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Decaying nature of super cyclone of Orissa after landfall

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सार – इस शोध–पत्र में उड़ीसा में आए महाविध्वंसकारी चक्रवात (अक्तूबर 1999) से लैंडफाल के उपरांत पवन की अधिकतम गति के ह्रास की प्रकृति का अध्ययन करने का प्रयास किया गया है। जहाँ तक इस चक्रवात के उपलब्ध कुछ प्रेक्षणों का संबंध है उनमें यह पाया गया है कि लैंडफाल के उपरांत पवन की अधिकतम गति काफी कम हो गई थी। गति में ह्रास के कारण आए घुमाव से यह पता चलता है कि पवन की अधित लघु किन्तु शून्येत्तर मान तक कम हो गई है। लैंडफाल के उपरांत समय के साथ पवन गति से संबंधित आनुभविक समीकरण विकसित किया गया है। ह्रास का मान निरतंर (प्रति घंटा) 0.0991 पाया गया है। अक्तूबर 1999 के भीषण चक्रवातीय तूफान से लैंडफाल के बाद की पवन गति का पूर्वानुमान करने के लिए इस तकनीक का परीक्षण भी किया गया है। जिसके कारण 17 अक्तूबर 1999 के मध्य रात्रि को उड़ीसा के गोपालपुर के समीप हुई लैंडफाल हुआ। इस तकनीक का प्रयोग करते हुए आकलित की गई पवन की गति प्रेक्षणों के अनुरूप पाई गई।

ABSTRACT. An attempt has been made in this paper to study the nature of decay of maximum wind speed of Orissa Super Cyclone (October 1999) after landfall. From the scanty observations that became available in respect of this cyclone, it is found that the maximum wind speed decreased exponentially after landfall. The decay curve indicates that the maximum wind speed got reduced to a small but non zero value. An empirical equation relating wind speed with time after landfall has been developed. The value of decay constant (per hour) is found to be 0.0991. The technique is also tested to predict the wind speed after landfall for the very severe cyclonic storm of October 1999 which made landfall near Gopalpur in Orissa in the mid night of 17 October 1999. The wind speed estimated applying this technique is found to be consistent with the observations.

Key words – Super cyclone, Decay constant, Maximum wind speed, Empirical technique.

1. Introduction

Orissa was battered by a super cyclone on 29 October 1999 that made landfall near Paradip. It was one of the most intense tropical cyclones in the history of Orissa over last 100 years. The system attained its peak intensity (T No.7.0, estimated maximum wind speed 140 knots) just before landfall. Fig. 1 shows the track of this cyclone. After crossing the coast it moved inland, nearly at right angles to the coast line, very slowly a little further to the northwest and lay near Lat.20.5° N / Long. 86.0° E close to Bhubaneswar. It was stuck up near Bhubaneswar in absence of any steering current as it was sandwiched between two upper air anticyclones (Kalsi *et al*. 2002). The system remained practically stationary till 0000 UTC of 31 October and weakened gradually. It caused exceptionally heavy rains on 29 October (amounts exceeding 20 cm in 24 hours period) over most stations in Orissa. Heavy to very heavy falls continued on the second day also (*i.e.*on 30 October). Inland effects of the storm were due to wind and storm surge and loss of life was around 10,000. Storm surge of about 5 to 6 metres above astronomical tide of about 1 metre forced the sea to an elevation of about 6-7 metres and storm tide penetrated inland upto 15 km. Development process of this cyclone is described by Kalsi *et al*., 2002.

Many studies are available (Basu and Ghosh, 1987; Mishra and Gupta, 1976; Holland, 1980 etc.) on the estimation of wind speed around a cyclonic storm over sea area . But no such study for estimating wind speed after landfall is presently available over Indian region. A method of predicting decaying rate after landfall over United States of America has been developed by Kaplan and Demaria (1995). The inland wind speed decreases due to loss of oceanic heat source, absence of moisture supply and increased surface roughness over land which the cyclone encounters immediately after landfall. This super cyclone of Orissa is a unique system which maintained the intensity of cyclonic storm for about 36 hours even after landfall. Using wind data associated with this system and following Kaplan and Demaria (1995), in this paper, a simple empirical technique has been developed to estimate the decay constant of the maximum wind of the storm after landfall. In order to assess the predictive capability of this technique in case of other severe tropical cyclones,

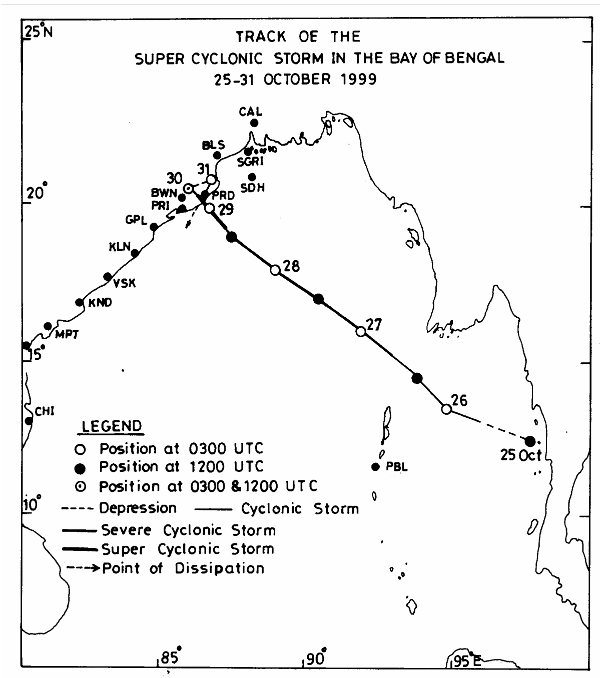

Fig . 1. Track of super cyclone of Orissa during 25-31 October 1999

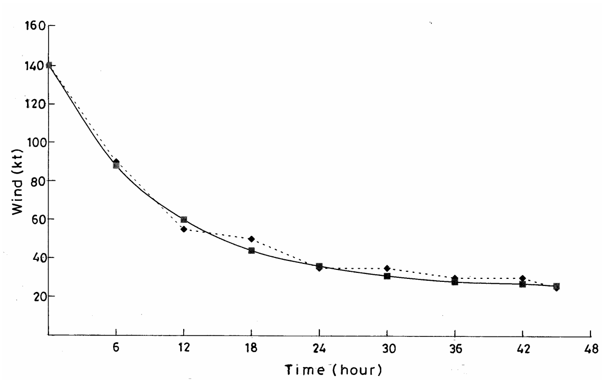

Fig . 2. Decay curves of the super cyclone based on Table 1 (dotted line) and estimated wind speed from the empirical equation (continuous line)

the method is applied for the very severe cyclonic storm of October 1999 which made landfall near Gopalpur in Orissa in the midnight of 17 October .

2. Data and methodology

Data used to derive the empirical equation consists of wind data obtained from RSMC (Regional Specialized Meteorological Centre) of India Meteorological Department (IMD). These are estimated from post storm synoptic analysis based on all available observations (incorporating data received late). Intensity of landfall, central pressure of the system and other synoptic information is also taken from the records of Cyclone Warning Division of the India Meteorological Department as shown in Table 1.

TABLE 1

Super cyclonic storm – October 1999

Time (hour)	Estimated central pressure (hPa)	Estimated maximum sustained wind (kt)	Intensity
Landfall time	912	140	Super cyclone
6	968	90	Very severe cyclonic storm
12	993	55	Severe cyclonic storm
18	996	50	Severe cyclonic storm
24	1002	35	Cyclonic storm
30	1002	35	Cyclonic storm
36	1004	30	Deep depression
42	1004	30	Deep depression
45	1006	25	Depression

The decaying curve prepared based on this data is shown in Fig. 2. The dotted line in this figure is the plot of data in Table 1 and the continuous curve is an exponential fit using the time constant of decay as derived in section 2.1. The wind speed data recorded at Bhubaneswar after landfall have been used for the comparison with this decay curve. Fig. 3 presents the inter-comparison of decay curves based on these two data sets. The selection of this station (Bhubaneswar) is due to consideration that it was closed to storm centre. More over it being a major Meteorological Centre observations are considered to be more reliable.

2.1. *Derivation of decay equation*

From the decay curve (dotted line in Fig. 2), it is seen that the maximum wind speed decreases exponentially . So if $v(t)$ is the wind speed after time t since the landfall then we can write

$V(t) = V_0 \exp(-at)$ where a is the decay constant and V_0 is the maximum wind speed at the time of landfall

Differentiating above equation,

$$\frac{dv}{dt} = -av \qquad (1)$$

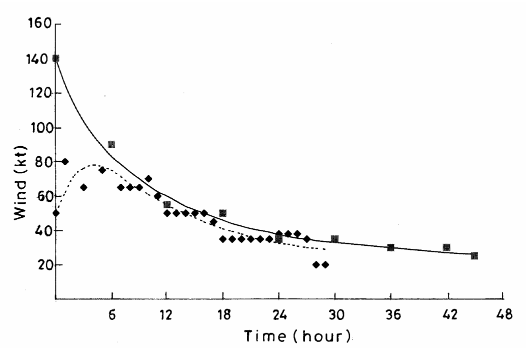

Fig . 3. Comparison of decay curves of the super cyclone based on Table 1 (continuous line) with respect to recorded wind speed of Bhubaneswar (dotted line)

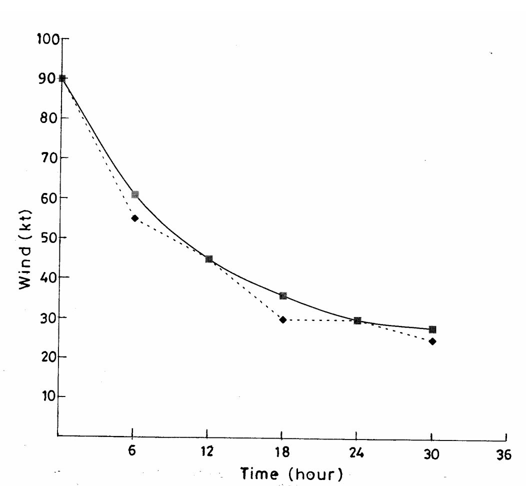

Fig . 4. Comparison of decay curves of the very severe cyclonic storm of 17 October 1999 based on Table 3 (dotted line) and wind data estimated (continuous line) from the empirical equation

Fig. 2 suggests that the intensity of the cyclone reduces to a constant value (25 knots) after about 36 hours of landfall when decay rate became nearly zero. Kaplan and Demaria (1995) in his study termed this constant value as background wind speed (v_b). If we include the effect of background wind speed (v_b) then equation (1) can be written as

$$\frac{dv}{dt} = -a(v-v_b)$$

or, $\ln(v-v_b) = -at + c$ where c is integration constant.

At $t = 0, v = v_0$ *i.e.* $c = \ln(v_0 - v_b)$

TABLE 2

V_0(kt)	V(kt)	V_b(kt)	t(hr)	a(hr^{-1})
140	60	25	12	0.0991

so $\ln(v-v_b) = -at + \ln(v_0 - v_b)$

$$\text{or,} \quad v = v_b + (v_0 - v_b) \exp(-at) \qquad (2)$$

From the decay curve it is seen that v_b = 25 kt. Maximum wind speed (v_o) at the time of landfall was 140 knots (Kalsi *et al*., 2001). Taking t = 12 hours when $v(t)$ is 60 knots, decay constant calculated is shown in the Table 2.

3. Results and discussion

It is clear from the decay curve (dotted line in Fig. 2) that the wind speed of the storm decays exponentially with time after landfall, that is rate of decay at any time is directly proportional to its wind speed at that time. So the decay rate is maximum just after landfall and this decay rate gradually decreases with time. Finally, the decay curve reaches to 25 knots (background wind speed) and becomes constant (decay rate becomes zero).

It also appears from the Fig. 3 that for nearly first four hours wind speed of Bhubaneswar gradually increases towards the maximum wind speed of the storm and thereafter both curves follow very closely for the remaining hours. The increase of wind speed at Bhubaneswar during this period of four hours indicates the local response to the cyclone as it is approaching Bhubaneswar. The wind speed started increasingly locally when the storm moved towards the station. In Fig. 2, the wind speed estimated applying equation (2) has been plotted at six hours interval (continuous line) and compared with the decay curve obtained using wind data of Table 1 (dotted line). It is apparent from this comparison that the prediction skill of the technique is reasonably good. Maximum error of magnitude 6 knots (under estimated) occurs at 18 hours of landfall

In order to apply this empirical technique for another cyclone we consider the case of very severe cyclonic storm of October 1999 which made landfall in the mid night of 17 October near Gopalpur in Orissa. As the decay rate is dependent on surface roughness and availability of moisture over the area, the selection of this particular system is due to the consideration of its occurrence in same coastal segment (Orissa) and during the same season (post monsoon). Intensity of landfall, estimated central pressure and maximum sustained wind

TABLE 3

Very severe cyclonic storm – October 1999

Time (hour)	Estimated central pressure (hPa)	Estimated maximum sustained wind (kt)	Intensity
Landfall time	968	90	Very severe cyclonic storm
6	993	55	Severe cyclonic storm
12	998	45	Cyclonic storm
18	1002	30	Deep depression
24	1002	30	Deep depression
30	1004	25	Depression

for this cyclone as obtained from RSMC report of IMD is shown in Table 3.

Fig. 4 shows the inter-comparison of decay curves of this cyclone from the use of wind data of Table 3 and the estimated wind speed applying equation (2) for this very severe cyclonic storm using the same time constant of decay. The inter-comparison indicates that predicted wind speed are reasonably good. Maximum error of magnitude 6 knots (over estimation) occurs at 6 hours and 18 hours of landfall.

4. Concluding remarks

In this paper an attempt has been made to visualize temporal weakening of the super cyclone of October 1999 after landfall using available observations and also estimates of maximum winds encountered in this cyclone . The study shows that the wind speed associated with the Orissa super cyclone decays exponentially with time after landfall and value of time constant of decay is 0.0991 per hour.

The wind speed after landfall estimated for the very severe cyclonic storm (Gopalpur) of October 1999 applying this empirical technique is found to be consistent with the observed field.

For the operational practices there has been a growing demand to derive an empirical method for predicting wind field associated with tropical cyclones after landfall. The empirical method calibrated based on Orissa super cyclone appears to be promising in this regard. However, further work is needed to calibrate the technique in a more general manner incorporating reasonably good number of cyclone cases for varying coastal segments and seasons. Our future attempt would be in that direction.

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