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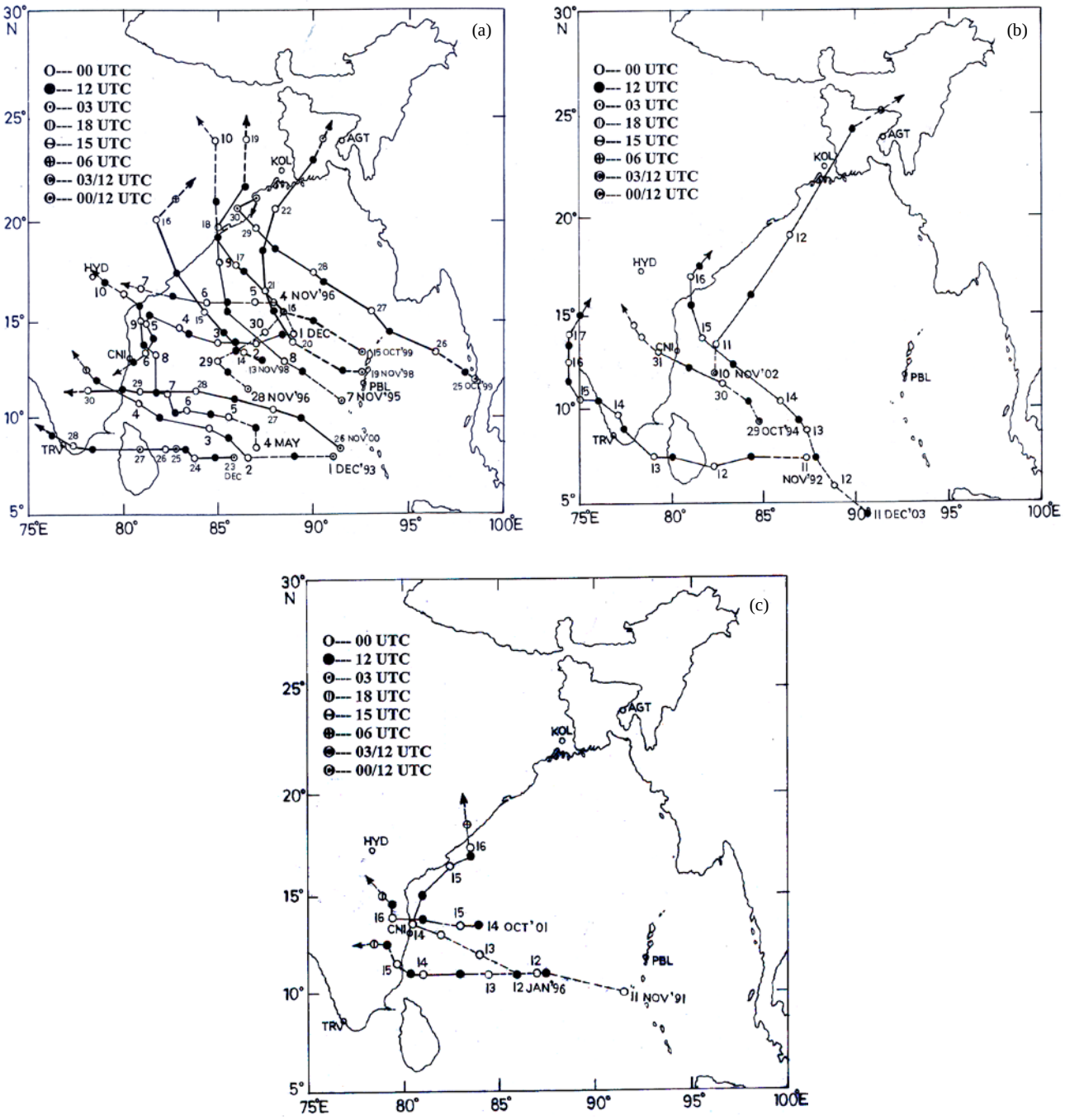
BEHAVIOR OF TROPICAL CYCLONES ALONG THE EAST COAST OF INDIA PRIOR TO LANDFALL

1. East coast of India is frequently affected by tropical cyclones. During the period 1891-2003, about 112 severe cyclones crossed the east coast of India (IMD, 2002, RSMC-Reports). These are responsible for large casualties and considerable damages to property and agricultural crops. Some of the methods of mitigating cyclone hazards are its timely warning and risk assessment. The India Meteorological Department (IMD) provides cyclone warning in four stages namely pre-cyclone watch, cyclone alert, cyclone warning and post landfall outlook. The warnings are issued at three hourly intervals giving the latest position of the cyclone, its intensity, Maximum Sustained Surface Wind Speed (MSSWS) and likely time and point of landfall together with storm surge height, rainfall and nature of damages expected. Knowledge of tropical cyclone climatology is essential for the risk assessment of an area. Detailed tropical cyclone climatology of the North Indian Ocean(NIO) region has been studied by (Mandal, 1991). In this paper an attempt has been made to study the behaviour of tropical cyclones prior to their landfall during the period 1990-2003 in respect of rate of intensification, speed of movement and decay. Information could be useful in preparing Cyclone Warning Bulletins.

It is well recognized that the data period is short for presenting cimatological analysis of this type. However, intension here is to use only RSMC data sets for homogeneity of data, that are available from 1991 only after the creation of RSMC at New Delhi around that time. These data also contain many additional details.

2. Data used in this study are based on the Reports of the Regional Specialized Meteorological Centre (RSMC) – New Delhi. Originating in the Bay of Bengal, 11 Very Severe Cyclonic Storms (VSCS), 4 Severe Cyclonic Storms (SCS) and 3 Cyclonic Storms (CS) crossed the east coast of India during the period 1990-2003. Some characteristic features of these storms utilized for study are given in Table 1. The tracks of VSCS is shown in Fig. 1(a) and the tracks of SCS and CS in Fig. 1(b) and Fig. 1(c).

Average of the MSSWS and Speed of Movement of the System (SMS) of VSCS are shown in Fig. 2, SCS+CS in Fig. 3. Super Cyclone 25-31 October, 1999 and SCS of 1-17 November, 1992 are shown in Fig. 4 and Fig. 5



Figs. 1(a-c). The tracks of Very Severe Cyclonic Storms (VSCS) in the Bay of Bengal (1990-2003), (b) The tracks of Severe Cyclonic Storms (SCS) in the Bay of Bengal (1990-2003) and (c) The tracks of Cyclonic Storms in the Bay of Bengal (1990-2003)

respectively. 13 cases of cyclones from 1991 to 2003 have been considered to calculate the speed of movement of the cyclone, of which 12 cases were also tracked by radars. Speeds of 12 cyclones calculated with the help of radar tracks are given in Table 3. Out of 12 cases of cyclones, 4 cyclones crossed the Indian coast.

TABLE 1

Some characteristic features of cyclonic disturbance which formed over Bay of Bengal during the period 1990-2003

Cyclonic Storm / Depression	Time taken (hrs) from dep. to Storm	Point of landfall over east coast of India	Life time from dep. to the landfall
VSCS, 4-10 May, 1990	24	Andhra Pradesh coast near mouth of river Krishna	126
CS, 11-15 November, 1991	24	Tamilnadu coast near Kriakal	90
SCS, 11-17 November, 1992	12	Tamilnadu coast near Tuticorin	54
VSCS, 1-4, December 1993	24	Tamilnadu coast near Karikal	66
SCS, 29-31 October, 1994	24	Tamilnadu coast near Chennai	45
VSCS, 7-10 November, 1995	21	Andhra Pradesh coast near Ichchapuram	50
SCS , 12-16 June, 1996	36	Andhra Pradesh coast close to Visakhapatnam	89
VSCS, 5-7 November, 1996	18	Andhra Pradesh coast south of Kakinada	49
VSCS, 28 Nov – 4 Dec, 1996	93	Andhra Pradesh coast close to Machilipatnam	208
VSCS, 13-16 November, 1998	21	Andhra Pradesh coast close to Visakhapatnam	47
VSCS, 19-23 November, 1998	24	West Bengal coast east of Sagar Island	47
VSCS, 15-19 October, 1999	24	Orissa coast near Gopalpur	68
SuCS, 25-31 October, 1999	21	Orissa coast near Paradip	96
VSCS, 26-30 November, 2000	30	Tamilnadu coast near Cuddalore	80
VSCS, 23-28 December, 2000	48	Tamilnadu coast near Tuticorin	116
CS, 14-17 October, 2001	24	Andhra Pradesh coast near Nellore	36
SCS , 10-12 November, 2002	30	Crossed West Bengal coast near Sagar Island	54
SCS, 11-15 December, 2003	24	Crossed the coast near Machilipatnam	89

TABLE 2

Average speed of movement and average rate of intensification, in terms of Maximum Sustained Surface Wind Speed (MSSWS) of cyclones that formed in Bay of Bengal during the period 1990-2003

12 hourly time Interval	Average speed of movement of the system (kmph)		Average rate of intensification of Maximum Sustained Wind Speed (kts)	
	Very Severe Cyclonic Storm (VSCS)	Severe Cyclonic Storm and Cyclonic Storm (SCS & CS)	Very Severe Cyclonic Storm (VSCS)	Severe Cyclonic Storm and Cyclonic Storm (SCS & CS)
(48-36)	17.6	14.8	09.0	05.8
(36-24)	19.4	20.8	09.8	02.6
(24-12)	17.4	28.0	12.5	09.0
(12-00)	17.2	26.2	00.8	02.0

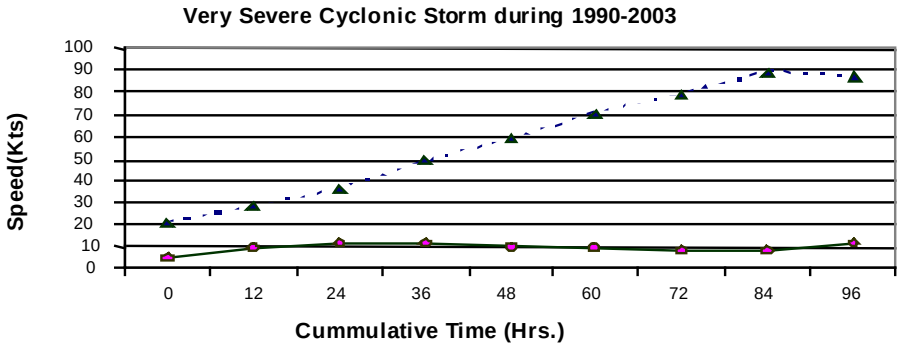


Fig. 2. Average speed of movement of the system (kmph) and MSSWS (kts) of VSCS during 1990-2003

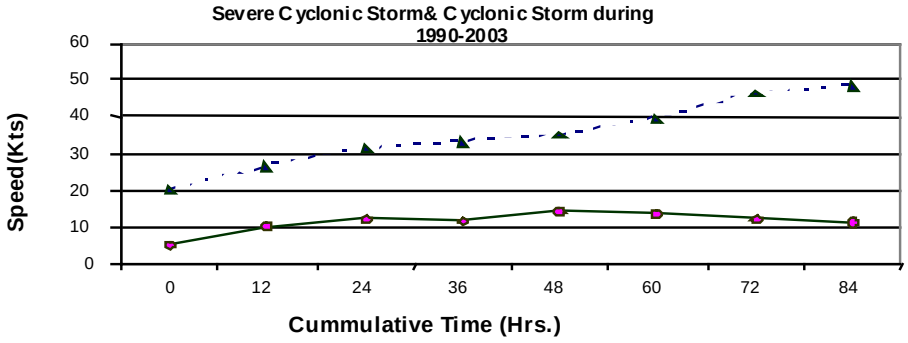


Fig. 3. Average speed of movement of the system (kmph) and MSSWS (kts) of SCS and CS during 1990-2003

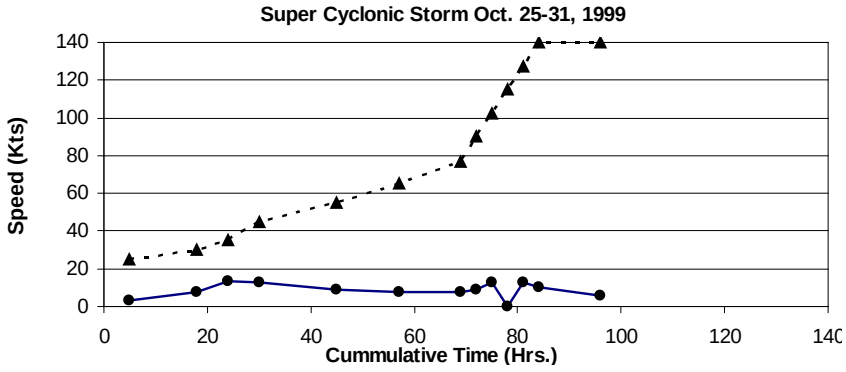


Fig. 4. Average speed of movement of the system (kmph) and MSSWS (kts) of Super Cyclone during 25-31 October, 1999

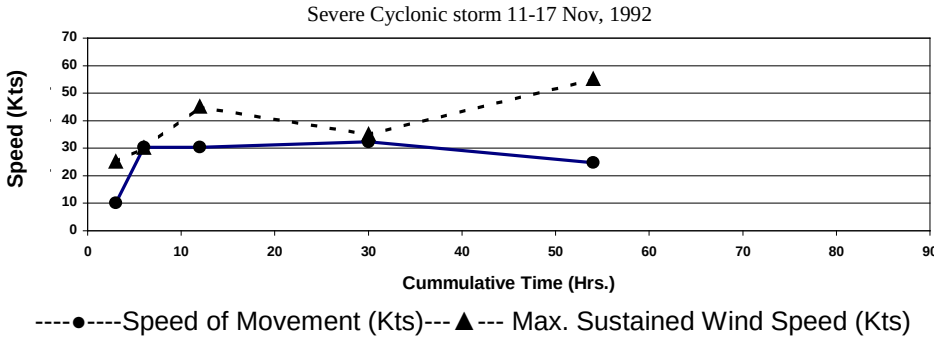


Fig. 5. Average speed of movement of the system (kmph) and MSSWS (kts) of SCS during 11-17 November, 1992

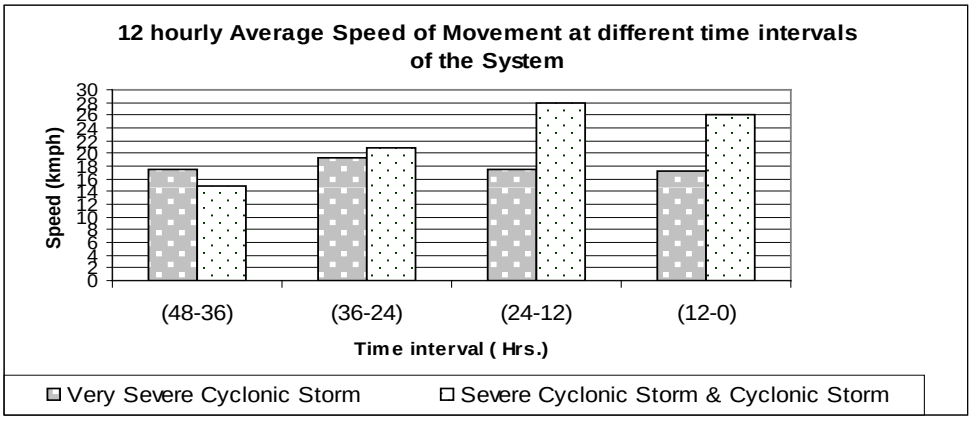


Fig. 6. Average speed of movement of the system (kmph) of VSCS, SCS and CS during 1990-2003

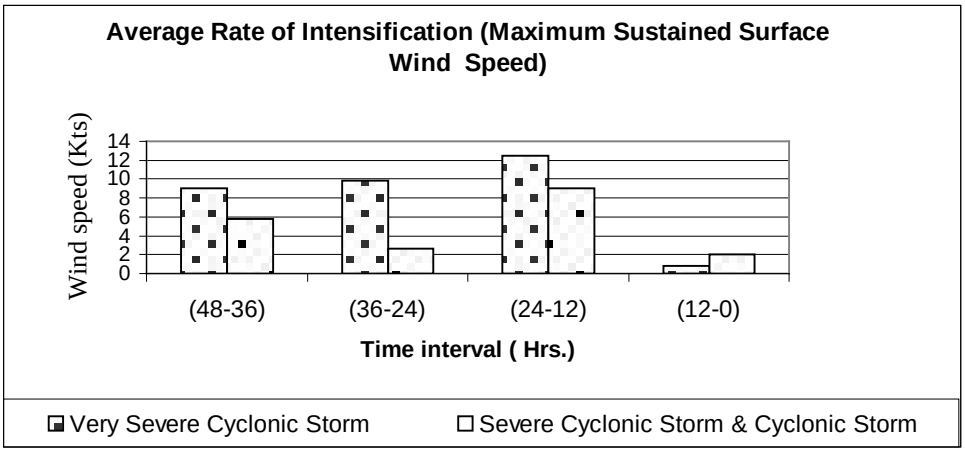


Fig. 7. Average rate of intensification of MSSWS (kts) of VSCS, SCS & CS during 1990-2003

The average speed of movement of tropical cyclone at 12 hourly intervals starting from initial time as the landfall time V_{mo} is obtained by $(V_{m0} + V_{m12})/2$ for (0-12) hours, $(V_{m12} + V_{m24})/2$ for (12-24) hours and so on. The mean for all the VSCS, SCS and CS have been given in Table 2 and plotted as bar chart in Fig. 6.

The rate of intensification MSSW at 12 hour interval starting from the landfall time V_{i0} is given by $(V_{i12} - V_{i0})$, $(V_{i24} - V_{i12})$, - - - . Mean for all the VSCS, SCS and CS have been given in Table 2 and plotted as bar chart in Fig. 7.

3. From Table 1, it is found that the average time from depression to cyclone is 25 hours *i.e.*, about one day. The average lifetime from depression to landfall is about 71 hours *i.e.*, three days.

It is observed that the intensity curves of VSCS comprises of generally 3 slopes. In the formation stage the slope increases gently of about 1 T - Number per day. Subsequently the intensity of the system is rapid and the increase in T - Number is 1.5 to 2.0 per day. Thereafter as the system approaches the land the increase in intensity is either arrested or decreases (Fig. 2). From the intensity curve of SCS and CS (Fig. 3) it can be inferred that the intensification is generally about 1 T - Number in 24 hours. However, there is a decrease in intensity when it approaches coast.

In the case of Super Cyclone of 25-31 October, 1999 (Fig. 4), the intensity curve shows vary rapid intensification of about 4.0 T - Numbers in a day, which is an exceptional case and was never observed in NIO earlier. Development of this Super Cyclone and its impact has been studied in detail by Kalsi *et al.*, 2002.

TABLE 3

Average speed of movement of cyclones, observed by different Cyclone Detection Radar (CDRs) during the period 1991-2003

S. No.	Intensity & cyclone period	Cyclone Detection Radar	Radar observed track		Speed (kt)
			From	To	
1	VSCS, 24-30 Apr 1991	Paradip	29 Apr 1991 (0300 UTC)	29 Apr 1991 (0900 UTC)	21.0
2	VSCS, 1-4 Dec 1993	Chennai	03 Dec 1993 (1700 UTC)	04 Dec 1993 (0400 UTC)	21.6
3	SCS, 29-31 Oct 1994	Chennai	30 Oct 1994 (0500 UTC)	31 Oct 1994 (0300 UTC)	15.2
4	VSCS, 29 Apr – 2 May, 1994	Cox's Bazar	02 May 1994 (0300 UTC)	02 May 1994 (1300 UTC)	20.8
5	VSCS, 21-25 Nov, 1995	Paradip	24 Nov 1995 (1600 UTC)	25 Nov 1995 (0000 UTC)	32.2
6	VSCS, 28 Nov - 6 Dec, 1996	Chennai	04 Dec 1996 (0300 UTC)	06 Dec 1996 (0800 UTC)	16.5
7	VSCS, 15-20 May 1997	Cox's Bazar	19 May 1997 (0600 UTC)	19 May 1997 (1200 UTC)	24.0
8	SCS, 23-27 Sep 1997	Vishakhapatnam	24 Sep 1997 (0300 UTC)	25 Sep 1997 (1100 UTC)	10.8
9	SCS, 23-27 Sep 1997	Paradip	25 Sep 1997 (2200 UTC)	26 Sep 1997 (1100 UTC)	22.7
10	VSCS, 15-19 Oct, 1999	Paradip	16 Oct 1999 (1600 UTC)	17 Oct 1999 (2300 UTC)	21.2
11	SuC, 25-31 Oct, 1999	Paradip	28 Oct 1999 (0800 UTC)	28 Oct 1999 (2300 UTC)	9.2
12	SCS, 11-16 Dec 2003	Chennai	14 Dec 2003 (1200 UTC)	15 Dec 2003 (0500 UTC)	20.8
	Average Speed in (kmph)				19.6

From Fig. 6 it is inferred that the speed of movement of VSCS is roughly same during different 12 hourly intervals ranging between 17.4 to 19.4 kmph. However in the case of SCS and CS the speed of movement increases from 14.8 kmph at (48-36 hours) to 20.8 kmph at (36-24 hours). It further increases to 28.0 kmph at (24 -12 hours). Thereafter slight decrease in speed of movement is observed as the system approaches the coast. However, there are exceptions. As may be seen from Fig. 5, the SCS of 11-17 November, 1992 moved with an average speed of 55.6 kmph. Scalar and vector speed of tropical cyclones over NIO for the period of 1891-1989 (Mandal, 1991) vary from 14-18 kmph to 9-16 kmph.

Speed of movement of cyclones for the period 1991-2003 calculated from radar tracks are shown in Table 3. The average speed of movement, (considering 12 cases of CS) works out to be 19.6 kmph, which is almost similar to the speed calculated synoptically. The speeds of 5 cyclonic storms, as calculated from radar tracks for the period 12-0 hrs prior to landfall, ranged between 15 to 22 kmph with an average of 18 kmph.

The rate of intensification in terms of MSSWS of tropical cyclone was found to be maximum in the (24-12 hrs) interval prior to landfall with values of 12.5 kts/12 hour in the case of VSCS and 9.0 kts/12 hrs for SCS & CS. The same is minimum 12 hrs prior to landfall with values of 0.8 kts/12 hrs for VSCS and 2.0 kts/12 hours for SCS & CS, bringing out an important fact of rapid intensification of cyclones in the Bay of Bengal just prior to their landfall.

4. In summary, from the analysis of RSMC data, life period of a tropical cyclone in the Bay of Bengal from the time of depression to the time of landfall is about 3 days. The average time period of intensification from depression to a cyclonic storm is about a day.

The intensity curves (in terms of MSSWS) of VSCS revealed three different rates of intensification. In its formation stage the rate of increase is about 1 T-Number per day which subsequently increases to 1.5 to 2.0 T-Number per day. Thereafter, as the system approaches the land the intensity remains constant or decreases slightly. The rate of intensification in terms of MSSWS is minimum during 12 to 0 hrs period prior to landfall and maximum during 24-12 hrs period prior to landfall. The speed of movement of VSCS generally increases upto 12 to 24 hours ahead of time of landfall and decreases slightly later. The mean speed of movement, as obtained from radar data, during the period 12-0 hrs was 18 kmph.

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