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The skill of tropical cyclone position forecasting in the Australian region

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An evaluation is made of the performance of the methods available for forecasting tropical cyclone positions in the Australian region. The measure of skill used is the accuracy relative to a climatological-persistence (CLIPER) scheme. The CLIPER technique used in this study is described in some detail and is similar to the classical scheme of Neumann. It is intended to be used both as a forecasting aid and a no-skill benchmark for other forecasting techniques.

Of the techniques presently available to the Australian Bureau of Meteorology, only the statistical-synoptic regression scheme developed by Keenan has significant skill, measured relative to CLIPER. All the other techniques have no significant skill relative to CLIPER. Significant gains in skill may be obtained simply by combining the present forecasting techniques in an optimal linear manner. In particular, when forecasts from CLIPER and the Australian region numerical weather prediction model are optimally combined, an improvement over CLIPER of 15 per cent and 17 per cent is obtained at 24 and 36 hours respectively. This latter result suggests that large gains in forecasting skill for tropical cyclone motion should prove to be readily achievable in the Australian region.

Introduction

The Australian tropics is one of the regions of the world most affected by tropical cyclones. Accurate and timely forecasts are therefore of great economic and social importance. However, this has proven to be an extremely difficult problem to solve, especially as the Australian region is regarded as the most difficult of all for obtaining accurate predictions of tropical cyclone motion (Pike and Neumann 1987).

There are presently a number of operational and research methods used by the Australian Bureau of Meteorology for the prediction of tropical cyclone motion. These may be grouped into three main categories: *numerical weather prediction* (NWP) models, such as the Australian region primitive equations model (Leslie et al. 1985), and the ECMWF and UK models; *statistical-synoptic* models based on regression procedures (Keenan 1985); and a *quasi-analytical* model which uses advection and propagation by the mean 850–200 hPa deep layer wind (Holland and Evans 1988). The official manual Bureau of Meteorology forecasts are issued by the Tropical Cyclone Warning Centres.

In an attempt to improve the accuracy of the methods described above, the Bureau of Meteorology Research Centre (BMRC) is both developing new techniques and collaborating in a major international effort to understand the mechanisms of tropical cyclone motion. The attempt to reduce mean position errors is taking a number of directions. These include a substantial research effort into the development of a numerical analysis and prediction system designed specifically for the tropics, the investigation of a number of statistical techniques such as optimally combining independent forecast methods, and the testing of a Markov chain model.

At present, skill in predicting tropical cyclone position is commonly measured relative to the climatology-persistence scheme originally developed by Neumann (1972). This method is very simple and requires as input only the storm position, motion and pressure at the analysis time, the storm position and motion 12 hours earlier, and the Julian day. Since this scheme incorporates persistence and climatology it provides an excellent benchmark for other schemes. No operational CLIPER scheme has been developed previously for the Australian region.

There are three main aims in this study. The first is to describe the CLIPER scheme developed by BMRC. The second is to evaluate and compare the performance of existing forecasting techniques using best track and operational data. The third is to demonstrate how the current skill levels may be raised significantly by the introduction of new techniques. Towards this end, a workstation-centred approach is being undertaken in collaboration with the Severe Weather Program Office of the Bureau of Meteorology's Services Policy Branch.

Forecast methods

CLIPER

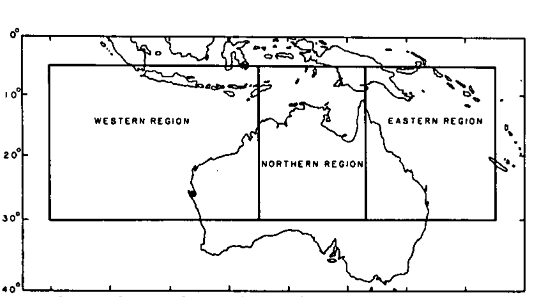
The CLIPER scheme developed in BMRC for the Australian region closely follows the original approach of Neumann (1972). Separate CLIPER equations were developed for the three distinct Western, Northern and Eastern regions shown in Fig. 1. A total of eight primary predictors were used. They are defined as follows:

X : the initial longitude of the tropical cyclone centre
Y : the initial latitude
U : the initial eastward speed
·U : the eastward speed 12 hours previously
V : the initial northward speed
V-: the northward speed 12 hours previously
P : the initial central pressure
D : the modified Julian day (July 1 is D=1).

The predictands are the eastward and northward displacements of the tropical cyclone centre at 12-hourly forecast intervals out to 72 hours.

The values of the predictands are obtained from a stepwise screening regression technique using a standard package. All possible products of the eight primary predictors up to third order were used, which produced a total of 164 predictors after symmetry is taken into account. Other potential predictors such as cyclone size or outer structure were not included because of a lack of data.

Fig. 1 Division of the Australian region into Western, Northern and Eastern regions for development of separate CLIPER equations. Note that these regions differ slightly from the official regions of forecast responsibility.



Data for the CLIPER model were the archived six-hourly 'best track' data consisting of tropical cyclone date/time, position, central pressure, speed, direction of movement and a binary indicator of whether the cyclone was over land or ocean. Data from 1958 to 1979 inclusive were used to develop the regression coefficients. Data available prior to 1958 were regarded as too unreliable (Holland 1981). The archived data for the period 1980 to 1988 were used for an independent assessment of the performance of the scheme.

Only those predictors that explained a prespecified percentage of the variance were selected. The variance was specified between 0.1 and 1.0 per cent, depending on the region, in order to obtain a reasonable number (no less than eight) of predictors for each region. The resulting predictors are shown in Table 1 for each of the three (Western, Northern and Eastern) regions. The same predictors (but with different coefficients) can be used for all forecast periods out to 72 hours. In this study only forecasts out to 48 hours were assessed as no operational 72-hour forecasts are routinely made.

NWP model

The numerical weather prediction model tested in this study was the Bureau of Meteorology's operational regional model, run twice-daily at 0000 UTC and 1200 UTC out to 36 hours. Currently the model is a 12-level semi-implicit primitive equations model with a horizontal resolution of 150 km. Full details of the model are given in Leslie et al. (1985). The position of the forecast tropical cyclone centre is obtained using a simple centre-finding routine on the 850 hPa stream function field.

Analogue method (CYCLOGUE)

This is an operational method based on track analogue technique and developed by Annette (1978). Forecasts are produced by blending persistence and track analogues.

Statistical-synoptic method (TOPEND)

In this operational method the eastward and northward displacements of the tropical cyclone centre are calculated using past track data, track analogue (CYCLOGUE) forecasts and synoptic analyses as predictors (Keenan 1985). The regression equations were derived using a stepwise screening procedure. Predictors were included in the regression equations until they contributed to a reduction in the variance of less than 1 per cent.

Table 1(a). **Predictors selected for the northward displacement of tropical cyclone position for the Western, Northern and Eastern regions. See text for definition of regions and predictors. Products of predictors up to third order are included. For example X X X = X^3.**

	Region		
	Western	*Northern*	*Eastern*
Predictors	X X X	X X X	X V D
	X X U-	X X V	X P P
	X Y V	X Y V	Y Y V
	X Y P	X P P	Y V D
		X	
	X Y	U V- D	Y
	X U- V	U D D	V V V
	X V P	U- V V	V V D
	X V D	P	V D
	X V		V-
	U U V		
	U U V-		
	U U		
	U U- V		
	U U- D		
	U V- V-		
	U- V V		
	U- V D		
	U- V		
	U- V- V-		
	V V D		
	V V- V-		
	V- V- D		
	P P P		

Table 1(b). **As in Table 1(a) except for eastward displacement of tropical cyclone position.**

	Region		
	Western	*Northern*	*Eastern*
Predictors	X X U-	X V V-	X X U
	X X V	Y Y P	X X U-
	X Y U	Y U	X X V
	X U D	Y P P	X X V-
		Y P	
	X V D	U P P	X U- V
	Y Y P	U D D	Y Y Y
	Y U P	U- V V	Y Y P
	Y V V	V D D	Y U- V
	Y P P		Y U- D
	U V V		U U U
	U V V-		U U- V
	U P P		U P- P
	U P		U P D
	U		U
	U- V V		U- D
	V V P		V- V- P
	V V D		

Official Bureau forecasts

The official Bureau of Meteorology forecasts were obtained from the Severe Weather Program Office archives of operational forecasts for the years 1985/86 to 1988/89, issued by the individual Tropical Cyclone Warning Centres in Brisbane, Darwin, and Perth.

Results

CLIPER

The CLIPER technique was developed on the archived best track data set from 1958/59 to 1978/79. Its accuracy was then tested initially on two best track data sets of equal time spans. The first data set was a dependent best track data set for the period 1971/72 to 1978/79. The numbers of cyclones and six-hourly data points for each region are given in Table 2. The mean position errors for each region over the 12 to 48-hour period are shown in Fig. 2(a); they exhibit the typically observed linear error in the Western and Eastern regions, but a much smaller error growth rate in the Northern region. The Northern region results may reflect the small number of tropical cyclones (10) present in the data.

Table 2. **Best track data for the development and verification of the CLIPER equations.**

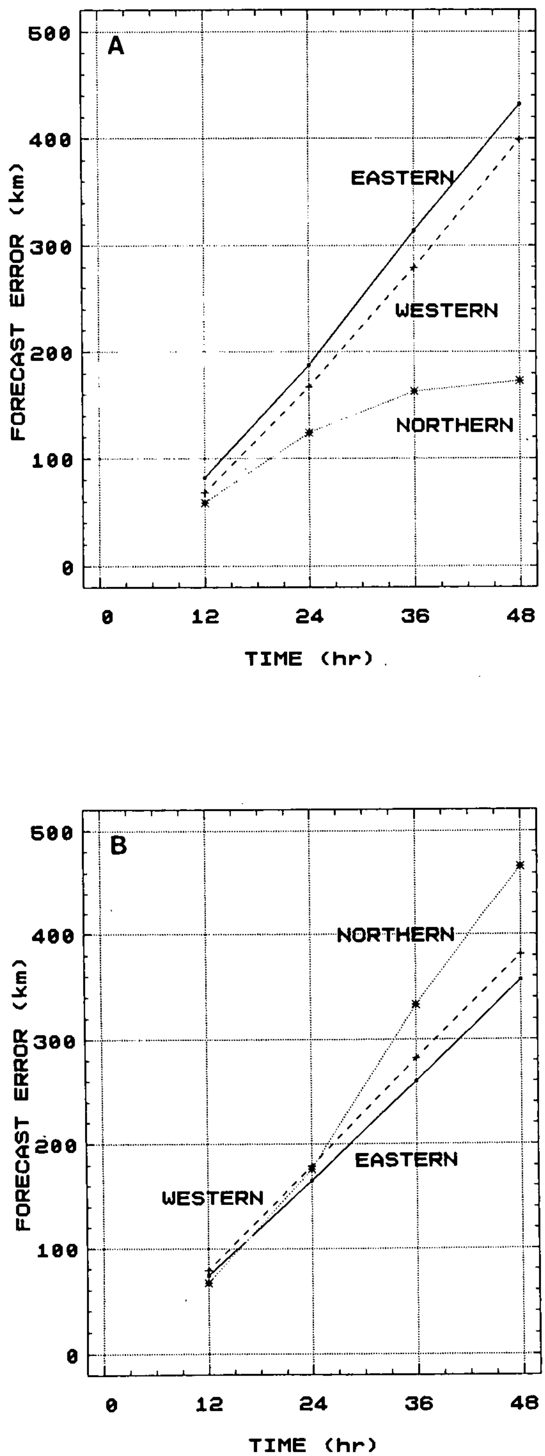
Data set	*Region*	*Tropical cyclone numbers*	*6-hourly data point numbers*
	West	65	1414
Dependent	North	10	102
	East	28	462
	West	54	1365
Independent	North	9	43
	East	29	554

The second data set was an independent best track data set for the period 1979/80 to 1987/88 and the results are presented in Fig. 2(b). In this case the Eastern and Western region results were very similar to those obtained with the dependent data set except that they had interchanged positions in terms of accuracy. The Western region was about three per cent less accurate than the Eastern region, whereas it was approximately five per cent more accurate with the dependent data set. The Northern region is much less accurate than the other two regions, particularly after 24 hours. Again, this result may be heavily influenced by the small number of cyclones (9) occurring in the eight-year period.

Skill of current operational methods

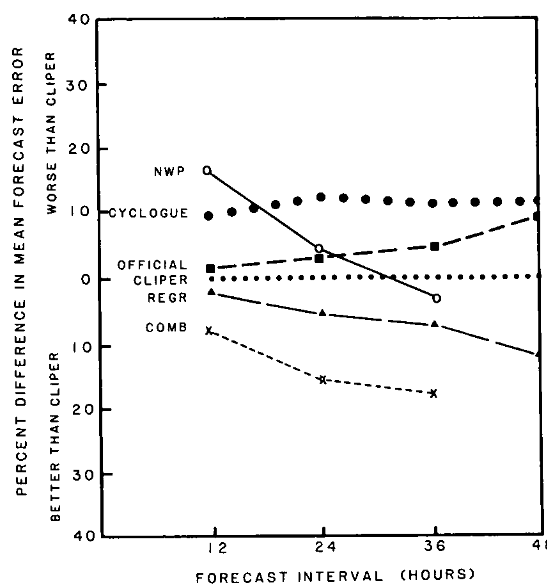
Following the development of the CLIPER method as the standard or benchmark, a comparison was made of three of the methods presently available to the operational forecasters. A fourth operational technique, the quasi-analytical model of Holland (Holland and Evans 1988), has been available only for the past two seasons and was therefore not included because insufficient data are available.

Fig. 2 (a) CLIPER forecast errors out to 48 hours for the dependent best track data set 1971/72 to 1978/79.
(b) As for (a) except using the independent data set 1979/80 to 1987/88.



The three methods were run and evaluated on all three regions combined using operational data, as distinct from best track data, for the four tropical cyclone seasons 1985/86 to 1988/89. The methods evaluated were CYCLOGUE, the statistical-synoptic method (TOPEND), and the Australian region NWP system. The official forecasts over the same seasons were also verified out to 48 hours and are compared with the other methods in Fig. 3.

Fig. 3 Evaluation of existing operational methods for predicting tropical cyclone position measured relative to CLIPER. The operational methods are Australian region NWP system, CYCLOGUE, TOPEND (denoted by REGR) and the official Tropical Cyclone Warning Centre forecasts. An optimal linear combination of NWP and CLIPER is denoted by COMB.

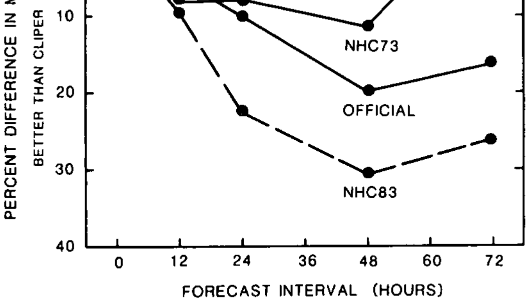


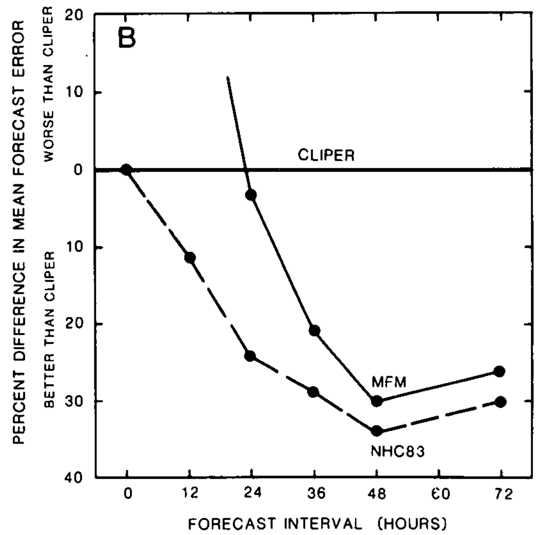
The results indicate clearly that only the statistical-synoptic regression method (known as TOPEND, but referred to as REGR in Fig. 3) performs with any skill, that is, greater accuracy than CLIPER. At 48 hours TOPEND is approximately 11 per cent superior to CLIPER. The NWP system clearly suffers initialisation problems in the first 12 hours but is comparable with CLIPER at 36 hours. This result is similar to that recorded elsewhere (see Fig. 4), and is due to a combination of factors such as poor data and initial location errors compared with CLIPER, and 'spin-up' problems. The cyclone analogue method (CYCLOGUE) performs much worse than CLIPER at all 12-hour periods and seems to be of minimal value. The official forecasts are close to

CLIPER out to 24 hours but show a marked relative decrease in skill between 36 hours and 48 hours.

Enhancement of skill in the Australian region
A comparison of the results of tropical cyclone motion forecasting in the Australian region (Fig. 3) with that reported at the National Hurricane Center (NHC) in Miami (Fig. 4) shows that the NHC forecasts are substantially more accurate than CLIPER and are comparable in skill with all available techniques other than NHC83, which is by far the most skilful technique. This suggests that Australian operational forecasting skill could be improved by up to 30 per cent if a strong research effort is maintained and if research improvements can be translated into operational practice. This improvement could come from a combination of three directions. Firstly, the existing techniques could be improved. For example, the NWP system will be increased in resolution in the near future. Alternatively, existing forecasts could be combined in the manner described below. Secondly, new techniques could be and are being developed, including a Markov chain model for predicting sudden changes in tropical cyclone motion. Thirdly, the research can provide a quantitative basis for developing new observing programs, such as aircraft reconnaissance.

Fig. 4 Similar to Fig. 3 except for the National Hurricane Center in Miami (from Neumann 1988):
A Performance of 'official' forecasts and other models (excluding NWP models), relative to CLIPER.
B Performance of NHC83 and the MFM (Moveable Fine Mesh) NWP models, relative to CLIPER.





As an illustration of the potential for reducing mean position error using existing forecast techniques, the forecasts from the Australian region NWP scheme and the CLIPER scheme were combined in an optimal linear manner (Fraedrich and Leslie 1989). The resulting error reduction is given in Fig. 3 (COMB) and shows a mean position error reduction over CLIPER of 15 per cent and 17 per cent at 24 hours and 36 hours respectively. This technique is therefore much closer in skill to the best techniques at NHC for Atlantic tropical cyclone motion forecasting.

Over the next few years other methods will be developed and evaluated, with the overall aim of reducing current mean position error by 20 to 30 per cent.

Summary and conclusions

We have described the development and testing of a CLIPER scheme for use in forecasting the position of tropical cyclones in the Australian region. The CLIPER scheme is available as a quick, minimal resource forecasting technique and a zero-skill reference level for the Bureau of Meteorology's tropical cyclone forecasts.

An evaluation was made of some operational and guidance forecasts presently used for the Australian region. These were: the Australian region NWP system; the statistical techniques referred to as CYCLOGUE and TOPEND; and the official Tropical Cyclone Warning Centre forecasts. Of these schemes only TOPEND exhibited any positive skill relative to CLIPER out to 24 hours. This was true in the cases of both independent best track and operational forecasts. Beyond 24 hours TOPEND had a significant positive skill, reaching 11 per cent improvement over CLIPER at 48 hours. By comparison, most of the north Atlantic forecast methods, including the official forecasts, are on average 10 to 20 per cent more skilful than CLIPER forecasts.

In an attempt to improve the skill of tropical cyclone forecasting in the Australian tropics, BMRC is undertaking a major research effort as well as collaborating in an international research program sponsored by the US Office of Naval Research. There are two main research directions. Research into the basic dynamics of tropical cyclone motion is being undertaken to provide a basis for conceptual models for use by forecasters, and for designing optimal data bases for operations. Further development of forecasting techniques is also occurring using a variety of statistical and numerical procedures. The first of these new forecasting techniques was based on the simple statistical fact that two independent forecasts may be combined in an optimal linear manner to produce forecasts with mean errors lower than either of the schemes used individually. The results presented here showed that significant skill increases of up to 15 to 20 per cent may be obtained immediately from this approach. Other techniques being developed include statistical methods such as Markov chain models and a major initiative in improving the resolution and representation of physical processes in the Australian region NWP sytem.

The proliferation of forecasting techniques and diagnostic fields obtained therefrom has major consequences for the forecaster as a user of the output from the methods. Joint work between BMRC and the Services Policy Branch of the Bureau of Meteorology is being carried out on the development of a microcomputer-based workstation that will provide the forecaster with the ability to select the 'best' forecast method based on expert system rules.

Acknowledgments

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