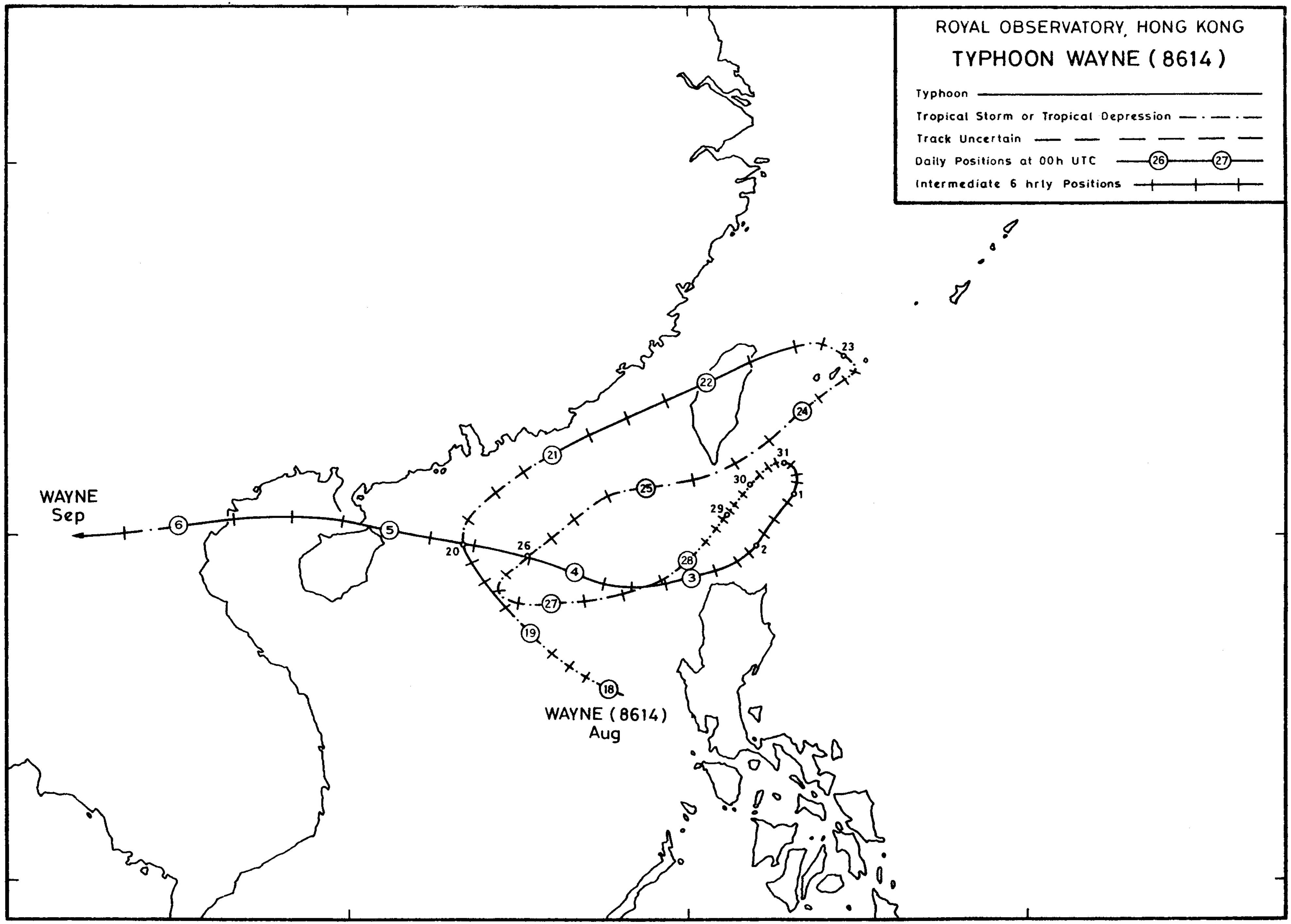


Fig. 1 Best-track of Typhoon Wayne as derived from post-analysis by the Royal Observatory, Hong Kong.

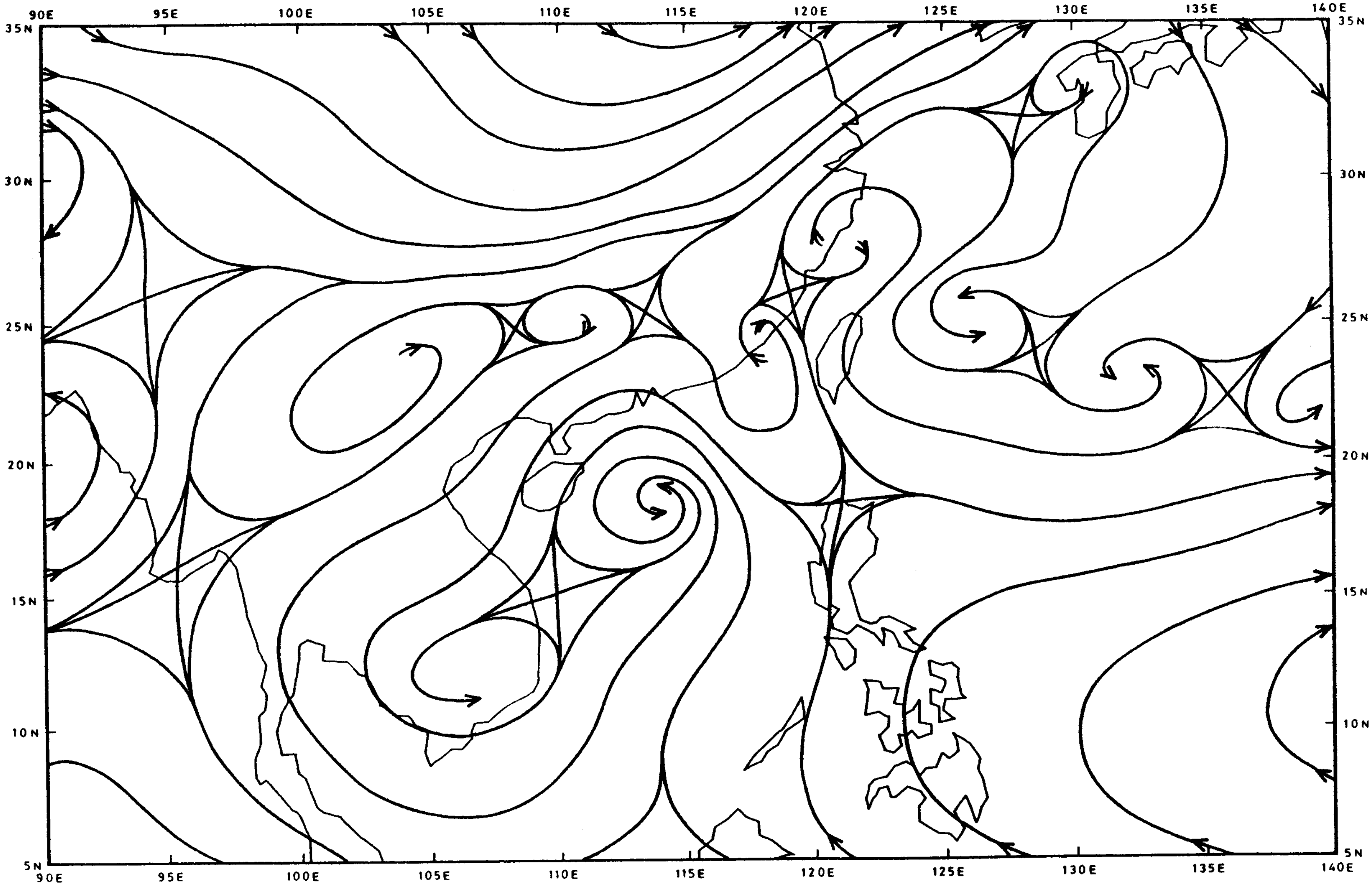


Fig. 2a 500 hPa streamline analysis at 1912.

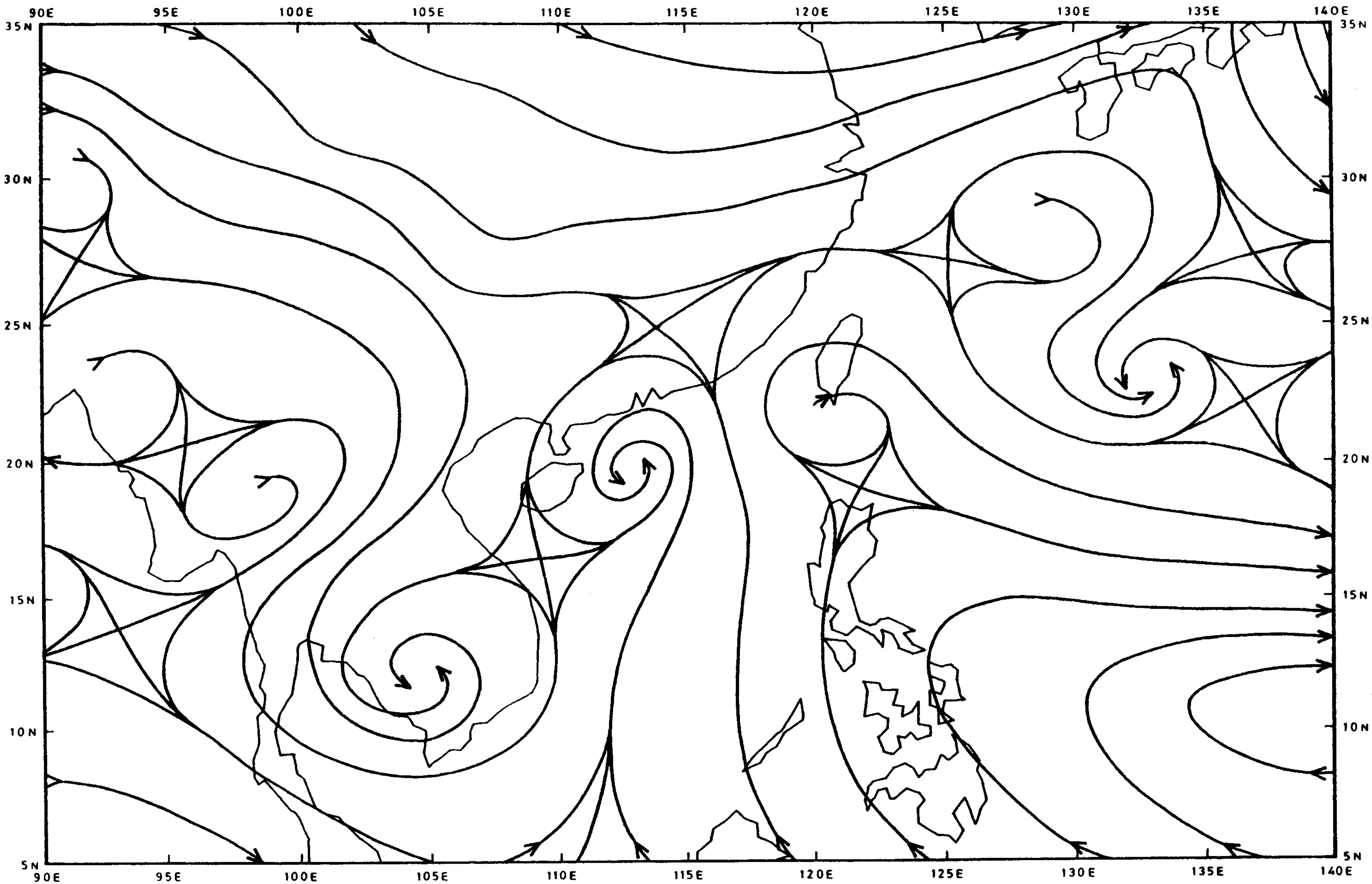


Fig. 2b 500 hPa streamline analysis at 2000.

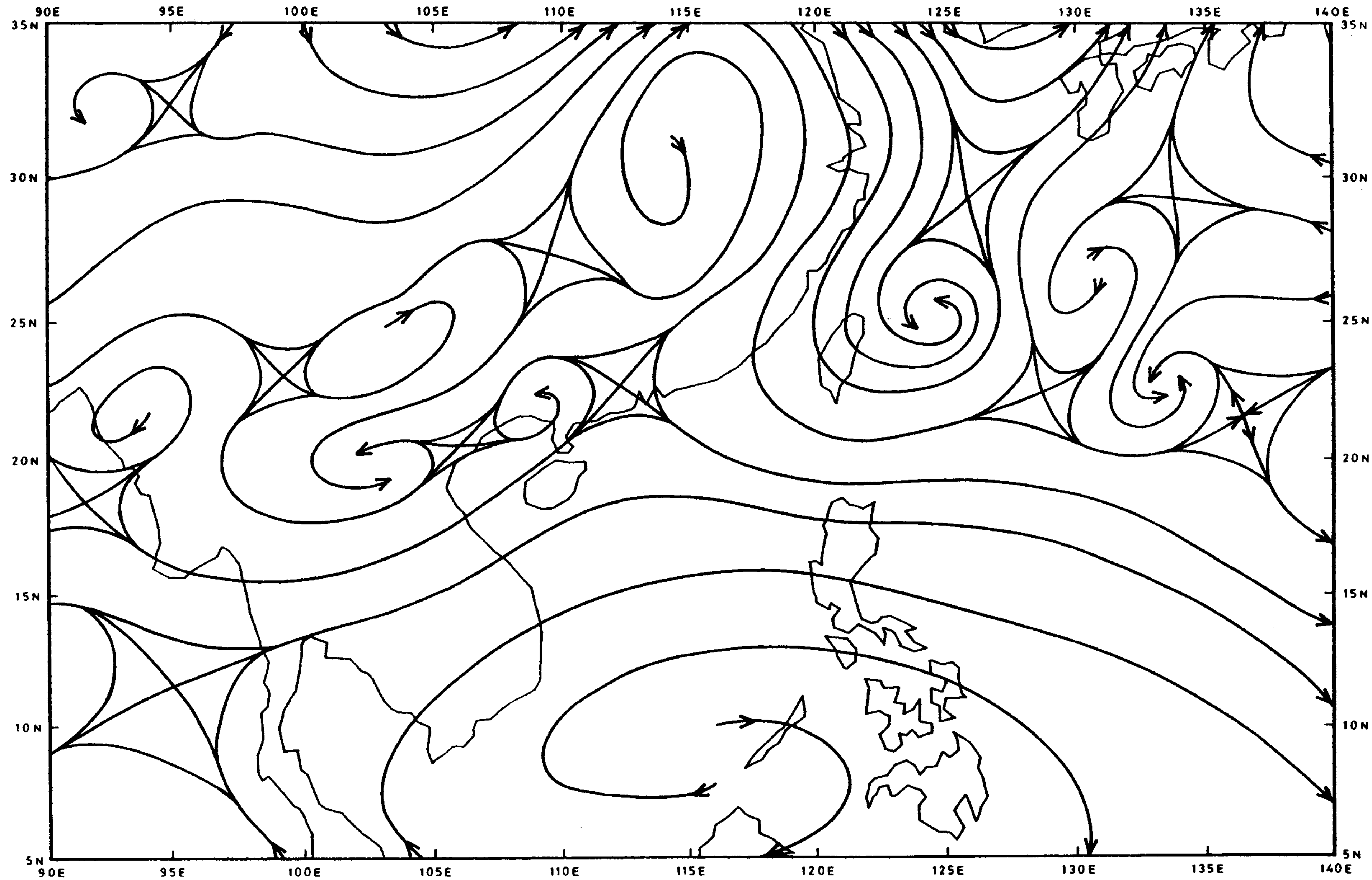


Fig. 3 500 hPa streamline analysis at 2300.

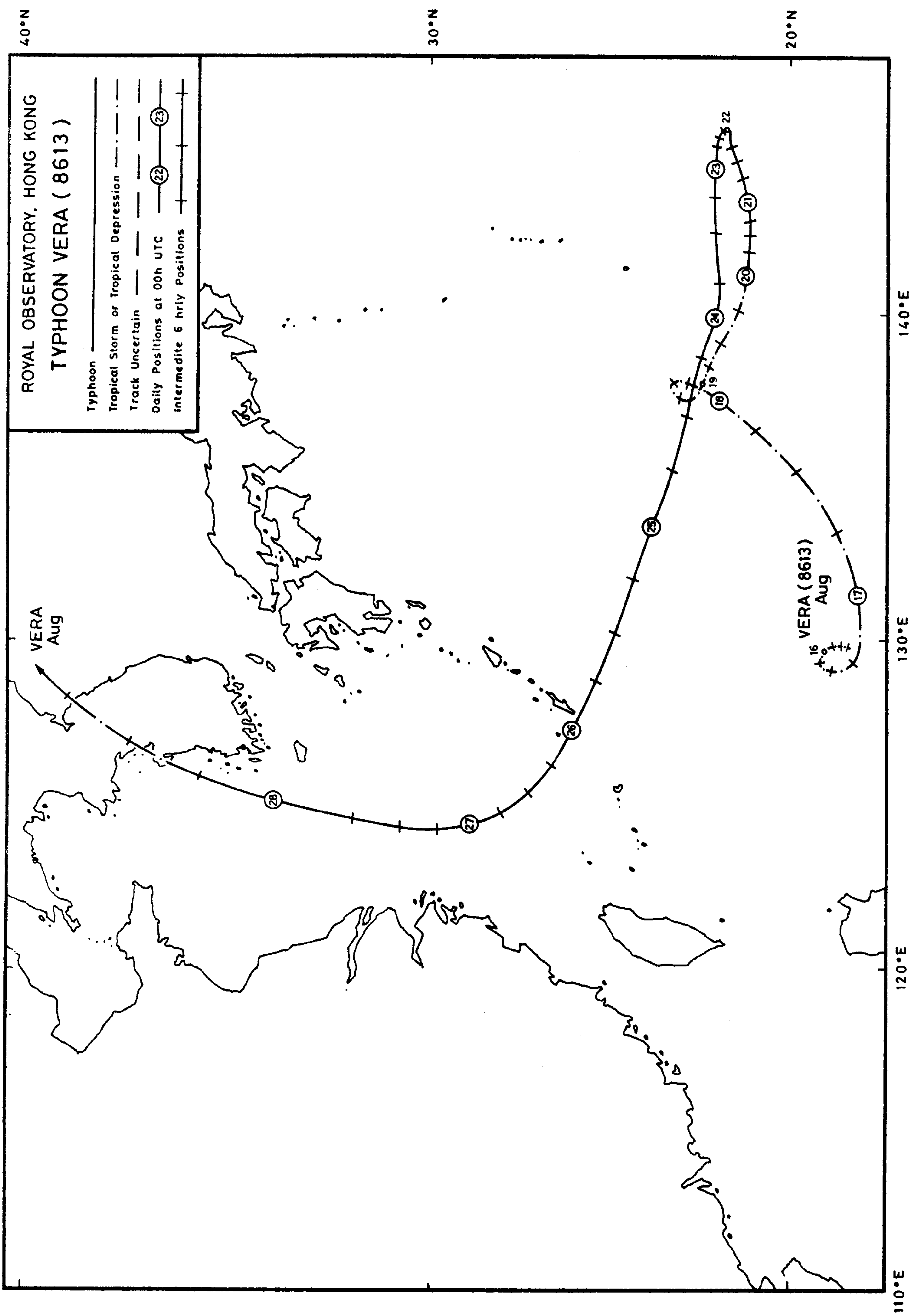


Fig. 4 Best-track of Typhoon Vera as derived from post-analysis by the Royal Observatory, Hong Kong.

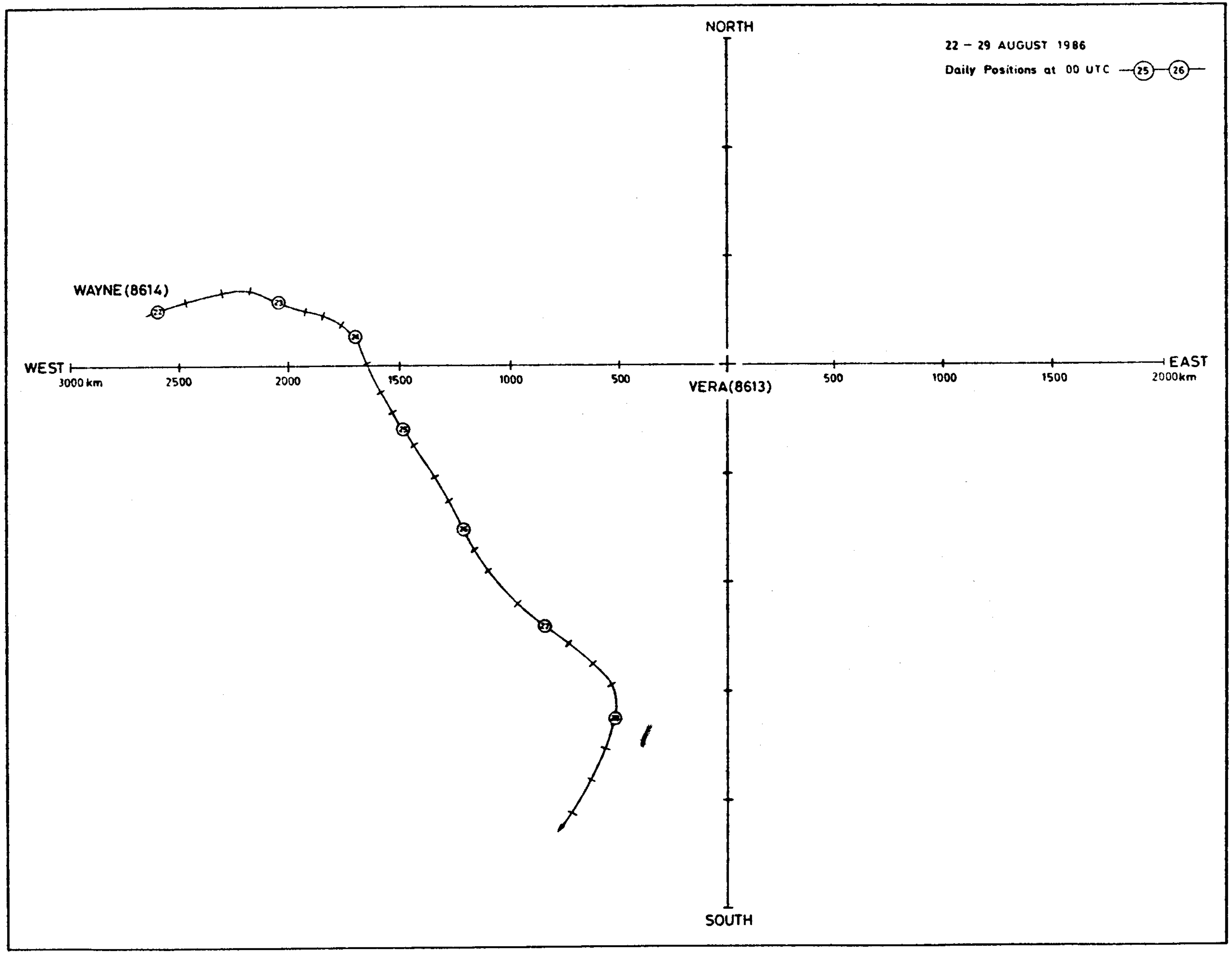


Fig. 5 Movement of Typhoon Wayne relative to Typhoon Vera between 22-29 August 1986.

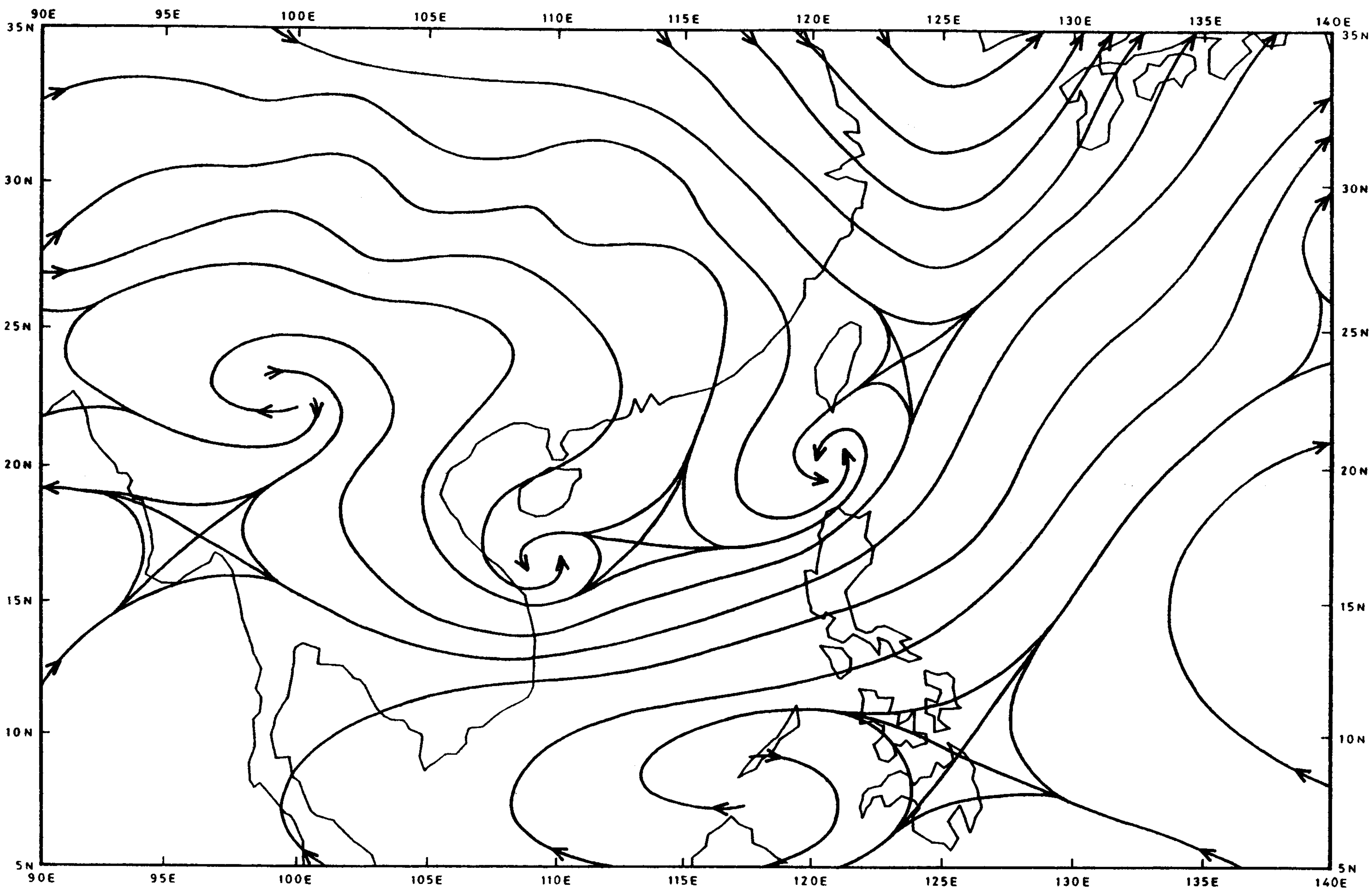


Fig. 6 500 hPa streamline analysis at 2812.

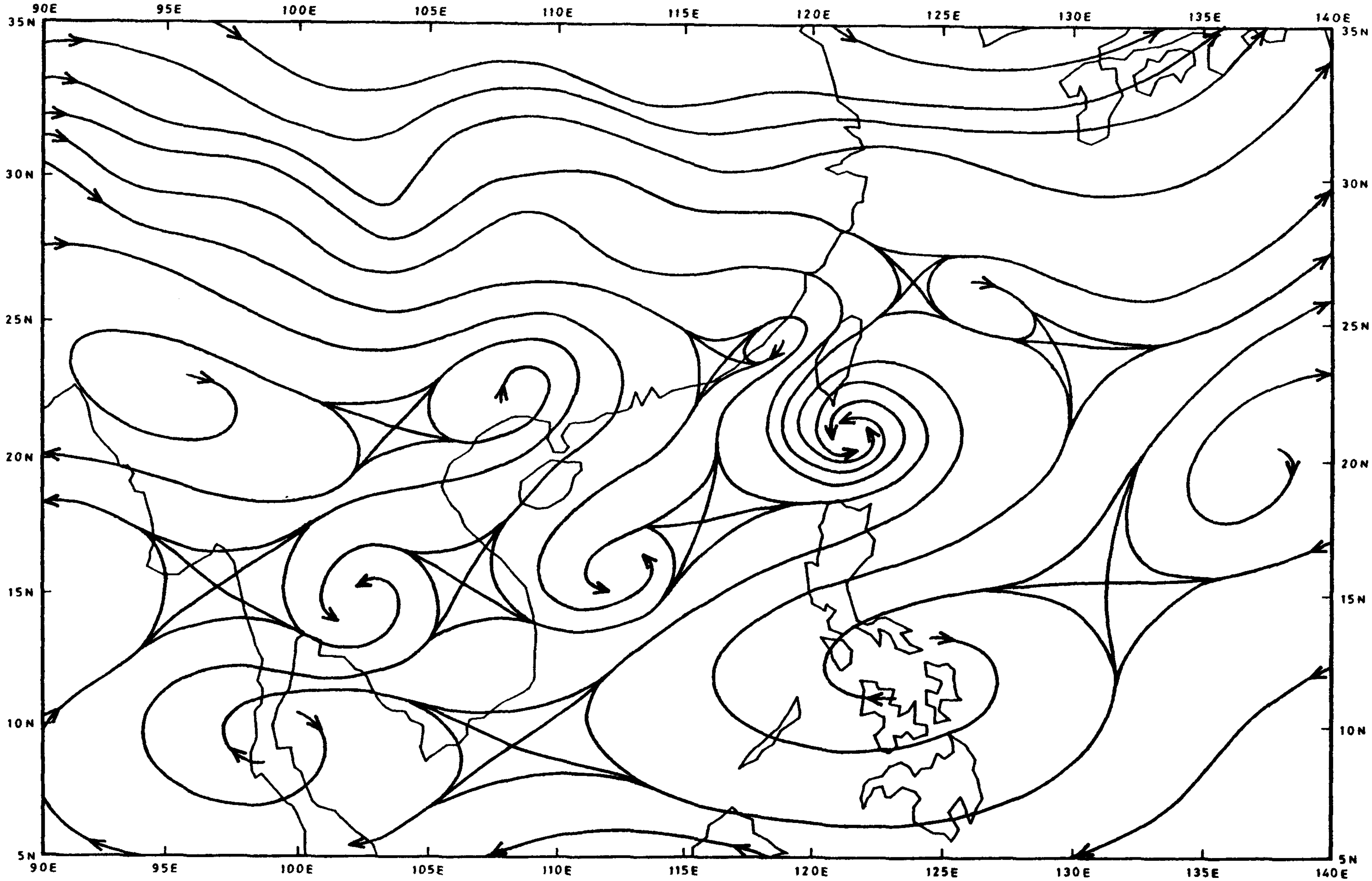


Fig. 7 500 hPa streamline analysis at 2912.

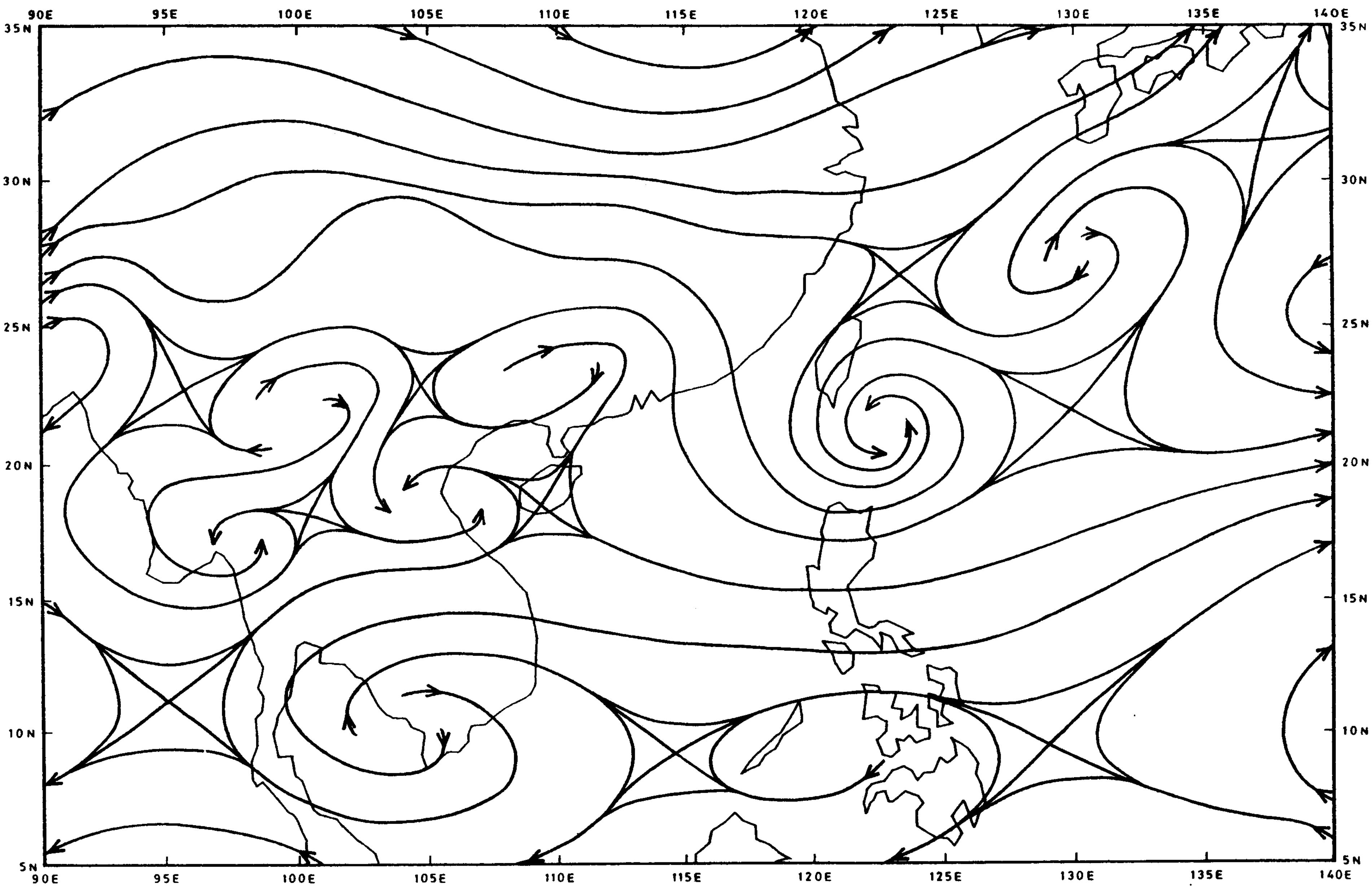
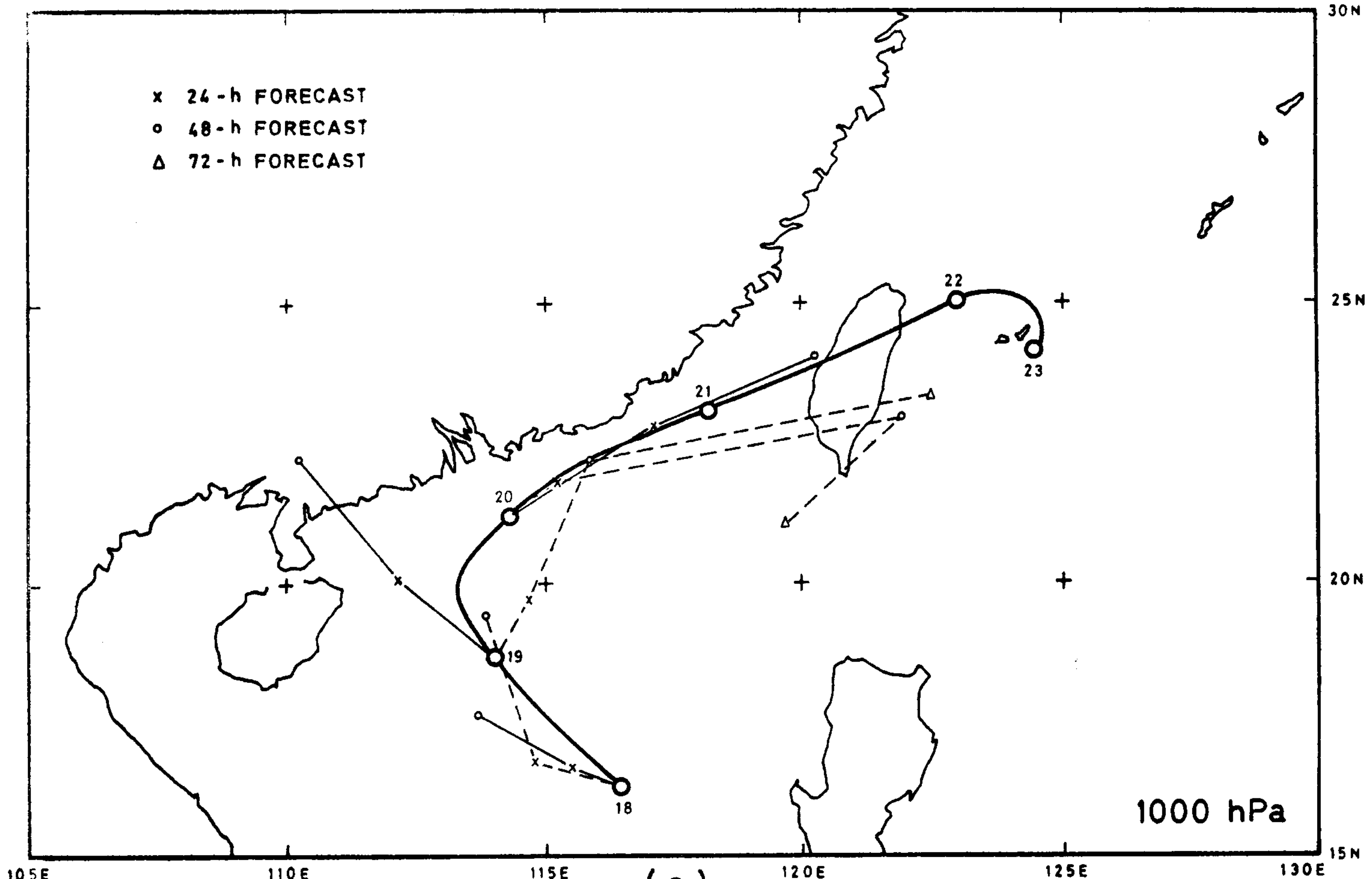
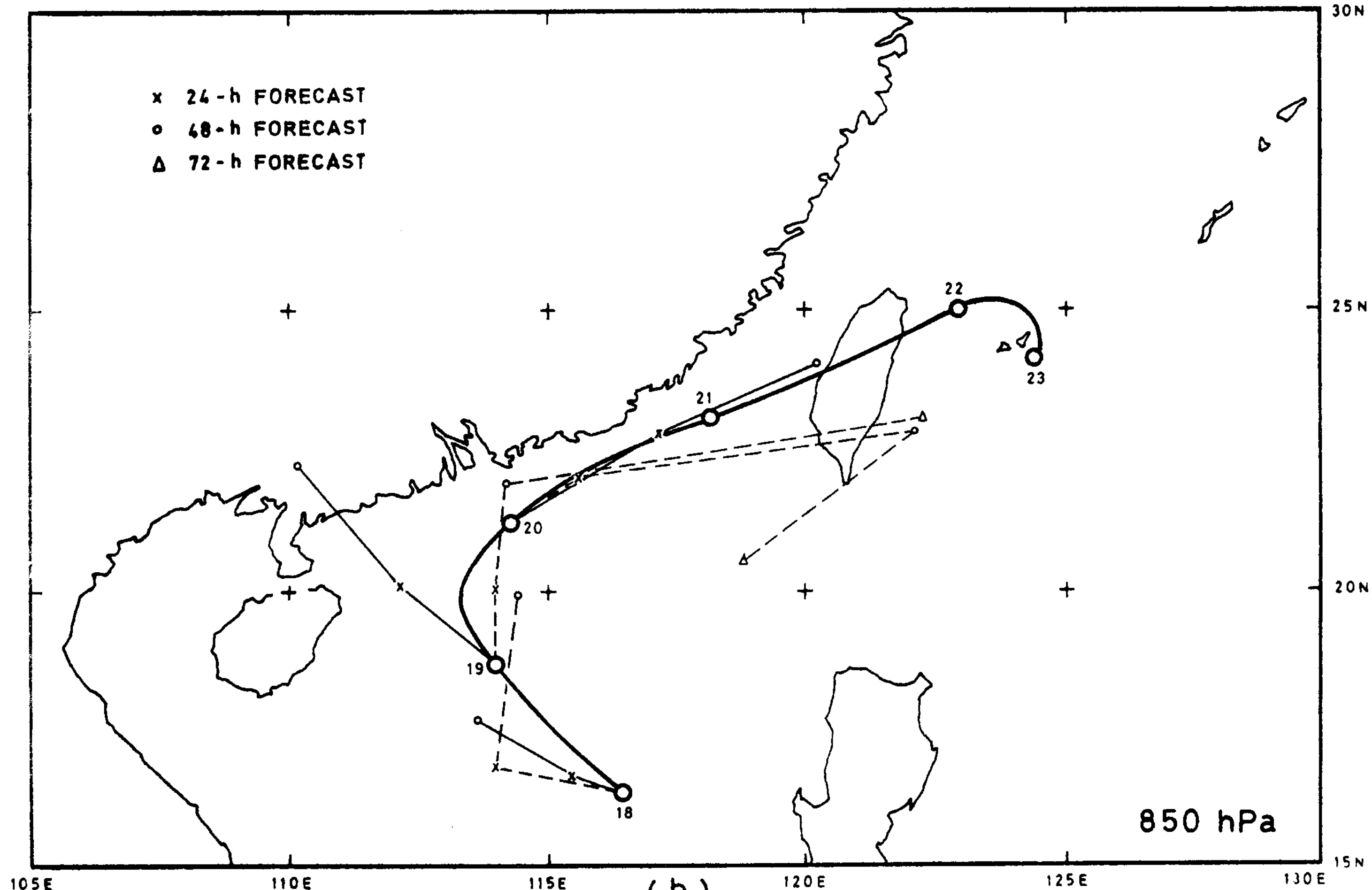


Fig. 8 500 hPa streamline analysis at 0100.



(a)



(b)

Fig. 9 The best-track segment of Wayne (thick solid) between 1612-2012 and the forecast tracks of the RO (thin solid) and those based on the ECMWF winds (dashed). Numbers in the circles along the best track indicate the day at 12 UTC. (a) 1000 hPa (b) 850 hPa.

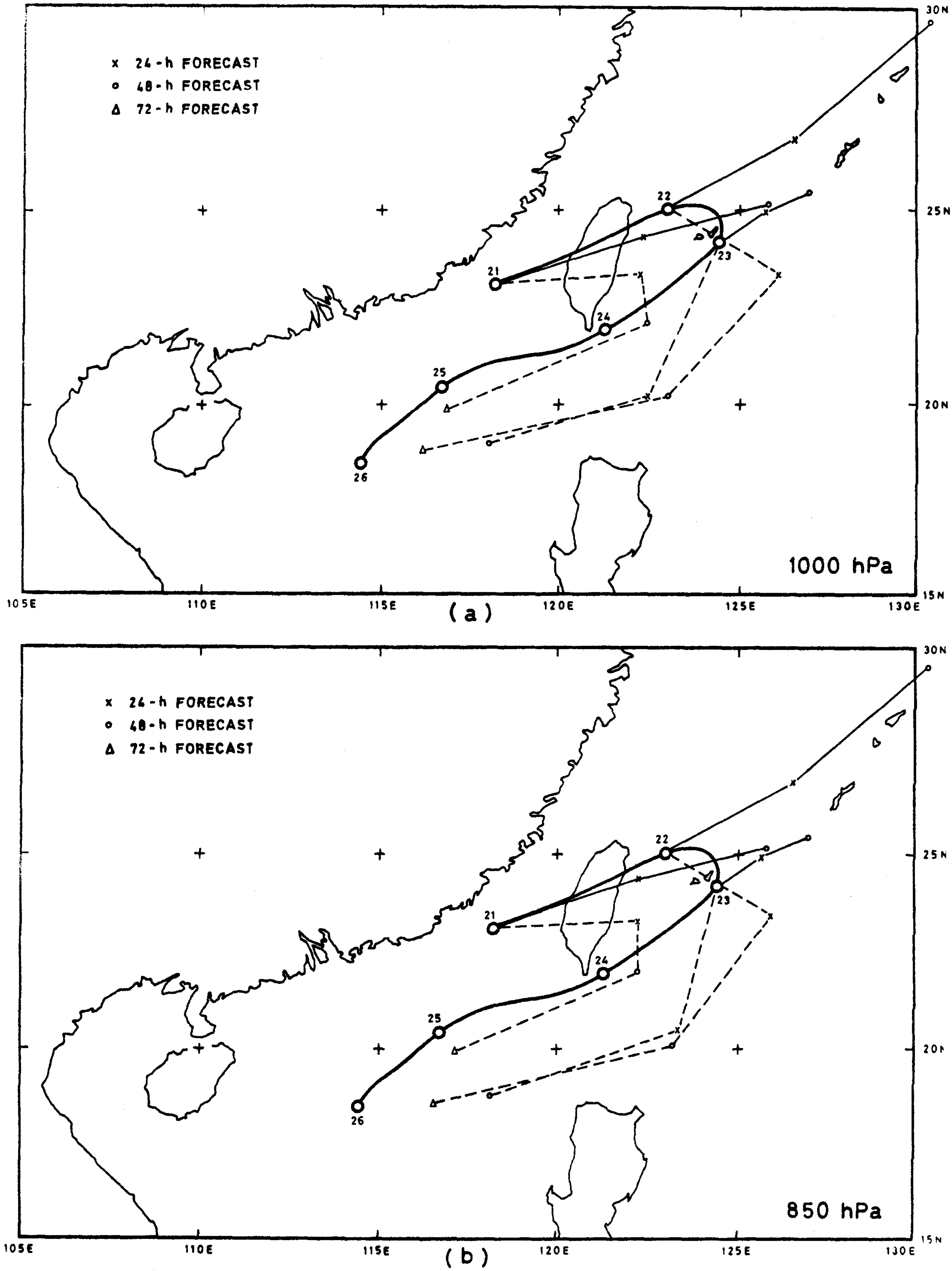
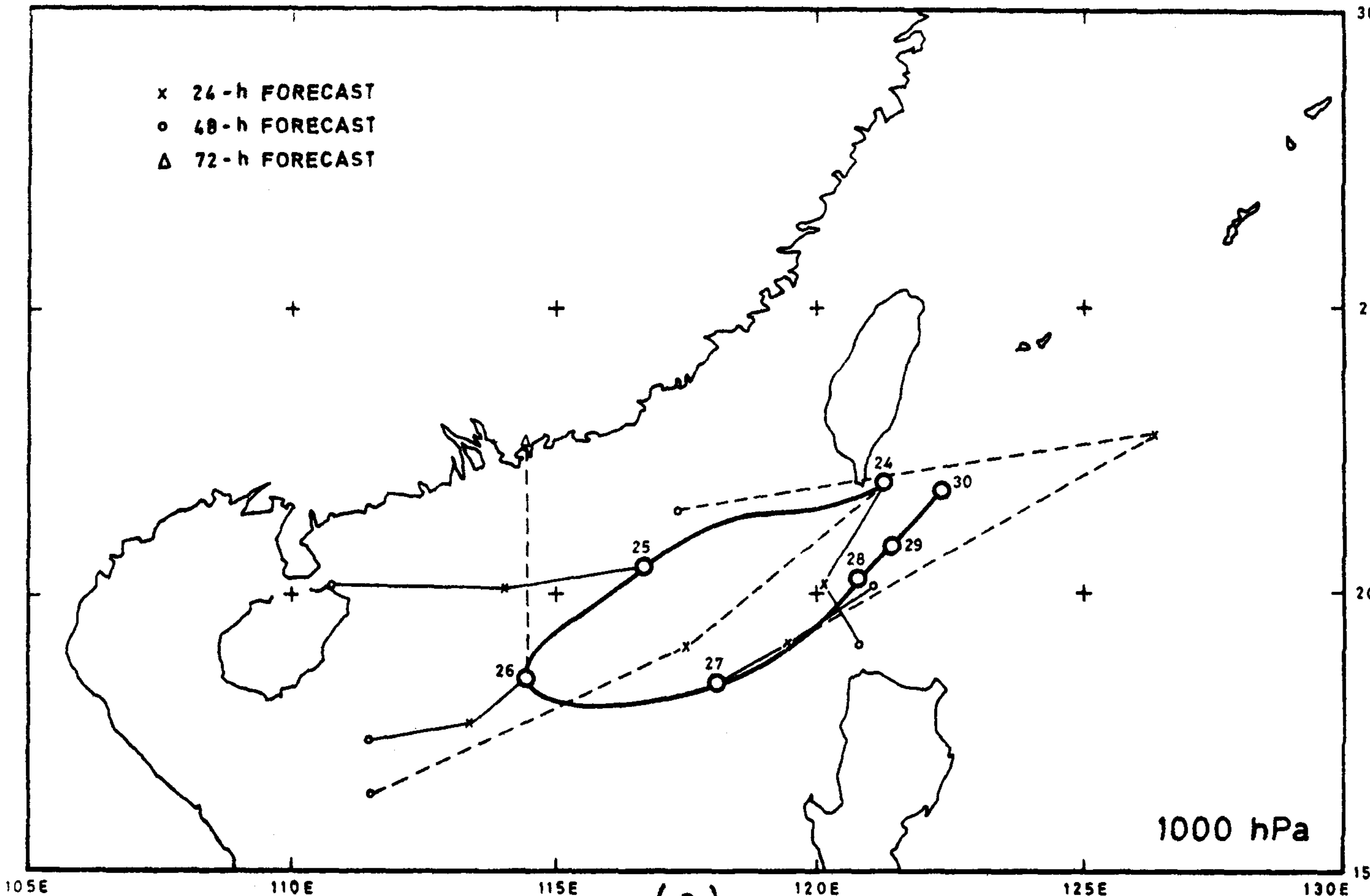
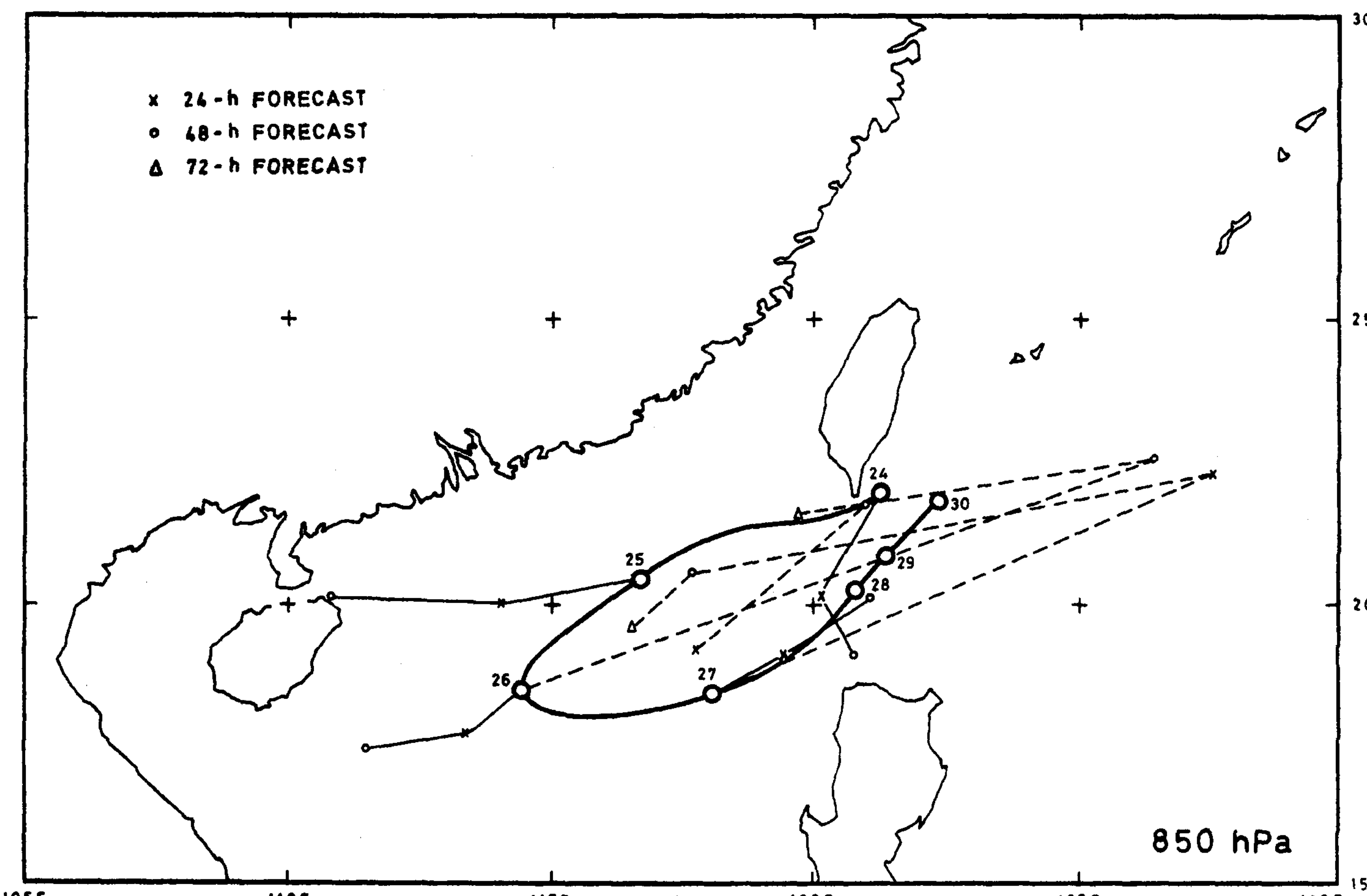


Fig. 10 The best-track segment of Wayne (thick solid) between 2112-2312 and the forecast tracks of the RO (thin solid) and those based on the ECMWF winds (dashed). Numbers in the circles along the best track indicate the day at 12 UTC. (a) 1000 hPa (b) 850 hPa.



(a)



(b)

Fig. 11 The best-track segment of Wayne (thick solid) between 2412-2712 and the forecast tracks of the RO (thin solid) and those based on the ECMWF winds (dashed). Numbers in the circles along the best track indicate the day at 12 UTC. (a) 1000 hPa (b) 850 hPa.

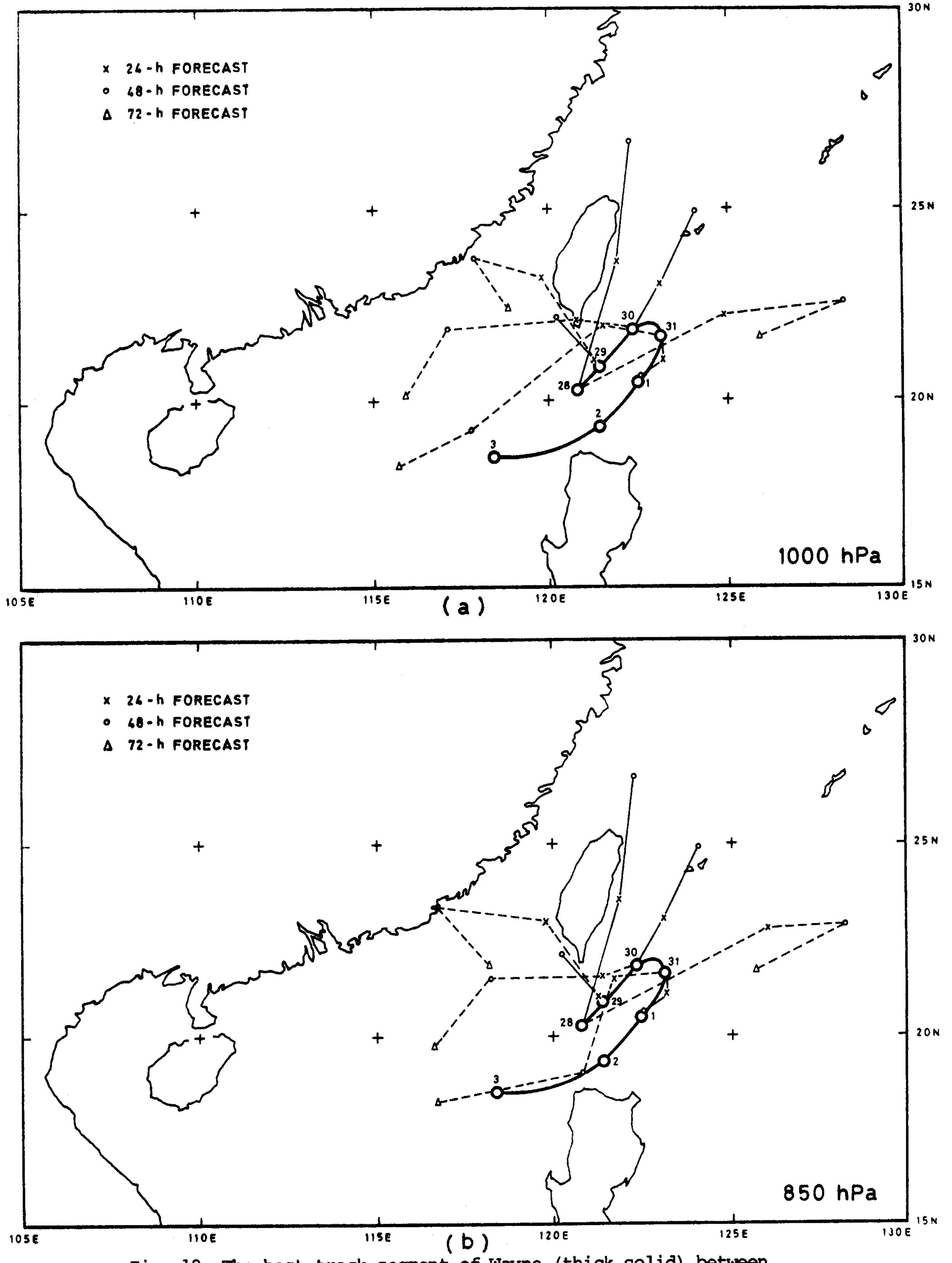


Fig. 12 The best-track segment of Wayne (thick solid) between 2812-3112 and the forecast tracks of the RO (thin solid) and those based on the ECMWF winds (dashed). Numbers in the circles along the best track indicate the day at 12 UTC. (a) 1000 hPa (b) 850 hPa.

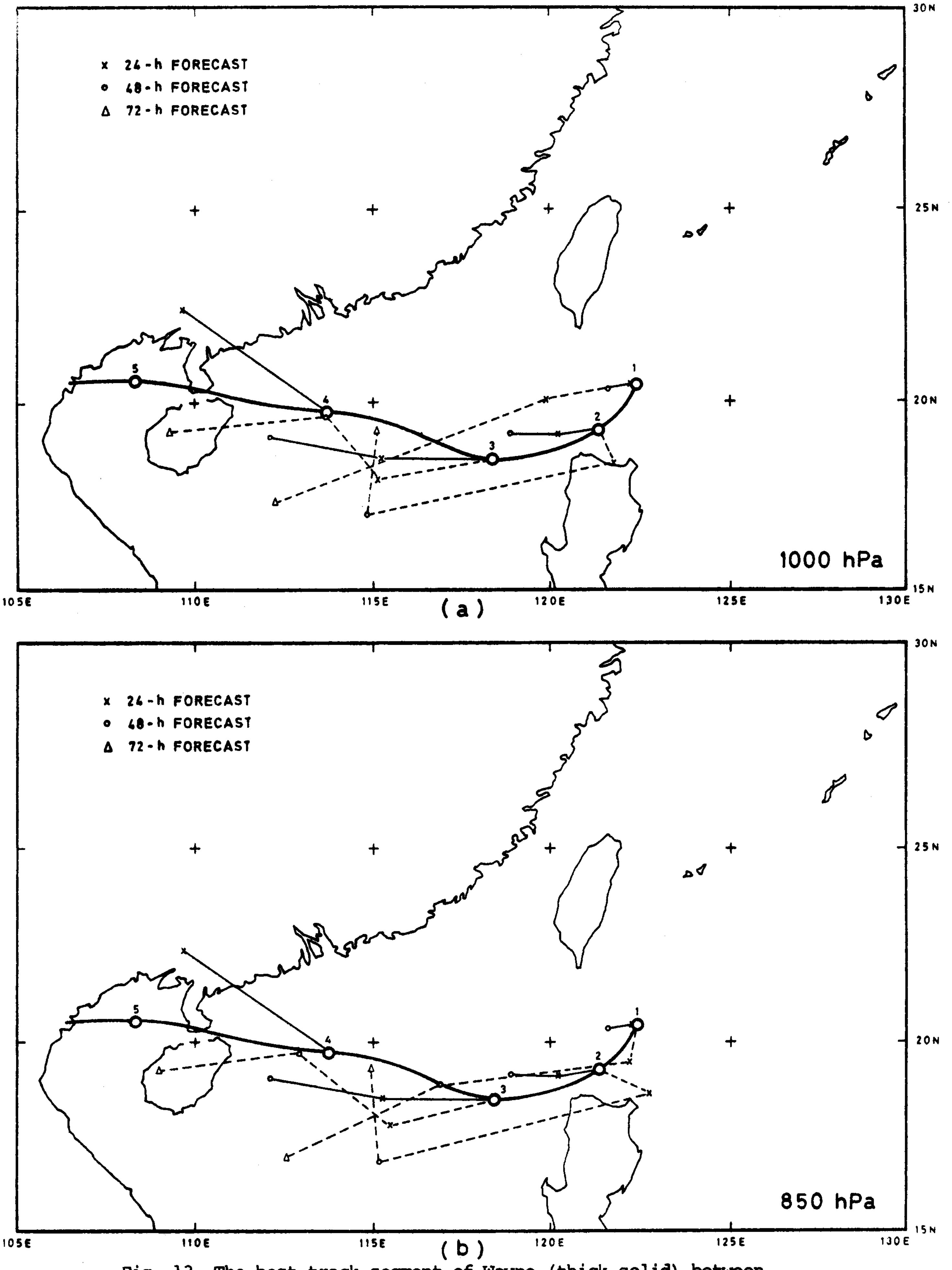


Fig. 13 The best-track segment of Wayne (thick solid) between 0112-0412 and the forecast tracks of the RO (thin solid) and those based on the ECMWF winds (dashed). Numbers in the circles along the best track indicate the day at 12 UTC. (a) 1000 hPa (b) 850 hPa.