MAUSAM, **54**, 2 (April 2003), 351-358

551.515.2(267.64)

An evaluation of cyclone genesis parameter over the Bay of Bengal using model analysis

S. K. ROY BHOWMIK

India Meteorological Department, New Delhi-110 003, India

(*Received 27 November 2001, Modified 11 June 2002*)

सार – अधिकांश महासागरों में उष्णकटिबंधी चक्रवातों के बनने के लिए आवश्यक ऊष्मागतिकीय अवस्था प्रायः संतोषप्रद पाई गई जबकि गतिकीय अवस्थाओं में दिन–प्रतिदिन की भिन्नताएं अत्याधिक मात्रा में पाई गई है। जेहर (1992) ने उत्पत्ति प्राचल (जी.पी.) नामक एक प्राचल की अभिकल्पना की है जिसमें पर्यावरण की तीन गतिकीय अवस्थाएं सम्मिलित हैं। इस शोध–पत्र में बंगाल की खाड़ी में उत्पत्ति प्राचल के प्रारंभिक मानों का पता लगाने के लिए हाल ही में विकसित और अविकसित किए गए कुछ निम्न दाब प्रणालियों से संबद्ध उत्पत्ति प्राचलों की अंतरतुलना की गई है। जी.पी. के परिणामों को प्राप्त करने के लिए विभेदन 1°× 1° अक्षांश/देशांतर पर निदर्श विश्लेषण फील्ड का उपयोग किया गया है। इस अध्ययन से यह पता चला है कि टी. सं. 1.5 के विपरीत लगभग 20×10^{-12} से. $^{-2}$ के जी.पी. मान से भीषण चक्रवाती तूफान के आने की संभावना है। अक्तूबर 1999 में उड़ीसा के महाविध्वंसकारी चक्रवात और मई 1997 में प्रभंजन पवनों के क्रोड के साथ आए बंगलादेश के अत्यंत भीषण चक्रवाती तूफान दोनों में टी.सं. 3.5 पर जी.पी. की तीव्रता अपनी चरमसीमा पर थी। इस दौरान जी.पी. मैक्स और प्रणाली की तीव्रता की चरमसीमा के मध्य लगभग 24–36 घंटों का अंतराल था। ऐसा देखा गया है कि ये प्रचालनात्मक चक्रवात चेतावनी कार्य के लिए उपयोगी प्रागुक्ति के सिगनल उपलब्ध कराते हैं।

ABSTRACT. The thermodynamical condition necessary for tropical cyclogenesis are commonly satisfied over most of the oceans while the dynamical conditions have large day to day variations. Zehr (1992) designed a parameter known as Genesis Parameter (GP) which involves three dynamical conditions of the environment. In this paper an intercomparison of Genesis Parameter associated with some recent developing and non-developing low pressure systems is made with a view to get an idea of its threshold value for the Bay of Bengal. Model analysis field at the resolution $1° \times 1°$ lat./long. is used for derivation of GP. The study reveals that GP value around 20×10^{-12} sec^{-2} against T. No. 1.5 has the potential to develop into a severe cyclonic storm. Both for the Orissa super cyclone of October 1999 and the Bangladesh very severe cyclonic storm with core of hurricane winds of May 1997, GP attained its peak intensity at T. No. 3.5. There was a time lag of about 24-36 hours between GP max. and highest intensity of the system. It appears to provide useful predictive signals for the operational cyclone warning work.

Key words – Tropical cyclone, Genesis parameter, Objective analysis, Synthetic vortex.

1. Introduction

One of the most outstanding problem in tropical cyclone prediction is to adequately understand the mechanism leading to the genesis of tropical cyclone. By contrast, the processes of intensification and movement of an already formed cyclone is much better understood. Though recent improvement in the numerical model interms of improved physics and resolution has shown good promise in the cyclone prediction but they often do not capture the early stage of cyclogenesis Gray (1975) designed a parameter known as cyclogenesis parameter, which involves three thermodynamical and three dynamical conditions of the environment where the cyclone is likely to originate. Later on McBride (1981), McBride and Zehr (1981) noted that the thermodynamical conditions necessary for tropical cyclogenesis are commonly satisfied but yet the formation of tropical disturbance usually does not occur. Zehr (1992) observed significance of three dynamical parameters in the initiation of cyclogenesis and combined them to define a quantity known as Genesis Parameter (GP). In an extensive work of tropical cyclone he described two distinct stages of cyclogenesis. The beginning of stage-I makes the onset of enhanced convection associated with the formation of low level circulation with a distinct center. Beginning of stage-II is the formation of depression. The end of stage-II is marked by the formation of tropical storm. In this stage tropical cyclogenesis is said to be completed. Further evolution to a mature cyclonic storm is attributed to the intensification processes. His work is based on the tropical storms during 1983-84 over the western north Pacific.

The present paper deals with the analysis of Genesis Parameter for some recent cyclonic storms (during 1997-2000) over the Bay of Bengal.

2. Data and methodology

According to Zehr (1992) Genesis Parameter (GP) is defined as

$$GP = (850\ VOR^*) \times (850{-}DIV^*) \times (S)$$

Where,

850 VOR* (sec^{-1}) = 850 hPa relative vorticity, if 850 hPa vorticity > 0 = 0, otherwise

850 DIV* (sec^{-1}) = 850 hPa convergence, if 850 hPa convergence > 0 = 0, otherwise

S = Shear co-efficient
= [25.0 ms^{-1} – (200 hPa – 850 hPa shear in ms^{-1})]/20 ms^{-1}.

For the comparison of GP between developing and non-developing tropical disturbance, Zehr (1992) used objective analysis data at the resolution 2.5° × 2.5° lat./long. In the present study analysis fields at resolution 1° × 1° lat./long. from the operational forecasting system of India Meteorological Department (IMD) known as Limited area Analysis and Forecast System (LAFS) are used for derivation of GP values. The LAFS is a complete system consisting of real time processing of data received on Global Telecommunication System (GTS), decoding and quality control handled by amigas software, 3-D multivariate optimum analysis scheme for objective analysis and multilayer primitive equation model. The first guess field for running the analysis scheme is obtained online from the global spectral model run (T-80) of the National Center for Medium Range Forecasting (NCMRWF), New Delhi. The analysis procedure also incorporates a bogusing scheme for initialization of cyclonic vortex through synthetic data inferred from synoptic charts and satellite imagery following Holland (1980). The basic inputs for generating the systematic vortex are parameters like central pressure of the storm, its environment pressure, radius of maximum winds, current position and intensity of the storm. The detailed of the synthetic vortex procedure is described by Prasad *et al.*, 1997.

TABLE 1

Genesis Parameter (x 10^{-12} sec^{-2}) associated with the super cyclone during 23-29 October, 1999

Time & date	GP	T. No.
00231099	3.6	-
12231099	6.1	-
00241099	8.5	1.0
12241099	8.8	1.0
00251099	22	1.5
12251099	22	1.5
00261099	51	2.0
12261099	62	3.0
00271099	67	3.0
12271099	91	3.5
00281099	40	4.0
12281099	43	6.0

In this paper an intercomparison of GP values associated with developing and non-developing low-pressure systems is made with a view to get an idea of its threshold value for the Bay of Bengal. In section 3 of this paper, case studies of GP values associated with some recent tropical disturbances are illustrated. An inter-comparison of GP values with reference to T. No. for developing and non-developing systems are made in section 4 and finally conclusion is drawn in section 5.

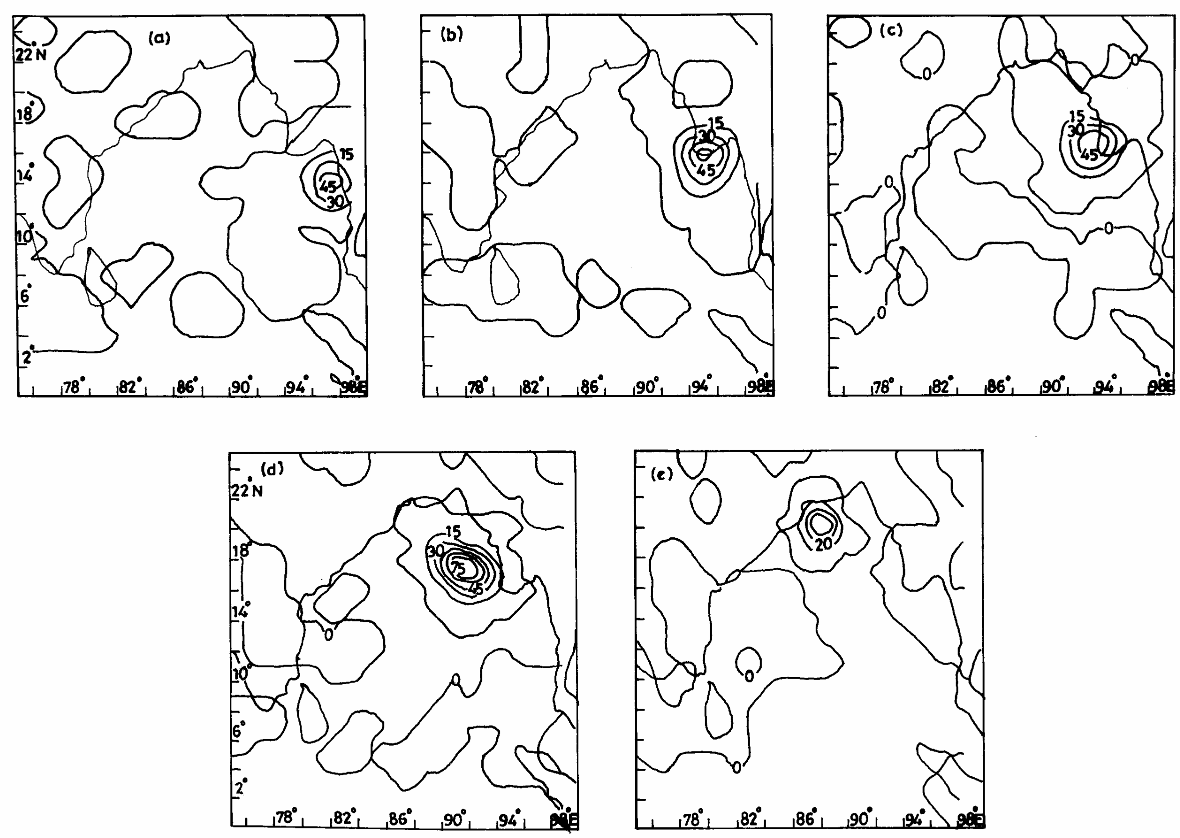
3. Case studies

In this section case studies of GP values associated with a super cyclone, a very severe cyclonic storm with a core of hurricane winds, a very severe cyclonic storm, a cyclonic storm and a depression are presented and discussed.

Case I : Super cyclone over the Bay of Bengal during 25-29 October, 1999

The initial vortex was spotted over the Gulf of Thailand at 0000 UTC of 24 October 1999. It intensified further into a severe cyclonic storm at 0300 UTC of 27 October. The system became very severe cyclonic storm at 1500 UTC of 27 October. It became super cyclone at 1500 UTC of 28 October. The system made landfall near Paradip (Orissa) between 0600 UTC and 0900 UTC of 29 October.

The GP values associated with the system during the genesis period is shown in Table 1. The gradual increase



Figs. 1(a-e). Distribution of Genesis Parameter ($\times 10^{-12}$ sec^{-2}) associated with the super cyclone of October 1999 based on model analysis field of (a) 0000 UTC of 26 October, (b) 1200 UTC of 26 October, (c) 0000 UTC of 27 October, (d) 1200 UTC of 27 October and (e) 0000 UTC of 28 October

of GP is noticed from 0000 UTC of 23 October. At 0000 UTC of 25 October GP was 22 against T. No.1.5 (for the convenient of description we express GP with numeric part only whose unit is 10^{-12} sec^{-2}) and maintained the same intensity till 1200 UTC of the day. Rapid increase of GP is noticed at 0000 UTC of 26 when GP became 51 against T. No. 2.0. It maintained the steady rise to 67 on 0000 UTC of 27 October at T. No. 3.0 and attained its peak intensity of amplitude 91 on 1200 UTC of 27 October at T. No. 3.5. It is very interesting to note that GP fell off rapidly to amplitude 40 at T. No. 4.0 on 0000 UTC of 28 October following its maximum value at T. No. 3.5 even though intensification process of the system continued. The system attained intensity of super cyclone at 1500 UTC and the highest intensity at 1800 UTC of 28 October. Thus, there was a time lag of 24-30 hours between GP max. and super cyclone stage. The reason for GP max. at the time of T. No. 3.5 may be due to the rapid formation of a warm core about that time, perhaps leading to the formation of an eye which appears to be associated with the minimum value of vertical shear. In fact, an eye structure was already visible in RADAR though it was not visible in concomitant geostationary Meteosat and INSAT imageries (Kalsi *et al.*, 2001). The subsequent decrease of GP may be due the increasing vertical shear, which is influenced by the upper tropospheric outflow.

Figs. 1(a-e) illustrates the GP contour pattern during developing stage (0000 UTC of 26 October to 0000 UTC of 28 October) of the system. As the system was moving northwesterly GP max zone also followed same direction, but location of GP max. was slightly to the north. Rapid increase of GP at the developing stage has given clear indication of potential of the system to reach hurricane intensity.

Case II : Bay of Bengal very severe cyclonic storm with a core of hurricane winds [VSCS(H)] during 15-20 May 1997

A well-marked low-pressure area formed over south west Bay of Bengal and adjoining south Andaman Sea in the morning of 15 May 1997. It intensified into a severe cyclonic storm at 0900 UTC of 17 May, very severe cyclonic storm at 0300 UTC of 18 May and by the evening it crossed Chittagong (Bangladesh) coast.

TABLE 2

Genesis Parameter (×10 $^{-12}$ sec^{-2}) associated with the VSCS (H) during 15-20 May, 1997

Time & date	GP	T. No.
00150597	25	1.5
12150597	39	1.5
00160597	45	2.0
12160597	49	2.0
12170597	94	2.5
00180597	93	3.5
00190597	21	5.0

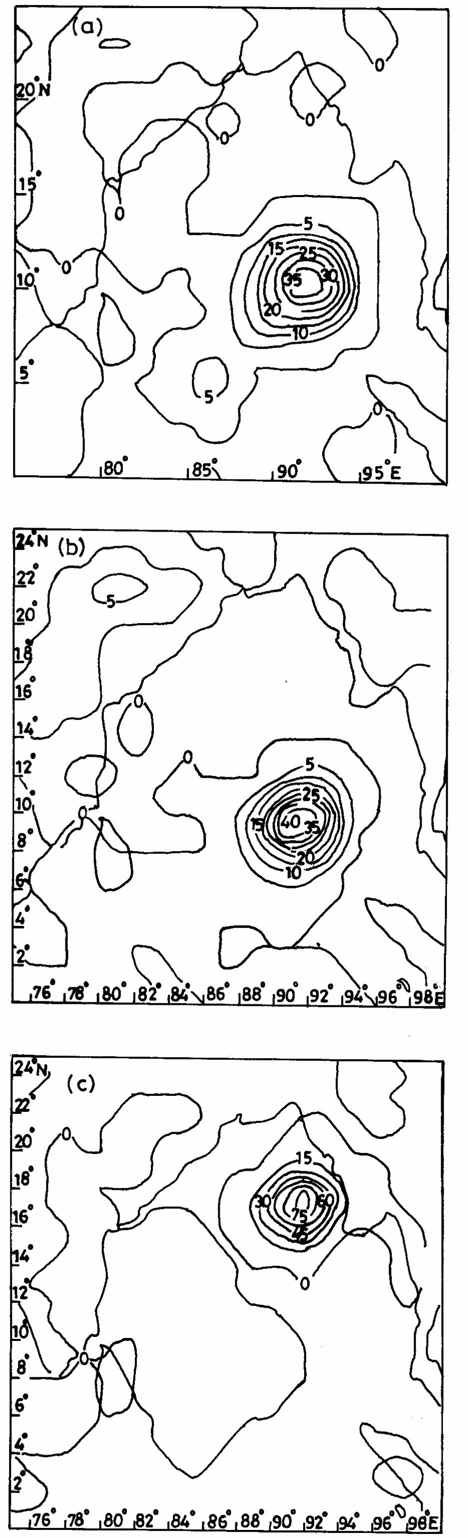
The first indication of possible development of the system came at 0000 UTC of 15 May when a value of GP = 25 was obtained against T. No. 1.5 over south Bay of Bengal (Table 2). By 0000 UTC of 16 May, the GP increased to 45 at T. No. 2.0. Subsequently explosive development took place when GP increased to 94 at T. No. 3.5 on 1200 UTC of 17 May and fell off rapidly to 21 at 0000 UTC of 19 May at T. No. 5.0. It is noticed again that GP fell off rapidly following its max. at T. No. 3.5 on 1200 UTC of 17 May, even though the intensification process of the system continued. It became very severe cyclonic storm with core of hurricane winds at 0300 UTC of 18 May and attained its peak intensity of T. No. 5.0 at 0000 UTC of 19 May. Thus, there occurred a time lag between the GP max. and peak intensity of the cyclone around 30-36 hours.

As the system was moving northerly center of GP also moved northerly. Figs. 2(a-c) illustrates the GP contour pattern during developing stage (1200 UTC 15 May, 0000 UTC 16 May and 1200 UTC 17 May) of the system. Thus, indication of possible development of the disturbance came at the depression stage on 15 May morning when GP reached 25 at T. No. 1.5. The indication for further intensification into a severe one is noticed when GP increased rapidly to 45 on 16 May at 0000 UTC against T. No. 2.0.

Case III : The very severe cyclonic storm (VSCS) over the Bay of Bengal during 15-19 October 1999

The initial development of this system occurred over north Andaman Sea in the morning of 15 October. It intensified into a very severe cyclonic storm that crossed Orissa coast near Gopalpur around midnight of 17 October.

The first indication of the vortex is observed at 0000 UTC of 14 October when GP value was 11 at T.No. 1.0.



Figs. 2(a-c). Same as in Fig. 1 for the very severe cyclonic storm with core of hurricane winds of May 1999 (a) 1200 UTC of 15 May, (b) 0000 UTC of 16 May and (c) 1200 UTC of 17 May

TABLE 3

Genesis Parameter (×10 $^{-12}$ sec^{-2}) associated with the VSCS during 10-16 October 1999

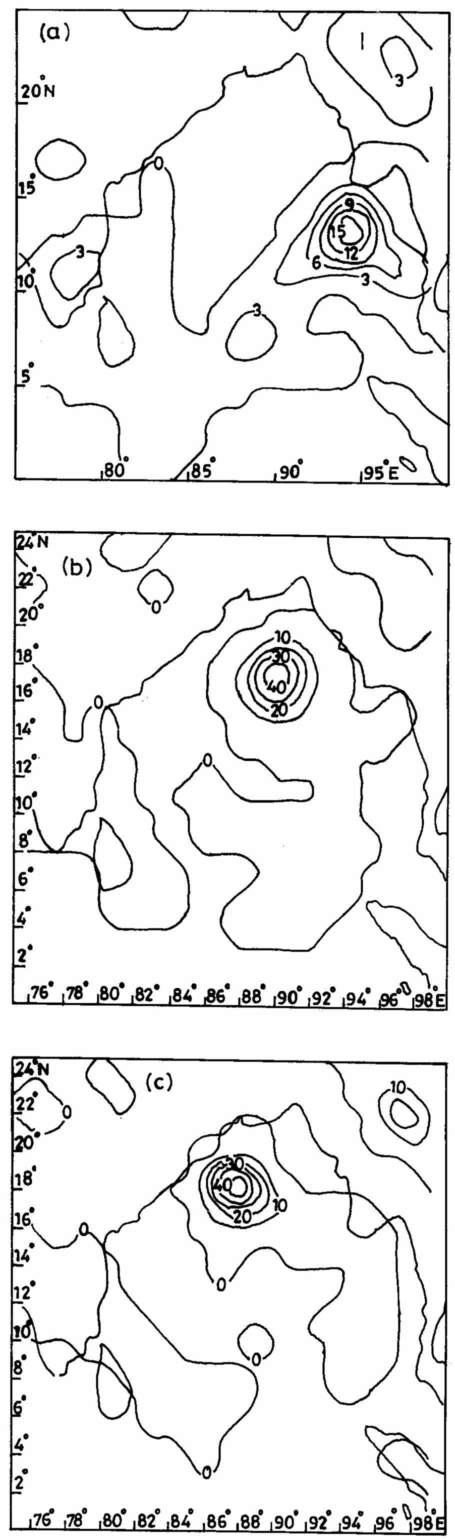
Time & date	GP	T. No.
00111099	4.6	-
00121099	6	-
12121099	8	-
00131099	6	-
12131099	8	-
00141099	11	1.0
12141099	13	1.0
00151099	13	1.5
12151099	18	1.5
00161099	48	2.0
12161099	60	3.0

GP value increased to 18 at 1200 UTC of 15 October at T.No. 1.5 (Table 3). At 0000 UTC of 16 October GP was 48 at T. No. 2 and became 60 at 1200 UTC of 16 October at T. No. 3.0. Increase of GP from 1200 UTC of 15 October to 1200 UTC of 16 October was remarkable. The system became very severe cyclonic storm on 17 October morning. GP for 17 and 18 October could not be derived due to non-availability of corresponding analysis field. Figs. 3(a-c) illustrates the GP pattern during 0000 UTC of 15 October to 1200 UTC of 16 October. The rapid increase of GP from 18 at T.No. 1.5 on 0000 UTC of 15 October to 48 at T.No. 2.0 at 0000 UTC of 16 October was a clear indication of further intensification of the system into severe one.

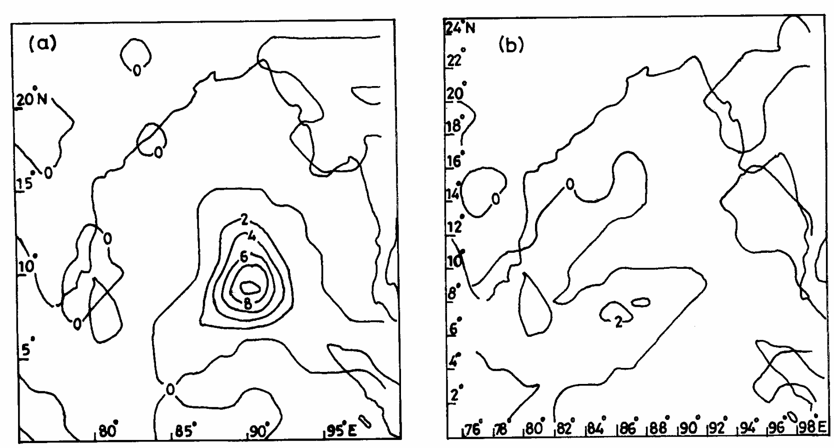
Case IV : Cyclonic storm over the Bay of Bengal during 1-3 February 1999

The system was observed as depression over the central parts of south east Bay of Bengal on 1 February 1999, intensified into a cyclonic storm during the night of 2 February and weakened into a depression over the north western parts of the south east Bay of Bengal by the midnight of 3 February and finally dissipated over the sea itself.

At 0000 UTC of 1 February GP was 11 at T. No. 1.5, but at 1200 UTC of 1 February and 0000 UTC of 2 February it fell down and amplitude range between 6 and 8. (Table 4). Though GP increased to 28 at 1200 UTC of 2 May at T. No. 2.0 and 34 at 0000 UTC of 3 May for T.No. 3.0 but rapidly fell to 13 same day evening. Even though the GP for a time period was high, genesis did not take place. The low trend and poor response of GP with



Figs. 3(a-c). Same as in Fig. 1 for the very severe cyclonic storm of October 1999 (a) 0000 UTC of 15 October (b) 0000 UTC of 16 October and (c) 1200 UTC of 16 October



Figs. 4(a&b). Same as in Fig. 1 for the cyclonic storm of February 1999 (a) 0000 UTC of 1 February and (b) 0000 UTC of 2 February

TABLE 4

Genesis Parameter ($\times 10^{-12}$ sec^{-2}) associated with the cyclonic storm during 1- 3 February, 1999

Time & date	GP	T. No.
00010299	11	1.5
12010299	6.2	1.5
00020299	8.3	1.5
12020299	28	2.0
00030299	34	3.0
12030299	13	1.5

TABLE 5

Genesis Parameter ($\times 10^{-12}$ sec^{-2}) associated with the depression during 7-10 December, 1999

Time & date	GP	T. No.
12071299	5	1.5
00081299	6	1.0
12081299	13	1.5
00091299	14	1.5
12091299	13	1.5
00010299	3	1.5

respect to T. No. has given some indications of non-development of the system. The contour pattern of GP for 0000 UTC of 1 and 2 February is shown in Figs. 4(a&b).

Case V : Depression over the Bay of Bengal during 8-10 December 1999

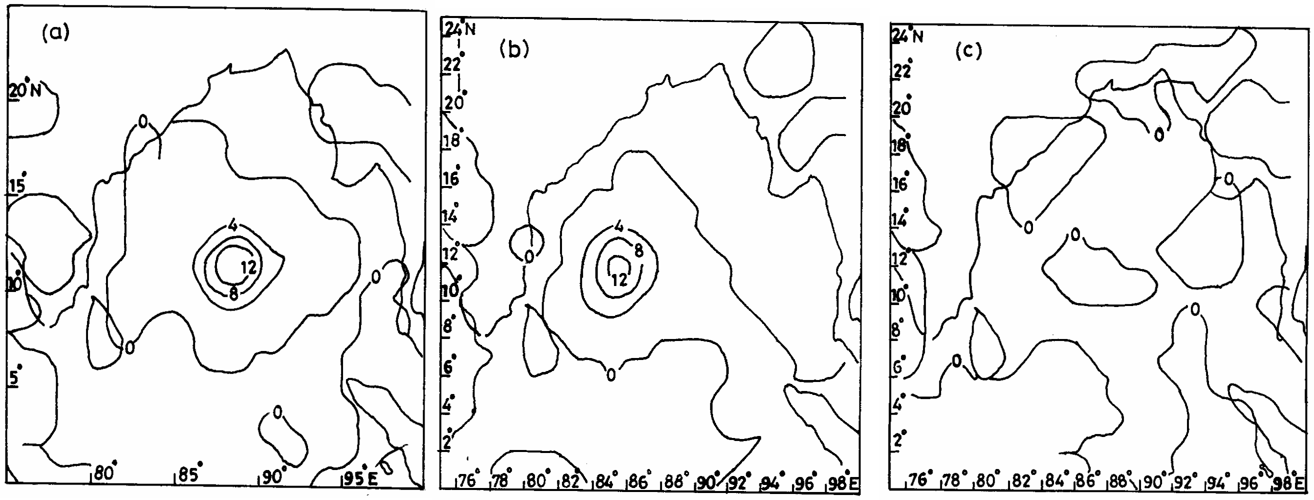
This system developed *in situ* over south east Bay of Bengal on 8 December. Moving westwards it dissipated over south west Bay of Bengal on 10 December.

During 8 - 10 December GP maintained (Table 5) more or less same intensity (GP value 6-14) for T. No. 1.0 to 1.5 and genesis did not occur. Figs. 5(a-c) shows the GP pattern during 0000 UTC of 8- 10 December 1999.

4. Comparison of GP between developing and non-developing system

An inter-comparison of GP against T. No. associated with some recent developing and non-developing systems are given below. The low pressure systems considered are: (a) super cyclone of October 1999, (b) very severe cyclonic storm with core of hurricane winds of May 1997, (c) very severe cyclonic storm of October 1999, (d) very severe cyclonic storm of December 2000, (e) very severe cyclonic storm of November 2000, (f) severe cyclonic storm of February 1999, (g) severe cyclonic storm of October 2000, (h) depression of June 1999, (i) depression of July 1999 and (j) depression of December 1999.

T. No.	*GP Values ($\times 10^{-12}$ sec^{-2})*									
	Super Cycl. Oct '99	*VSCS (H) May '97*	*VSCS Oct '99*	*VSCS Dec '2k*	*VSCS Nov '2k*	*CS Feb '99*	*CS Oct '2k*	*Dep Jun '99*	*Dep Jul '99*	*Dep Dec '99*
1.0	6-9	10-12	9-17	5-10	4-11	5-8	3-5	5-10	5-10	4-6
1.5	22	25	18	18	16	8	5	12	14	13
2.0	51	45	48	35	36	28	-	20	26	-
2.5	-	49	-	39	38	-	-	-	-	-
3.0	67	93	60	37	36	34	-	-	-	-
3.5	91	94	-	-	40	-	-	-	-	-



Figs. 5(a-c). Same as in Fig.1 for the depression of December 1999 (a) 0000 UTC of 8 December, (b) 0000 UTC of 9 December and (c) 0000 UTC of 10 December

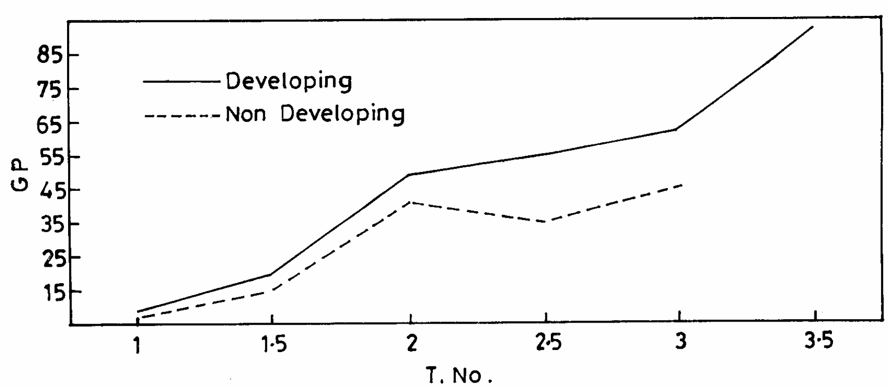


Fig. 6. Intercomparison of GP ($\times 10^{-12}$ sec^{-2}) against T. No. for developing and non-developing systems

No appreciable difference of GP values between developing and non-developing systems is noticed at T.No. 1.0. The table shows that a low pressure system even with the GP value 10×10^{-12} sec^{-2} at T.No.1.0 has the potential to reach upto hurricane intensity. With the incorporation of synthetic vortex at T.No. 1.5, steady growth of GP for the developing systems are noticed. The GP values illustrated above shows that pre-tropical storm disturbances are typically associated with GP around 20×10^{-12} sec^{-2} at T. No. 1.5 and GP around 40 at T.No. 2.0. While for the non-developing disturbances GP is less than 15 at T.No. 1.5 and less than 30 at T.No. 2.0. Fig. 6 shows the comparison of corresponding mean GP values between developing and non-developing system with reference to T. No. Though both the curves look alike but in case of developing system GP value is very distinctly higher from T.No. 1.5 onwards.

5. Concluding remarks

For the operational practices there is a demand to specify a threshold value of GP which is a difficult task due to lack of necessary data base. The analysis of individual few cases in this paper indicates the potential applicability of GP analysis for the operational cyclone warning.

No appreciable difference of GP values between developing and non-developing systems is noticed at T.No. 1.0. With the incorporation of synthetic vortex, a low pressure system for the GP value around 20 against T.No. 1.5 has shown the potential to develop into a severe cyclonic storm and for the GP value greater than 45 at T.No. 2.0 has the potential to reach upto the hurricane intensity. It is very interesting to note that GP attained its peak intensity at T. No. 3.5 for both super cyclone of 1999 and VSCS (H) of 1997 and fell off rapidly thereafter even though the intensification process of the system continued. There was a time lag of about 24-36 hours between GP max. and highest intensity of the system. The reason for GP max. at time of T.No. 3.5 may be due to the rapid formation of warm core about that time, perhaps leading to the formation of an eye which appears to be associated with the minimum value of vertical shear. The subsequent decrease of GP may be due to increasing vertical shear, which is much influenced by the upper tropospheric outflow.

The GP index derived from the model analysis field appears to provide useful predictive signals. In the near future improved and more realistic analysis fields are expected with the availability of various satellite inputs and better analysis scheme. GP index in this context seems to be very promising for the operational cyclone warning work. Further work is needed in this direction to identify the critical limit of this index for the Indian seas utilizing improved analysis field with reasonably good number of cyclone cases.

Acknowledgements

The author is grateful to the Director General of Meteorology, India Meteorological Department, New Delhi for providing all facilities to carryout this study. The author is also thankful to Shri S. R. Kalsi, Deputy Director General of Meteorology for his encouragement and keen interest in this study.

References

Gray, W. M., 1975, "Tropical cyclone genesis", Dept. of Atmos. Sc., Paper No. 232, Colorado State University, Port Collins Co. USA, p121.

Holland, G. J., 1980, "An analytical model for wind pressure profile in the hurricane", *Mon. Wea. Rev.*, **108**, 1212-1218.

Kalsi, S. R., Roy Bhowmik, S. K., Gupta, D.C. and Nath, S. M., 2001, "Development of super cyclone of Orissa and its impact", Proceedings of the National Symposium TROPMET-2001 held in Mumbai during February 2001.

McBride, J. L., 1981, "Observational analysis of tropical cyclone formation, part 3: Budget analysis", *Journ. of Atmos. Sci*., **38**, 1152-1166.

McBride, J. L. and Zehr, R. M., 1981, "Observational analysis of tropical cyclone formation, part 2: Comparison of developing versus non-developing system", *Journ. of Atmos. Sci*., **38**, 1132-1152.

Prasad, K., Rama Rao, Y. V. and Sen, S., 1997, "Tropical cyclone track prediction by a high resolution limited area model using synthetic observations", *Mausam*, **48**, 351-366.

Zehr, R. M., 1992, "Tropical cyclogenesis in the western north Pacific, NOAA Tech. Res. NESDIS 61, p181.