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Formulation of Genesis Potential Parameters by utilizing atmospheric variabilities for identifying type of cyclonic storms over the Bay of Bengal

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Abstract

A Genesis Potential Parameter (GPP) is formulated by adopting atmospheric varibilities like relative vorticity (V) of 850 hPa, mid tropospheric relative humidity (M), thermal instability (T_{850}-T_{500}) and vertical wind shear (S) between 850 hPa to 200 hPa for identifying developing and non developing families of Cyclonic storms over Bay of Bengal (BOB). Individual genesis variables and GPP value for both families are compared. Then performance of GPP for detecting developing and non developing cases is examined by using skill score analysis where GPP showed 82% accuracy. Finally GPP is evaluated for few systems of (BoB) and is compared with the corresponding averages, which shows a satisfactory agreement between the cases and averages. Except shear parameter, all other genesis variables and GPP values are higher for the developing cases as compared to the non developing cases.

Key words: Atmospheric Instability; Wind Shear; Cyclone; Genesis Potential Parameter.

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1. Introduction

Tropical cyclones are the most energetic and devastating severe weather manifestations of the atmosphere. It is mainly developed over the warm oceanic regions where the atmospheric conditions are favorable for organized convective activity. A number of empirical studies suggested that cyclone usually form over the relatively warm ocean (SST ≥ 26.5 ^{o}C) [Palmen ,1948; Gray ,1968], follows the track along areas of warm water and weaken when move over cooler water [Fisher 1958]. Every year, the coastal regions of Indian sub continent are affected by the tropical cyclones developed in the Bay of Bengal (BoB), a very favorable region for cyclone development and it accounts for almost 5% of the global annual total of the tropical cyclones. Though the cyclones developed in Indian Ocean are relatively weaker compared to those developed in Atlantic or Pacific basin, these are highly devastating from the socio economic points of view.

Dynamical and thermodynamic parameters of the atmosphere are used to track the genesis, intensification and movement of the tropical cyclones [Gray 1975] developed a cyclone Genesis Parameter (GP) for the tropical cyclones using three dynamic and three thermodynamic parameters. His work based on Coriolis force, vertical wind shear, relative vorticity and Sea Surface Temperature (SST) above 26^{0}C, mid tropospheric relative humidity and vertical potential temperature gradient. But SST threshold of (26^{0}C) limits the direct use of Gray's GP at different climatic conditions [Camargo *et al.*, 2007] and [Royer *et al.*, 1998] studied the impact of greenhouse gas on the frequency of tropical cyclones using Global Circulation Model. They studied the cyclogenesis frequency by replacing thermal potential part of Gray's seasonal GP by convective potential and developed a yearly genesis parameter (YGP). McBride [1981] defined a Daily Genesis potential Parameter (DGP) as the vorticity difference between 900-200 hPa levels over the thermodynamic and dynamic regions around tropical systems and concluded that the DGP is three times greater for the developing systems as compared to the non developing systems. [Zehr, 1992] used vorticity and divergence of 850 hPa and vertical wind shear to define a cyclone genesis parameter (GP). Mandal *et al*., [1981] calculated a GPP for cyclone occurring over the Arabian Sea and found their findings comparable with those estimated by Gray for Pacific Ocean. Camargo *et al.*, [2007] used a genesis potential index to diagnose ENSO effect on tropical cyclone genesis in various ocean basins. His genesis potential index was developed using four variables, 850hPa vorticity, 600hPa relative humidity, 850hP to 200hPa vertical wind shear and potential intensity. [Kotal, 2009] defined a Genesis Potential Parameter using two dynamical and thermo dynamical variables for differentiating between developing and non developing low pressure systems over Indian Ocean. He estimated all the variables by averaging of grid points within a circle of radius 2.5^0 around the center of the cyclone for computation of GPP and concluded that for developing systems than for non developing systems GPP is three times higher.

In this study a GPP for 43 cyclones developed over the BoB during the period 2000-2010 is proposed. Systems are broadly classified as developing and non-developing on the basis of their intensities and GPP values. Developing systems are further categorized as Cyclonic Storm (CS), Severe Cyclonic Storm (SCS), and Very Severe Cyclonic Storm (VSCS) and the characteristics of the corresponding GPP values are estimated.

A few case studies focusing on the behavior of the GPP and the different dynamical and thermo dynamical inputs involved in GPP formulation are presented for developed and non-developing low pressure systems. The characteristics of GPP and the associated parameters for both categories are compared with the corresponding average characteristics.

2. Data and methodology

For study of the proposed 43 tropical low pressure systems developed during the period 2000-2010 over BoB, low pressure system details are collected from India Meteorological Department (IMD) web site (www.imd.gov.in). The cyclonic systems are first categorized as non-developing (intently no. $T<3$) and developing ($T\geq3$) based on the intensity as given in Table 1, the cyclones under consideration are listed Table 2. Out of the 15 developing systems 8 are VSCS, 5 are SCS and 2 are CS. Dynamical and thermo dynamical variables for calculating Genesis Potential Parameter (GPP) are derived from National Center for Environmental Prediction (NCEP). These data are available from 1999 to the present with a spatial resolution of $(1^0\times1^0)$ and temporal resolution of 6 hours at 00, 06, 12 and 18 hrs. The variables used for computing GPP are averaged over an area of 3^0 with respect to the center of the low pressure system and is calculated from the stage T. No. ≥ 1.5.

Table I

T. No. classification of cyclonic systems and corresponding wind criteria

Classification of cyclonic system	T. No.	Wind Speed (kt)	Wind criteria (kt)
Low (L)	1	-	< 17
Depression (D)	1.5	25	17-27
Deep depression (DD)	2	30	28-33
Cyclonic storm (CS)	2.5	35	34-47
Cyclonic storm (CS)	3	45	34-47
Severe cyclonic storm (SCS)	3.5	55	48-63
Very severe cyclonic storm (VSCS)	4	65	64-119
Very severe cyclonic storm (VSCS)	4.5	77	64-119
Very severe cyclonic storm (VSCS)	5	90	64-119
Very severe cyclonic storm (VSCS)	5.5	102	64-120
Very severe cyclonic storm (VSCS)	6	115	64-121
Super cyclonic storm (SUCS)	6.5	127	≥120
Super cyclonic storm (SUCS)	7	140	≥120
Super cyclonic storm (SUCS)	7.5	155	≥120
Super cyclonic storm (SUCS)	8	170	≥120

Genesis potential parameter formulation

In this present work, two dynamical variables (wind shear and relative vorticity) and two thermodynamic (relative humidity and temperature) parameters are used for calculation of GPP. Low level relative vorticity is one of the most important factors for cyclogenesis [Grey 1968; McBride *et al.*, 1981] and large values of relative vorticity can produce cyclonic spiraling. Therefore low level relative vorticity (850 hPa) is taken as one of the parameters for GPP formulation. Wind shear is another essential condition for tropical disturbances [Grey, 1968; McBride *et al.*, 1981], [Zeng *et al.*, 2007]. Low value of vertical wind shear helps to maintain a vertically coherent ax symmetric vertical structure. Hence vertical wind shear between pressure level 850 hPa to 200 hPa is included as another parameter for GPP estimation. During the development stage of tropical cyclones, huge amount of latent heat will

Table II
Cyclonic systems under consideration for the period 2000-2010.

Period	Year	T. No	Min Central pressure	Max wind (kt)	Lat (^{0}N)	Lon (^{0}E)
27-30 March	2000	3.0	998	45	7.5	90.0
15-19 October	2000	2.5	998	35	14.5	88.5
25-29 October	2000	2.5	998	35	13.5	93.0
26-30 November	2000	5.5	958	102	8.5	91.5
23-29 December	2000	5.0	970	90	8.0	86.0
14-16 October	2001	2.5	998	35	13.5	84.0
10-12 November	2002	3.5	996	45	12.0	82.5
23-28 November	2002	2.5	1000	35	10.0	87.0
21-25 December	2002	2.5	1000	35	4.0	77.0
10-19 May	2003	4.5	980	75	6.0	90.5
25-28 July	2003	2.0	988	30	21.0	89.0
6-9 Oct	2003	1.5	998	25	16.5	84.0
11-16 December	2003	3.5	990	55	4.5	90.5
16-19 May	2004	5.0	952	90	17.0	91.5
11-14 June	2004	2	990	30	15.5	90.0
2-4 October	2004	1.5	1006	25	11.5	87.0
13-17 January	2005	2.5	1000	35	5.5	87.0
12-16 September	2005	1.5	992	25	20.0	88.0
26-29 October	2005	2.0	998	30	12.0	84.5
20-22 November	2005	1.5	1002	25	8.0	84.5
15-21 December	2005	2.0	1000	30	8.0	87.0
25-29 April	2006	5.5	954	100	9.5	90.5
2-5 July	2006	2.0	982	30	20.0	89.5
2-5 August	2006	2.0	986	30	20.5	87.5
28-30 September	2006	1.5	1002	25	18.0	89.0
3-5 May	2007	1.5	998	25	13.5	93.0
21-23 June	2007	2.0	988	30	15.5	86.0
28-30 June	2007	2.0	986	30	18.5	87.0
5-7 August	2007	2.0	988	30	20.0	88.5
11-16 November	2007	6.0	944	115	10.0	92.0
27 April-3 May	2008	5.0	962	90	12.0	87.0
16-18 June	2008	1.5	988	25	21.5	90.0
15-19 September	2008	2.0	986	30	19.5	88.5
13-16 November	2008	2.5	994	40	11.5	85.5
4-7 December	2008	2.0	1004	30.0	6.5	90.0
14-17 April	2009	2.5	996	40	12.5	88.0
23-26 May	2009	3.5	970	55	16.5	88.0
12-15 December	2009	3.0	996	45	6.5	85.0
17-21 May	2010	3.5	986	55	10.5	88.5
13-16 October	2010	2.0	995	30	17.5	90.0
20-23 October	2010	5.5	950	105	17.5	91.5
4-8 November	2010	3.5	988	60	8.0	92.0
7-8 December	2010	1.5	1000	25	14.0	82.0

be released due to intense convection and this helps in further intensification process of the system. Following Gray, [Kotal *et al.*, 2009] developed a relative humidity parameter (M) using mean of 700 hPa to 500 hPa relative humidity.

$$M = \frac{[RH - 40]}{30}$$

Another important condition for cyclogenesis is the gradient of temperature with altitude. This should be sufficiently large so that air that has become saturated with water vapor can undergo further adiabatic lifting. Temperature difference between pressure levels 850-500 hPa is a very good estimation of the middle tropospheric thermal instability [George, 1960].

In our study relative vorticity (V) of 850 hPa, relative humidity (M), thermal instability (T_{850}-T_{500}), vertical wind shear (S) between 850 hPa and 200 hPa are used to calculate GPP. All these parameters are estimated by using the following parameter over an area of radius 3^0 around the center of the cyclonic system. These relations are defined by the following equations,

$$GPP \quad \propto Vorticity(V)$$

$$\propto Humidity\ (M)$$

$$\propto Thermal\ instability\ (T_{850} - T_{500})$$

$$\propto 1/Shear(S)$$

Hence

$$GPP = \frac{V \times M \times (T_{850} - T_{500})}{S}$$

3. Results and discussion

The mean values of the genesis variables i.e. wind shear, vorticity, instability and humidity are then used in GPP calculation. The results so obtained are plotted against different storm intensity T No.s (Figure1). The figure shows that mean wind shear for the developed cases are lower as compared to the non developing cases because for developed systems shear variable are found to vary from 3.4 ms^{-1} to

6.2 ms^{-1} and the same varies from 10.1 ms^{-1} to 11.1 ms^{-1} for the non developing cases. Vorticity, in case of the developed system is observed to increase slightly with the increasing T No. and for non developed cases a gradual decrease is noted. Because vorticity in case of developed cases when vary from 3.6×10^{-5} s^{-1} to 4.2×10^{-5} s^{-1} ,the variation is from 2.1×10^{-5} s^{-1} to 3.2×10^{-5} s^{-1} for non developing cases. Thermal instability parameter also shows higher value at each of the T No's for developing cases as compared to the non developing ones. This indicator shows a magnitude of 21.8^{o}C to 22.6^{o}C for developing cases while in case of non developing cases the range is 21.7^{o}C to 22.2^{o}C. Humidity parameter is higher for the developed cases as compared to the non developing ones. Variations of humidity parameter for developing and non developing cases are respectively 1.1 to 1.4 and 0.7 to 1.1. Finally it is seen that while magnitude of vorticity, humidity index and thermal instability is higher for developing systems as compared to the non-developing cases, average shear value for developing systems is lower than the non-developing systems.

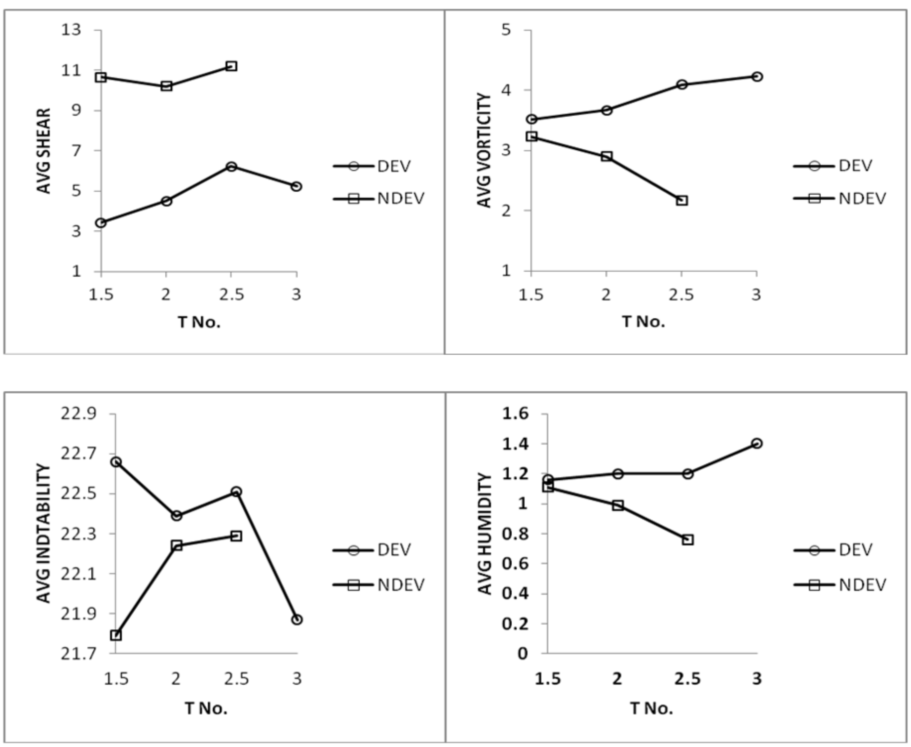

Figure 1. Comparison of dynamic and thermo dynamic variables used in the GPP at different T No.s for the developing and non-developing systems

A large number of cases are then taken up for calculation of GPP both for developed and non developed situations. A few such cases are shown in figure 2 for T. No. 1.5, 2.8 and 2.5. It is seen from

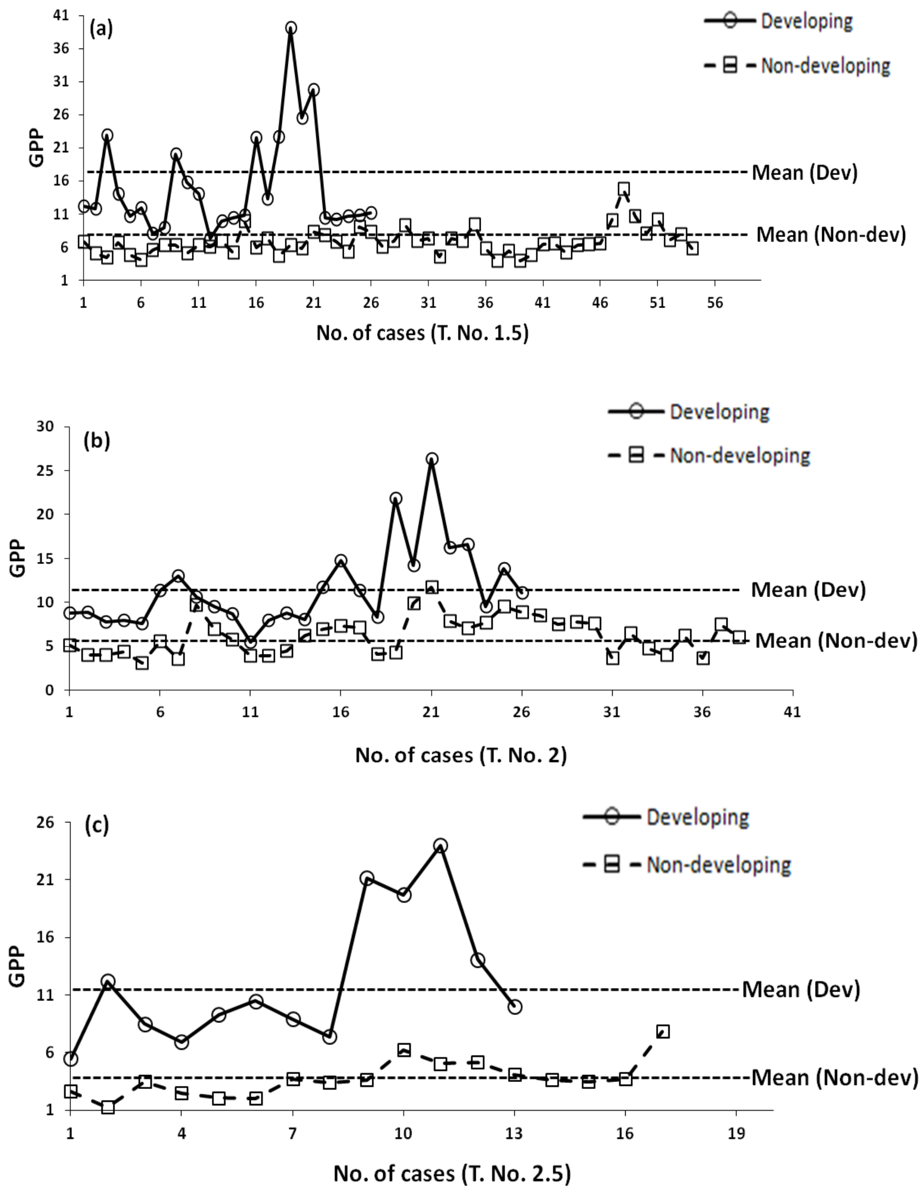

Figure 2. Variation of GPP value with T. No. 1.5 (a), 2 (b) and 2.5 (c), for developing and non developing cases and dashed lines represent the mean GPP

Fig. 2(a) that at T. No. 1.5, GPP value for developing cases varies from 7.2 to 39.0 and for non developing cases it varies from 3.9 to 14.9. Similarly at T. No. 2, GPP for developing cases lies between 5.6 to 26.3 but it comes down 3.0 to 11.7 for non-developing cases (Fig.2 (b)). Fig. 2 (c) also shows that at T. No. 2.5, GPP variation for developing and non developing cases ranges from 5.4 to 24.0 and 1.2 to 7.8respectively. Therefore the analysis shows that GPP values for developing cases are higher than the non developing ones.

Then the average value of GPP is calculated by taking all the cases individually for each T Nos. The result is presented in Figure 3 which shows the characteristics of the average GPP value with T. No's. It is seen that average GPP value for developing cases is high (15.1) at T. No. 1.5 and attains almost a constant value thereafter at T. No. 2, 2.5 and 3 (11.5, 12.1 and 12.1 respectively). For the non developing cases the average GPP is high at T. No. 1.5 (6.7) and reduces slowly at T. No. 2 and 2.5 (6.2 and 3.7 respectively).

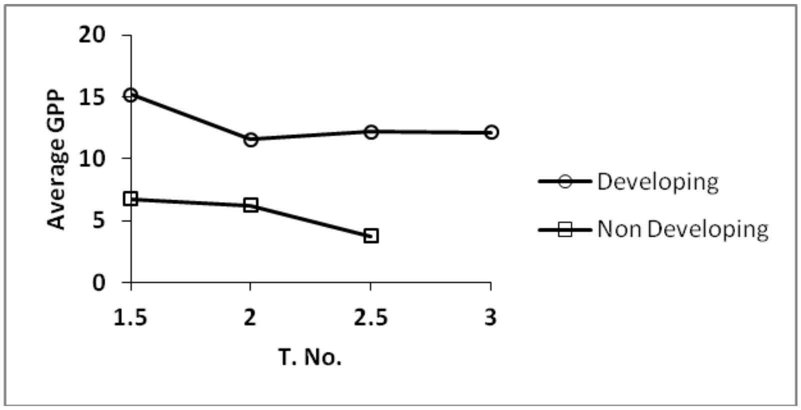

Figure 3. Variation of the mean GPP value with T. No. for developing and non developing systems.

3.1 Performance of GPP

From the above analysis it is seen that there are few cases where, GPP values for few non developing cases overlap the developed case GPP values. On the other hand there are some cases where the calculated GPP is low but in real the system is a developed one. Hence it is necessary to check the performance of GPP to include as predictor for the system development. To evaluate the performance of GPP, we use the yes/no contingency table. From the output of the table some special statistical conclusions can be drawn. A contingency table gives the following statistical results:

1. Accuracy= (hit + correct negative)/total Range: 0 to 1 and perfect score: 1
2. BIAS= (hit+ false alarm)/(hit+misses) Range: 0 to ∞ and perfect score : 1
3. False alarm ratio(FAR)=false alarm/(hit+false alarm) Range: 0 to 1 and perfect score : 1
4. Threat score(TS)=hit/(hit+misses+false alarm) Range: 0 to 1 and perfect score : 1

Accuracy measures the strength of the parameter to produce a true output.

Bias indicates whether the forecast system has a tendency to under forecast *(BIAS<1)* or over forecast (BIAS>1) events.

FAR gives information about the sensitive to false alarms, but ignores misses.

TS measure the fraction of observed and/or forecast events that were correctly predicted.

For a statistical evaluation of the performance of GPP we define the following conditions:

Hit: when GPP is high and observed system is a developed (high intensity) one

Correct negative: GPP is low and observed system is a non-developing (low intensity) one

False alarm: GPP is high but the system is a non-developing one

Miss: GPP is low and observed system is a developed one

For this analysis we have considered 100 samples and the events are tabulated according to the calculated GPP and observed results,

Table 3 Table to check GPP performance

GPP output	Observed result (Cyclone intensity)		
	High	Low	TOTAL
High	17	7	24
Low	11	65	76
TOTAL	28	72	100

$$Accuracy = \frac{17 + 65}{100} = 0.82$$

$$BIAS = \frac{17 + 7}{17 + 11} = 0.85$$

$$FAR = \frac{7}{17 + 7} = 0.29$$

$$TS = \frac{17}{17 + 11 + 7} = 0.48$$

It is seen from the values of accuracy, BIAS, FAR and TS, the parameter performance is satisfactory.

3.2 Individual case studies

Genesis variables and GPP for few individual cyclonic systems developed over BOB are presented here. The values of the genesis variables for those events are compared with the corresponding average values at different T Nos. In all the cases the variable and GPP values are very close to the corresponding average values. Resultant plots for the cyclonic systems are given below,

Developed cases:

Case 1: (Cyclone Nargis)

On April 27, 2008 at 0300 hrs a depression was developed in the BOB and at 1200 hrs of the same day the system was upgraded to deep depression. The corresponding GPP values at those two stages were 11.9 and 10.6 respectively. Then the system intensifies to a cyclonic system at 0000 hrs of 28th April and the corresponding GPP at that stage was 8.5 at T No 2.5 and 8.1 at T No. 3. It is noticeable that GPP was high during the development of the system and then started decreasing a little and afterwards maintained a constant value up to T No. 3. The characteristics shown by the genesis variables are found satisfactory when compared with the respective averages.

Case 2: (Cyclone Aila)

The severe cyclonic storm Aila formed at the BOB on 23rd May 2009 as a low pressure system and intensified to a depression on the same day at 0600 hrs. At 1200 hrs of 24th May the system amplified in to a cyclonic storm and finally crossed the West Bengal coast close to east of Sagar Island between 0800 & 0900 hrs of 25th May. The GPP value at T No. 1.5, 2, 2.5 and 3 were 16.4, 13.4, 12.9 and 13.4 respectively. GPP together with the profiles of the related genesis parameters are showing good matching with the corresponding average values.

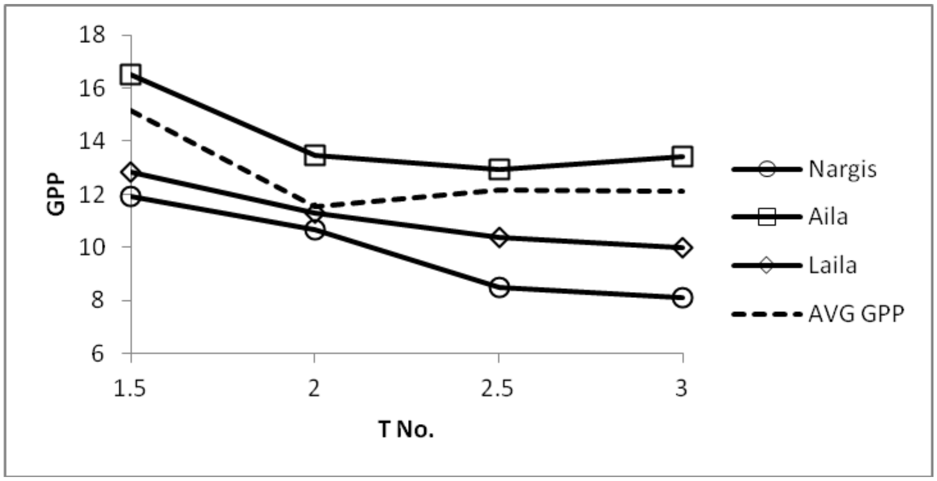

Figure 4. Comparison of the GPP for Narsgis, Aila and Lila cyclone (developed cases) with the corresponding GPP average value at different T. Nos.

Case 3: (Cyclone Laila)

Severe cyclonic storm Laila was formed over BOB on May 17, 2010 and intensified in to a depression at 0600 hrs of the same day. The GPP of the system at this stage was 15.1. As the system intensified to deep depression and cyclonic storm at T No. 2 and 2.5 respectively, the corresponding values are reduced to 11.3 and 10.3 respectively. At T No. 3 the GPP value was 10, when the cyclone crossed Andhra Pradesh coast near Bapatla (16.00 N/80.50E) between 1100-1200 UTC. The GPP value was higher at the beginning of the system and it reduced afterwards and attained almost constant magnitude.

Genesis variables are also showing matching characteristics with the corresponding average variables profiles.

Non developing cases:

Case 1: (Bijli)

GPP values at different T. No's are shown for the system Bijli developed over BOB on 14 April 2009 as a depression. The system persisted over BOB from 14th to 17th April but the maximum intensity did not exceeded T No. 2.5. GPP value for this system at T No. 1.5, 2 and 2.5 are 5.61, 3.1 and 4.1 respectively which are less than the average GPP values at different T No.s for developed systems.

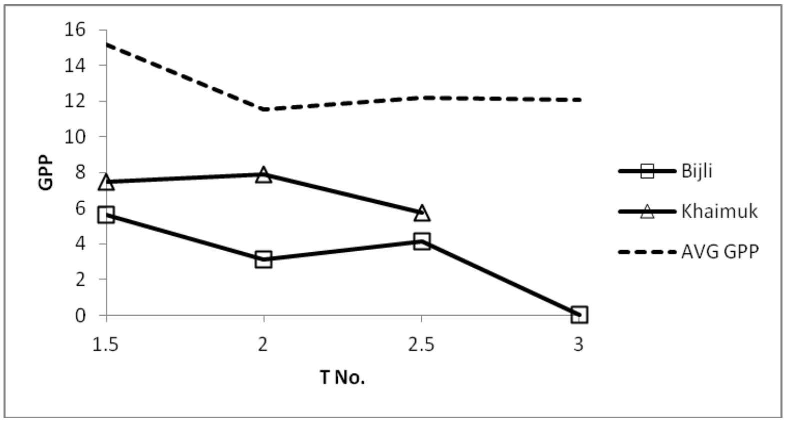

Figure 5. Comparison of the GPP for Bijli and Khaimuk (non developing cases) with the corresponding GPP average value at different T. Nos.

Case 2: (Khaimukh)

Khaimukh developed over BOB on 13 November 2008, as a depression which further intensified in to T No. 2.5. GPP at different T Nos. for this system are compared with the respective average for developed cases. Initially GPP was nearly constant, at T No. 1.5 and 2 the values are 7.5 and 7.8 respectively. But at T No. 2.5 it is reduced bellow 5.7. Hence the system was not a developed one.

4. Summary and conclusions

In the current study a genesis potential parameter for cyclones developed over BoB is formulated using four genesis variables, 850 hPa relative vorticity, relative humidity, thermal instability between 850mb to 500mb and vertical wind shear between 850 hPa and 200 hPa. Categorizing the cyclonic storms as developing and non developing, the average characteristics of the genesis variables are estimated. It is seen that all the genesis variables, except wind shear shows higher values for developing cases in comparison to non developing cases. For non developing cases wind shear is much higher which restricts the system's further intensification. Average GPP value for both developed and non developing cases are compared. It is seen that for developed cases it is higher at the beginning (at T. No. 1.5) and then held almost a constant (at T. No. 2 and 2.5) value, but for the non developing cases average GPP value is lower by a factor ~0.5 at each T. No. in comparison to developed cases. Then GPP performance is evaluated using skill score analysis. GPP shows an Accuracy of 82%, BIAS of 85%, FAR of 29% and TS of 48%. Individual case studies for developed and non developing systems show good agreement with the average GPP profiles for the respective systems.

Hence genesis potential parameter for a low pressure system at the initial stage may be helpful for predicting the future intensification of the system.

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