

Evaluation of the use of satellite photography in determining the location and intensity changes of tropical cyclones in the Arabian Sea and the Bay of Bengal

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ABSTRACT. Location of tropical cyclones in the Arabian Sea and the Bay of Bengal as determined by satellite photography are compared against the 'best track' data for the years 1965-68. Median and average vector differences between the cyclone centres determined by satellite and best track are presented separately for weak and intense vortices and the errors are found to be of comparable magnitude to those reported for the Pacific and Atlantic regions by other authors. The intensity of the tropical cyclones determined from satellite photography are also compared against the intensity as given in the weather bulletins based on conventional methods and the agreement between the two is found to be 90 per cent within one stage difference in category.

1. Introduction

Easily recognisable tropical vortex cloud patterns in satellite photographs have been studied by different workers (Koteswaram 1961, Boucher *et al.* 1963, Sadler 1964, Widger, Sherr and Merrit 1964, Fett 1963, 1964a, 1964b & 1966, Fritz, Hubert and Timchalk 1966, Merrit 1964, Shiroma and Sadler 1965). A semi-objective method to estimate the intensity of the fully developed tropical cyclone in terms of maximum sustained wind speed from the examination of the satellite picture was given by Fritz, Hubert and Timchalk (1966). Fett (1966) also suggested a model describing the cloudiness associated with the various stages in the development of tropical cyclone and related the clouds organisation with the probable maximum wind speed in the circulation.

Tracking as well as intensity determination of tropical cyclones in the Arabian Sea and the Bay of Bengal is done conventionally by ships' observations only as aircraft reconnaissance facility is as yet not available in this area. However, through the satellite storm bulletins issued by APT station at Bombay and by the National Environmental Satellite Centre (NES-C), Washington, the operational forecasters in this area draw support from the satellite observations in reporting on the tropical cyclones, particularly when the ships' data are inadequate. The factors which contribute to the differences between the interpretation of the tropical storms from the conventional synoptic data and satellite picture data are the paucity of data in the case of the former and the quality of the satellite picture, experience of the satellite picture analyst and the limitations of the gridding and camera system etc., in the case of the latter. The

present study is aimed towards comparing the locations and intensity determinations of tropical cyclones by the satellite observations against those by conventional operational methods used in the region. The results of the comparison may serve as guide lines in the operational use of satellite observations. Since the satellite bulletins from Washington are received by the operational offices in India after a lapse of quite a few hours from the time of read out, the study also attempts to evaluate the capability of the APT product from Bombay for the use of operational work, as the APT satellite messages are available soon after the orbit time.

2. Data used in the study

The study refers to the tropical cyclones of the pre and post monsoon seasons (May, October, November, December and January). All the tropical cyclones which were detected by the global read out pictures received in Washington for the period May 1965 to December 1968 and on which storm bulletins were prepared have been considered. Similarly APT pictures of tropical cyclones received in Bombay for the period from the end of September 1966 to December 1968 and the bulletins issued on them have been examined. The cases of the cyclones after entering inland have not been included since the cloud structure of the cyclone breaks up rapidly after striking the coast and interpretation of its intensity from satellite photography becomes very difficult.

For the purpose of comparison against the satellite locations the 'best track' position have been used as the standard. The 'best track' in the India Meteorological Department is finalised at the end of the storm season after examination of all

TABLE 1

Intensity of systems considered	No. of fixes	Average vector error	Median vector error	Lowest error	Highest error	Lower quartile error	Upper quartile error
		(n.m.)	(n.m.)	(n.m.)	(n.m.)	(n.m.)	(n.m.)
(a) Comparison of best track positions against global read out (Washington) pictures position							
Tropical storms and higher intensity	59	56	46	7	179	23	78
Depressions and deep depressions	72	81	65	2	253	49	101
(b) Comparison of best track positions against APT pictures positions (Bombay)							
Tropical storms and higher intensity	71	54	46	2	175	29	70
Depression and deep depressions	82	86	73	2	307	41	120

TABLE 2

Comparison of operational intensity determination

Year	Satellite No category		Satellite depression					Satellite deep depression					Satellite-cyclonic storm					Satellite-severe cyclonic storm						
	DP	DDP	N	L	DP	DDP	CS	N	L	DP	DDP	CS	SCS	L	DP	DDP	CS	SCS	L	DP	DDP	CS	SCS	
	1	2	-2	-1	0	1	2	-3	-2	-1	0	1	2	-3	-2	-1	0	1	4	3	2	1	0	
(Operational categories)																								
(a) Against global read out pictures interpretation (nearer to 03 or 12 GMT operational bulletins)																								
1965			1	3	2				3					1		2	1		1	1	2	3	4	
1966			4	3	12	2		2	2	4	5	1		1	2	3	3			3	1	8	8	
1967	1	5	1	10	10	2	2		1	1	3	2					1		1		2	2		
1968				3	5		1			1	1	1			1	3	3	1			1	0	10	
(b) Against APT pictures interpretation (Bombay)																								
1966	2		6	7	18	4		1	3	5	7			1	2	2	7			4	1	10	13	
1967	4			12	11	5		1	2	5	3	1			3		2	1			2	3		
1968	1			3	5				1		1	2				1	6	1					13	

N—No category, L—Low, DP—Depression, DDP—Deep depression, CS—Cyclonic storm and SCS—Severe cyclonic storm

ships' reports (including logs). It is possible that in the case of tracks under comparison, some bias in the 'best tracks' may be also toward the satellite information when the ship's data were meagre. However, no attempt has been made to exclude this bias in the best track, if it existed. All centre locations as determined by Nimbus 2 and ESSA series of APT satellites have been combined for the purpose of comparison against the 'best track' as the gridding errors may be of the same type. The best track positions were, however, interpolated to the time of the satellite observations for comparison. As the location of tropical cyclones by the help of satellite pictures in the formative stages are known to be less accurate than in the mature stages (Frank 1966 and Haraguchi 1967), the location errors have been examined separately for weaker and intense systems. The categorisation of the cyclones into different intensities for this

comparison was done on the basis of the satellite information only. The method adopted for this purpose is described below.

Operationally the tropical systems in the Indian region are categorised in the following way—

Category	Wind speed (kt)
Depression	17—27
Deep depression	28—33
Tropical storm	34—47
Severe tropical storm	48 and above

The severe tropical storms may also contain core of hurricane winds exceeding 63 kt in strength. As our aim is to evolve the use of satellite pictures as operational aid, an attempt was made to build a parallel scale of intensity which could be obtained by examining the satellite pictures. For this purpose the satellite pictures obtained in Washington as

well as the storm bulletins issued by NESC, Washington were examined with reference to the nomogram of Timchalk *et al.* (1965) in the case of intense systems (tropical storms and severe tropical storms) on the basis of category of banding and central overcast. An exception from Timchalk's method was, however, made in the case of systems categorised as stage X, category 1 and diameter three which according to nomogram may have the maximum speed of 35 kt but were categorised in the present study as deep depressions because of marginal difference with respect to operational criterion. The weaker systems were examined with reference to Fett's (1966) model and thus all stage C and stage C+ systems were categorised as Depressions and Deep Depressions respectively. The quality of the facsimile product in the case of APT pictures is less satisfactory in comparison to the picture received at Washington. The APT pictures at times do not have the contrast and the estimate of the central overcast area is likely to be on the higher side. The tendency of the larger central overcast in the APT pictures may be also possibly due to the inclusion of irregular thin cloud areas in the central overcast region which are seen with breaks in between in the pictures received at Washington and hence are not included by NESC analysts while estimating the central overcast diameter. Based on the examination of the APT bulletins as well as the corresponding APT pictures and keeping in view the results of satellite studies on the tropical cyclones, the following tentative criteria were adopted in assigning intensity category to each case.

<i>Description in the APT bulletins</i>	<i>Intensity category assigned</i>
(i) Cyclonic circulation or vortex with bands in some sector.	Depression
(ii) Active cyclonic circulation or vortex with bands in all sectors, centre getting defined with evidence of some outflow aloft.	Deep Depression
(iii) Vortex with bandings and central overcast of less than 3 degrees and cirrus outflow in some sectors.	Tropical storm
(iv) Vortex with central overcast of 4 degrees and above, tight bands and pronounced cirrus outflow.	Severe tropical storm
(v) Vortex with eye seen	Severe tropical storm

For the purpose of comparison of intensities between the satellite interpretation and the operational methods in current use, the operational bulletins issued by the Storm Warning Centre, Calcutta for the cyclones of the Bay of Bengal and those issued by the Storm Warning Centre, Bombay for the cyclones of the Arabian Sea, have been used. As the satellite pass time differs from the synoptic hour chart on which the operational bulletin is issued, the intensity as determined by

satellite picture interpretation is compared to the intensity assigned in the nearer of either 03 or 12 GMT operational bulletin. The differences in the satellite pass time for the cases under study from either of the above synoptic chart time were mostly less than three hours.

3. Discussion of Results

3.1. Comparison of location of the cyclone centres

3.1.1. *Best track positions vs global read out (Washington) picture positions*—Table 1(a) shows the results of the comparisons for storms of different intensity. The median and the average vector errors for intense storms were 46 and 56 nautical miles (n.m.) respectively and for weaker systems are 65 and 81 n.m. respectively. The intense storms also included 10 eye fixes. The average vector error for the eye fixes alone was 36 n.m. The larger error in the case of weaker systems compared to the intense storms is due to very much asymmetric cloud structure of the weaker systems. Haraguchi (1967) for the West Pacific region has reported median and average errors for weaker (wind speed less than 35 kt) storms as 90 and 102 n.m. respectively and for the intense storms (wind speed greater than 35 kt) as 35 and 43 n.m. respectively. The error reported in this study are of comparable magnitude although they are slightly on the higher side of the Pacific region in respect of intense systems. This may be due to the absence of aircraft reconnaissance reports for determination of the best track.

Fig. 1 shows the distribution of the location of the satellite positions with respect to the best track positions taken at the origin of the coordinate axes. It is seen that the majority of the satellite positions are within 90 miles of the best track position. However in the case of the higher difference the satellite positions seem to be biased towards the west.

3.1.2. *Best track positions against APT picture positions (Bombay)*—The results of the comparison are shown in Table 1(b). The average and median errors in the case of intense storms were 54 and 46 n.m. respectively and were again much less than in the case of weaker storms (86 and 73 n.m. respectively). Although the individual storms fixes included in the preparation of Table 1 (a) does not have one to one correspondence but the average error in the case of APT fixes, is of comparable magnitude to the errors of the global read out pictures.

Fig. 2 shows the distribution of the APT locations for all categories of storms with respect to the best track taken on the origin of the coordinate axes. Here again in the case of higher differences the satellite locations are found to lie to the west of the best track.

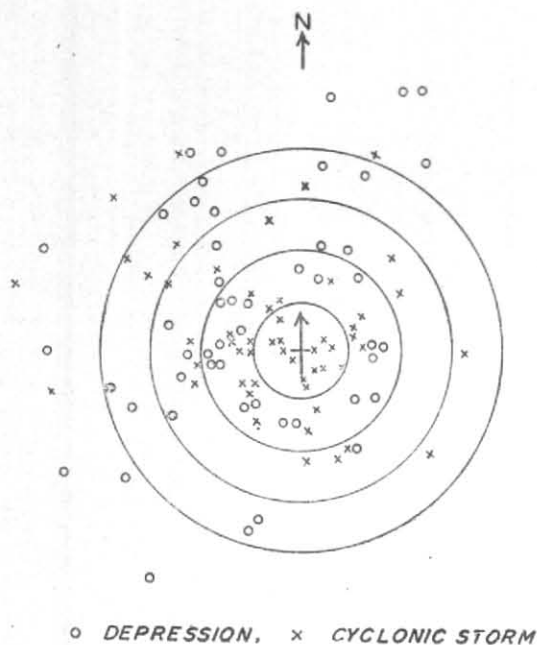


Fig. 1

Location of the satellite determined centres of tropical disturbances from global read out pictures with respect to the best track positions taken at the origin of the co-ordinate axes. Concentric circles are drawn with 30 nautical miles radii. Small circles and crosses indicate positions of depressions and cyclonic storms in the satellite pictures.

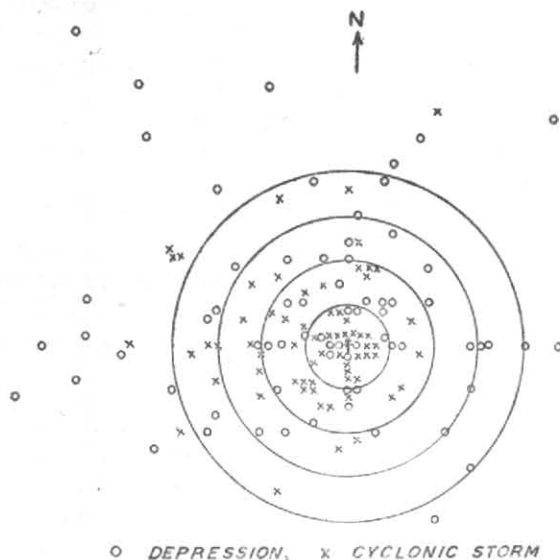


Fig. 2

Explanation is same as Fig. 1 but the satellite locations are from the APT pictures.

3.2. Comparison of intensity changes in the tropical cyclones

3.2.1. *Operational intensity determination against intensity determination from global read out pictures (Washington)*—Table 2(a) presents the results of the intensity as obtained from the interpretation of the satellite pictures obtained in Washington compared to the cyclone intensity indicated in the operational storm bulletins. In order to interpret the results conveniently the table has been so prepared that corresponding to the satellite interpretations of cyclones of a particular intensity are listed the number of cases of different operational categorisations. This shows as to how the operational categorisation stood with respect to the categorisation based on satellite picture interpretation. Below each operational categorisation in the table is shown the figure indicating its stage difference with respect to the category based on satellite picture interpretation. For example, if the satellite categorisation is severe cyclonic storm and the operational is depression, the stage of the latter with respect to former is three stages lower (—3).

Table 3(a) shows the same data in the form of the frequency distribution of the stage difference between operational and the satellite category. The data shown in Table 2(a) and 3(a) show that the exact agreement between the operational and satellite categorisation is rather low but the agreement is satisfactory within one stage of category difference. The agreement within one stage of category also appears to have improved from the year 1965 to 1968.

The data were also examined with respect to the highest intensity reached by each storm in its life history and it was found that operational and satellite categorisations agreed very well in that respect.

3.2.2. *Operational intensity determination against APT picture interpretation (Bombay)*—The results of the comparison of operational and APT picture categorisation on similar basis as given in the previous paragraph are given in Tables 2(b) and 3(b). These figures also show that although the exact agreement of the satellite intensity with respect to the operational categorisations, is not very high, the two categorisations agree very well within one intensity stage. The agreement within one stage of category also appears to have improved in the year 1968 in comparison to the year 1966. Here again in the majority of differences, the operational category is of lower stage in comparison to satellite intensity stage.

TABLE 3
Frequency distribution of stage difference

Year	No. of cases	Frequencies of stage differences in categorisation							Percentage No. of cases with category differences within one stage
		(Operational—Satellite)							
		2	1	0	-1	-2	-3	-4	
(a) Between the storm category in operational bulletins and global read out picture interpretations (Washington)									
1965	25	0	0	8	8	6	2	1	64
1966	58	0	3	27	15	9	4	0	78
1967	44	3	8	16	13	1	3	0	84
1968	28	1	2	19	5	1	0	0	93
(b) Between the storm category in operational bulletins and APT picture interpretations (Bombay)									
1966	93	0	6	45	24	12	6	0	81
1967	55	0	11	19	19	5	1	0	90
1968	34		4	25	4	1			97

3. 2. 3. *Intensity determination by APT picture interpretation (Bombay) against the global read out picture interpretation (Washington)*—It would be worthwhile to compare the intensities determined from the APT pictures on the basis of the criteria as suggested in Section 2 against the intensities determined from the global read out pictures in Washington messages.

Tables 4 and 5 summarise the results of these comparisons. It is seen that the exact agreement in intensity stage of the cyclones as interpreted from APT pictures and global read out pictures is quite good (about 60 per cent), keeping in view the difference in pass time of the two types of satellites which was generally about 3-6 hours. The agreement is almost 100 per cent with regard to category difference within one stage. The reasons for the differences are (i) rapid intensification or weakening during the period between the times of the APT picture and global read out picture, (ii) poor quality of the APT picture or storm being at the edge of the picture and (iii) subjectivity introduced in interpretation of the picture by the analyst in marginal cases. While reason (i) is a genuine synoptic cause, the other two reasons are due to the operational limitations in the system.

4. Remarks on the operational use of satellite data on tropical cyclones

Satellite tracking and intensity determination of the tropical cyclones in the Bay of Bengal and the Arabian Sea have been found to agree well with the conventional methods in use in the area based primarily on ships reports. The average

vector difference of the positions of the systems by satellite photography and best track position for weak systems like depressions and deep depressions (pre-storm stage) are found to be higher than in the case of intense systems. This has been also reported from other tropical oceanic areas. This is so because in the pre-storm stages of the tropical cyclone development, the cloud distribution within the circulation has pronounced asymmetry which subjects the centre estimation from the satellite picture to greater limitations. However, in the case of intense system, particularly when an eye fix in the picture is available, the median difference between the satellite and the best track position is about 50 n.m. Since, in the absence of aircraft reconnaissance the position of the storm centre by different operational centres on the average also differs by about 50 n. m., the satellite-determined centre can be put to optimum use for operational work at least in those cases where the ships reports are inadequate.

The operational criteria for assigning the intensity stage to the cyclone are based on the wind strength in the circulation. It is well known that in the case of hurricanes and severe tropical storms the most intense winds are present only in the narrow area outside the ring of maximum convective activity associated with the wall clouds and in the more active regions of the spiral-bands. The area of high winds varies with a number of factors such as the maturity of the storm, the pressure gradient and the central pressure etc. For the storms of the Indian Seas Koteswaram and Gaspar (1956) have found a ring of 60 n. m. strong winds only within 60 n. m.

TABLE 4

Comparison of intensity determination by APT picture interpretation (Bombay) against global read out (GR) picture interpretation (Washington)

Year	GR picture No category, i.e., lower than DP		GR picture depression					GR picture deep depression					GR picture cyclonic storm					GR picture-severe cyclonic storm				
	DP	DDP	L	D	DDP	CS	CSC	L	D	DDP	CS	SCS	L	D	DDP	CS	SCS	L	D	DDP	CS	SCS
	1	2	-1	0	1	2	3	-2	-1	0	1	2	-3	-2	-1	0	1	-4	-3	-2	-1	0
1966			4	9	1	2		1	9	11	1		1	3	6					1	4	23
1967	4		4	15	8			5	5	1			1	2						1	2	5
1968			1	6	2				2	1						4	1				3	8

TABLE 5

Frequency distribution of stage differences between the storm category with APT picture interpretation (Bombay) and global read out picture interpretation (Washington)

Year	No. of cases	Frequency of stage differences in categorisation (APT-GR pictures)							Percentage No. of cases with category difference within one stage
		2	1	0	-1	-2	-3	-4	
1966	74	0	2	49	20	3	0	0	96
1967	53	0	13	25	13	2	0	0	96
1968	28	0	4	20	4	0	0	0	100

in diameter round the centre. Winds of force of about 30 n. m. associated with the large severe tropical storms with core of hurricane winds may some time cover 500-800 miles in diameter. The stronger winds are also known to have asymmetric distribution with respect to the centre of the storm from one storm to the other (Hughes 1952, and Koteswaram and Gaspar 1956).

Due to the storm warning system for shipping, the ships try to avoid the destructive region of high winds in the storm with the result that the operational forecaster very rarely gets reports of hurricane winds from the ships. Thus in the absence of aircraft reconnaissance facility in the Indian Ocean region, the operational forecaster is greatly handicapped in assigning the intensity stage to the cyclones of 'storm' or higher intensity stage. The satellite data can excellently supplement

the information available to the forecaster on the intensity stage of the storm. The empirical rules or 'keys' to interpret the satellite cloud for organisation in the storm circulation are based on changes in the cloud organisation, the spiral bandings and cirrus out flow etc and are linked with the dynamic changes which accompany the development of the storm from the depression stage to the storm of most intense stage. While there may be differences in the early stage of the development which are difficult to identify in the clouds as at that stage the recognisable cloud vortex patterns are not clear, the satellite information can be said to be dependable in the 'tropical storm' or higher stage of development. The data presented in the present study on the comparison of intensity determination by satellite photography and operational methods has the limitation that the latter method did not have

the wind information from aircraft reconnaissance reports. However, it is found that on the large majority of occasions the two methods agreed within one stage of category difference. In case of difference the operational category is mostly on the lower side of the satellite categorisation and the former is found to be invariably raised to the higher category given by the satellite information within about 12 to 36 hours. This along with the information on the structure of the intense storms would suggest that in the absence of sufficient ship reports within say about 2 degrees of the estimated centre of the storm, the intensity assigned to the storm in operational work may be weighted more towards the satellite information. The

results of this study strongly favour that the difference between the operationally determined intensity and that inferred from the APT information or satellite storm bulletins from Washington may not be kept more than one stage.

Acknowledgement

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DISCUSSION

SHRI B. M. CHHABRA : When the two categorisations differed by one stage, which technique indicated the higher stage ?

SHRI D. R. SIKKA : Satellite pictures, in the majority of the cases.

SHRI R.K. DATTA : How did the two methods compare when the system was near the coast ?

SHRI SIKKA : The two categorisations agreed. In the higher stages also there was good agreement.