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Characteristics of Precipitation Systems over Iraq Observed by TRMM Radar

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ABSTRACT: *Estimates of precipitation from satellite data are less direct and less accurate than either gauges or radar, but have the advantage of high spatial resolution and complete coverage over oceans, mountainous, desert regions where other sources of rainfall data are not available. The aim of this research is to study the characteristics of precipitation systems over Iraq using the Tropical Rainfall Measurements Mission (TRMM) Precipitation Radar (PR). Analysis of 14 years TRMM PR precipitationdata over Iraq and nearby border regions with neighbouring countries indicated that north eastern part of the country receives the highest annual precipitation. The results indicated that the contribution to precipitation form from MCSs is higher than the contribution from thunderstorms and in the afternoon the contribution from MCSs reaches its minima while contribution from thunderstorms reaches its maxima. The results showed that the MCSs are main mechanism of precipitation formation over the area except during summer month when precipitation only comes from few thunderstorms that sometimes occur over the north and eastern part of the country. Comparisons between contributions from 20, 30, and 40 dBz radar reflectivity indicated that the contribution from 20 dBz reflectivity is higher than that from 30 dBz, and 40 dBz reflectivity. The contributions of reflectivity values were increasing with altitude until reaching their peaks then they were decreasing upwards.*

Keywords: *TRMM, Precipitation, Radar, Iraq.*

I. INTRODUCTION

Precipitation is one of the more difficult observational challenges of meteorological parameter to measure due to its spatial and temporal variability [1]. The main techniques used to measure precipitation are rain gauges, radar, and satellites. Each technique has its own advantages, and disadvantage. Satellite is the only instrument able to obtain data for rainfall over land and water. The use of satellite-derived products to estimate precipitation over land is important for monitoring the spatial and temporal distributions of precipitation [2]. The Tropical Rainfall Measuring Mission (TRMM) is the first space mission dedicated to measure tropical and subtropical rainfall through microwave and visible/infrared sensors, including the first space borne Precipitation Radar, PR [3]. There are numerous research papers on precipitation investigations using TRMM PR data. Nesbitt (2003) [4] showed that the diurnal cycle of rainfall that associated with Mesoscale Convective Systems (MCSs) over land is larger than over ocean where it was minimum in the midmorning hours, maximum in the afternoon, and slowly decreasing through midnight. Wilton (2005) [5] analyzed TRMM PR reflectivity fields to determine the vertical structure of precipitating cloud systems over South Asian. The statistics indicate that the eastern Himalayan region tended to have greater stratiform areas than the western Himalayan region. Hence (2011) [6] analyzed vertical structure of TRMM PR data that is seen in tropical cyclones for ten years. She found that the upper-troposphere portions of the outer eyewalls are weak and uniform like the inner rain bands, but the lower portions were more intense and uniform than rain bands of single eyewall storms and the distant rain bands were weaker, sparse, highly convective and less vertically constrained. Shrestha (2012) [7] compared the analysis of precipitation mechanisms over the rugged topography under moist and rather dry atmospheric conditions using TRMM data. He found that the precipitation occurs because of forced lifting and low-level moisture condition which is a key component to determine the precipitation mechanisms around the mountainous regions. Zagrodnik (2012) [8] evaluated TRMM rainfall retrieval algorithms in tropical cyclones and showed that the differences between PR and TMI retrievals related to the storm region and the convective nature of the precipitation as measured by radar reflectivity and ice scattering signature. Balogun and Adeyewa (2013) [9] analyzed storm structure of major climate regions in Africa and over adjacent Atlantic Ocean by using TRMM PR data. The analysis showed that the storm height over land was higher than that over sea and there were high storm counts over land at 250 mb whereas the storm counts were high over ocean at 700 mb.

Rapp et al. (2014) [10] analyzed TRMM PR features to understand the role of storm characteristics on the seasonal and diurnal cycles in Costa Rica. They found that the relative importance of convective precipitation increases on the Caribbean side during wintertime cold air surges, but for the coastal Caribbean domain, most regions showed a strong diurnal cycle with an afternoon peak in convection followed by an evening increase in stratiform rain. Yang and Nesbitt (2014) [11] revealed the statistical properties of tropics-subtropics precipitation for 13 years of TRMM PR measurements. They showed that the contributions from large rain intensity events are very importation in total precipitation, especially over land. In addition, the results showed that the statistical properties of precipitation could be utilized as a baseline in the assessment of precipitation from operational numerical weather prediction and climate models. Anders and Nesbitt (2015) [12] used TRMM PR data of rainfall and ERA-I reanalysis to study variability in surface precipitation rate-elevation relationship across the tropics. They found four-precipitation regime with distinct precipitation mechanisms.

II. MATERIALS AND METHODS

2.1 STUDY AREA

Iraq lies between 29.03° to 37.25° N latitudes and 38.75° to 48.75° E longitude (see Figure 1). The climate of Iraq is characterized by sub-tropical, continental, arid to semi-arid with dry hot summers and cooler winters. Rainfall is low in central and southern of Iraq (100-200 mm) but it concentrates in northern of Iraq which reach about 1000 mm and falls in November to April [13]. Roughly 90 percent of the annual rainfall occurs between November and April, most of it in the winter months from December through March. The remaining six months, particularly the hottest ones of June, July, and August, are dry. Except in the north and northeast, mean annual rainfall ranges between ten and seventeen centimeters [14].

2.2TRMM PR DATA

TRMM is a joint mission between the National Aeronautics and Space Administration (NASA) of the United States and the Japan Aerospace Exploration Agency (JAXA) of Japan. The satellite was launched in November 27, 1997 and is currently continuing to operate. The objectives of TRMM are to measure rainfall and energy (i.e., latent heat of condensation) exchange of tropical and subtropical regions of the world from the space. The PR is crucial to the TRMM mission because of its ability to see the precipitation field with high resolution in both the horizontal and vertical. The PR operates at a frequency of 13.8 GHZ (2.17 cm wavelength, K_u band). The data used in this study was downloaded from University of Utah TRMM database for a zone bounded by longitude 38-50^o E and latitude 28-36^o N. The data set covers the period from 1998 to 2011. The domain of Utah TRMM database is 36^o S - 36^o N and – 180^o - 180^o.

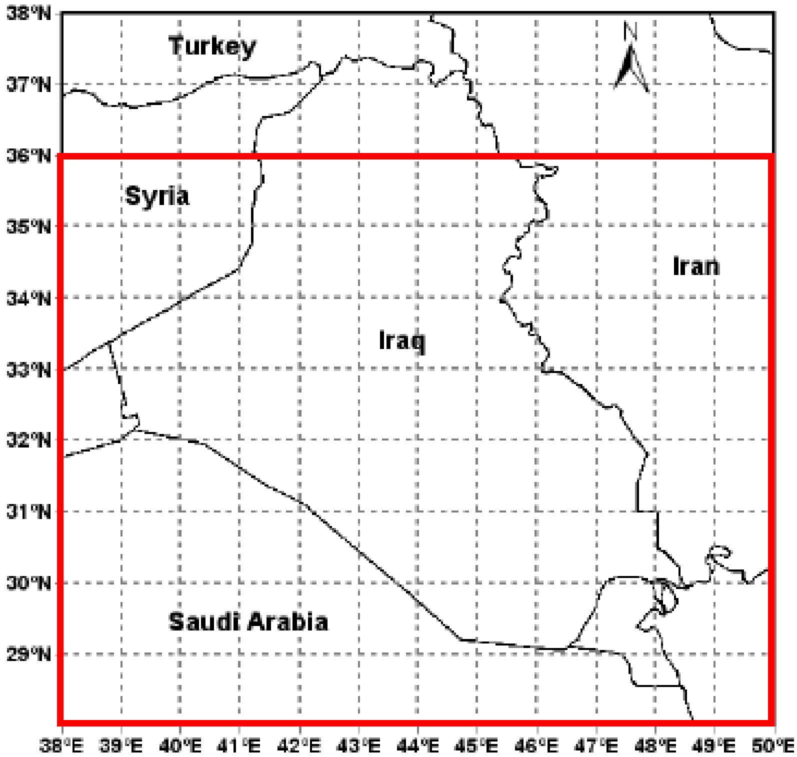

Figure 1. Map of Iraq showing the bounded zone.

III. RESULT AND DISCUSSION

Figure 2 shows the 14 years mean annual precipitation. It is seen that the mountain area of the north eastern part of the country and the eastern strip close to the border with Iran receives the higher amount of precipitation, more than 400 mm/year. The desert area in the western and south western part receive an amount of less than 130 mm/year.

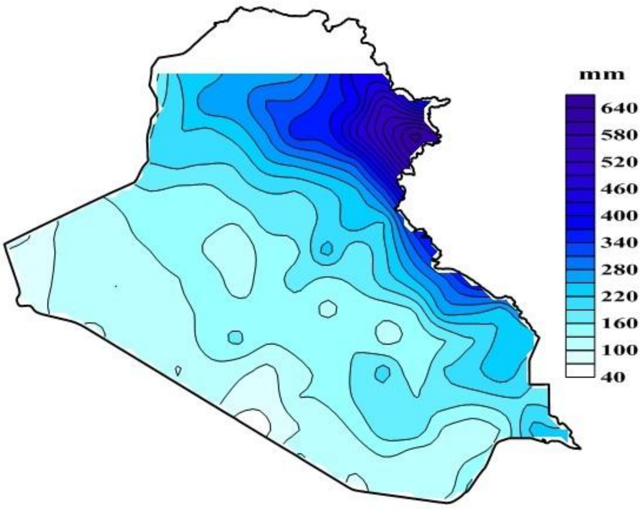

Figure 2. Mean annual rainfall (mm) over Iraq for 1998-2011.

Figure 3 gives the contribution of hourly precipitation from Thunderstorms, and Mesoscale Convective Systems (MCSs) over the bounded zone. It is seen that the MCSs was larger than the thunderstorms in all the times where the values of precipitation contribution for MCSs was ranging between 68% to 85%, while the values of precipitation contribution for the thunderstorms was ranging between 29% to 69% and it is notable that the behavior of both of them contrasts with time when during day. The MCSs were higher than during night while the thunderstorms during night was higher than during day. This is attributed to the strong convection that usually occurs during afternoon and evening times over the zone.

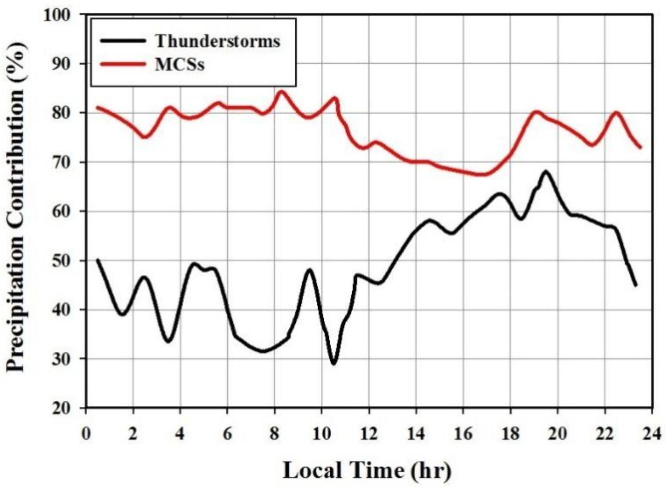

Figure 3. Precipitation contribution from Thunderstorms, and MCSs over zone of Lon 38-50^oE, Lat 28-36^oN for period 1998-2011.

Figure 4 shows the contribution of monthly precipitation from Thunderstorms, and MCSs over the zone. It is clear that the contribution from MCSs during the rainy season in Iraq (October to May) is higher than that from the thunderstorms. During summer months the contribution from MCSs is very low, less than 30% while the contribution from thunderstorms is less than 50%. It notable that during the months of May, and Sep thunderstorms have its peaks of contribution, more than 70%. During these months' warm temperatures and availability of moisture may cause convection processes leading to thunderstorms.

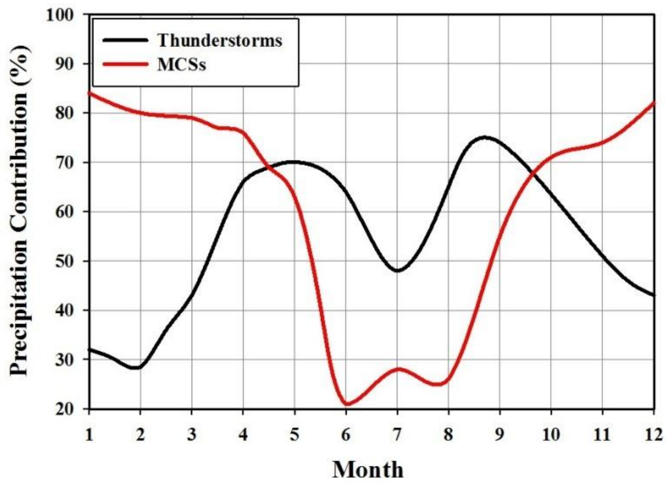

Figure 4. Monthly Precipitation contribution from Thunderstorms, and MCSs over zone of Lon 38-50°E, Lat 28-36°N for period 1998-2011.

Figure 5 gives the Cumulative Distribution Function (CDF) of the precipitation system size (left diagram) and echo top height (right diagram) for different seasons over the zone. The CDF of the precipitation size shows that 90% of the projections indicate an increase in precipitation size of less than 10^3 km^2 for months of DJF (December, January, and February), MAM (March, April, and May), and SON (September, October, and November) while for months of JJA (June, July, and August) 95% of the projections indicate an increase in precipitation size of less than 10^3 km^2. The CDF behavior is almost the same for DJF, MAM, and SON months while for the JJA months CDF is slightly higher by about 5%. This is due to the fact that low random precipitation activities occur during summer months so change in precipitation size is expected to be higher than changes during other seasons. The projected change in the middle of the range is an increase of 2×10^2 km^2 for DJF, MAM, and SON months, and for JJA months the increase is 10^2 km^2. The CDF of the echo top height shows that for DJF, MAM, and SON months 90% of the projections indicate an increase in echo top height of less than 10 km. Similarly, 5% of the projections indicate an increase in echo top height of less than 4 km.The values of the CDF were being higher for DJF months and lower for JJA months compared to the CDF of those for MAM and SON months. The projected change in the middle of the range is an increase of 3 km for DJF months, 5 km for MAM and SON months, and 7 km for JJA months.

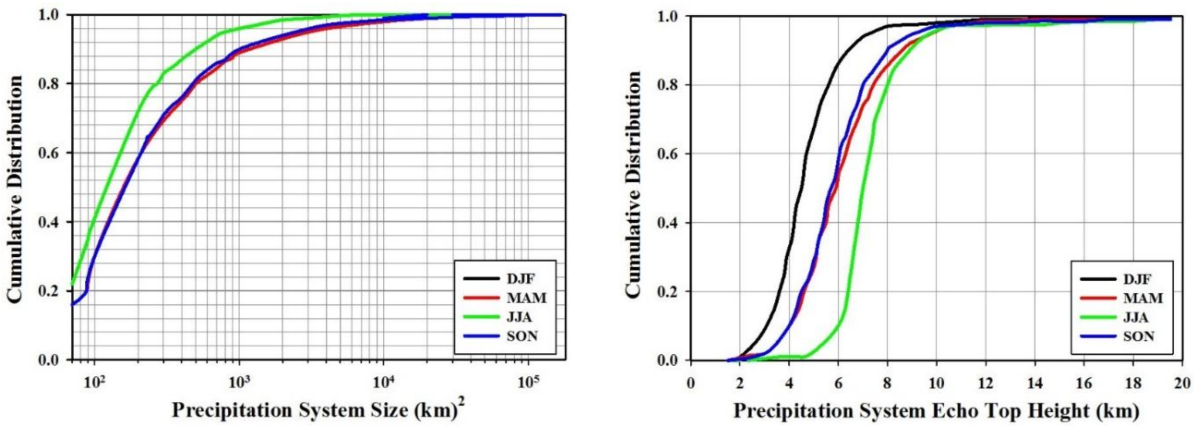

Figure 5. Cumulative distribution of precipitation. Left plot represents precipitation system size (km^2), Right plot represents precipitation system echo top height (km) over zone of Lon 38-50°E, Lat 28-36°N for period 1998-2011.

Figure 6 shows the rainfall contribution to the precipitation system size (left diagram) and echo top height (right diagram) for different seasons over the zone. It is obvious that the behavior of rainfall contribution is oscillating with precipitation system size in all seasons and ranging between 0 to 6.2%. From the plot, it is clear that the rainfall for DJF, MAM, and SON months have the symmetric behavior where it was oscillating and increasing gradually until the size of 2×10^4 to $6\times10^4 km^2$ then it begins to decrease rapidly, while the rainfall in JJA months increasing until the size of 1×10^3 km^2 then it decreases rapidly and continues to decrease. The value of rainfall for JJA months was higher in range of precipitation system size between 7×10^1 to 2×10^3 km^2 than other months, while in range between 2×10^3 to 2×10^5 km^2, JJA months islower than other months. The right side plot shows that the rainfall contribution has the oscillation behavior with precipitation system echo top height for all seasons and ranging between 0 to 11%. It is also notable that the behavior of rainfall for all months increasing in the beginning then decreasing with depth and the maximum value of rainfall contribution happened in JJA months in precipitation system echo top height of 8 km, while for the rest of months the top value of rainfall was approximately 6.5% obtained in ranging of precipitation system echo top height between 6 to 9 km.

Figure 7 illustrates the vertical profiles of TRMM PR reflectivity values of 20, 30, and 40 dBz over the zone. It is obvious that the contribution of 20 dBz is the highest and the contribution of the 40 dBz is the lowest among the three reflectivity values. For all reflectivity values, the contributions were increasing with altitude from about 1 km and reached their maximum near the altitude of 2 km. The altitude of the peaks is slightly different, being highest for the 20 dBz and lowest for the 40 dBz. Beyond the peaks, the contributions decrease gradually with increasing height. At altitude of about 13 km the contributions of 20 and 30 dBz tend to be constant while the contribution from 40 dBz continues to decrease.

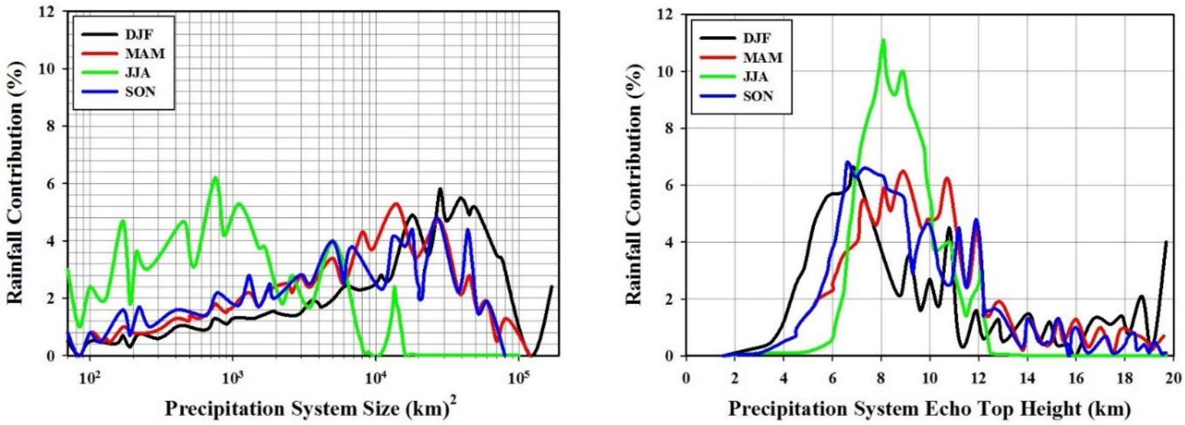

Figure 6. Seasonal rainfall contribution. Left plot represents precipitation system size (km^2), Right plot represents precipitation system echo top height (km) over zone of Lon 38-50^{o}E, Lat 28-36^{o}N for period 1998-2011.

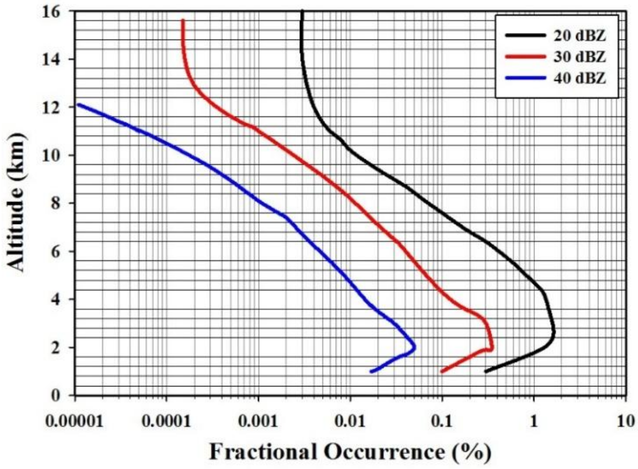

Figure 7. Vertical profiles of TRMM PR reflectivity at different altitudes over zone of Lon 38-50^{o}E, Lat 28-36^{o}N for period 1998-2011.

IV. CONCLUSION

In this research, the estimated precipitation data obtained from the TRMM PR satellite during 1998-2011 over Iraq were analyzed. Results indicated that the mountain area of the country receives the highest annual precipitation while lowest precipitation falls over desert area. The main contribution to precipitation comes from MCSs and thunderstorms contribution is sensible in the afternoon times. During dry summer month, precipitation only produced by thunderstorm that sometimes occur over the area, particularly over the north and north eastern parts of the country. Analysis of the radar reflectivity factor showed that the contribution from 20 dBz reflectivity is higher than that from 30 dBz, and 40 dBz reflectivity suggesting that the majority of precipitation is very light to light rain.

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