Mausam, (1991), **42**, 4, 347-352

551.577 : 551.501.777 (267)

Assessment of satellite-observed HRC data for rainfall estimates over the tropical Indian Ocean

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(*Received 2 February 1990*)

सार— कई वायुमण्डलीय अध्ययनों में महासमुद्रीय क्षेत्रों पर वर्षा के आकलन बहुत ही उपयोगी सिद्ध होते हैं। उष्णकटिबन्धीय हिन्द महासागर पर खुली महासमुद्र वर्षा का निगमन करने के लिए जनवरी 1971 से दिसम्बर 1983 तक के 13 वर्षों के उपग्रह प्रेक्षित उच्च परावर्ती मेघ (एच. आर. सी.) अत्यधिक परावर्ती मेघ (हायली रिफ्लेक्टिव क्लाउड) आंकडों का इस शोधपत्र में उपयोग किया गया है। इस उद्देश्य से उष्णकटिबन्धीय हिन्द महासागर पर आठ द्वीप केन्द्रों पर मासिक वर्षा और उपग्रह प्रेक्षित मासिक एच.आर.सी. की तुलना की गई। 1248 केन्द्रों की मासिक वर्षा के साथ रेखीय समाश्रयण सम्बन्ध देखने के लिए एच.आर.सी. की मासिक प्रायिकताओं की जांच की गई। एच.आर.सी. प्रायिकता और वर्षा के बीच रेखीय समाश्रयण समीकरण आर= 64.7 + 48.9 एच (जहां आर=अनुमानित वर्षा और एच=मासिक एच.आर.सी प्रायिकता है) और सहसम्बन्ध गुणांक (0.74) 1% स्तर पर अत्यधिक महत्वपूर्ण पाए जाते हैं। समीकरण के मान्यकरण के लिए वर्ष 1987 के लिए एक पृथक एच.आर.सी. आंकड़े समूह का परीक्षण किया गया। इस वर्ष एच.आर.सी. आंकड़ों से प्राप्त समवर्षण प्रतिरूपों की तुलना भारत मौसम विज्ञान विभाग द्वारा इन्सैट–1 बी विकिरण आंकड़ों का उपयोग करके बनाए समवर्षण प्रतिरूपों के साथ की गई। दोनों समवर्षण प्रतिरूपों में समान लक्षण दिखाई देते हैं। अवधि 1971–1983 के लिए एच.आर.सी. आंकड़ों से प्राप्त माध्य समवर्षण प्रतिरूप, उष्णकटिबन्धीय हिन्द महासागर पर घटती जलवायवी सार रूपी घटनाओं से अच्छी तरह जुड़ती है। अतः यह सुझाव है कि उष्णकटिबन्धीय हिन्द महासागर पर वर्षा आकलनों के लिए एच. आर. सी. आंकड़ों का कुछ विश्वास के साथ उपयोग किया जा सकता है।

ABSTRACT. Satellite-observed HRC (Highly Reflective Cloud) data of 13 years from January 1971 to December 1983 are used for deducing open ocean rainfall over the tropical Indian Ocean. For this purpose, a comparison is made between satellite-observed monthly HRC frequency and monthly rainfall of eight island stations over the tropical Indian Ocean. Monthly frequencies of HRCs are statistically tested for linear regression relationship with 1248 stations months' rainfall. Linear regression equation $R=64.7+48.9\ H$ (where R=Estimated rainfall and H=Monthly HRC frequency) and correlation coefficient (0.74) between HRC frequency and rainfall are found to be highly significant at 1% level. For the validation of the equation, an independent HRC data set for the year 1987 has been tested. Isohyetal patterns for this year obtained from HRC data are compared with isohyetal patterns prepared by India Meteorological Department using INSAT-1B radiance data. Both the isohyetal patterns almost reflect the similar features. Mean isohyetal patterns derived from HRC data for the period 1971-1983 are found to be in good agreement with the climatological synoptic events persisting over the tropical Indian Ocean. Therefore, it is suggested that HRC data can be used with some confidence for rainfall estimates over the tropical Indian Ocean.

Key words — Highly reflective cloud, Linear regression, Radiance, Quantitative precipitation estimate.

1. Introduction

Estimation of rainfall over the oceanic areas is of great importance not only from the point of view of its practical utility but also as an input to various atmospheric disciplines. Convection is the main source of rainfall in the global tropics. Latent heat released from this convective rainfall is considered as one of the major forcing mechanism of the general circulation of the atmosphere. Rasmusson and Carpenter (1982) have shown that large-scale anomalies in the tropical rainfall are closely associated with global scale circulation anomalies. Therefore, knowledge of rainfall estimates averaged over the large areas is essential. Mintz (1981) has suggested that the information on rainfall estimates is most important for both numerical weather prediction and general circulation models. In the recent years several scientists (*e.g.*, Arkin 1979, Stout *et al.* 1979, Griffith *et al.* 1981, Rao *et al.* 1989 and Bhandari *et al.* 1987) have devised and tested several diagnostic methods to estimate rainfall using satellite data. Martin and Scherer (1973), Barrett and Martin (1981) and Manikiam (1986) made a comprehensive review of these methods. Recently an extensive study on the relationship of highly reflective clouds to tropical climate anomalies has been carried out by Hastenrath (1990). Barrett (1970) used ESSA nephanalyses for estimating monthly rainfall distribution. Griffith *et al.* (1978) proposed an excellent method of rainfall estimates based on visible and infrared imagery from geosynchronous satellite by including the information on the stages of cloud development. This method was successfully tested during the GATE experiment and was found to yield good results. However, this method based on hourly digital infrared data may not be feasible for practical application to global scale rainfall estimates, as it requires tremendous amount of computer time. Kilonsky and Ramage (1976) devised a simple and inexpensive method of rainfall estimates based on monthly frequency of highly reflective cloud (HRC) obtained by ESSA visible daily picture mosaics over the tropical Pacific Ocean. Garcia (1981) used HRC data to produce rainfall estimates over the tropical Atlantic Ocean. The estimates proved to be reasonably close to those obtained by more sophisticated techniques such as shipboard radar data etc.

Thus, HRC data have been proved to be useful for rainfall estimates over the tropical Pacific and the tropical Atlantic Oceans. However, how far this data would be useful for the tropical Indian Ocean has been assessed in this paper. Therefore, thirteen years of HRC data are used to establish an empirical relation between monthly HRC frequency and monthly rainfall of eight island stations over the tropical Indian Ocean. Based on this relationship, rainfall estimates over the oceanic areas are made. A comparison is made between HRC rainfall estimates and INSAT-1B rainfall estimates for the year 1987 and mean monthly isohyetal patterns derived by this method for the monsoon months (June-September) are presented.

2. Data

Monthly rainfall data of eight island stations, *viz.*, Amini Divi, Minicoy, Sandheads, Long Islands, Port Blair, Hut Bay, Car Nicobar and Nancowry over the Arabian Sea and the Bay of Bengal are used. Their locations are shown in Fig. 1. Monthly frequency of highly reflective clouds from visible satellite picture mosaics are extracted from the atlas of 'highly reflective clouds over the global tropics' (Garcia 1985). HRC data used here are the record of subjectively identified areas of large-scale organised convection over the Indian Ocean on daily day time Mercator projection mosaics for 13 years period from 1971 to 1983. The convection areas appear as highly reflective clouds in the visible range mosaics and as white areas in the infrared (IR) range. HRC is defined as a deep, organised tropical convective system extending at least 200 km horizontally. HRCs are composed of many individual convective cells embedded within a common cirrostratus canopy. These cloud systems commonly known as cloud clusters are considered to be responsible for most of the tropical rainfall (Houze 1982).

Until now, the most widely used indicator of large-scale convection over the global tropics has been outgoing longwave radiation (Gruber and Krueger 1984). In the tropics low values of OLR are found over areas covered by high clouds with low cloud-top temperatures. In most cases, such clouds are convective in nature. However, low OLR values are also associated with non-convective clouds such as cirrostratus plumes. In contrast to OLR data, the HRC data used here deliberately exclude non-convective cold clouds.

The monthly mean frequency of HRC in the $1° \times 1°$ square where each island is located is used for comparison. The analysed period is for 156 months for each station from January 1971 through December 1983 and the domain of the study is 15° S to 25° N and 40° E to 100° E.

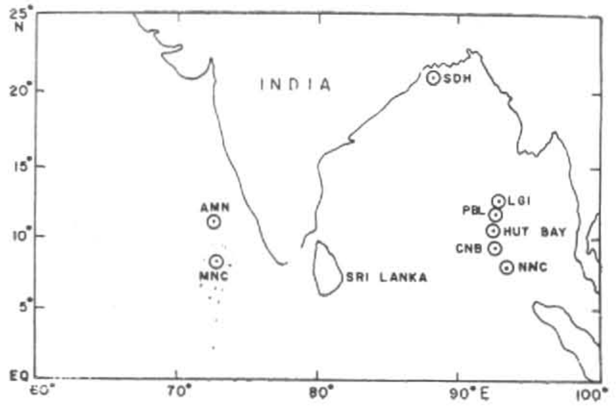

Fig. 1. Locations of island stations over the tropical Indian Ocean used in the study

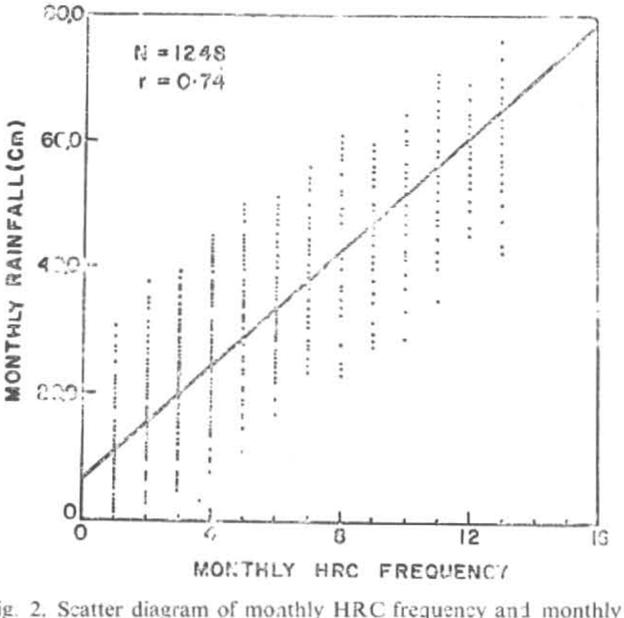

Fig. 2. Scatter diagram of monthly HRC frequency and monthly rainfall of all island stations used in the study. The straight line is the least square best fit. Here, standard error of estimates is 3.32 cm

Quantitative Precipitation Estimates (QPE) derived from INSAT-1B radiance data, prepared by India Meteorological Department for the year 1987 are used for comparison with HRC rainfall estimates.

3. Methodology

Monthly HRC frequency at the exact geographical location of each island station is picked up from the atlas, 'highly reflective clouds over the global tropics' for the period January 1971 to December 1983 and listed as the independent variable H. Monthly mean rainfall of each island station is considered as the dependent variable R. Using these two variables linear regression equations are derived and correlation coefficients are computed for eight island stations (Table 1). These equations are statistically tested for their significance. Similarly regression coefficients of all equations are tested and found statistically not differing from one another. In order to obtain a detalied relationship

TABLE 1

Results of regression analysis

Station	Equation	r	Level of sign. (%)	Stations height (m, a.s.l.)	Location Lat. (°N)	Long (°E)
Amini Divi	$R=44.1H+22.9$	.81	1	4	1107	7244
Minicoy	$R=37.2H+56.9$	.74	1	2	818	7309
Sandheads	$R=54.9H+71.9$	.64	1	10	2051	8815
Long Island	$R=55.4H+79.3$	.80	1	25	1225	9256
Port Blair	$R=46.3H+94.6$	.75	1	79	1140	9243
Hut Bay	$R=52.5H+75.7$	.81	1	5	1035	9233
Car Nicobar	$R=44.9H+71.8$	.73	1	10	910	9250
Nancowry	$R=39.8H+67.9$	.76	1	26	759	9332
All Islands as a whole	$R=48.9H^*+64.7$	.74	1			

where, R — Monthly rainfall in mm,

H — Monthly HRC frequency in 1°×1° grid over that specific island, and

H^* — Monthly HRC frequency at the location over the tropical Indian Ocean 1°×1° grid where the rainfall estimates are required.

between HRC frequency and rainfall, all the data of eight island stations are clubbed together and a single scatter diagram is plotted (Fig. 2). Hence, both the variables comprise 1248-station months' data for the entire period from January 1971 to December 1983. Using this data, a representative linear regression equation is derived for the tropical Indian Ocean and it is as follows :

$$R = 64.7 + 48.9H$$

where, R — Monthly rainfall in mm,

and, H — Monthly HRC frequency.

Analysis of variance is made for testing the significance of the regression relationship and correlation coefficient. For the validation of this equation an independent HRC data are tested for the year 1987. Rainfall estimates for this year are computed and isohyetal patterns are drawn. These isohyetal patterns are then compared with the isohyetal patterns obtained from INSAT-1B radiance data prepared by India Meteorological Department (IMD) for the year 1987. Mean isohyetal patterns for each month are constructed using thirteen years of HRC data for the tropical Indian Ocean. These isohyetal patterns are compared with climatological synoptic scale events of the monsoon season. A plot of observed and estimated rainfall is made for 4 island stations (Fig. 3).

4. Results

Based on the computations made under the methodology, the following inferences are drawn :

(*i*) Analysis of variance indicate that regression relationship and correlation coefficient between monthly HRC frequency and monthly rainfall of all island stations are highly significant at 1% level (Table 1).

(*ii*) A good coherency between the fluctuations of the observed and estimated rainfall series for each island station is observed.

(*iii*) Comparison between isohyetal patterns obtained from HRC data and INSAT-1B radiance data shows the similar features of high and low regions of rainfall estimates, both in time and space for the year 1987.

(*iv*) Mean isohyetal patterns for the period 1971-1983 are found to be in good agreement with the climatological synoptic events persisting over the tropical Indian Ocean.

5. Discussion

The studies of Kilonsky and Ramage (1976) and Garcia (1985) have shown the potential use of HRC data for rainfall estimates over the tropical Pacific and the tropical Atlantic Oceans. These data have been assessed first time for rainfall estimates over the tropical Indian Ocean.

Fig. 2 shows a scatter diagram of monthly HRC frequency and monthly rainfall of eight island stations for a period of thirteen years from January 1971 to December 1983. In this diagram though the scatter is more, the regression line is almost equidistant from abscissa and ordinate and passes close to the origin. Therefore, these rainfall estimates based on the regression equation have a wide range of confidence. Much of the scattering may be due to only one observation during day time by satellite, whereas rain could and did occur at any time. In future one may use multiple imagery per day or at least use optimal time of observation to improve the fit with ground data. Based on the regression equation, time series of estimated rainfall is made for all eight island stations. Fig. 3 depicts

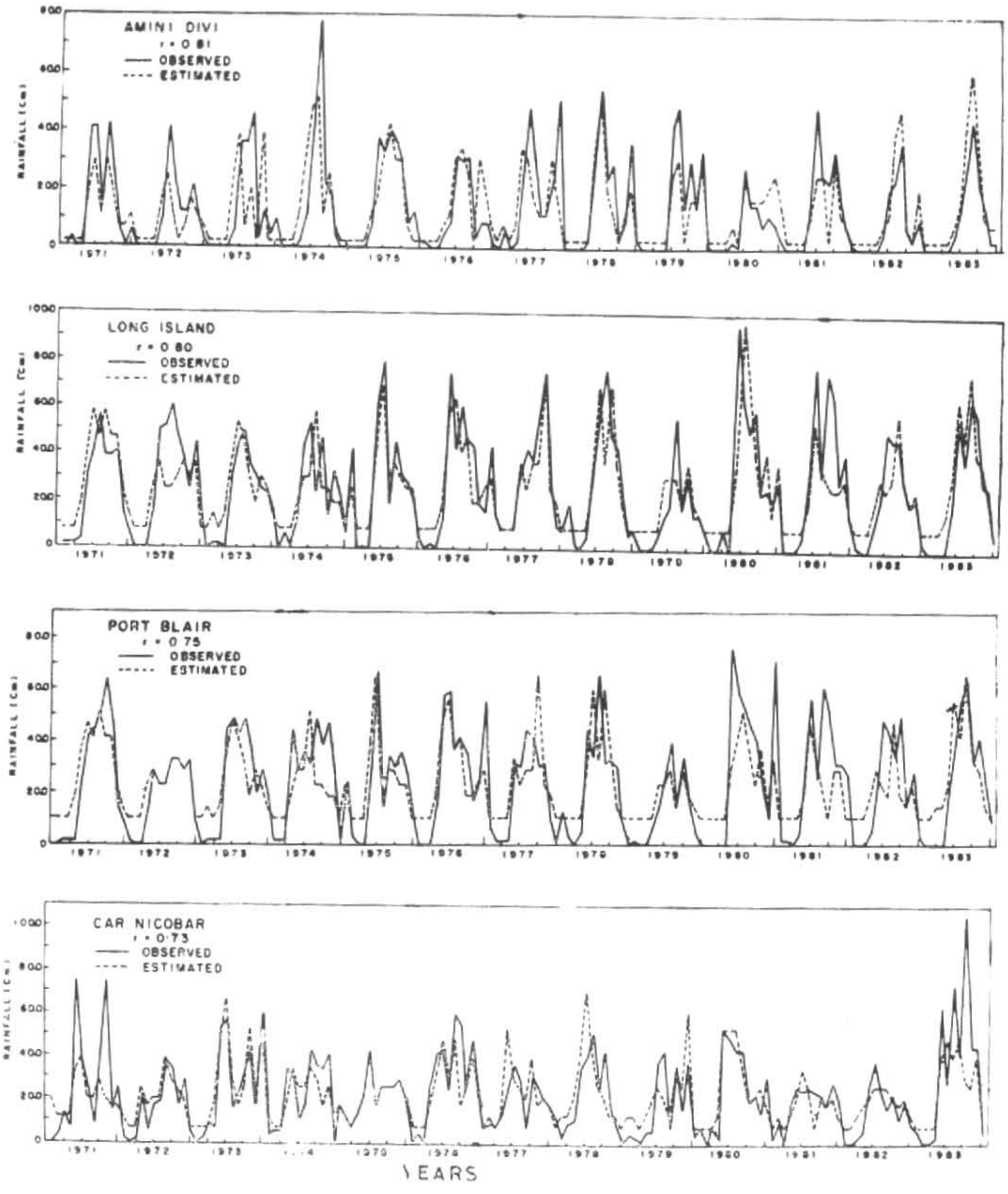

Fig. 3. Time series of observed and estimated rainfall for Arabian and Bay islands

the time series of observed and estimated rainfall of four island stations, *i.e.*, Amini Divi, Long Island, Port Blair and Car Nicobar. A good coherency is seen between observed and estimated rainfall series. Figs. 4 & 5 depict QPE based on HRC data and INSAT-1B thermal infrared radiance data respectively. The details of estimation of QPE from INSAT-1B thermal infrared radiance data are given by Arkin *et al.* (1989). Areas of minimum precipitation covered by 10 and 20 cm isohyets are indicated with vertical hatched lines and areas of maximum precipitation are indicated in horizontal hatched lines. Isohyetal patterns obtained from HRC data show a fairly good agreement with the isohyetal patterns obtained from INSAT-1B radiance data. Both the patterns reflect almost the similar features of high and low regions of the rainfall estimates, both in time and space. This suggests that HRC data can be used for rainfall estimates over the tropical Indian Ocean.

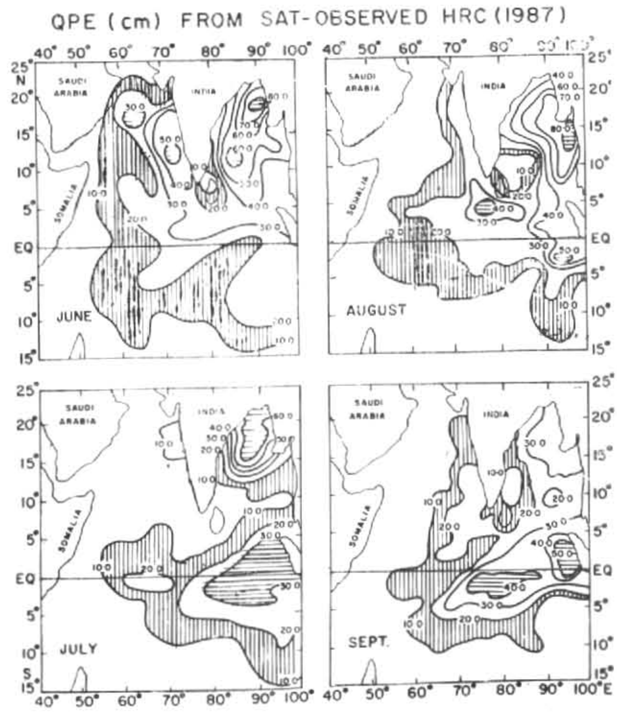

Fig. 4. Quantitative precipitation estimates derived from satellite observed HRC data

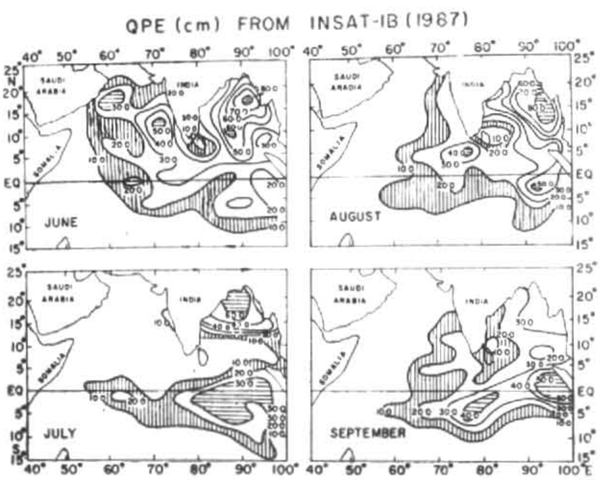

Fig. 5. Quantitative precipitation estimates based on INSAT-1B infrared radiance data

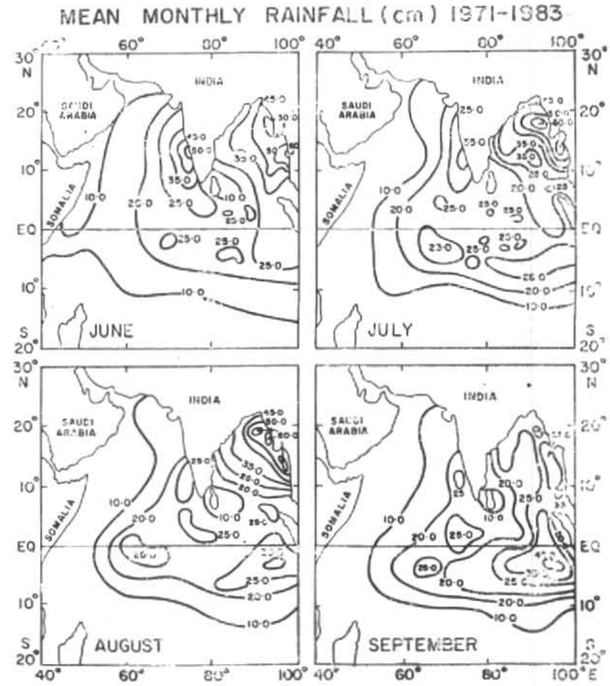

Fig. 6. Distribution of mean monthly rainfall during Jun to Sep (1971-83)

Fig. 6 demonstrates distribution of monthly rainfall during June to September for 13 years (1971-1983) derived from monthly HRC frequencies. This figure indicates that during June heavy rainfall area is situated off the west coast of India with more compact isohyetal pattern over SE and NE Arabian Sea. This may be due to the presence of active ITCZ and occasional formation of cyclonic vortices over these areas during the onset phase of the southwest monsoon. As the season advances the heavy rainfall distribution off the west coast of India decreases due to less convective activity over this region. Heavy rainfall areas are now shifted over north Bay during July and August as compared to June and September. This is because monsoon depressions form more often during these months over north Bay. During the withdrawal phase of monsoon (*i.e.*, during September) the heavy rainfall area is observed to the south of equator. This may be due to large-scale convective activity associated with oceanic ITCZ of the southern hemisphere.

Meteorological Data Utilisation Centre (MDUC), New Delhi has started archiving quantitative precipitation estimates (QPE) based on the sixteen class of histograms using INSAT-1B radiance data (Rao *et al.* 1989). The archiving of QPE in the domain 20°S to 35°N and 40°-100°E by India Met. Dep. is a part of Global Precipitation Climatology Project (GPCP) which is a part of TOGA (Tropical Ocean Global Atmosphere) programme. Archiving of QPE has started since 1986 and this project will continue for a decade.

Before the launch of INSAT-1B there was no geostationary meteorological satellite available over the Indian Ocean. During summer Monex-1979 GOES satellite of United States of America was specially brought for few months, for observing monsoon over the Indian Ocean. However, if one requires QPE for earlier years, *i.e.*, from 1971 to 1985 over the tropical Indian Ocean then one has to be dependent on the data available from polar orbiting satellites. Therefore, the empirical relation developed in the study would be useful to get rainfall estimates for the earlier years.

6. Conclusions

In this study an empirical relation between satellite observed monthly HRC and monthly rainfall has been illustrated, for deducing open ocean rainfall over the tropical Indian Ocean. How far this relationship holds good, is tested by comparing isohyetal patterns prepared by this method with those obtained by sophisticated technique using INSAT-1B thermal infrared radiance data. Isohyetal patterns obtained by both these methods reflect almost the similar features of low and high regions of rainfall estimates over the tropical Indian Ocean. This suggests that HRC data can be utilised with some confidence for rainfall estimates over the tropical Indian Ocean. Thus, rainfall estimates obtained by this method could be used in association with other meteorological parameters (*e.g.*, wind field, evaporation estimates and sea surface temperature) for several studies on various disciplines like numerical weather prediction models, climatology and oceanography.

Acknowledgements

Authors wish to thank Shri D.R. Sikka, Director, Indian Institute of Tropical Meteorology, for providing facilities and keen interest in the study. Thanks are also due to Dr. S.S. Singh, Head, Forecasting Research Division for his encouragement and guidance. Authors' thanks are extended to Dr. S. Rajamani, Dr. S.N. Bavadekar and Shri P.P. Kamte for critically going through the manuscript and offering valuable suggestions. Authors are grateful to Dr. R.R. Kelkar and Dr. A.V.R.K. Rao, MDUC, New Delhi for useful discussions. Thanks are also due to Smt. C. Bardhan for neatly typing the manuscript.

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