# THE EFFECT OF TROPICAL CYCLONES ON GLOBAL TROPICAL RAINFALL

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Submitted for the Siemens Westinghouse Competition
1 October 2003

# ABSTRACT

The tropical cyclone rainfall climatological study performed for the North Pacific by Rodgers et al. (2000) was expanded to the global level to assess the impact of tropical cyclones on the global rainfall.

Passive microwave satellite observations used to estimate monthly tropical rainfall amounts were used to attain the global totals for each year. These amounts were compared to estimates of tropical cyclone rain rates from a satellite-based computer model to evaluate the impact of tropical cyclone rainfall on the global tropical rainfall per year.

The results of these comparisons show that tropical cyclones contribute to 6.0% of the global rainfall in 1998, 4.6% in 1999, 5.6% in 2000, 5.8% in 2001, and 5.6% in 2002. It is also shown that TCs contribute the most rainfall to latitude bands that do not receive much global tropical rainfall.

## I. Introduction

Massive tropical cyclones (TCs) are propelled by the same energy that evaporates a tiny liquid water molecule off the Earth's surface. This energy is commonly known as latent heat -- the heat associated with phase changes of water. As the surrounding air is warmed and rises, the water vapor molecules rise along with it until they cool down and, in turn, condense to form liquid water molecules in clouds. The latent heat that drove the initial phase change is not lost. Instead, it is released during condensation and thus warms the air, causing it to remain buoyant. More air then flows in as this air rises and, through changes in the weight of the air pressure, wind is formed. This constant latent heat release (LHR) of billions of water molecules drives the wind patterns in the atmosphere (i.e. trade winds, westerlies, easterlies, etc.) and powerful TCs. As part of the continuous weather cycle, TCs also release a significant amount of latent heat and rainfall, making them an important source of energy transport in the tropics (Rodgers et al. 2000).

Rodgers et al. (2000) raised the question of the impact of TCs on the general circulation in their analysis of TC rainfall in the North Pacific. Data obtained from Special Sensor Microwave Imager (SSM/I) instruments on board satellites of the Defense Meteorological Satellite Program (DMSP) were used to estimate the mean monthly rainfall during the 11-year period of their study. These satellites orbit

Earth 14.1 times a day at an altitude of 833 km. The SSM/I is a passive radiometer – an instrument that measures the microwave energy emitted by Earth and the atmosphere on different frequencies. For the SSM/I, these frequencies are 19.4 GHz, 22.2 GHz, 37.0 GHz, and 85.5 GHz. The SSM/I is able to measure rain rate because bodies of water emit only half the microwave energy specified by Planck's law. Therefore, they appear to have only about half the actual surface temperature, which causes them to look "cool" to the radiometer. However, raindrops have a normal temperature, which contrasts against these "cool" bodies of water. Thus, it is possible to accurately obtain rainfall rates over water based on the present measured temperatures (Hollinger 1991).

Land, unlike water, is viewed by the microwave imager with most of its actual temperature. This difference between land and ocean emissions minimizes the visible contrast of the "warm" raindrops against a "cool" background. However, the 85.5 GHz high frequency microwaves are very easily scattered by ice in the intense convections of storms. This scattering, in turn, reduces the microwave signal at the satellite, offering the desired contrast against the warm land background and enabling surface rain measurements to take place, although they are less reliable than the open ocean measurements. (Kummerow et al. 1998).

This study expands on the basin-specific work of Rodgers et al. to attain TC rainfall contributions for the tropical regions of the entire globe for each year in the five year period of 1998 to 2002 and takes advantage of several advances in the field, such as the initiation of the Tropical Rainfall Measuring Mission (TRMM) and a satellite-based Rainfall Climatology and Persistence Model (R-CLIPER).

## II. Data and Method of Analysis

Launched in November of 1997, TRMM is a joint venture by the National Aeronautics and Space Administration (NASA) of the United States and the National Space Development Agency (NASDA) of Japan to measure tropical rainfall on a global level through the use of a satellite. The TRMM satellite orbits Earth at an altitude of 350[1] kilometers once every 90 minutes, which is 15 times a day. On board the satellite are several instruments – a visible and infrared radiometer system (VIRS), precipitation radar (PR), and the TRMM Microwave Imager (TMI) (Lonfat et al. 2003).

The TMI, like the SSM/I of the DMSP, is a passive radiometer. However, it operates on five different frequencies instead of four: 10.7 GHz, 19.4 GHz, 21.3 GHz, 37.0 GHz, and 85.5 GHz. From these measurements the TMI is capable of quantifying the water vapor, cloud water, and rainfall intensity in the atmosphere accurately over the oceans.

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[1] The TRMM orbit altitude was raised to 405 km in August 2001.

The results of the overall surface rain measurements give precipitation characteristics as a function of storm intensity, wind speed, and location (Lonfat et al. 2003). In order to identify any TMI orbits pertaining to TCs, a linearly interpolated best track file for all the storms is needed and can be obtained from any global hurricane forecast center. This file provides the following information at 6-hour intervals of each storm: location, intensity, speed, and direction of motion. Those TMI orbits matching the track file data with a distance between the storm and the sub-satellite point on the Earth of less than 500 km are added to the climatology. To date, the climatology consists of 482 storms spanning the period from 1 January 1998 to 31 December 2002. These storms are representative of the major global TC basins: Atlantic, East-Central Pacific, Northwest Pacific, South Pacific, North Indian, and South Indian. Figure 1 shows the distribution by basin of the storms over the 5-year period of the study and Figure 2 shows the number of storms for each year in the study.

The TMI rain climatology is the backbone of the satellite-based Rainfall Climatology and Persistence (R-CLIPER) computer model developed by Dr. Frank D. Marks, Jr. and Mark DeMaria in 2001 to overcome the limitations of the original gauge-based R-CLIPER. These models estimate the mean rain rate distribution of TCs according to their storm track and intensity. The satellite-based R-CLIPER uses the climatology partitioned by storm intensity to provide the mean rain rate distribution out to a 500 km radius from the storm center. When storm track data is provided, the R-CLIPER calculates an integrated rain distribution in 0.25° x 0.25° grids for the length of the storm. R-CLIPER's estimates, upon comparison to the gauge data taken during actual storms, were found to consistently underestimate the actual value by a factor of 2, but a feasible explanation for this has not yet been proposed (Marks et al. 2001). This underestimation is taken into account when calculating the total rainfall for each year.

To run the R-CLIPER, text files containing the latitude, longitude, and peak wind speed (in knots) for each 6-hour interval of the storm's existence were created for every storm in the climatology. These files were then individually run through the R-CLIPER to obtain the total rain (in inches) for each quarter-degree of latitude and longitude along the storm track. This data is stored onto an individual output text file for each storm. A computer program was then written in the Interactive Data Language (IDL) to attain a yearly total of rain from these individual storm totals. This program takes as input the R-CLIPER file for each storm in the desired year and outputs the total rain (in inches) for each quarter degree of latitude and longitude throughout the entire year. Plotting this output using a spreadsheet/graphing program simplifies the process of working with the data to achieve the final sum. The data is plotted as total cm of rain. Integration of the graph yields the yearly rainfall sum in cm.

The global annual tropical rainfall totals come from the TRMM-derived monthly best-estimate precipitation rates (Algorithm 3B-43). The data is a merged rainfall analysis based on a 1.0º x 1.0º spatial resolution global band extending from 40.0º S to 40.0º N latitude. The product represents the best rain estimates from the TMI over the oceans and gauges over the land. These data can be downloaded as monthly files from the TRMM website[2]. The process of attaining a yearly sum from the 3B-43 files is very similar to that of the R-CLIPER files. In fact, the program used to sum the 3B-43 files is actually a modified version of the program used for the R-CLIPER files. It asks for each monthly file in the desired year as input and outputs the total rainfall in mm for each degree of latitude and longitude. This output is converted into total cm of rain, plotted versus latitude for each 1.0º latitude belt, and integrated to find the total rain for the desired year.

## III. Results and Discussion

An analysis of the resultant plot of global tropical rain, as shown in Figure 3, reveals some key features about the years being studied. A constant trend is a general double-peak shape in all five years. This occurs because the amount of rain

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[2] http://trmm.gsfc.nasa.gov/

decreases as the Equator is approached. 1998's graph is the only graph that looks somewhat symmetrical, though. The other four years have a much higher peak in the positive latitudes, which represent the Northern Hemisphere, than in the negative latitudes, which represent the Southern Hemisphere. As seen in Figure 3, 1998 has a significantly higher peak in the Southern Hemisphere than any other year. In fact, 1998 is the only year that has a higher peak in the Southern Hemisphere than in the Northern Hemisphere. This is most likely due to the effects of the El Niño Southern Oscillation (ENSO). 2002, however, has the highest peak in the Northern Hemisphere and overall in the graph, but has the least amount of rain globally of the five years. The largest amount of global tropical rain comes in 1999.

More information is revealed in the graph of TC rainfall as shown in Figure 4. Double peaks are again present since no hurricanes cross the Equator or form on it. This is because "…tropical cyclones do not form within 3° of the Equator. The Coriolis parameter vanishes at the Equator and increase to extremes at the poles. Hence, a threshold value of Earth vorticity (*f*) must exist for a tropical cyclones to form. However the likelihood of formation does not increase with increasing *f*. Thus, nonzero Earth vorticity is necessary, but not sufficient to produce tropical cyclones" (Marks, 2003). There is, however, a feature in this graph which is not seen in the global rainfall graph, and that is a third peak, which is seen forming around 24.0º-27.0º N latitude in three of the years (1998, 2001, and 2002). A geographical plot of the TC rainfall for the years was made, as shown in Figure 5, to further investigate this anomaly. However, there doesn't appear to be a constant trend that causes this peak. The most probable cause is the variation of TC locations in these years.

The total TC rainfall amounts for 1998 match the trend set in the global tropical rainfall graph. TCs contribute significantly more rain to the Southern Hemisphere in 1998 than in any other year and it thus has a much higher peak in that area. It strays from the global tropical rainfall graph, though, in that the peak in the Northern Hemisphere is greater than that of the Southern Hemisphere. This leads to its having the greatest amount of TC rainfall in the five year period. 1999, however, does not carry on the trends set by the global tropical rainfall data. Although it has the largest amount of global tropical rain in the five years, it conversely has the least amount of TC rainfall. The other years are fairly constant. Comparing the TC rainfall sums with the global tropical rainfall totals yields the following percent contribution of TCs: 6.0 % in 1998, 4.6 % in 1999, 5.6 % in 2000, 5.8 % in 2001 and 5.6% in 2002. Despite the expansion of these comparisons to produce a global set of data, the TC rainfall to total rainfall comparison is only slightly less than that calculated by Rodgers et al. for the North Pacific basin, which was 7.0% (2000). Such consistency indicates that TCs contribute enough rainfall globally to compensate for those areas lacking in TC activity.

## IV. Conclusions and Future Work

An examination of the global tropical rainfall amounts and the global TC rainfall amounts for the five-year span of 1998-2002 yields several conclusions. First, this shows that TC rainfall is generally consistent with the global tropical rainfall of the year. With the exception of 1999, which has the least amount of TCs of the five years, the trends set by the global tropical rainfall were also seen in the TC rainfall. This consistency can lead to more accurate predictions for the amount of TC-related rainfall an area receives in a year.

Also, the latitude bands receiving the most TC rainfall, ± 15.0º - 30.0º do not receive high amounts of global tropical rain. In fact, these latitude bands are typically associated with deserts and other arid areas. Such high TC rainfall amounts in these low-rainfall areas are indicative of the significance of TC rainfall, as it is likely that they contribute up to 20-30% of the total rainfall there.

Rodgers et al. took this extra step in their study to calculate specific percentages for the western, eastern, and central regions of the North Pacific (2000). Such specificity can be applied to the global study of TC rainfall in the future, especially in the latitude bands of ± 15.0º - 30.0º. Furthermore, Rodgers et al. also found the areas of the North Pacific where TC rainfall had the greatest percent contributions to be off the lower Baja California coast and northeast of the Philippine Islands (2000). Future studies dedicated to finding such maximum contribution areas, whether globally or in specific basins, should give more insight as to the nature of the impact of TCs on the general atmospheric circulation and the associated ecological and/or economical effects.

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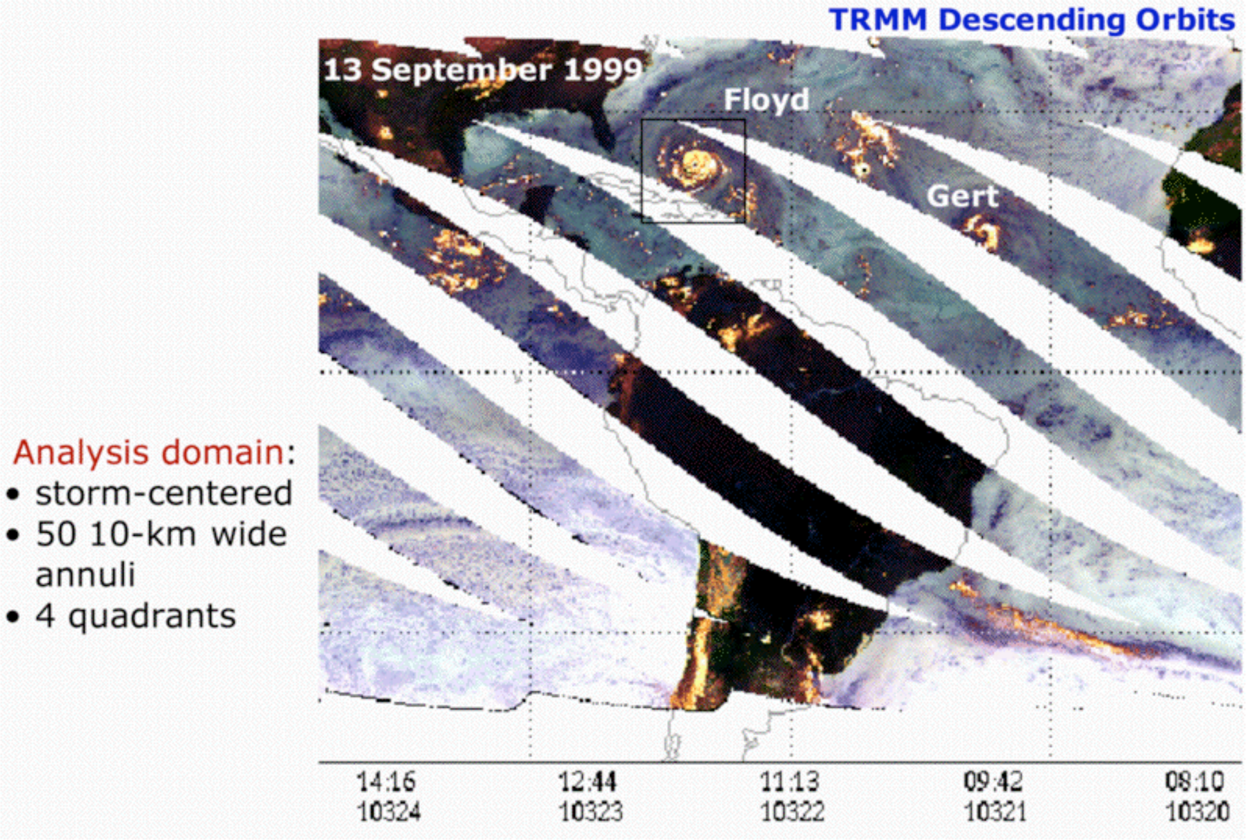
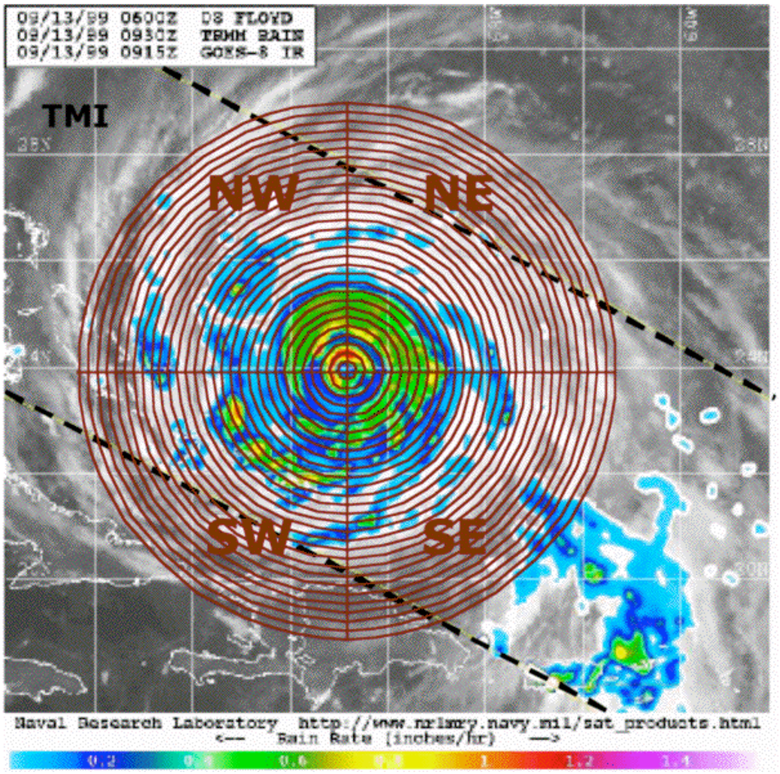
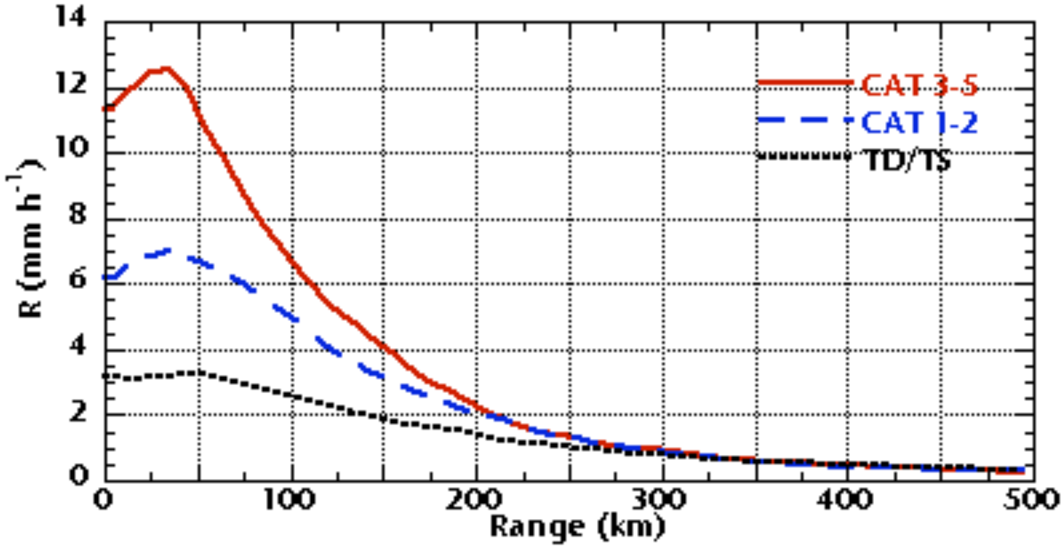
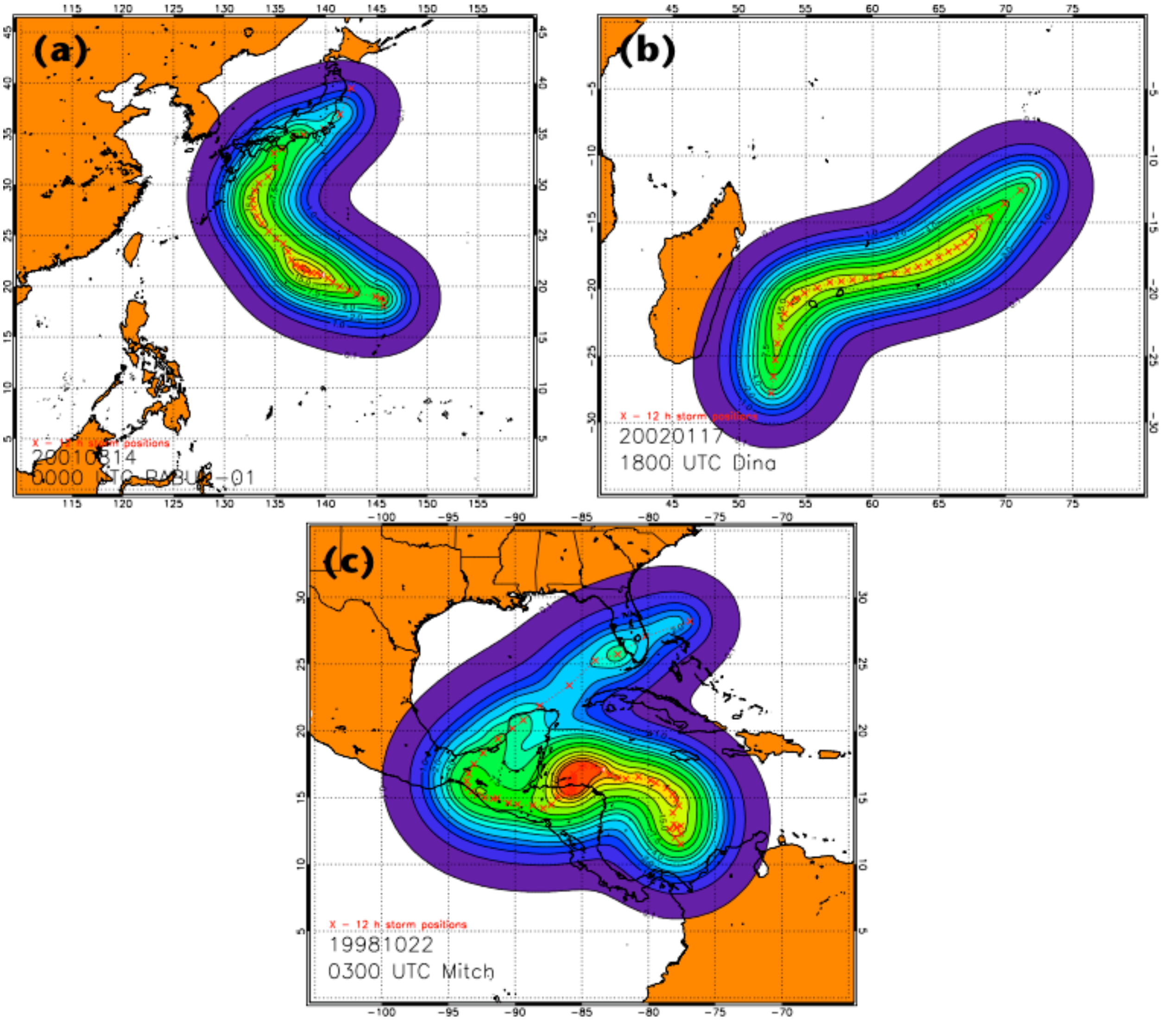
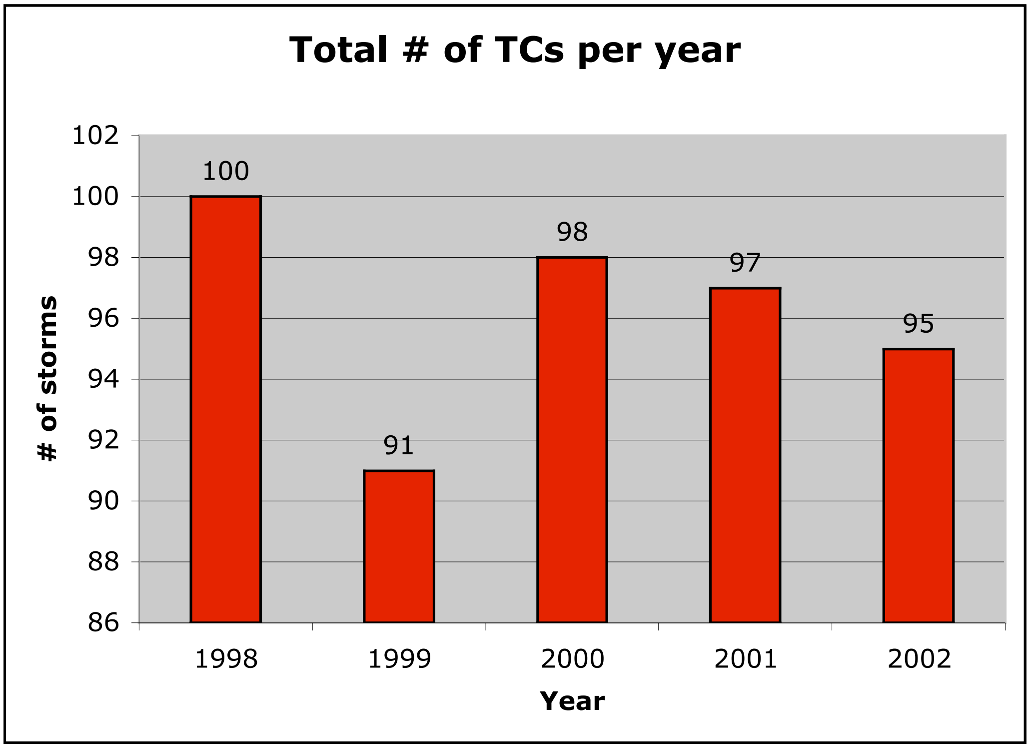
Figure captions:

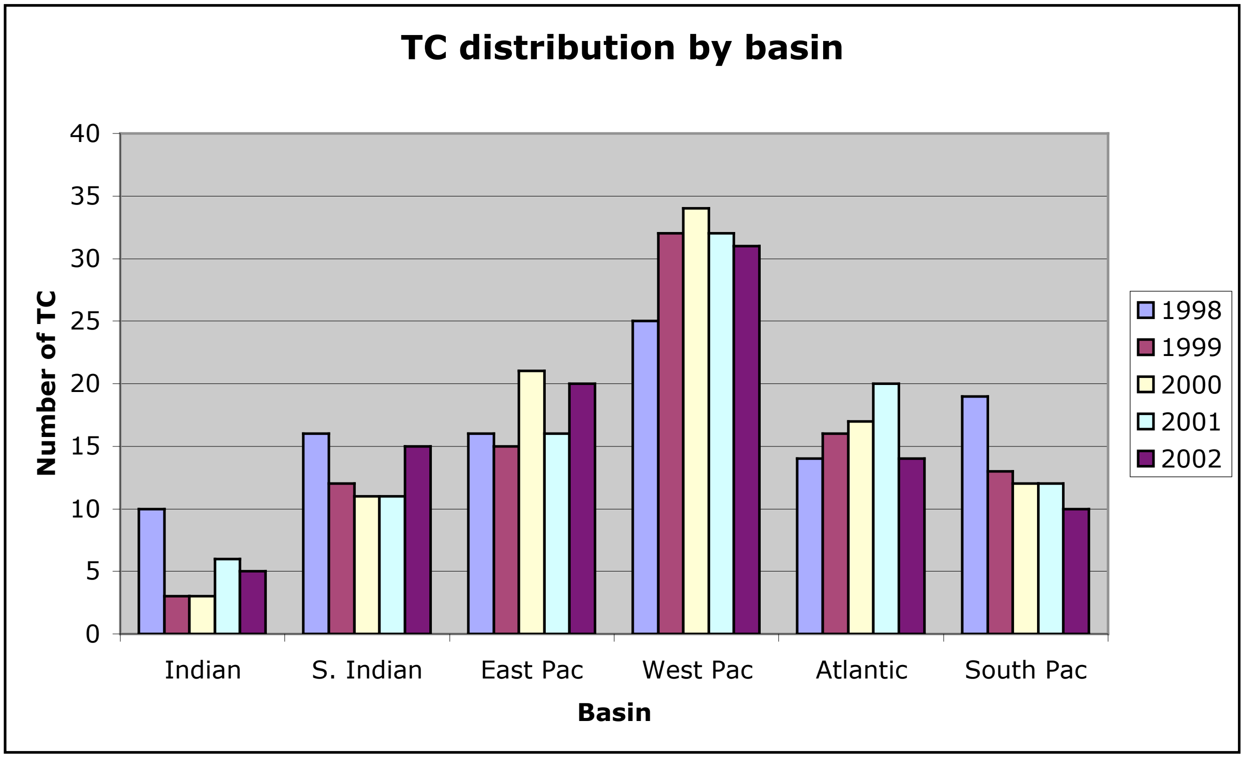


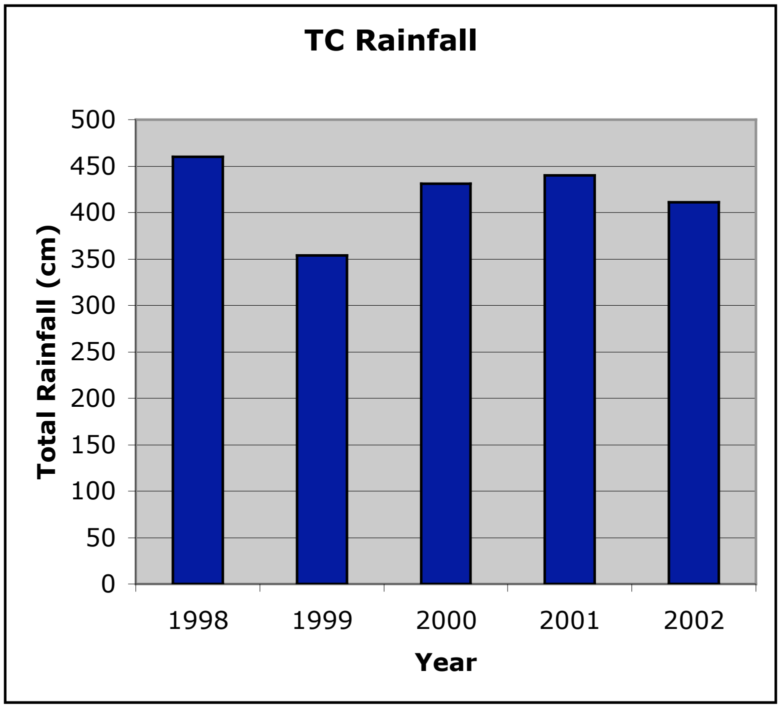


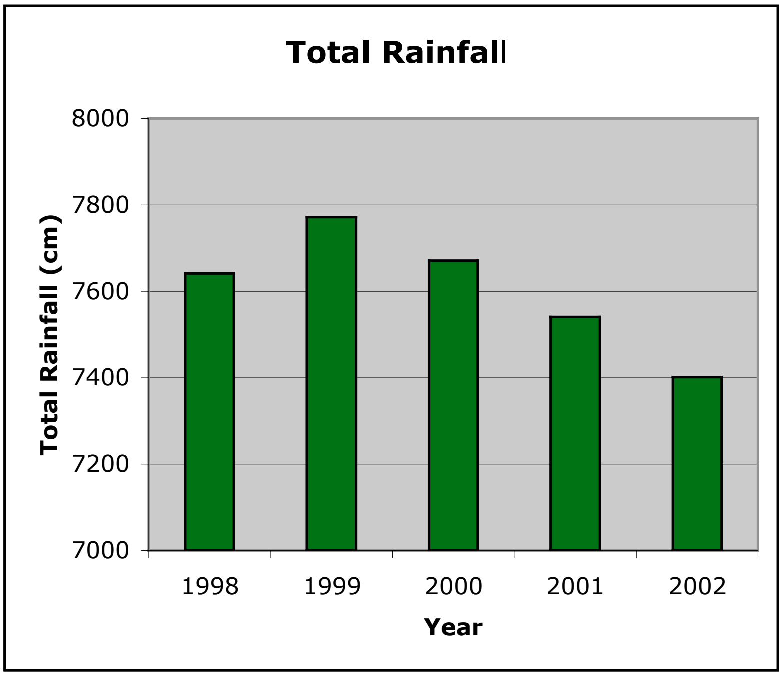

R (mm h$^{-1}$)
Range (km)
0
2
4
6
8
10
12
14
0
100
200
300
400
500
CAT 3-5
CAT 1-2
TD/TS

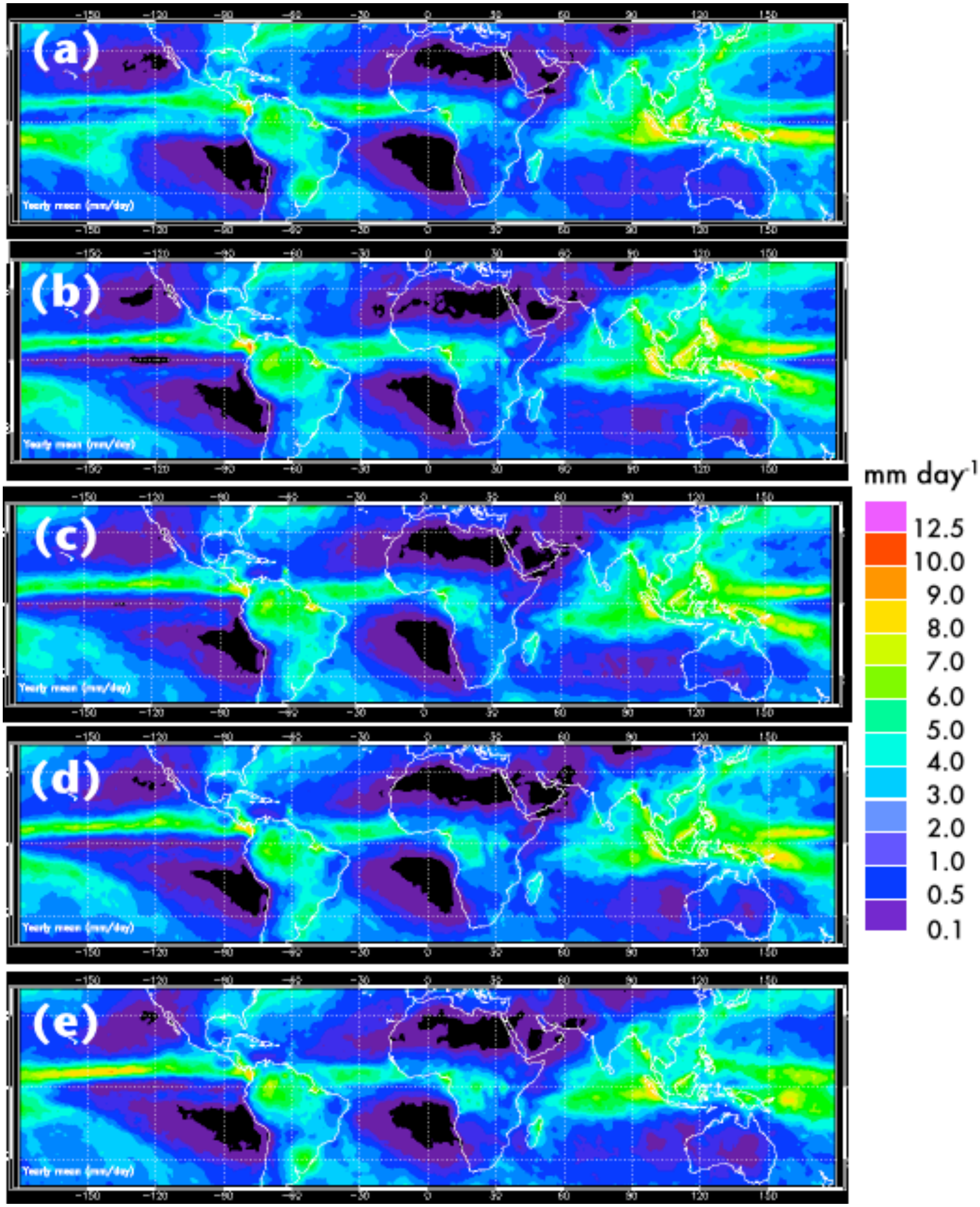

(a)
X = 12 h storm positions
20010814
0000 UTC PABUK-01
(b)
X = 12 h storm positions
20020117
1800 UTC Dina
(c)
X = 12 h storm positions
19981022
0300 UTC Mitch

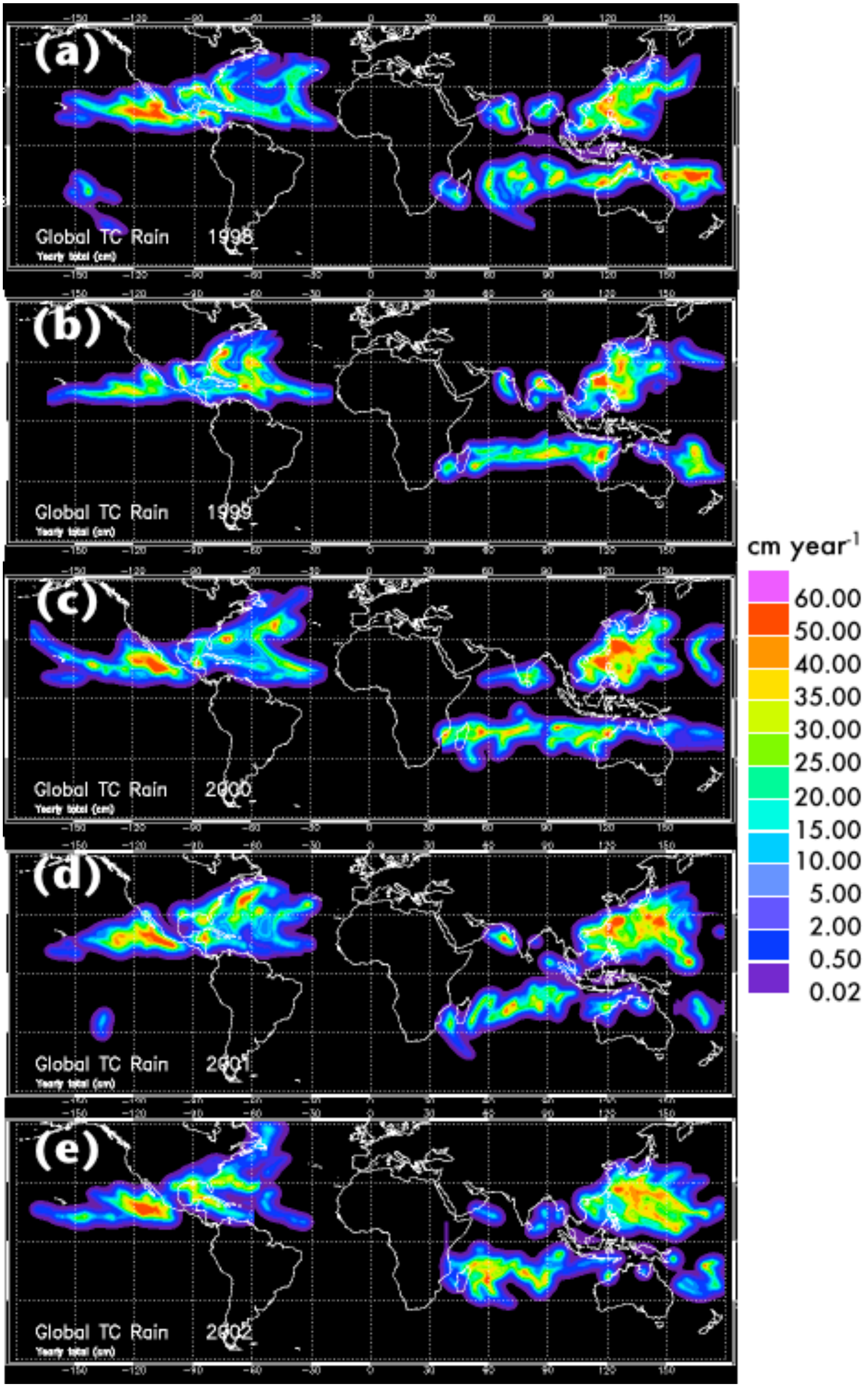

Total # of TCs per year
# of storms
102
100
98
96
94
92
90
88
86
100
91
98
97
95
1998
1999
2000
2001
2002
Year

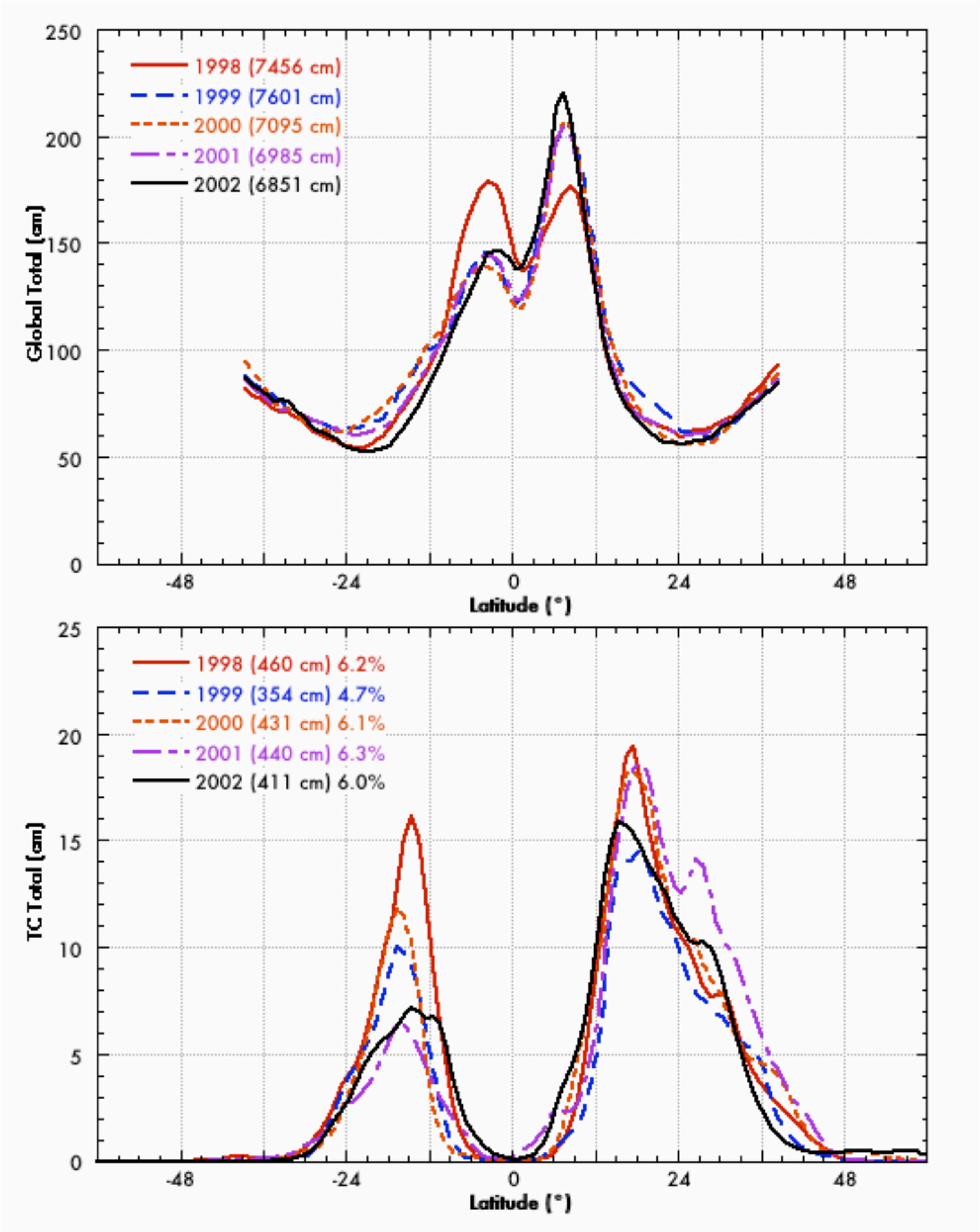

TC distribution by basin
Number of TC
40
35
30
25
20
15
10
5
0
Indian
S. Indian
East Pac
West Pac
Atlantic
South Pac
Basin
1998
1999
2000
2001
2002


TC Rainfall
Total Rainfall (cm)
500
450
400
350
300
250
200
150
100
50
0
1998
1999
2000
2001
2002
Year


Total Rainfall
Total Rainfall (cm)
8000
7800
7600
7400
7200
7000
1998
1999
2000
2001
2002
Year


(a)
(b)
(c)
(d)
(e)
Yearly mean (mm/day)
−150
−120
−90
−60
−30
0
30
60
90
120
150
mm day⁻¹
12.5
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.5
0.1


(a)
Global TC Rain 1998
Yearly total (cm)
(b)
Global TC Rain 1999
Yearly total (cm)
(c)
Global TC Rain 2000
Yearly total (cm)
(d)
Global TC Rain 2001
Yearly total (cm)
(e)
Global TC Rain 2002
Yearly total (cm)
-150
-120
-90
-60
-30
0
30
60
90
120
150
cm year$^{-1}$
60.00
50.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
2.00
0.50
0.02


250
200
150
100
50
0
Global Total (cm)
1998 (7456 cm)
1999 (7601 cm)
2000 (7095 cm)
2001 (6985 cm)
2002 (6851 cm)
-48
-24
0
24
48
Latitude (°)
25
20
15
10
5
0
TC Total (cm)
1998 (460 cm) 6.2%
1999 (354 cm) 4.7%
2000 (431 cm) 6.1%
2001 (440 cm) 6.3%
2002 (411 cm) 6.0%
-48
-24
0
24
48
Latitude (°)