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Cyclone track forecast by combining persistence, climatology and synoptic method

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सार – ऊष्णकटिबंधीय चक्रवात विनाशकारी प्राकृतिक आपदा होते हैं। इनसे जान माल की बड़ी हानि होती है। चक्रवात के धरातल से टकराने के बाद मुख्य विनाश उसकी प्रचंड पवनों तथा तूफानी जल तरंगों से होता है। चक्रवात के धरातल से टकराने के सही स्थान का पूर्वानुमान करना पूर्वानुमानकर्ताओं तथा एजेन्सियों, जो सुरक्षा के उपायों अथवा पुनर्वास कार्यों में लगे हैं, के लिए अत्यंत महत्वपूर्ण होता है। इस शोध पत्र में चक्रवात के धरातल से टकराने के स्थान तथा समय का पूर्वानुमान करने का प्रयास किया गया है। व्यक्तिगत कंप्यूटर पर आधारित मार्ग पूर्वानुमान मॉडल भारत मौसम विज्ञान विभाग के विभिन्न पूर्वानुमान कार्यालयों में उपयोग में है। प्रचलित मॉडल के लिए द्रोणी के चक्रवात मार्ग की जलवायु तथा चक्रवातों के पूर्व की स्थिति की जानकारी की आवश्यकता होती है। सामान्यतयः चक्रवात के धरातल से टकराने के 24 से 36 घंटे पूर्व तट के किनारे का वायुदाब कम हो जाता है। इस अध्ययन में मार्ग पूर्वानुमान के लिए इस प्राचल का समान महत्व के अन्य दो प्राचलों के संयोजन के साथ अर्थात् 1/3 (स्थायित्व + जलवायु + दाब परिवर्तन) उपयोग किया गया है। इसके परिणाम केवल जलवायु एवं स्थायित्व (क्लाइमेट एण्ड परसिस्टेंट) के उपयोग से प्राप्त किए गए परिणामों की तुलना में ज्यादा सही हैं।

यदि चक्रवात के धरातल से टकराने के 12 से 24 घंटे के अंदर की उसकी प्रक्रिया पर विचार किया जाय तो 24 घंटे के अंदर का दाब परिवर्तन, जलवायु एवं स्थायित्व की तुलना में अधिक महत्वपूर्ण हो जाता है तथा धरातल से टकराने के 12 घंटे पूर्व का घंटावार दाब परिवर्तन चक्रवात के धरातल से टकराने के सही स्थान का पता लगाने में मदद करता है।

ABSTRACT. Tropical cyclones are deadly natural disasters. They came large loss of lives and properties. After the landfall, the main damages from cyclones are due to strong winds and storm surges. The forecast of landfall point is most important to forecasters as well as the agencies who are engaged to take safety measures or rehabilitation works. In this paper an attempt has been made to forecast point and time of landfall. Personnel computer based, track forecast models are already in use, in India Meteorological Department's (IMD) different forecasting offices. The existing model requires cyclone track climatology of the basin and past positions of cyclones. Generally pressure falls along the coast, 24 to 36 hours in advance of cyclone's landfall. This parameter, in combination with other two, with equal weightage *i.e*., 1/3 (Persistence + Climatology + Pressure change) have been used for track forecasting in this study. Results are comparatively superior to the results obtained only by using climatology and persistence.

When the system is within 12 to 24 hour prior to landfall, the 24 hour pressure change becomes more important than Climatology and Persistence and 12 hour prior landfall the hourly pressure change helps in pinpointing the landfall point.

Key words – Persistence, Climatology, Weightage, Pressure change.

1. Introduction

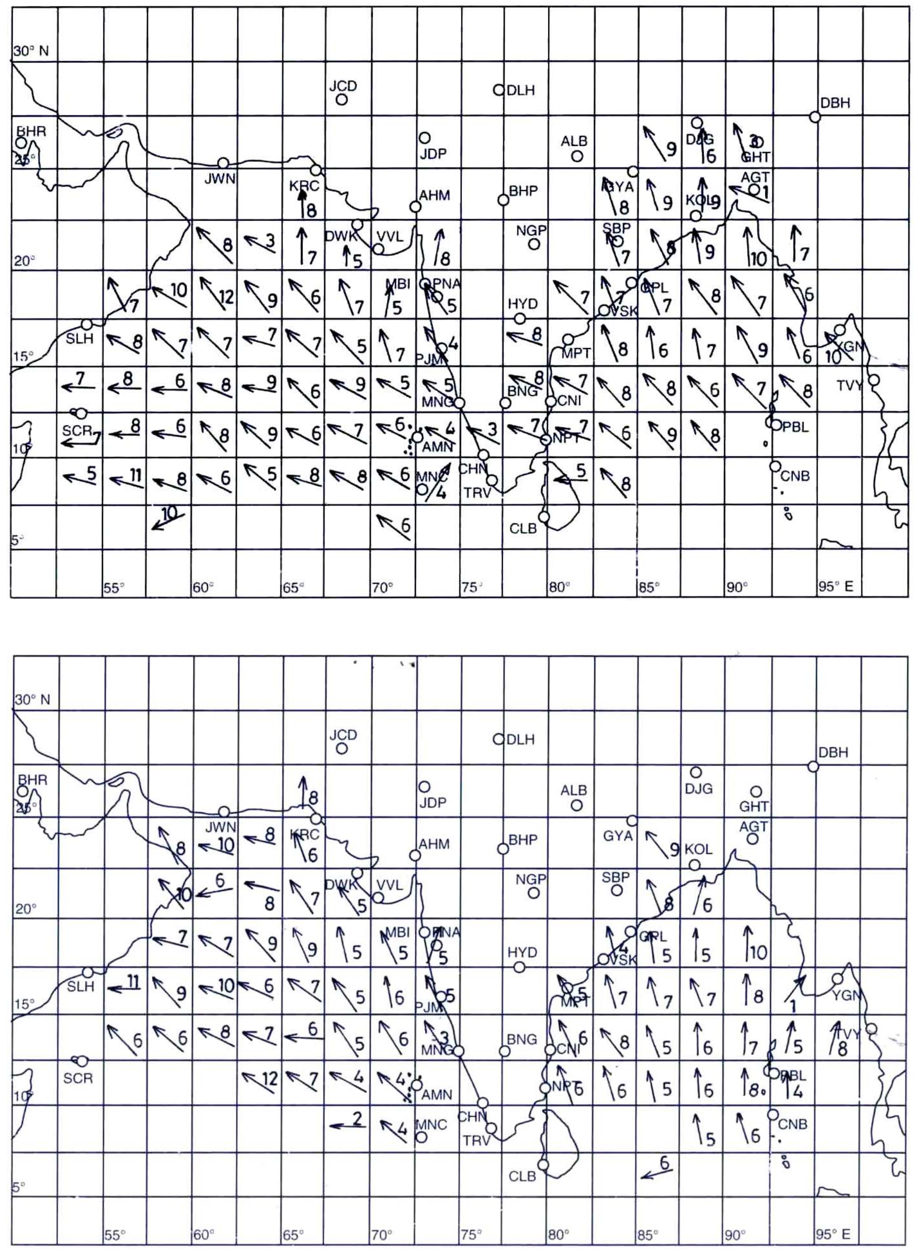
Forecasting future location of a tropical cyclone is an important components of tropical cyclone warning. The storm surges and gale winds associated with cyclones are the major causes of damage and destruction. The prediction of storm surge and strong winds over the Indian coast well in advance, helps disaster managers to take precautionary measures. Due to its importance large number of forecast techniques have been developed globally using wide range of approaches, from empirical through statistical and dynamical.

Comprehensive reviews of forecasting techniques are available in WMO/TD No. 196 (1997), WMO/TD No-430, Mandal (1991) and Neumann (1985). Sen Sarma (1983) reviewed the path prediction techniques used in India and summarised various past works on the subject. Various forecast schemes for the North Indian Ocean (NIO) were designed by Sikka and Suryanarayan (1972), Datta and Gupta (1975), Neumanm and Mandal (1978), Prasad (1997) and Chan (1997).

Extended range forecasts (36-72 hours) are used mainly as an alert and preparation guide, and to provide an initial envelope for determining the shorter period forecasts. Dynamical and Statistical techniques dominate for the preparation of track forecast in this time scale and the use of probabilistic forecasts proved to be useful aid to objective planning (WMO/TD No-560).

(a)

(b)



Figs. 1(a&b). Climatological monthly mean direction (degree) and speed (kts) of (a) Pre-monsoon cyclone season (April-June) and (b) Post-monsoon cyclone season (October- December) for the period 1891-2003.

Short range forecast (less than 36 hours) period is used mainly for establishing warning zones and initiating civil defence procedures, such as evacuation of coastal zones. Persistence, climatology and statistical techniques become more useful relative to the dynamical techniques (WMO/TD No-560) for track forecasting in shorter time scale within 24 hours.

Like elsewhere in the globe, Persistence and Climatological (CLIPER) forecasts technique is in use in India. In such technique, equal weightage [½ (C+P)] are given to the climatology and persistence track and an average forecast is worked out. The Persistence vector is obtained by the linear extrapolation of smoothed past 12 hours motion. The climatology vector is based on the

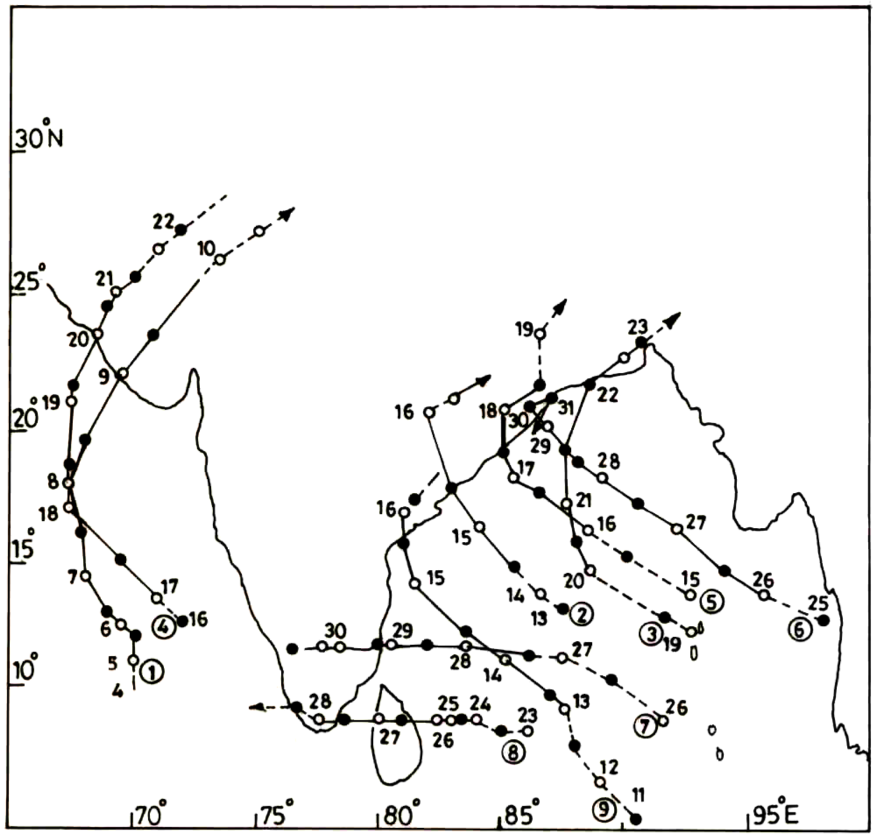


Fig. 2. Tracks of Severe Cyclonic Storms (SCS), Very Severe Cyclonic Storms (VSCS) and Super Cyclone (SuC) crossed Indian coasts during 1998-2003

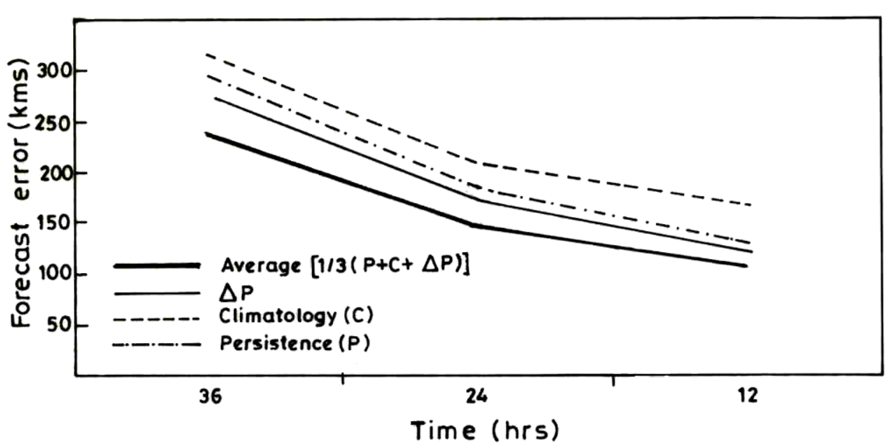
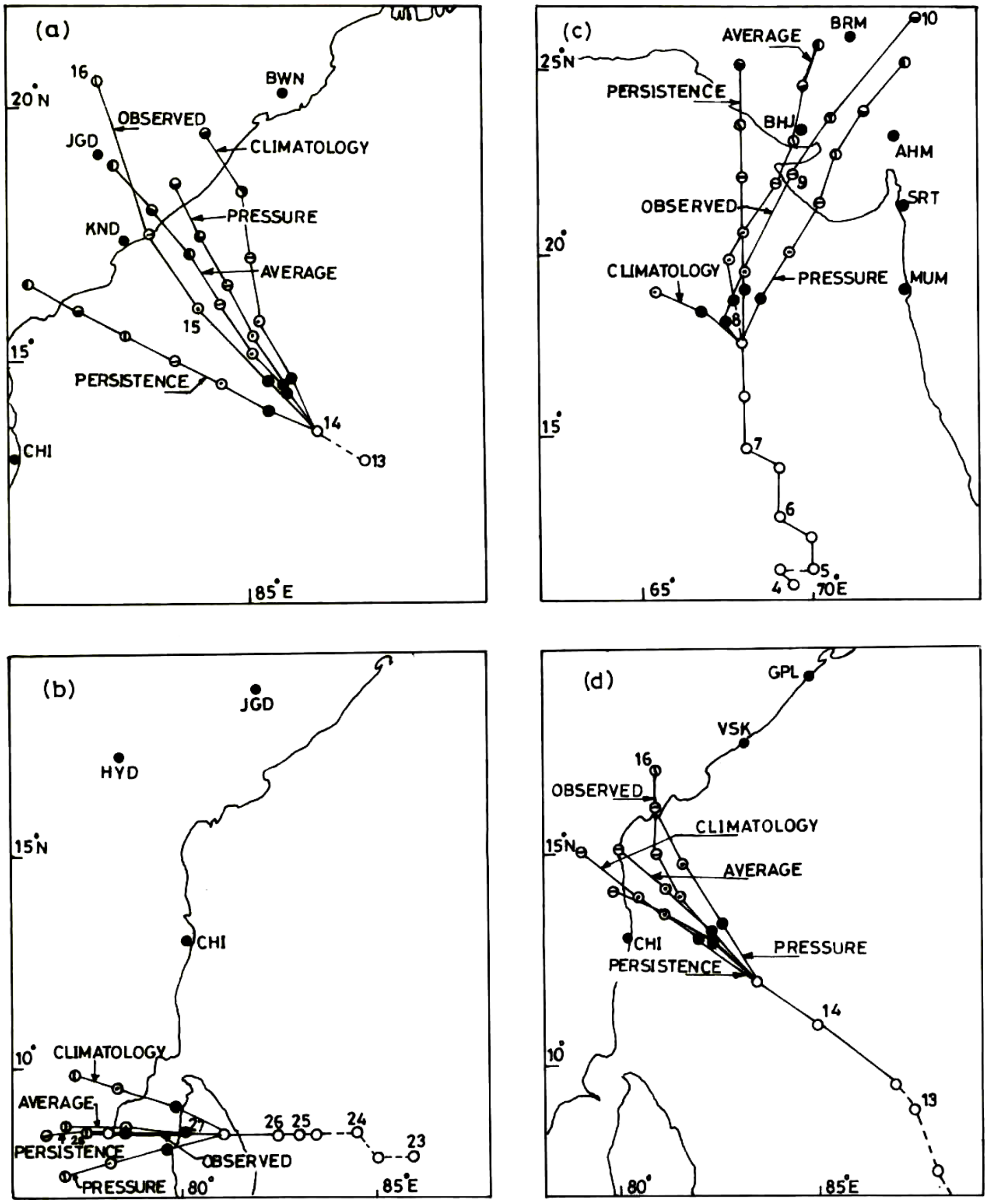


Fig. 3. Comparative models performance

regional climatology for the current location and time (season) of tropical cyclones. The forecast position usually for 12, 24 & 36 hours ahead is the mid-point connecting the two positions obtained from persistence and climatology when plotted on a mercator chart. Track forecast by CLIPER is considered as standard for comparing forecasts of different regions and is still used in number of forecasting offices, WMO, TD No. 560,



Figs. 4(a-d). Different track model forecast along with observed track of (a) VSCS 13-16, November 1998 over Bay of Bengal, (b) VSCS 23- 28, December 2000 over Bay of Bengal, (c) VSCS 4-10, June 1998 over Arabian Sea and (d) SCS 11-16, December 2003 over Bay of Bengal

(1993). In India, the forecast positions based on CLIPER for tropical cyclones in the north Indian Ocean are given in the yearly Regional Specialized Meteorological Centre (RSMC) report published by IMD.

Past studies and observational facts indicate that the tropical cyclones move towards the area of maximum pressure fall. In this study a combination of climatology, persistence and pressure change has been used for forecasting the point of tropical cyclone.

2. Data

For the present study, nine cases of severe cyclonic storms, that formed over the Bay of Bengal & the Arabian Sea and crossed Indian coast (east & west) during the

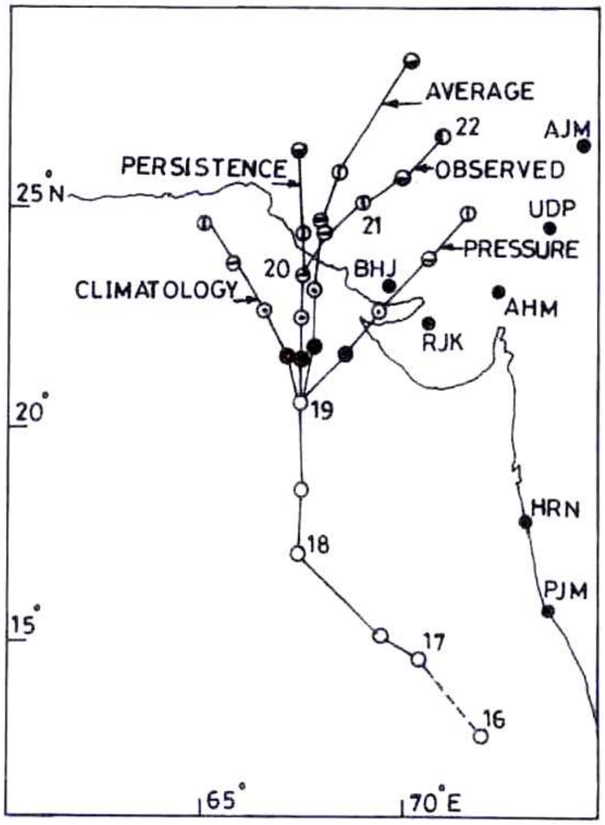
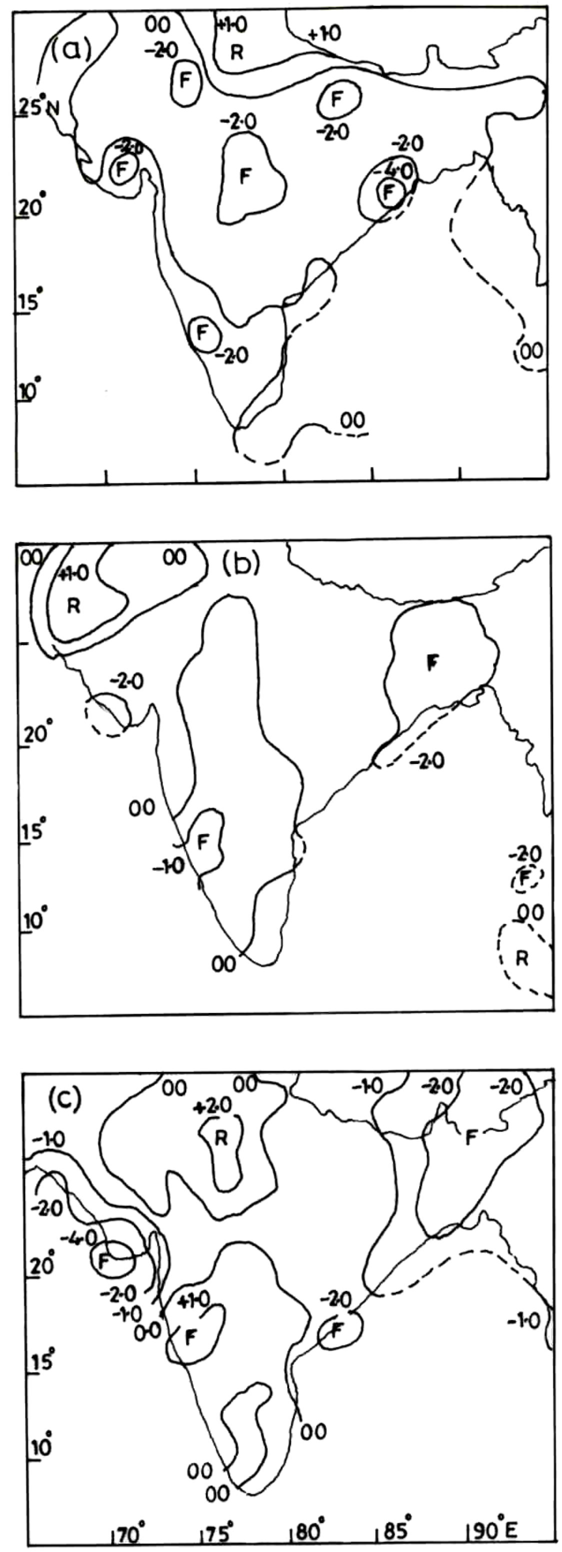


Fig. 5. Track forecast with different techniques along with observed track of VSCS 16-22, May 1999 over Arabian sea



Figs. 6(a-c). Pressure change (a) 36, (b) 24 and (c) 12 hrs prior to landfall of the cyclone

period 1990-2003 were considered. Pressure change data in 36, 24 and 12 hours prior crossing of the coast are taken from 0000 and 1200 UTC observations from the plotted charts of the Northern Hemisphere Analysis Centre (NHAC). The climatological monthly and seasonal mean direction and speed have been prepared for the period 1891-2003. The track position of the cyclones (Lat./Long.) and other synoptic information used in the study are based on the Annual Reports of the RSMC-Tropical Cyclone New Delhi.

3. Methodology

Methodologies for calculating various forecast positions by different techniques are given below :

3.1. *Persistence method*

This method is based on the assumption that during the preceding 12 hour, tropical cyclone would move in the same direction and speed as it did during the past 12 hour. This can be referred as

$$\triangle \text{ lat p} = [(\phi_0 - \phi_{t0}) * 12.0] / \triangle t \quad (1)$$

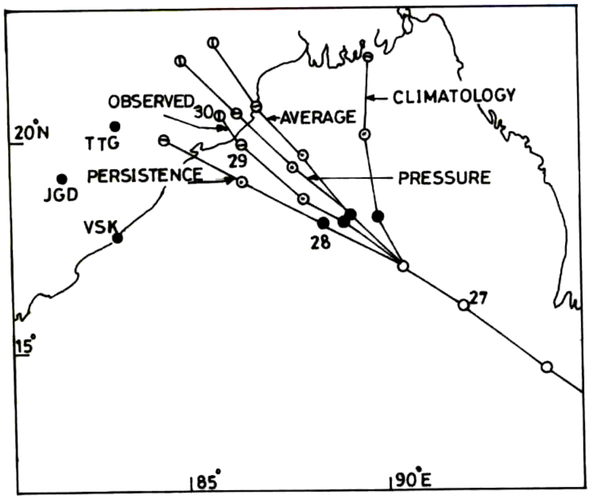


Fig. 7. Track forecast with different techniques along with observed track of super cyclone 25-31, October 1999 over Bay of Bengal

$$\triangle \text{lon p} = [(\lambda_0 - \lambda_{t0}) *12.0] / \triangle t \qquad (2)$$

where ϕ_0, λ_0 are represent latitude and longitude of the observed system.

And ϕ_{t0}, λ_{t0} are latitude and longitude of the system before $\triangle t$ hour.

The forecast latitude position at 12, 24 and 36 hours will therefore be computed as :

$$\phi_{p12} = \phi_0 + \triangle \text{ lat p} \qquad (3)$$

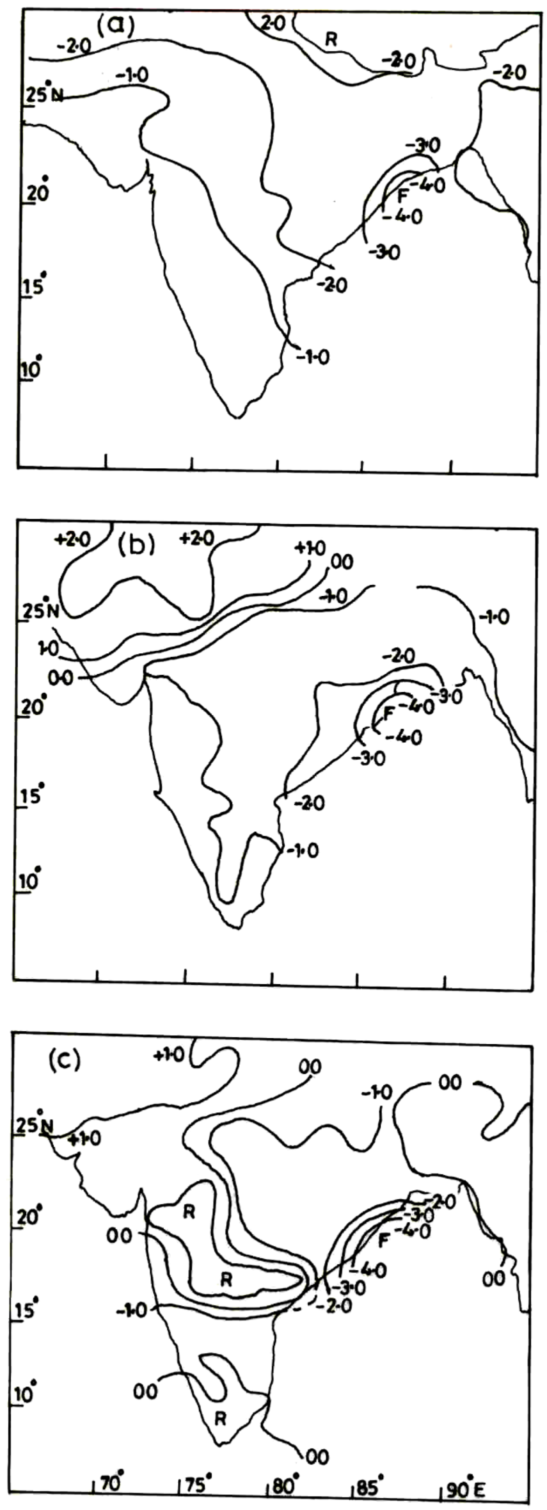
$$\phi_{p24} = \phi_{p12} + \triangle \text{lat p} \qquad (4)$$

$$\phi_{p36} = \phi_{p24} + \triangle \text{ lat p} \qquad (5)$$

Similarly the forecast longitude position for different time projection can be obtained by using $\triangle$lon p.

3.2. *Climatology*

In this method it is assumed that a tropical cyclone would move in the mean direction (DIR) and speed (SPD) of all cyclones that had formed the same latitude and longitude box during the month of previous years. Climatological monthly mean direction (degrees) and speed (kts) of cyclonic disturbances passing through 2.5° Latitude/Longitude square grid for the period 1877-1974 is given by Mandal (1991). On a similar line climatological monthly mean direction and speed have been computed for the period for 1891-2003 which have been used in the study. The climatological monthly mean



Figs. 8(a-c). Pressure change (a) 36, (b) 24 and (c) 12 hrs prior to landfall of the cyclone

TABLE 1

Period of cyclone, intensity of cyclone, basin of occurrence of the cyclone and forecast errors in kms encountered by different model forecasts

S. No.	System	Persistence			Climatology			ΔP			Average		
		36	24	12	36	24	12	36	24	12	36	24	12
1.	VSCS (ARB) 4-10, Jun 1998	-	158	55	-	483	169	-	172	115	-	239	87
2.	VSCS(BOB) 13-16, Nov 1998	28	110	55	248	108	531	221	91	45	218	72	36
3.	VSCS (BOB) 13-19, Nov 1998	550	275	174	463	183	108	681	349	198	561	267	159
4.	VSCS (ARB) 16-22, May 1999	277	132	110	253	118	34	312	248	118	12	46	48
5.	VSCS (BOB) 15-19, Oct 1999	662	389	258	304	168	143	499	275	185	433	236	181
6.	SuC (BOB) 25-31, Oct 1999	171	174	174	490	252	85	118	101	122	167	108	115
7.	VSCS (BOB) 26-30, Nov 2000	233	158	55	273	217	132	131	87	33	187	132	71
8.	VSCS (BOB) 23-28, Dec 2000	110	55	165	154	112	154	137	82	157	80	35	152
9.	SCS (BOB) 11-16, Dec 2003	311	174	94	327	216	128	099	124	116	237	158	107
	Total Average error	293	181	127	314	206	165	275	170	121	237	144	106

direction and speed of pre-monsoon cyclone season (April-June) and post-monsoon cyclone season (October-December) for the period 1891-2003 are shown in Figs. 1(a&b). Computational procedures are described below:

The projection latitude and longitude after 12 hours can be represented as :

$$\Delta \text{lat c} = \text{SPD}*12 \times \text{Cos (DIR)}/60 \quad (6)$$

$$\Delta \text{lon c} = \text{SPD}*12 \times \text{Sin (DIR)}/60 \quad (7)$$

The forecast latitude position at 12, 24 and 36 hours can be represented as:

$$\phi_{c12} = \phi_0 + \Delta \text{lat c} \quad (8)$$

$$\phi_{c24} = \phi_{c12} + \Delta \text{lat c} \quad (9)$$

$$\phi_{c36} = \phi_{c24} + \Delta \text{lat c} \quad (10)$$

Similarly the forecast longitude position λ_{c12}, λ_{c24} and λ_{c36} can be obtained by using Δlon c.

3.3. *Pressure change Δp*

In this case the speed of movement of the system is taken as average of climatology and persistence. The direction is the angle made by the line joining the system's position and the area where the pressure is minimum over the coast. With such direction and speed the forecast positions are obtained as in the case of climatology.

3.4. *Climatology and persistence [1/2 (P+C)] method*

The forecast latitude and longitude for different time projections by this technique are computed as follows :

$$\phi_{12} = 1/2(\phi_{p12} + \phi_{c12}) \quad (11)$$

$$\lambda_{12} = 1/2(\lambda_{p12} + \lambda_{c12}) \quad (12)$$

Similarly forecast positions for 24 (ϕ_{24}, λ_{24}) and 36 (ϕ_{36}, λ_{36}) hours can be obtained.

3.5. *Combination of CLIPER and Pressure change method [1/3 (P+C+ΔP)]*

The forecast latitude and longitude in this method are computed as follows :

$$\phi_{12} = 1/3(\phi_{p12} + \phi_{c12} + \phi_{\Delta p12})$$

$$\lambda_{12} = 1/3(\lambda_{p12} + \lambda_{c12} + \lambda_{\Delta p12})$$

Similarly forecast positions for 24 and 36 hours are obtained.

3.6. *Forecast errors*

Forecast errors can be computed by using the following formula

$$\text{Error (km)} = \sqrt{\left(X^2 + Y^2\right)} * (110) \quad (13)$$

TABLE 2

Point of maximum pressure fall, 12 and 24 hour prior to landfall and point of landfall

S. No.	System and basin	Date of the system	24 hour location of maximum pressure fall over the coast		Landfall point
			12 hours prior	24 hours prior	
1.	VSCS (ARB)	4-10, Jun 1998	21.5/69.5	21.0/70.0	21.5/69.0
2.	VSCS (BOB)	13-16, Nov 1998	17.5/83.5	17.0/82.5	17.0/83.5
3.	VSCS (BOB)	13-19, Nov 1998	21.5/87.5	20.0/86.0	22.0/89.0
4.	VSCS (ARB)	16-22, May 1999	23.7/68.5	23.7/68.5	24.0/68.5
5.	VSCS (BOB)	15-19, Oct 1999	18.5/84.0	18.5/84.0	19.2/85.0
6.	SuC (BOB)	25-31, Oct 1999	19.5/85.5	18.5/84.5	19.5/85.5
7.	VSCS (BOB)	26-30, Nov 2000	11.5/79.5	11.5/79.5	11.5/80.5
8.	VSCS (BOB)	23-28, Dec 2000	8.5/78.0	9.0/79.0	8.5/78.0
9.	SCS (BOB)	11-16, Dec 2003	16.0/81.0	15.0/80.0	16.0/81.0

TABLE 3

Forecast skill in % for 36, 24 and 12 hours prior to landfall by different model as Persistence, Climatology, Δ P and Average

Persistence (P)			Climatology (C)			Pressure change (Δ P)			1/3 (P + C + Δ P)		
36h	24h	12h	36h	24h	12h	36h	24h	12h	36h	24h	12h
-118	-15	-15	-29	-30	-50	-4	-8	-10	+11	+ 9	+ 4

Positive (+) skill indicates other model forecast is better than CLIPER and Negative (-) skill indicates the CLIPER forecast is better than other model.

Where $X = \phi_a - \phi_f$, $Y = \lambda_a - \lambda_f$

Where ϕ_a, λ_a are observed latitude and longitude (position) of the system.

ϕ_f, λ_f are forecast latitude and longitude (position) of the system.

3.7. *Forecast skill*

The forecast skill, expressed in %, relative to CLIPER model has been calculated by the formula given below :

$$\text{Forecast Skill} = \frac{\text{CLIPER} - \text{OM}}{\text{CLIPER}} \times 100 \qquad (14)$$

Where, CLIPER represents position errors based on CLIPER [(1/2 (P+C)] and OM represents position errors based on other methods like Persistence (P), Climatology (C), Pressure change ΔP and CLIPER [1/2(P+C+ΔP)].

Hence, forecast skill indicates how good or bad a model is respect to CLIPER.

4. Results and discussion

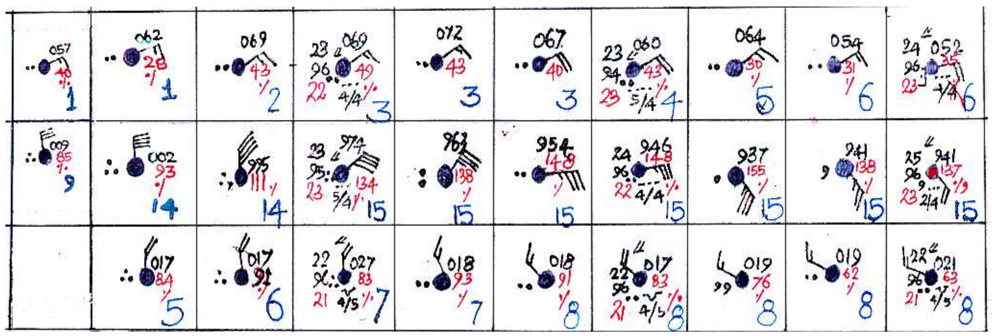
One of the simplest method of track prediction is the persistence method, in which it is assumed the cyclone will follow the same path as in the past. The physical basis for this assumption is that the entire tropical system has considerable inertia that can not be turned rapidly. If the vortex, large-scale flow, and the interaction processes do not change, the future motion should resemble the past motion of the cyclones. Thus, persistence is a reasonable, first-order approximation for predicting short-term motion of the cyclones. Eventually, the changes in the vortex and in the large-scale flow, plus the inherent non-linearity of the interaction between them, limit the usefulness of this approximation.

Climatological track prediction assumes that the present cyclone will move with the average direction and speed of all past cyclones near that location. To make a track prediction, the climatological vectors at the appropriate locations are multiplied by the time interval and the displacements are added to the present latitude and longitude. This simple application of climatology does

TABLE 4

Hourly observations from 151200 UTC to 152100 UTC suggesting landfall time & point around 151800 UTC close to south of Machilipatnam

Stations	1200 (UTC)	1300 (UTC)	1400 (UTC)	1500 (UTC)	1600 (UTC)	1700 (UTC)	1800 (UTC)	1900 (UTC)	2000 (UTC)	2100 (UTC)
Kakinada (43189)										
Machilipatnam (43185)										
Baptle (43220)										



not take into account the variability in past tracks through each location.

Since the pressure distribution in the field of tropical cyclone is well defined and has a large gradient, the isobaric configuration, pressure changes and their gradients may constitute an objective aid for forecasting storm movement. When the cyclone comes near the coast, pressure changes at coastal stations are very valuable. When a tropical cyclone forms over north Indian Ocean and heads towards the Indian coast, in most of the cases, 36 hours prior to landfall, a pressure fall is observed over the surface chart giving an idea about likely landfall area.

In this paper nine cases of severe cyclonic storm have been studied. Observed tracks of these systems are shown in Fig. 2. Utilising the equations given under methodology the 12, 24, and 36 hours forecast positions for Persistence, Climatology, Pressure Change, CLIPER [1/2 (P+C)] and CLIPER with $\triangle$P [1/3 (P+C+$\triangle$P)] have been calculated and results presents in Tables 1 & 2. From the forecast skill presents in Table 3, it is observed that for all the forecast projections, forecast by the combination of methods like CLIPER and CLIPER with $\triangle$P are better than the forecast by individual techniques. However the CLIPER with $\triangle$P [1/3 (P+C+$\triangle$P)] fairs better than Cliper [1/2 (P+C)] for 24, and 36 hours forecast with forecast skill of 9% and 11% respectively. The forecast error with different track forecast techniques is given in Fig. 3.

Forecast tracks by different methods of VSCS 13-16, November 1998 over the Bay of Bengal, VSCS 4-10, June 1998 over the Arabian Sea, VSCS 23-28, December 2000 over the Bay of Bengal and SCS 11-16, December 2003 over Bay of Bengal is shown in Figs. 4(a-d). From these figures it can be generally inferred that the CLIPER [1/3 (P+C+$\triangle$P)] gives a better estimation.

Track forecast with different techniques along with observed track of VSCS, 16-22 May, 1999 over the Arabian sea is given in Fig. 5. As can be seen from Fig. 6(a-c) pressure fall 36 hours prior to the landfall was observed over Saurashtra & Kutch. As the system moved near the coast the pressure fall was more marked.

Different model track forecasts along with observed track of Super Cyclone, 25-31 October, 1999 over the Bay of Bengal is given in Fig. 7. The pressure fall was observed approximately 36 hours prior to landfall over north Orrisa which became well marked and shifted slightly northeastwards when the system was near the coast, Figs. 8(a-c).

The locations of pressure falls approximately 12 and 24 hour prior to landfall along with the actual point of landfall is given in Table 3. From this table it can be inferred that 12 to 24 hour prior landfall, the pressure change parameter becomes more important than climatology or persistence for forecasting landfall point. Accuracy of track forecast depends upon the observation taken over the likely cyclone affected coastal area. When the system is within 12 hour range the hourly pressure fall can be used for pinpointing the landfall point. A typical case of SCS 11-16, December 2003 over Bay of Bengal which crossed coast near Machilipatnam around mid-night, hourly pressure fall from 151200 UTC to 152100 UTC is given in Table 4, where the hourly pressure fall helps in forecasting the landfall point and time.

However, the technique has its own limitations. In absence of coastal observations in close spacing and their non-availability in real time, it may be difficult to judge the point of maximum pressure fall and to draw the isolines of pressure change and that may introduce subjective errors.

4. Conclusion

Generally pressure starts falling along the coast 24 to 36 hour prior to cyclone's landfall indicating probable area of landfall. This parameter is utilised in combination with CLIPER 1/2(C+P) giving equal weightage 1/3(P+C+ΔP) to develop a new technique which seems to give better results in comparison to the techniques applied individually or to CLIPER.

Prior to 12 to 24 hours of cyclone's landfall, the 24 hour pressure change becomes more important than climatology and persistence and 12 hour prior landfall the hourly pressure change helps in deciding the landfall point.

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