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COMPARISON OF ENVIRONMENTAL WINDS OVER THE RYUKYU AREA FOR RECURVING AND NON-RECURVING TROPICAL CYCLONES

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1. Introduction

Many studies, notably George and Gray (1976) and Hodanish (1991), have demonstrated the important role played by environmental winds in determining the motion of tropical cyclones. The latter study, using a composite analysis, shows that a penetration of the upper westerlies within 6-degree latitudes northwest of the cyclone circulation is required for recurvature to take place.

In Hong Kong, an accurate assessment of the recurvature scenario is crucial when preparing an extended weather outlook. A recurving cyclone to the east of Taiwan tends to induce dry off-land flow across southern China and hence fine (and in mid-summer, very hot) weather in Hong Kong. A non-recurving cyclone will head towards the northern part of the South China Sea, bringing windy and rainy weather to the coastal areas of Guangdong.

Even though numerical models have proven their worth in forecasting tropical cyclone motion, particularly in the 48-hour and 72-hour forecast periods, systematic model biases such as the well-documented northward drift (Chan and Kay (1993), Muroi (1995)) are still not entirely removed. In some cases, premature recurvature is forecast which leads to large positional forecast errors (Typhoon Yancy in 1990 being a classic example). As such, supplementary objective tools are still essential for monitoring the reliability of the model prediction on a case-by-case basis.

To verify Hodanish's results and to evaluate its usefulness as an objective aid, Lai (1991) looked at four tropical cyclones (namely, Yancy, Dot, Ed and Gene) during the SPECTRUM/TCM-90 field experiment in the summer of 1990 as they passed through the sea area near 20°N and 128°E. This is a convenient point as a multitude of upper-air stations (Ryukyu, Taiwan and the southeast coast of China) lie within a range of 6 to 10 degrees northwest of any cyclone that passes by. The time was also convenient since the activation of IOPs (intense observation periods) in connection with the field experiment ensured the availability of upper-wind data. Unfortunately, as none of the four selected cyclones recurved during the observation periods and no recurvers entered the target sea area, the finding of no westerly penetration within 6-degree latitude offered, at best, a partial proof of Hodanish's hypothesis.

Adopting a similar approach but using historical cases over a 10-year period from 1985 to 1994, this paper is a follow-up of Lai (1991). An outline of the methodology is given in Section 2. By looking at more cases, useful statistics and more conclusive results are shown in Section 3. Discussion and implications on other aspects of tropical cyclone forecasting in Hong Kong can be found in Section 4.

2. Methodology

The main data source was the upper winds as measured at the Ryukyu island stations Ishigakijima (47918), Naha (47936) and Minamidaitojima (47945) (see Figure 1). Arcs centred on these stations and at a distance of 6-degrees latitude away were drawn. The location where these arcs intersected corresponded roughly to the sea area bounded by 19°N, 21°N, 127°E and 130°E. This was referred to as the target area.

From the Royal Observatory 6-hourly best track data, all tropical cyclones passing through the target area during the 10-year period from 1985 to 1994 were identified. "Recurvers" were defined as tropical cyclones which either had a sustained eastward component in their motion while in the target area, or started to have a sustained eastward component in their motion within 24 hours after leaving the target area. All other tropical cyclones which did not meet the criteria were classified as "non-recurvers".

Whenever there was a tropical cyclone in the target area, 500-hPa winds at the three Ryukyu stations were extracted. The wind vector was resolved into its zonal (u) and meridional (v) components. These winds were taken to represent the environmental winds at a range of 6-degree latitude north and northwest of the cyclone, regarded as important indicators for cyclone recurvature by Hodanish (1991). While it was generally accepted that the optimum steering level would vary depending on cyclone intensity, the 500-hPa level was considered a good enough middle-of-the-road choice given that cyclone intensity in this study ranged from tropical depression to typhoon and that there was no intensity stratification. In both Hodanish (1991) and Lai (1991), the choice of wind level (from 700-hPa to 300-hPa) did not appear to have any significant impact on the results.

As an extension of the study, the temporal changes in environmental wind as the cyclone traversed the target area were also examined. In this connection, the time when the cyclone was nearest to the centre of the target area (i.e. 20°N, 128.5°E) was taken to be the reference hour "T". Winds at 500-hPa level at the three Ryukyu stations from (T-12) hour to (T+12) hour (at 6-hourly interval) were extracted and then similarly resolved into their u and v components for analysis and comparison.

3. Results

There were altogether 27 tropical cyclones passing through the target area during the 10-year period from 1985 to 1994, of which 13 were non-recurvers and 14 were recurvers. The residence time of the non-recurvers was in general longer by about 6 hours owing to the shape of the target area. The number of observation times was 39 for 13 non-recurvers and 29 for 14 recurvers, i.e. the non-recurvers had on average 3 observation times per cyclone as compared to 2 for the recurvers. The full list of the 27 tropical cyclones and their corresponding observation times are tabulated in the Appendix.

The averaged zonal (u, positive for easterly) and meridional (v, positive for northerly) winds at 500-hPa at the Ryukyu stations for the recurving and non-recurving cases are summarised below. Standard deviations are given in bracket.

Table 1

	Station 47918		Station 47936		Station 47945	
	u / m s^{-1}	v / m s^{-1}	u / m s^{-1}	v / m s^{-1}	u / m s^{-1}	v / m s^{-1}
Non-recurvers	7.6 (4.9)	2.6 (4.3)	7.3 (4.4)	-1.1 (2.7)	6.7 (4.8)	-4.8 (2.8)
Recurvers	-3.2 (6.8)	-0.1 (4.5)	-3.5 (6.9)	-4.3 (4.5)	-0.9 (6.7)	-7.0 (6.6)

From the results, it can be seen that for the non-recurving cases winds are northeasterly at 47918, easterly at 47936 and southeasterly at 47945. This is consistent with the synoptic picture of a vortex nestled along the southern flank of the subtropical ridge (Figure 1(a)). For the recurvers, winds are westerly at 47918, southwesterly at 47936 and southerly at 47945. This brings to mind the typical scenario of a westerly trough hanging over the Ryukyu area (Figure 1(b)).

While the differences in the meridional winds are largely related to the east-west geographical locations of the three stations, the differences in the zonal winds reflect the extent of the mid-latitude westerlies. To test the statistical significance of the differences, the analysis was restricted to wind observations at reference time "T" (see Appendix) only, hence ensuring only one observation per cyclone in the samples. All wind data were therefore independent observations and those cyclones with long residence time within the target area would not dominate the analysis. The number of non-recurvers was reduced from 13 to 11 tropical cyclones for all three Ryukyu stations (observations not available for two tropical cyclones at time "T"). For the recurvers, the number was the original 14 for station 47945 but 13 for stations 47918 and 47936 (observations not available for one tropical cyclone at time "T"). The resultant means and standard deviations are tabulated in Table 2. By applying the t-test for small samples, the zonal wind differences between the non-recurvers and the recurvers were found to be significant at the 5% level for all three stations.

Table 2

	Station 47918		Station 47936		Station 47945	
	u / m s^{-1}	v / m s^{-1}	u / m s^{-1}	v / m s^{-1}	u / m s^{-1}	v / m s^{-1}
Non-recurvers	7.5 (4.2)	1.5 (3.7)	7.0 (3.2)	-1.6 (2.4)	5.9 (5.3)	-5.4 (3.4)
Recurvers	-2.5 (7.8)	-0.1 (5.5)	-3.8 (8.3)	-4.1 (5.2)	-1.9 (7.8)	-8.0 (6.9)

The result seems to substantiate Hodanish's notion that for tropical cyclones to recurve, penetration of the westerlies within 6-degree latitude northwest of the vortex is required.

Station-specific details in the zonal wind differences based on all available observation times are given in the following tables:

Table 3 **Station 47918**	**Available Cases**	**Maximum Easterlies**	**Maximum Westerlies**	**Easterlies > 5 m s^{-1}**	**Westerlies Occurrence**
Non-recurving	34	17 m s^{-1}	- 1 m s^{-1}	~ 80%	~ 6%
Recurving	27	12 m s^{-1}	- 20 m s^{-1}	~ 10%	~74%

Table 4 **Station 47936**	**Available Cases**	**Maximum Easterlies**	**Maximum Westerlies**	**Easterlies > 3 m s^{-1}**	**Westerlies Occurrence**
Non-recurving	34	18 m s^{-1}	- 0.5 m s^{-1}	~ 80%	~ 3%
Recurving	28	15 m s^{-1}	- 22 m s^{-1}	~ 10%	~82%

Table 5 **Station 47945**	**Available Cases**	**Maximum Easterlies**	**Maximum Westerlies**	**Easterlies > 3.5 m s^{-1}**	**Westerlies Occurrence**
Non-recurving	35	16 m s^{-1}	- 6 m s^{-1}	~ 80%	~ 9%
Recurving	29	13 m s^{-1}	- 19 m s^{-1}	~ 10%	~45%

To help forecasters monitor the reliability of the numerical models and "correct" their northward (premature recurvature) bias, some quantitative indices based on the Ryukyu upper winds can be derived. Referring to Tables 3, 4 and 5, 500-hPa westerly penetration at stations 47918 and 47936 is a useful predictor. For early detection, the strength of the easterlies can also be monitored. If we adopt the criteria of 5 m s^{-1}, 3 m s^{-1} and 3.5 m s^{-1} for stations 47918, 47936 and 47945 respectively, then the false alarm rate for recurvature forecast (when easterlies drop below criteria) is about 20% and the chance of missed recurvature (when easterlies remain above criteria) is only about 10%.

To examine any temporal changes in the environmental winds, zonal and meridional wind speeds are plotted in time series from 12 hours before to 12 hours after reference time T (Figures 2, 3, 4 for stations 47918, 47936, 47945 respectively).

At 47918, easterlies gradually back to northeasterlies as the non-recurvers approach. In contrast, easterlies veer to southeasterlies at 47936 and 47945 as the non-recurvers depart. Again the general picture is consistent with a vortex moving along the southern flank of the subtropical ridge.

For the recurvers, winds at 47918 tend to veer slightly from southwesterly to westerly. However, wind speeds are in general on the light side and the changes rather subtle. The southwesterlies, more prominent at 47936, appear to drop off and back to a more southerly flow. The increase in southerly steering is most noticeable at 47945 northeast of the recurvers. Taken together, the recurvers seem to be approaching a weak point in the ridge axis and moving around the western periphery of the Pacific high. Evidence in support of a significant increase in westerly steering for recurvature to take place is not obvious from this study.

4. Discussion

While the results obtained in Section 3 in general vindicate Hodanish's hypothesis of westerly penetration in recurvature cases, the picture that emerges also highlights the prominent role of the easterlies on the southern flank of the ridge. In a way, one may even say that the weakening of the easterlies, rather than the appearance of the westerlies, is the more obvious indicator. The westerly signal is understandably weaker as it has to counteract the easterly flow to the northwest of the cyclone circulation. In some cases, if the cyclone circulation is itself extensive, the westerly signal may well be masked and therefore overlooked by the forecasters. As an early alarm for probable recurvature, upper-air data over the Ryukyu area should be closely monitored for any significant decrease in the easterly winds.

An accurate assessment of recurvature near the Ryukyu areas will have a positive impact on the reliability of weather outlooks issued in Hong Kong. But for a more direct contribution to local weather forecasts relating to tropical cyclones, sudden northward turning motion over the South China Sea is more relevant. Potentially, the methodology used in this study can be similarly applied. Upper-air stations in Hong Kong, along the coast of Guangdong and over Hainan Island can be used and a target area about 6-degree out can be identified over the sea area west of Luzon (say between 16°N and 18°N, 115°E and 117°E). This also proves to be a rather strategic area. Sudden northward turn at this point, or the lack of it, will often decide whether the cyclone lands to the east or west, leading to totally different weather scenarios in Hong Kong.

But unlike recurvature over the Ryukyu area, tropical cyclone motion over the South China Sea is generally less straightforward, very often involving an interplay of a multiplicity of factors. Mechanisms such as the Luzon terrain effect and cyclone re-intensification following the passage of Luzon can all give rise to short-term track deviation from the environmental steering flow. However, it would be interesting to see if there are also discernible signals in the upper winds northwest of the cyclone despite the complications.

References

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(4) Lai, S.T. 1991 Comparison of different track scenarios for selected tropical cyclones during SPECTRUM 1990. *Presented in the 2nd Technical Conference on SPECTRUM, Guangzhou, China.*

(5) Muroi, C. 1995 Typhoon track forecast produced by JMA new operational global spectral model. *Presented in the 4th Technical Conference on SPECTRUM, Tsukuba, Japan.*

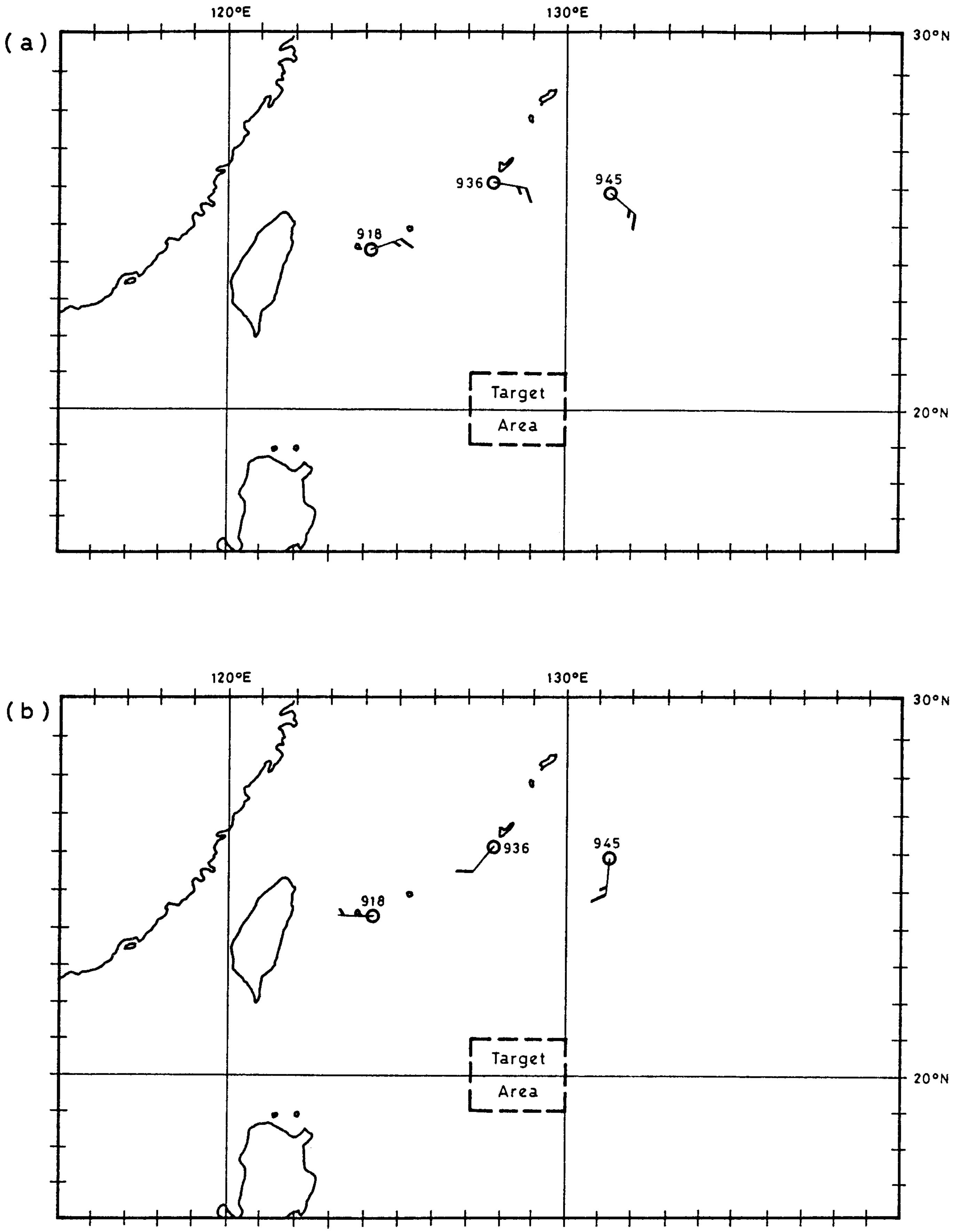
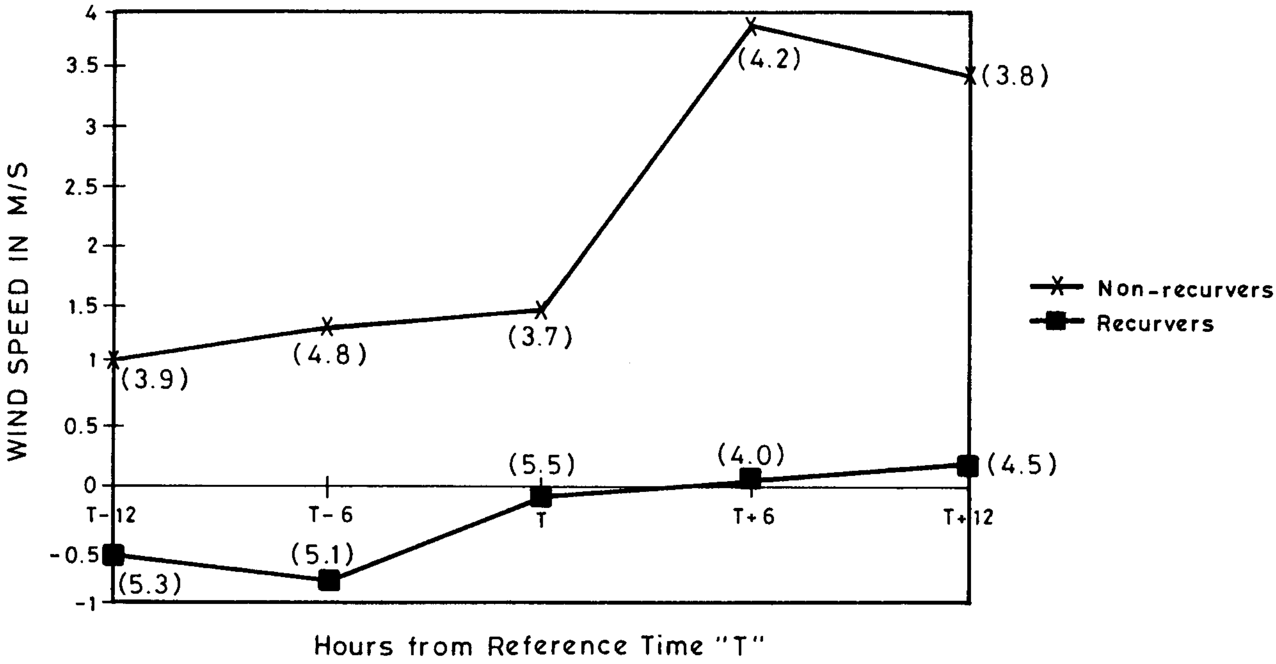


Figure 1 - Selected Ryukyu stations (circles labelled with last three digits of station numbers, i.e. 918, 936, 945) and their corresponding 500-hPa mean winds for non-recurving (top panel) and recurving (bottom panel) tropical cyclones.

Northerly Wind Component at Station 47918



Easterly Wind Component at Station 47918

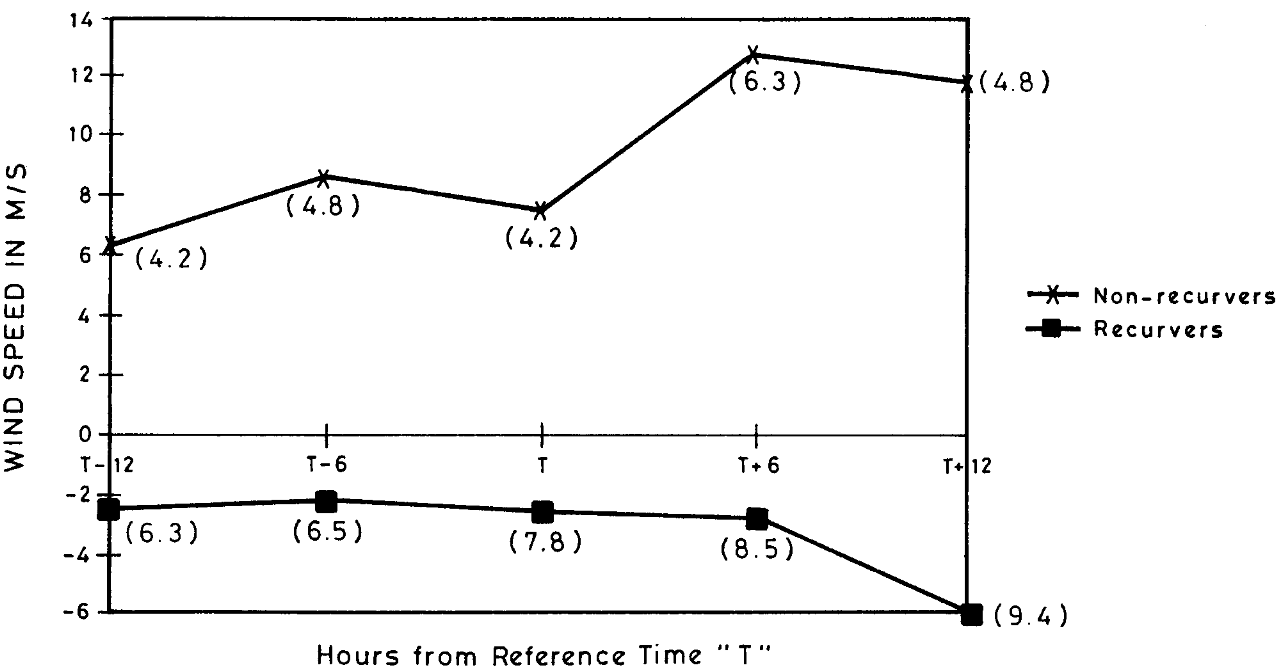


Figure 2 - Six-hourly 500-hPa mean winds (top: northerly component; bottom: easterly component) at Station 47918 for non-recurving and recurving tropical cyclones with reference to time "T". Standard deviations in ms^{-1} are shown alongside in bracket.

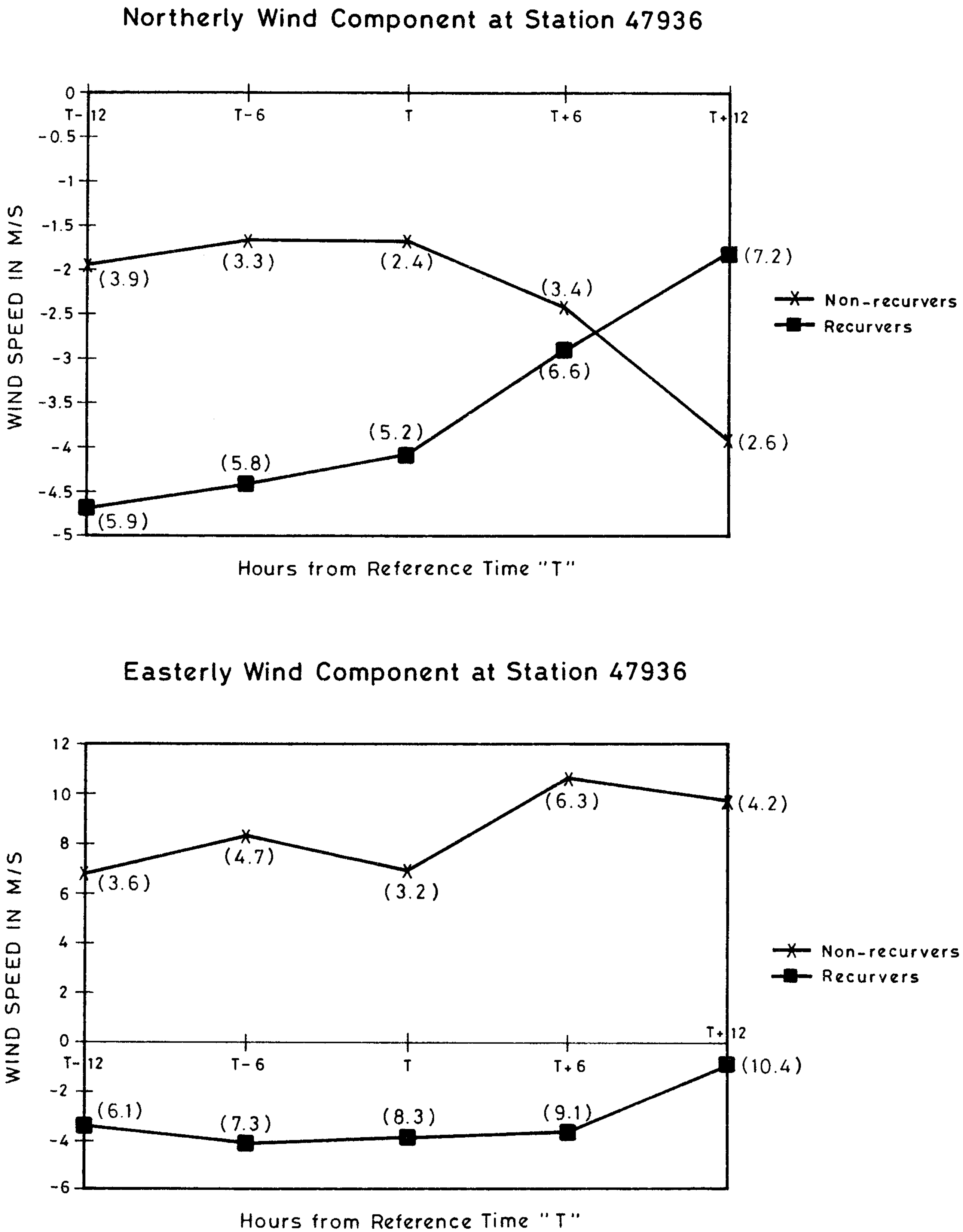
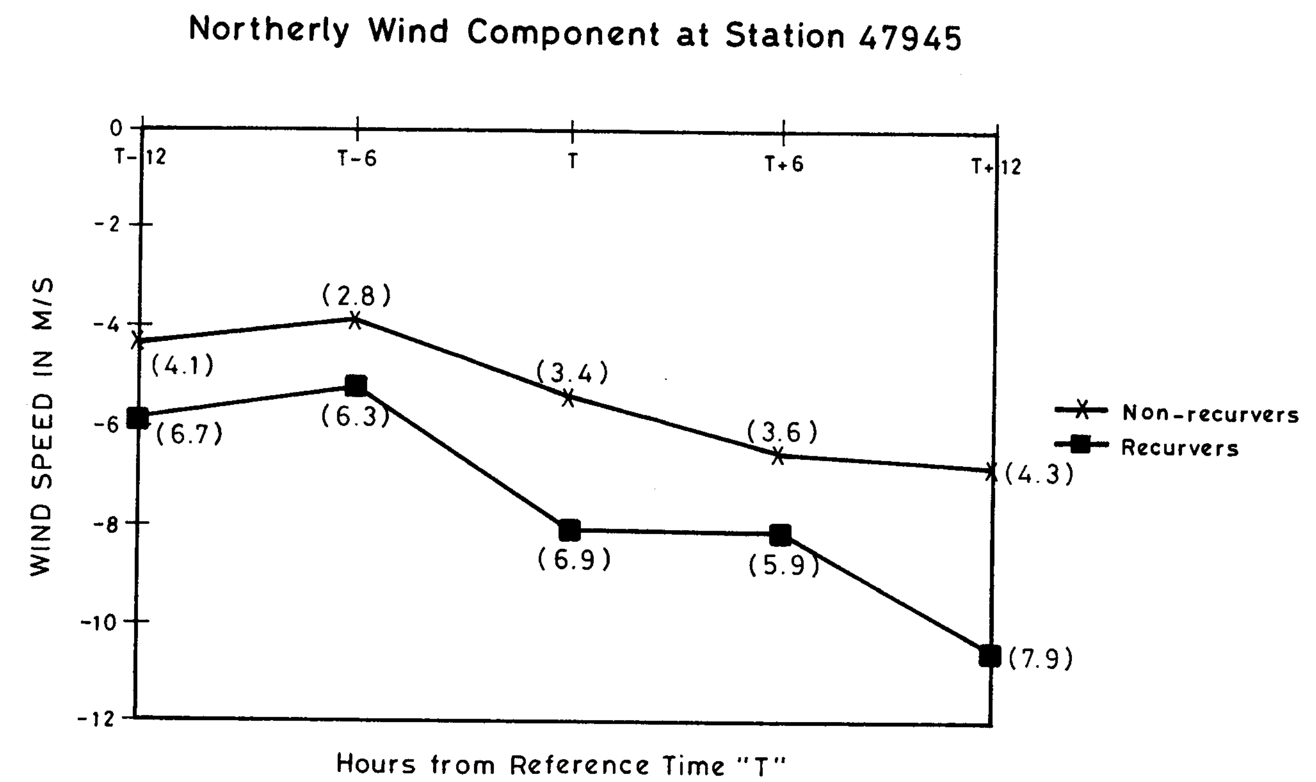


Figure 3 - Six-hourly 500-hPa mean winds (top: northerly component; bottom: easterly component) at Station 47936 for non-recurving and recurving tropical cyclones with reference to time "T". Standard deviations in ms^{-1} are shown alongside in bracket.



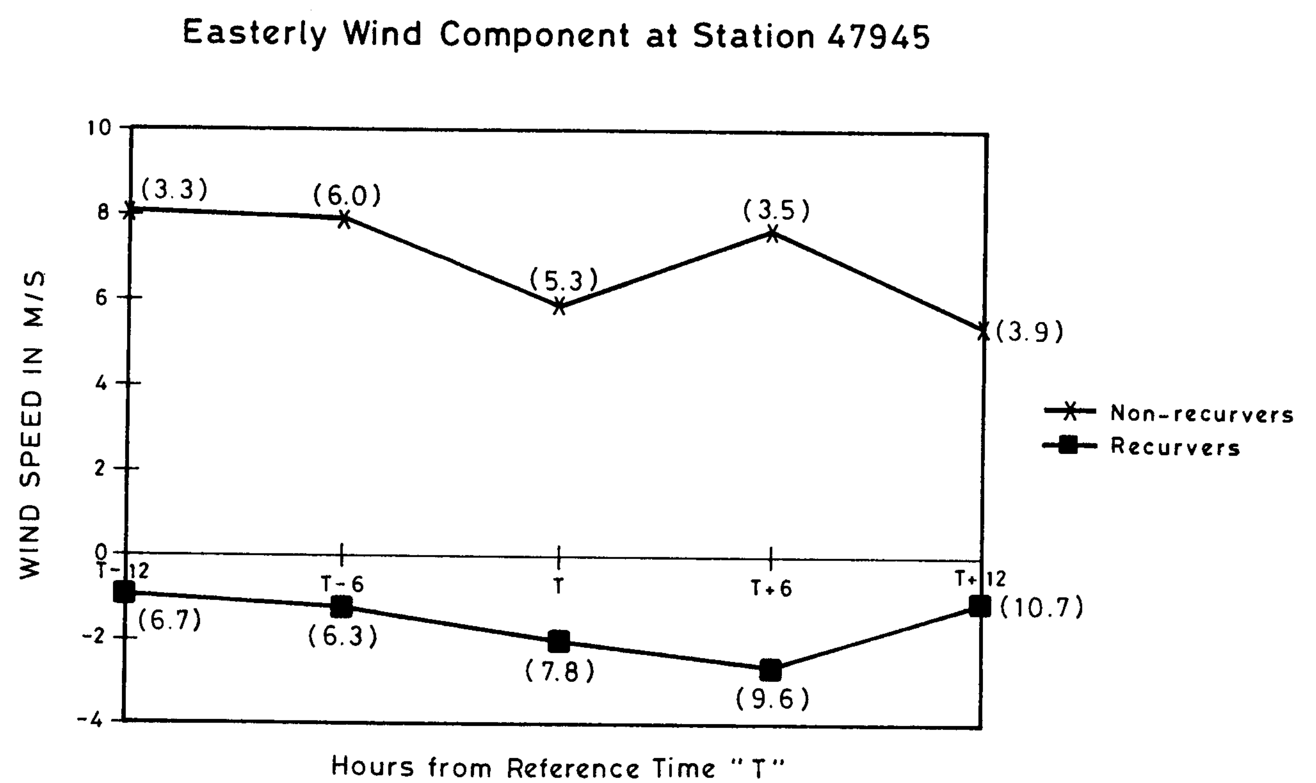


Figure 4 - Six-hourly 500-hPa mean winds (top: northerly component; bottom: easterly component) at Station 47945 for non-recurving and recurving tropical cyclones with reference to time "T". Standard deviations in ms^{-1} are shown alongside in bracket.

Appendix

List of tropical cyclones entering the target area during the 10-year period from 1985 to 1994. The corresponding observation times when the cyclones are inside the area are shown alongside.

Non-recurving	yymmddzz		Recurving	yymmddzz	
Val	85091512	*	Gay	85052312	
Abby	86091606		Gay	85052318	*
Abby	86091612		Gay	85052400	
Abby	86091618	*	Irma	85062806	*
Abby	86091700		Hope	85122312	*
Dinah	87082612		Owen	86063018	*
Dinah	87082618		Sarah	86080300	*
Dinah	87082700		Vera	86081600	
Dinah	87082706	*	Vera	86081606	*
Dinah	87082712		Lee	88092206	
Dinah	87082718		Lee	88092212	
Dinah	87082800		Lee	88092218	*
Yancy	90081612		Odessa	88101206	
Yancy	90081618	*	Odessa	88101212	
Yancy	90081700		Odessa	88101218	*
Yancy	90081706		Page	90112812	*
Becky	90082506	*	Deanna	92070206	*
Dot	90090600		Yvette	92101318	
Dot	90090606	*	Yvette	92101400	*
Ed	90091312	*	Yvette	92101406	
Gene	90092412		Yvette	92101412	
Gene	90092418		Gay	92112800	
Gene	90092500	*	Gay	92112806	*
Gene	90092506		Gay	92112812	
Caitlin	91072512		Zola	93090518	
Caitlin	91072518	*	Zola	93090600	
Mireille	91092400		Zola	93090606	*
Mireille	91092406		Brendan	94072906	
Mireille	91092412	*	Brendan	94072912	*
Mireille	91092418				
Yancy	93083018				
Yancy	93083100				
Yancy	93083106	*			
Yancy	93083112				
Caitlin	94080118	*			
Caitlin	94080200				
Fred	94081812				
Fred	94081818	*			

* Reference time "T", the time when the cyclone is closest to the centre of the target area.