Surface Wind and Precipitation Patterns of Indian Ocean Tropical Cyclone: A Study Using Satellite Observations

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Introduction

The relationship between the distribution of heating rates within a tropical cyclone and its intensity, as well as the changes in its inner core structure and future intensity had been demonstrated by a number of studies using satellite infrared (Gentry et. al, 1980, Strerenka et al, 1986) and passive microwave observations (Rodgers et al, 1981, Rodgers and Pierce, 1995). Using the quantitative rain-rate estimates from the observations of Special Sensor Microwave/Imager (SSM/I) onboard the DMSP (Defense Meteorological Satellite Program of US) satellite, Rodgers et.al., (1994) have shown that there is a direct relationship between the intensity of North Atlantic tropical systems and their rain-rates and the distribution of higher rain bands near the centres of these systems. In addition, the SSMI/I revealed that the correlation between changes in inner core latent heating and subsequent intensity became greater as these tropical systems became more intense. Similar studies have been carried out for the tropical cyclones occurring over the Pacific Ocean (Allis et al, 1992).

Intensifying tropical cyclones over the eastern Indian Ocean and crossing the coasts of the Indian subcontinent of the Bangladesh year after year, is a major cause of concern for the life and economy of these countries. Although there have been some attempts to understand the structure and characteristics of these systems using the satellite infrared observations, the studies employing the data from advance SSMI/I for quantitative estimates of the precipitation and latent heat release within the Arabian Sea and of Bengal tropical cyclones are limited.

The aim of the present study is to monitor the evolution of Arabian Sea cyclones' precipitation distribution using SSM/I observations and to access the relationship between the changes in inner-core heating and the subsequent intensity of these systems. Data from both DMSP F-11, 13 as well as 14 have been used to monitor the Arabian Sea cyclone of May-1999. This cyclone reached the very severe cyclonic stage.

Synoptic Aspects of Analyzed Cyclones:

Satellite observations for Arabian Sea tropical cyclone were analyzed for the present study. This cyclone formed over the Arabian Sea during 16-21 May, 1999. Fig. 1 shows the track of this storm. The synoptic situation of the storms can be identified by the line style (dashed line=depression/deep depression, solid line=storm of cyclonic intensity).

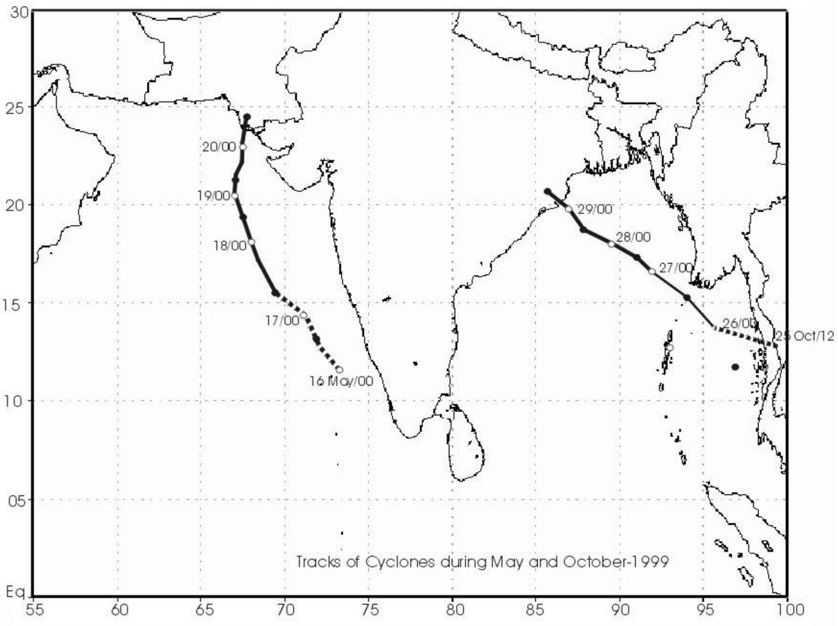

Fig. 1 Synoptic Aspect of Tropical Cyclones over Indian Seas

The SSM/I

SSM/I is a joint project of U.S. Navy and Air Force. The first sensor was flown on the DMSP-F8 operational spacecraft in June 1987. At present there are three such sensors onboard DMSP-F11, DMSP-F13, DMSP-F14 in orbit. These satellites complete 14.1 revolutions per day along a near sun-synchronous track at an altitude of 833 km. The SSM/I uses a conical scanner with an angle of incidence 53 degree. With an observational swath width of 1400 km., there is a 99% probability of viewing a storm in tropics, at least once per day and 89% probability of viewing it at least twice a day.

The SSM/I is a seven-channel, four frequency, linearly polarized microwave radiometric system. The instrument measures atmospheric/ocean surface brightness temperature at 19.3, 22.2, 37.0 and 85.5 GHz.

Results and Discussions

(a)Convective band cycle and intensification of tropical cyclone: The life span (the time between attainment of cyclonic storm strength and landfall) of Indian Ocean tropical cyclones varies from 3-5 days, which is much smaller compared to tropical cyclones forming over Atlantic or Pacific oceans. Considering the limited number of satellite observations, the study of evolutionary changes in these storms is somewhat difficult. Fortunately, for the Arabian Sea cyclone of May 1999, we had 17 passes by three DMSP satellites between 16 and 20 May, 1999. The equator crossing timings of three DMSP satellites are approximately 2-hours apart from each other. Considering large swath of SSM/I there is a good probability of observing a cyclone for four hours in three scenes, separated by about 2-hours. This pattern of observation then repeats after 12 hours. The patterns of rainfall intensity indicate that there is periodic formation and decay of convective bands in tropical cyclones. The decay of convective bands is followed by significant increase in rainfall intensity at core region after a lag of about 12 hours. Our limited set of SSM/I observations indicates a diurnal cycle of convective band formation and rainfall intensification at core. Also, it seems that the band formation is more likely to occur between afternoon (local time) and evening, while the decay of convective bands and core intensification takes place between midnight and early morning. There are specific processes involved with the diurnal modulation for the tropical cyclone deep convection. One process is the day-night difference in cloud top radiational cooling, wherein upper level night time cooling in cloudy areas decreases stability and enhances vertical

motion (Fingerhut, 1978, Anthes, 1982). This is contrasted with the opposite acting influences of daytime cloud top warming. Also, an outer radius diurnal increase in low level early morning convergence results from the differences in subsidence in the cloudy and clear areas as discussed by Gray (1977). The cyclone's cloudy areas also act to decrease the net tropospheric long wave radiation loss at night in comparison to the surrounding clear and partly cloudy areas. The greater tropospheric night time radiational loss in the cyclone's surrounding clear region drives a larger compensating subsidence. The greater morning low level divergence in the clear areas forces a morning outer radius increase in the low level convergence in the cyclone's cloudy areas. Deep convection in the cloudy areas is thus enhanced in the morning hours and reduced in the afternoon-evening. This convergence modulation manifests itself in outer radius (100-400 Km) deep convection variations. Fig. 2 shows a typical example of convective band decay, and core intensification between 17 May evening, and 18 May early morning.

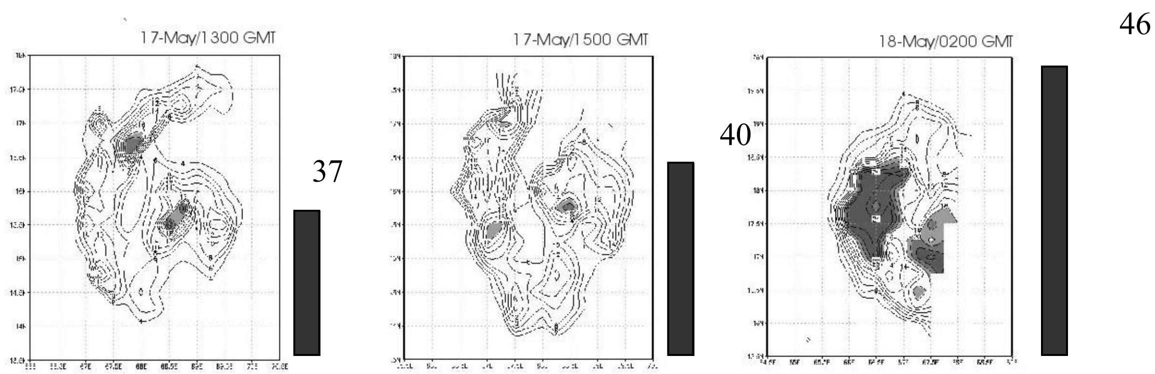

Fig. 2: SSM/I derived rain rates (mm/h) for 17 and 18 May, 1999. Values larger than 18 mm/h are shaded. (Bars on right show the maximum sustained wind speed in meters per second)

We also analyzed the rain rates averaged over different co-centric rings 50 km wide, centered at the center of the cyclone. Within the core region (Radius < 50), the rainfall rates increases in a step-wise manner and after each such enhancement, there is a tendency for maintenance of new precipitation rate levels. However, for the region outside 50 km radius, the mean rainfall rates show large variations during the life cycle of cyclone (Fig. 3). The regions of convection within the cyclone environment can be identified by intense rainfall rates. Most intense convection occurs within the eye-wall region of cyclone and also over the convective bands (Rodgers et al, 1981).

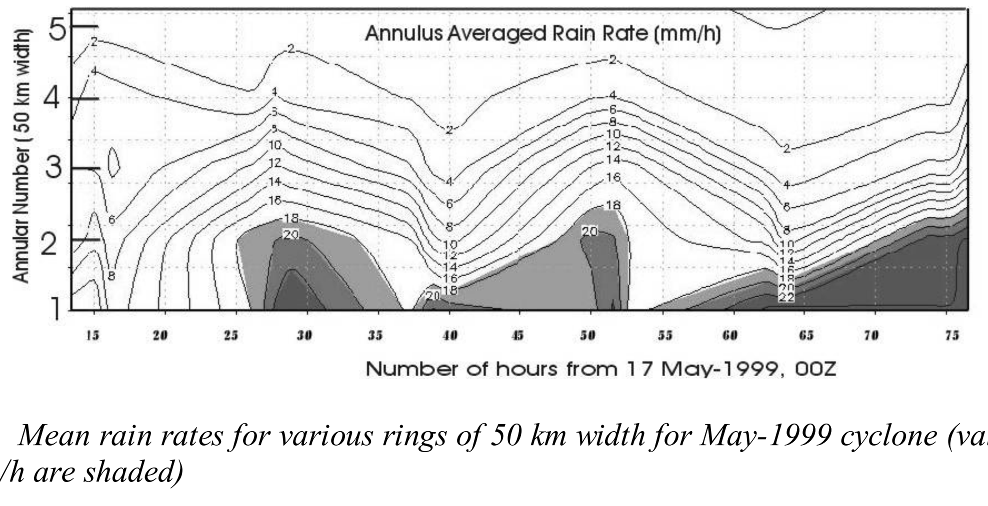

Fig. 3: Mean rain rates for various rings of 50 km width for May-1999 cyclone (values larger than 18 mm/h are shaded)

It is interesting to note that the fraction of intense rainfall (which may represent the convective regions) to total rainfall keep changing throughout the life cycle of tropical cyclone. A comparison of time series of intense rainfall with that of maximum sustained wind speed (MSW) shows that with each burst of low level circulation, the convective activity increases abruptly. It appears that with intensification of low level circulation, there is sudden increase in moisture convergence and vertical motion which result in deep and intense convection. However, the convective intensity gradually subsides with time, possibly due to stabilizing factors such as downdrafts, and cumulus friction. Next increase in convective activity again coincides with the time of increase of low level circulation. One more interesting point to note is that, the increase in the area of very intense convection (Rain rate > 16 mm/h) usually occurs about 24 hours before the increase in MSW takes place. This aspect is important as it indicates that the MSW, and hence the intensity of cyclone is governed by a small area of very intense convection that is usually associated with the eye-wall region. It has been observed that the changes in storm circulation respond to the enhanced latent heat release in core region with a lag of about 24 hours (Fig.4). However, the convergence that results from the latent heat release by these convective centers brings in further enhancement of convection that may appear in the form of convection bands outside the core region.

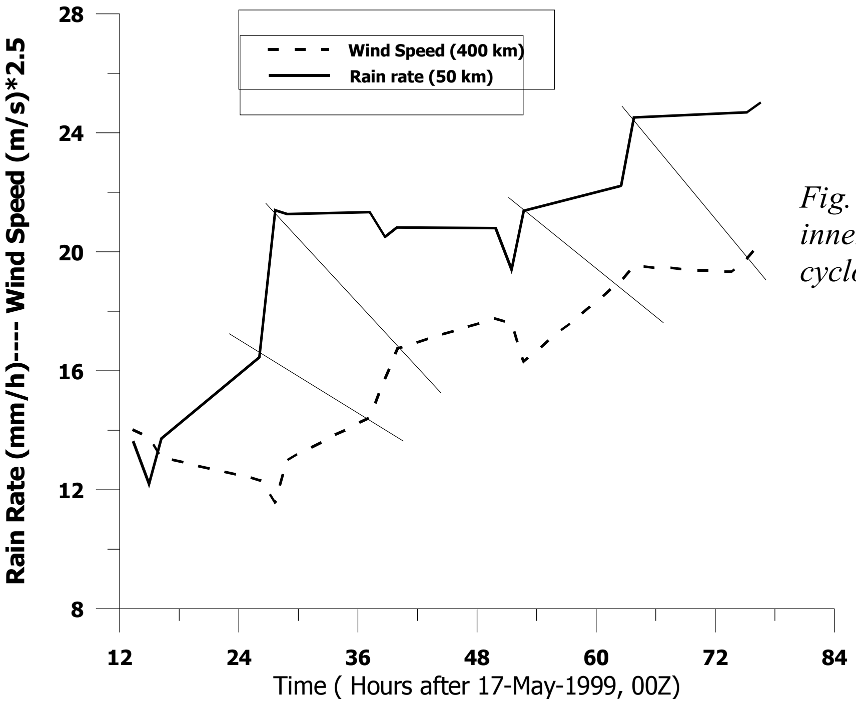

Fig. 4: Time series of rain rate at inner core and wind speed at cyclone periphery for May 1999.

Willoughby, (1990) and Kishtawal et al (1996) also noticed this phenomenon, and they termed this as “convective ring cycle” where the convective activity first appears in the form of convective bands, and slowly moves inwards and finally reaches the eye wall region. Our observations indicate that the increase in eye-wall convection (indicated by the areas with rain rates > 16 mm/h) is very rapid. This can be explained by the argument of the conservation of mass and angular momentum of moist air parcels, converging towards the center of a rotating air-field.

(b) Asymmetries in surface wind, moisture and rainfall fields:

To analyze the asymmetries in the geophysical parameters within the cyclone we computed the mean angular distribution of surface wind (SW), precipitable water (PW), and rainfall rates, for eight angular sections each 45^0 wide. Direction of movement of tropical cyclone was taken as reference axis from where the angles were measured. Since the retrieval of SW and PW is difficult in presence of intense rainfall, the values of these parameters within about 200 km from the cyclone center were unusable. However the variation of these fields beyond 200 km from center could still indicate a fair degree of asymmetry in cyclone structure. Fig. 5 shows the angular distribution of surface winds for intensifying and mature stages of cyclone. It is interesting to note very weak winds in the front-left section of the cyclone, which is in total contrast with the winds at upper-right section, where the winds are quite strong. PW fields also show similar behavior with PW anomalies in rear-left section almost twice as large as in front-left section. As the cyclone reaches mature

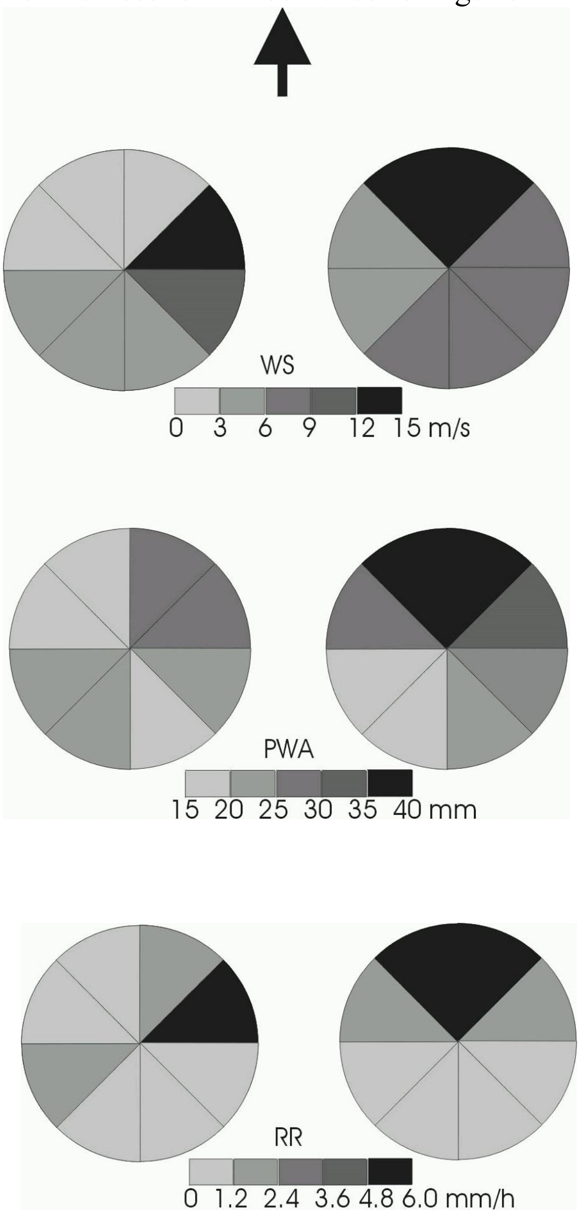

Fig. 5: Asymmetric structures of wind speed (WS), precipitable water anomalies (PWA), and rain rate (RR) for cyclone in developing (left) and mature (right) stage. Arrow on top shows the direction of cyclone motion.

stage, the average wind speeds at the front two quadrants (L & R) also increase. Willoughby (1990) noticed the asymmetries in convergence patterns within the tropical cyclones, with maximum convergence occurring at rear-left quadrant. This is usually accompanied by upper-level wind divergence and related subsidence in front of tropical cyclone. In less intense stage, the subsidence is at relatively smaller radial distance from the center, while this distance becomes larger as the cyclone gets stronger.

Conclusions :

SSM/I derived surface wind, PW, and rainfall fields have been analyzed for Arabian Sea tropical cyclone of May-1999. Convective precipitation of this cyclone shows a diurnal variation with deep convection increasing during early morning hours. Also, the intensification of rainfall at core follows the decay of convective bands, which shows a cyclic behavior during the life span of cyclone. Precipitation at cyclone core seems to have influence on wind speeds at outer radius (~ 400 km) with a lag of about 24 hours. Surface wind, PW, and precipitation fields show significant asymmetries. These asymmetries are of different nature for developing and mature stages of cyclone.

Acknowlegement:

One of the authors (FP) acknowledges the award of fellowship from SATCORE Project of Department of Ocean Development.

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