The Effect of Tropical Cyclones on the Global Annual Rainfall

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July 27, 2005

ABSTRACT

Simo (2003) expanded the tropical cyclone (TC) rainfall study performed for the North Pacific by Rodgers et al. (2001) globally to access the impact of tropical cyclones on the global tropical rainfall. This analysis carries on Simo's study to determine the impact of tropical cyclones on global annual rainfall with the inclusion of improved tools and a larger data set. Passive microwave satellite observations were used to attain the global rainfall totals for each year. These amounts were compared to estimates of tropical cyclone rainfall rates from a satellite-based Rainfall Climatology and Persistence (R-CLIPER) computer model to determine the impact of tropical cyclone rainfall on the global annual rainfall.

The results of these comparisons show that tropical cyclones yield the following percent contributions of TCs: 2.4 % in 1998, 1.8% in 1999, 2.3 % in 2000, 2.3 % in 2001, 2.2 % in 2002, 2.6 % in 2003, 2.8 % in 2004, and 2.6 % in 2005. It is also shown that TCs contribute the most rainfall to latitude bands that do not receive much global rainfall.

I. Introduction

As a valuable climatic variable, rainfall plays a significant role in the hydrological cycle of global atmospheric circulation. Rainfall is a natural resource, which helps to benefit the welfare of human beings. However, when extremes in rainfall arise it can produce a serious amount of flooding, such as the rain associated with tropical cyclones (TC). Significant amounts of precipitation are delivered by TCs daily. Rainfall is not a concern to society when a TC is over the ocean, however when it makes landfall it creates a serious threat to society from urban and inland flooding (Marks et al. 2001). Rainfall from TCs is not always unpleasant. They are important factors in the hydrologic cycle of places they impact, bringing much needed rain to dry regions. TC rainfall plays an essential role within the overall climatology of the Southern, Eastern and Southeastern United States along with areas in Mexico. Equally as important, Japan receives over half of its rainfall from typhoons. The amount of this rainfall can vary from a light drizzle to an extreme surge. The effect of this rainfall is broad in scope because it impacts local hydrologic, and agricultural, and societal needs (Gleason 2006).

Tropical cyclones form from frequently occurring groups of loosely organized deep cumulus clouds, referred to as tropical disturbances, which occur in a variety of tropical weather settings. Traditionally, areas of tropical cyclone formation are divided into six basins: Atlantic, East Pacific, North West Pacific, South Pacific, North Indian and South Indian. Most tropical cyclones evolve in the Intertropical Convergence Zone (ITCZ), an area of low pressure that develops where the Northeast trade winds meet the Southeast trade winds near the equator (Palmer 2005).

Since most tropical disturbances do not progress into powerful storms the category 3-5 hurricane is a rare occurrence. Tropical storms are defined as systems with wind speed between

18 and 33 ms^{-1}, category 1-2 (CAT 12) systems with wind speed between 34 and 48 ms^{-1}, and category 3-5 (CAT35) systems with wind > 49 ms^{-1} (Lonfat et al. 2004). Nearly all of these systems develop between 10^o and 30^o of the equator and 87% form within 20^o degrees of the equator. Tropical cyclones ordinarily do not form within a few degrees of the equator due to the Coriolis Effect, which initiates and maintain cyclone rotation; given that at the equator the Coriolis parameter is zero and very weak in regions surrounding the equator (Williams 2005).

Rodgers et al. (2001) performed a tropical cyclone rainfall climatological study for the North Pacific and North Atlantic basins. In their study they used passive microwave satellite observations to estimate the mean monthly rainfall within 444 km of the center of the tropical cyclones over an eleven-year period, 1987-1998. Observations acquired from the Special Senor Microwave Imager (SSM/I) tool on the Defense Metrological Satellite Program (DMSP) were used to examine geographical, seasonal, and interannual variations in the North Atlantic and North Pacific tropical cyclone rainfall (Rodgers et al 2001).

In 2003, Monica Simo expanded Rodgers et al. study to the global level to access the impact of tropical cyclones on the global annual rainfall, from 1998-2002. Passive microwave satellite observations, from the Tropical Rainfall Measuring Mission (TRMM), were used to attain the global totals for each year. These amounts were then compared to estimates of tropical cyclone rain rates from a satellite-based Rainfall Climatology Persistence (R-CLIPER) computer model to evaluate the influence of tropical cyclone rainfall on the global tropical rainfall per year (Simo 2003).

This analysis carries on Simo's study to determine the impact of tropical cyclones on global annual rainfall, with improved tools from both TRMM and the R-CLIPER computer model. In this assessment, each of the basins was examined over an eight-year period, 1998 to 2005.

II. Data and Analysis

One of the most difficult parameters to measure is precipitation due to the large difference in space and time. As a result, the idea of measuring rainfall from space using a combined instrument complement of passive and active microwave instruments was generated in the early1980s, which lead to the development of TRMM (Kummerow et al. 2000). TRMM is a combined mission between the U.S. National Aeronautics and Space Administration (NASA) and the Japanese National Space Development Agency (NASDA) (Lonfat et al. 2004). Launched November 27, 1997, the goal of TRMM is to measure global tropical rainfall and energy exchange of tropical and subtropical areas of the world (Kummerow et al. 1998). Furthermore, TRMM is NASA's first mission dedicated to observing and understanding the tropical rainfall and how it affects the global environment. The primary rainfall instruments on board TRMM are the TRMM Microwave Imager (TMI), the Precipitation Radar (PR), and the Visible and Infrared Systems (VIRS).

The TMI is a nine-channel passive microwave radiometer based upon the SSM/I aboard the DMSP. It runs on five different frequencies: 10.7 GHz, 19.4 GHz, 21.3 GHz, 37 GHz, and 85.5 GHz. From these frequencies the TMI is capable of calculating the water vapor, cloud water, and rainfall intensity in the atmosphere. The PR was the first rain radar in space. Working collectively with the passive, TMI and VIRS, sensor data the active PR aims to improve the overall TRMM precipitation retrieval accuracy. It provides a 3-dimensional structure of rainfall, particularly the vertical distribution. The PR also obtains quantitative rainfall amounts over land

and over the ocean as well. VIRS is a five-channel imaging spectroradiometer with bands in the wavelength ranging from 0.6μm to 12μm.

The data used from TRMM was from the 3B43 Algorithm. Algorithm 3B43 takes all of the rain estimates once per calendar month, combining two independent precipitation fields, to produce the single best estimate for the monthly mean precipitation rate and root-mean-square (RMS) precipitation error estimates. These estimates are the three-hourly merged high quality (HQ)/infrared (IR) estimates from the 3B42 algorithm and the monthly-accumulated Climate Assessment and Monitoring System (CAMS) or Global Precipitation Climatology Centre (GPCC) rain gauge analysis (3A45). After the data is compiled the gridded estimates are on a calendar month temporal resolution and a 0.25° by 0.25° spatial resolution global band extending from 50° South to 50° North (TRMM-GFSC).

To overcome the limitations of the original gauge-based Rainfall Climatology Persistence (R-CLIPER) model, Dr. Frank D. Marks, Jr. and Mark Demaria developed a computer R-CLIPER model, in 2001. R-CLIPER is a statistical model that uses a global satellite-based rainfall climatology, which includes rain estimates from the TMI microwave imager onboard the TRMM satellite (Marks et al. 2001). The TMI climatology is the backbone of the satellite-based R-CLIPER. The climatology consists of the following information for each TC at 6-hour intervals: location, intensity, speed, and direction of motion. The TMI rain climatology, partitioned by storm intensity, is used by the satellite-based R-CLIPER to provide the storm-centered mean rain rate distribution out to 500 km radius from the TC center (Marks et al. 2001).

The R-CLIPER model determines a climatological rainfall rate and then integrates the rainfall rate along the storm track. A number of studies have shown that the rainfall rate is directly related to the storm's intensity, with a tendency for higher rain rates for stronger storms.

This effect is taken into account in the R-CLIPER model (Tuleya et al. 2005). Other studies have shown that there are substantial azimuthal asymmetries in TC rain rates. These asymmetries are caused by a number of factors, but the storm's reaction to the environmental vertical wind shear seems to be the most important factor. Since this effect depends on the specific synoptic event, asymmetries are not taken into account in the R-CLIPER model (Tuleya et al. 2005). The simple R-CLIPER model generates a rainfall path dependent on storm track, intensity, and size, which is operational at a 0.25° by 0.25°- hourly resolution for the duration of the storm. (Marks et al 2001). Marks et al. found that R-CLIPER consistently underestimated the total rainfall amounts by as much as a factor of 2. This underestimation was taken into account when the total rainfall was calculated for each year in Simo's study. However, R-CLIPER has been improved and no longer underestimates the total rainfall.

The rain estimates for tropical cyclone and global rainfall are generated in a similar manner described by Simo (2003). The primary differences between the past study and the present one is the use of a higher resolution of the 3B43 data set used here, from 0.25^{o} by 0.25^{o} from 50^{o} N to 50^{o} S compared to 1^{o} by 1^{o} from 40^{o} N to 40^{o} S used in Simo's study (2003). Also, in this analysis the R-CLIPER output is used without correcting for the typical factor of 2 bias.

To run R-CLIPER, the TCs best track storm data must be downloaded from a global hurricane forecast center. Once the year is selected the data is copied into a blank text document and then opened in Excel. A spreadsheet/graphing program is used to sort the TC files according to their perspective names. A new file for each storm is then created. Next the latitude, longitude, and peak wind (in knots) are interpolated to six-hour intervals starting at 00UTC. Copying the interpolated latitude, longitude, and peak wind into a new text document creates an input file for R-CLIPER. The first four lines of the file include metadata for the model to use. Other significant information for each file is the storm number for the particular basin, year, month, day, starting hour, and the number of six-hour track points. The R-CLIPER model can now be run. After entering the input file name when requested, the model will run and return a R-CLIPER data file. The data file can be plotted using a computer program written in Interactive Data Language (IDL). This program is used to attain a yearly rainfall amount from the individual storm totals. This program takes as input the R-CLIPER file for each storm in the specified year and outputs the total rain (in centimeters) for each 0.25° of latitude and longitude throughout the year in a text file along with an image showing the distribution of the rainfall. The text file output is plotted using a spreadsheet/graphing program to attain the total sum of rainfall.

To accumulate the global rain using the 3B-43/TRMM data, the monthly 3B-43 TRMM global rain product in hierarchical data format (HDF) must be downloaded from the TRMM orbital data products site. Once the files are downloaded the surface rain data must be stripped from the HDF files. A program creates binary files of the surface rain with the same name as the 3B-43 files with a *.precipitation* extension. A list must be created of all the monthly *.precipitation* files as input for a program that converts them to a format for the IDL program. Then an input list is created for the IDL program that sums the 3B-43 monthly files. After the IDL program is run an output text file is created that contains the yearly mean rain rate, along with another graphic representation of the rainfall.

A comparison is then produced of the yearly TC rain from the R-CLIPER with the global mean rain from the 3B-43 TRMM product using another IDL program, whose input is the two text files, TC output and global output, produced from the previous IDL program. This IDL program lists the longitudinal mean rain rate for the TC and 3B-43 rain by latitude, and the ratio of the two. It also produces a graphic of the relative percent of TC rain at any 0.25^o X 0.25^o degree location.

III. Results and Discussion

There are only three aspects of the tropical cyclone that affects how the R-CLIPER model determines the total rainfall amount for each year: the number of storms, their duration, and the intensity of each storm. Figure 1 shows the total number of storms for each year in the study, from 1 January 1998 to 31 December 2005. Though there is not a significant difference when comparing the storm totals by year, there is a noticeable change when examining the differences in the hemispheres. The northern hemisphere storm totals are steadily increasing about two times faster than the southern hemisphere storms are decreasing. Another comparison of the storm totals is the distribution of the storms by basin over the 8-year period, shown in Figure 2. Usually the North West Pacific leads the other basins in TC totals, however in 2005 there was a dramatic decline in the number of storms in North West Pacific basin, which brought its total number of storms from 34 to only 25. Witnessed in the same year was a substantial increase in TC activity in the Atlantic basin, with a total of 31 TCs, nearly doubling its previous year in storm activity. As a result, in 2005 the Atlantic basin lead all other basins in TC activity. While there are different variations with the number of storms per basin and hemisphere there is only a slight variation in the total number of storms per year.

Another key feature in TCs is their duration. Figure 3 shows the total duration of storms for each year. 2004, with 522 days, had the longest duration of storms while 1999 had the shortest duration, 406 days, along with the lowest total of storms and the least amount of TC rainfall. However, when comparing the length of the average durations 2003 had the highest with 5.4 days. In 2003 half of the storms lasted 4.8 days, with the shortest and the longest storms being 12 hours and 21 days respectively. Though 2004 had one of the longest lasting storms, 21.75 days, it also had one of the shortest, lasting only 6 hours. Fifty percent of the storms lasted: 3.8 days in 1998, 3.6 days in 1999, 4 days from 2000 to 2002, 4.8 in days in 2003, 4.7 days in 2004 and 4.3 days in 2005. Accordingly, half of the storms last any where from 3.6 to 4.8 days with only a difference of about one day.

It has been noted that the rainfall rate is directly related to the storm's intensity; as a result R-CLIPER produces higher rain rates for higher intensities. Over the eight-year period, there were 780 TCs with 371 evolving into hurricanes, wind speeds of 64 knots or greater (Figure 4). The year with the least amount of hurricanes was 1999, 38, as compared to 2003 and 2005 which both received 52 hurricanes. A better relation of how the hurricanes influenced the perspective storm year is through percentages; since the total number of storms varied each year. 2003 had the highest percentage, 55%, since there were 52 hurricanes compared to only 95 total storms. In 1998 46% of the storms developed into hurricanes, 42% in 1999, 44% in 2000, 49% in 2001, 44% in 2002, 55% in 2003, 50% in 2004 and 50% in 2005.

An analysis of the resultant plot of TC rain, shown in Figure 5, reveals some key features about the years being studied. A constant trend is a general asymmetrical double peak shape in all eight years, due to the vanishing Coriolis parameter at the Equator; which prevents the formation of TCs in this region. There is also another third smaller peak seen forming from 27^{o} N to 33^{o} N. There does not appear to be a constant trend that causes this variation. The most likely reason is due to varied locations of TC formation in these areas. In the southern hemisphere TCs contributed much more rain in 1998 than in other years, which is also reflected with its much higher peak, 32^{o} S, in this region. This may because of the El Nino Southern Oscillation (ENSO). Collins (2005) stated that ENSO's effect on the southern hemisphere's rainfall is quite significant, as in the 1997- 1998 episode. The highest peak in the northern hemisphere, 15^{o} N, and overall in the graph was from 2004. Likewise, 2004 also contributed the most tropical cyclone rainfall overall, 1.44 X 10^{6} cm.

More information is revealed in the graph of global rainfall (Figure 6). Again there is a constant trend in the general double peak shape in all eight years. This occurs because the amount of rain decreases as the Equator is approached. The year 1998 deviates from the general trend because it is the only year that appears symmetrical, having a slightly higher peak in the southern hemisphere than the northern hemisphere. All of the other years have much higher peaks in the positive latitudes. The total global rainfall amounts for 1998 match the trend set forth in the TC rainfall graph. 2002 has the highest peak overall in the graph, 5^{o} N, although the largest amount of global rain comes from 1998, 55.8 X 10^{6} cm. This possibly results from the gradual decline of global rainfall. On the contrary, TC rainfall is continuously increasing. When comparing these results to Simo's study a discrepancy arises. Simo (2003) found that 1999 had the highest global rainfall total. This may be due to the different data sets that were used in this study compared to the data used by Simo (explained in the previous section). However, when comparing the lowest rainfall totals globally from 1998 to 2002, 2002 had the lowest rainfall totals just as in Simo's study.

When examining the images of the distribution of the rainfall from the R-CLIPER (TC rainfall) and the 3B-43 (global rainfall) several features are noticed. In the R-CLIPER images (Figure 7) one of the most noticeable features is the separation of rainfall surrounding the Equator. The North West Pacific basin has the heaviest amount of rainfall, which also has the most TCs compared to other basins. When comparing the hemispheres most of the TC rain in the western hemisphere is north of the Equator and in the eastern hemisphere majority of its rainfall is located in SE Asia and Australia. As compared to the other TC rain images 1998 is the only year where the increase in the rainfall in the southern hemisphere is noticeable. Unlike the northern hemisphere, rainfall in the southern hemisphere is not poleward. In the global rainfall image (Figure 8) there is a heavy band of precipitation centered on the Equator. As in the TC image there is an increase of rain in the SW hemisphere. Yet again, the greatest amount of rainfall globally is in the eastern hemisphere just as with the TC rainfall.

Comparing TC rainfall sums with the global rainfall totals yields the following percent contributions of TCs: 2.4 % in 1998, 1.8% in 1999, 2.3 % in 2000, 2.3 % in 2001, 2.2 % in 2002, 2.6 % in 2003, 2.8 % in 2004, and 2.6 % in 2005. Examining specific regions generates higher percentage contributions of tropical cyclone rainfall. In the latitudinal belt extending from 10^{o} N to 30^{o} N TCs contribute between 10% to 15% of the total rainfall and in the latitudinal belt 10^{o} S to 30^{o} S TCs make up 5% to 10% of the total rainfall there, most of which comes from the Eastern Hemisphere. Looking at even smaller areas produces greater percentages of TC rainfall. Rodgers et al (2001) found that TCs contribute, regionally, in the North Atlantic nearly 30% of the global rainfall, northeast of Puerto Rico. Comparable to the North Atlantic, Rodgers et al. also determined that TCs contribute approximately 7% of the rainfall during a tropical cyclone season in the North Pacific, with maximum regional contributions of approximately 30% northeast of the Philippines and 40% off the lower Baja California coast. On a global scale TCs only contribute about 2% to 3% of the total global rainfall but the higher percentages, up to 40%, of TC rainfall in certain regions indicate the significance of TC activity in these places.

IV. Conclusions

This study documents the global contributions of TCs to the tropical rainfall, using TRMM estimates of tropical rainfall and R-CLIPER TC rainfall totals, for the period from 1998-2005. It is found that:

- Globally, TCs contributes about 2% to 3% of the total global rainfall. The ratio varies from year to year with the largest contribution occurring during 2004 and the smallest contribution in 1999.
- The latitude bands receiving the most TC rainfall, 10^o to 30^o N and S, do not receive high amounts of global rain. These latitude bands are usually associated with deserts and other dry areas.

References

Collins, M., and the CWP Modeling Groups, 2005: El Nino- or La Nina- like climate change? Clim. Dyn., 24, 89-104.

Gleason, B., 2006: Characteristics of tropical cyclone rainfall in the United States. Reprints from the 27th *Conference on Hurricanes and Tropical Meteorology*, Monterey, CA, American Meteorological Society, Boston, MA.

Kummerow, C., Barnes, W., Kozu, T. Shiue, J., and J. Simpson, 1998: The tropical rainfall measuring mission (TRMM) sensor package. *J. Atmos. Ocean. Tech*., 15, 809-817.

Kummerow, C., J. Simpson, O. Thiele, W. Barnes, A. T C. Chang, et al., 2000: The status of the tropical rainfall measuring mission (TRMM) after two years in orbit. *J. Appl. Met*., 39, 1965-1982.

Lonfat, M., F.D., Marks, Jr., and S.S. Chen, 2004: Precipitation distribution in tropical cyclones using the Tropical Rainfall Measuring Mission (TRMM) microwave imager: A global perspective. *Mon. Wea. Rev*., 132, 1645-1660.

Marks, F. D., G., Kappler, and M. DeMaria, 2001: Development of a tropical cyclone rainfall climatology and persistence (R-CLIPER) model. Reprints of the 25th *Conference on Hurricanes and Tropical Meteorology*, San Diego, CA, American Meteorological Society, Boston, MA, 327-328.

Palmer, C., 2005: Intertropical convergence zone. USATODAY.com [http://www.usatoday.com/weather/witcz.htm]

Rodgers, E., Adler, R., and H. Pierce, 2001: Contribution of tropical cyclones to the North Atlantic climatological rainfall as observed from satellites. *J. Appl. Met.*, 40, 1785-1800.

Simo, M., 2003: Contribution of tropical cyclone rainfall to the global tropical rainfall. Submitted for the Siemens Westinghouse Competition.

Tuyela, R. E., M. DeMaria, R. J. Kuligowski, 2005: Evaluation of GFDL and simple statistical model rainfall forecasts for U.S. landfalling tropical storms. Accepted for publication in *Weather and Forecasting.*

Williams, J., 2005: Understanding the Coriolis force. USATODAY.com [http://www.usatoday.com/weather/resources/basics/coriolis-understanding.htm]

TRMM-GSFC, cited 2006: Algorithm 3B42. [http://trmm.gsfc.nasa.gov/3b42.html]

TRMM-GSFC, cited 2006: Algorithm 3B43. [http://trmm.gsfc.nasa.gov/3b43.html]

Figure 1

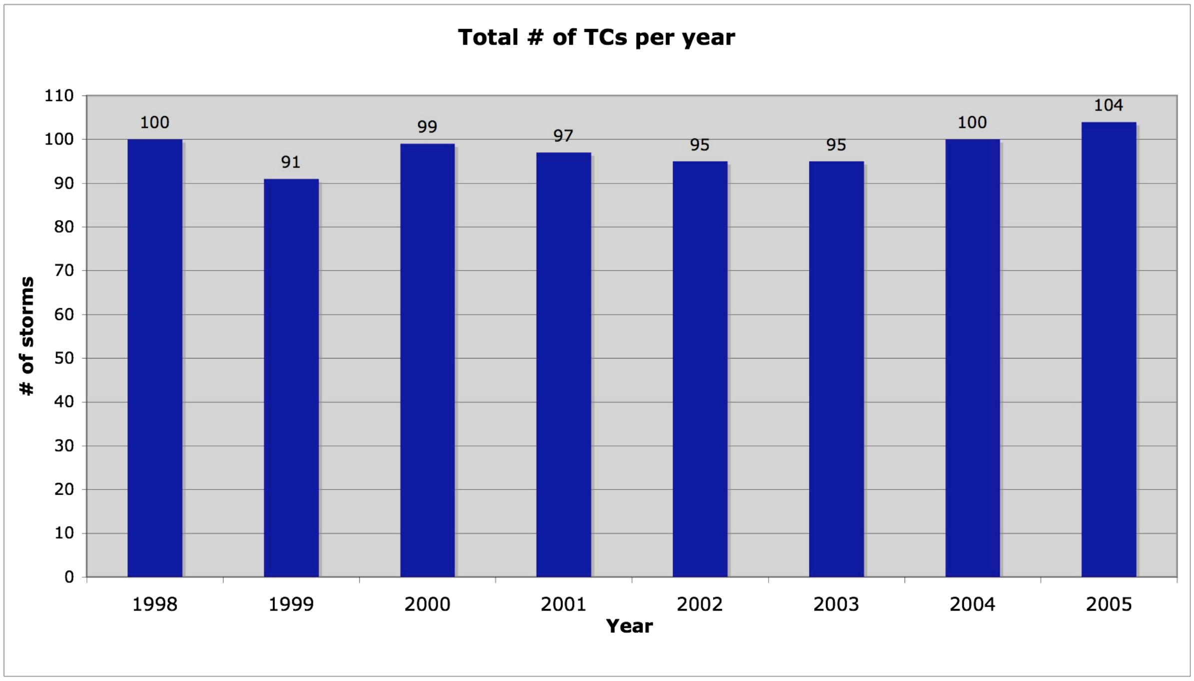


Figure 2

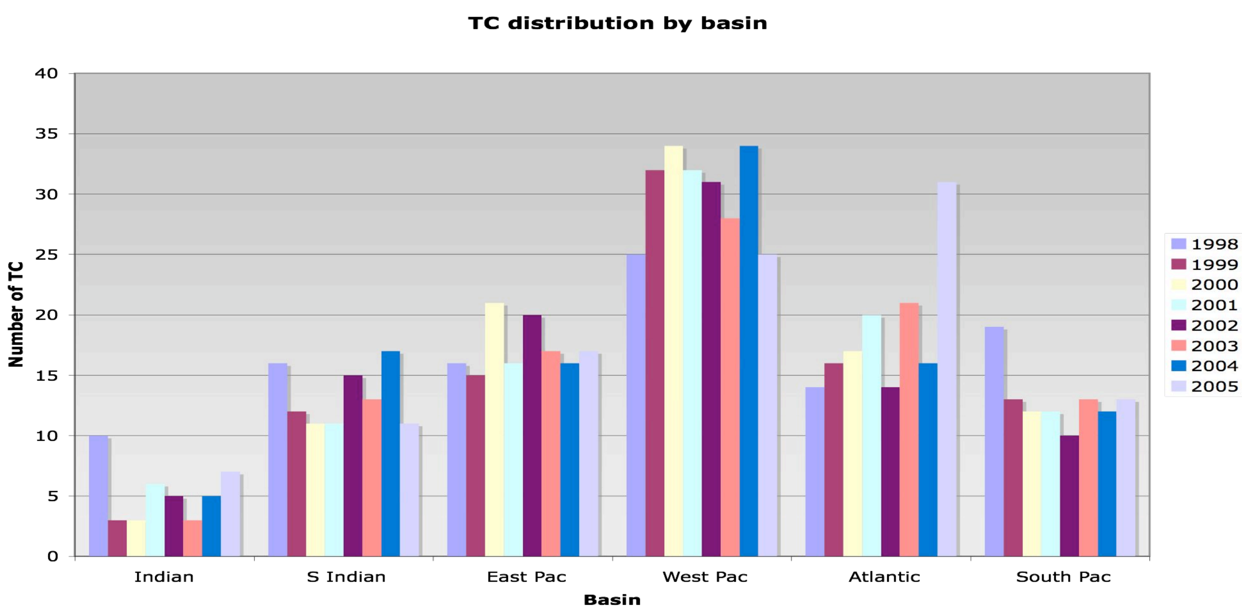


Figure 3

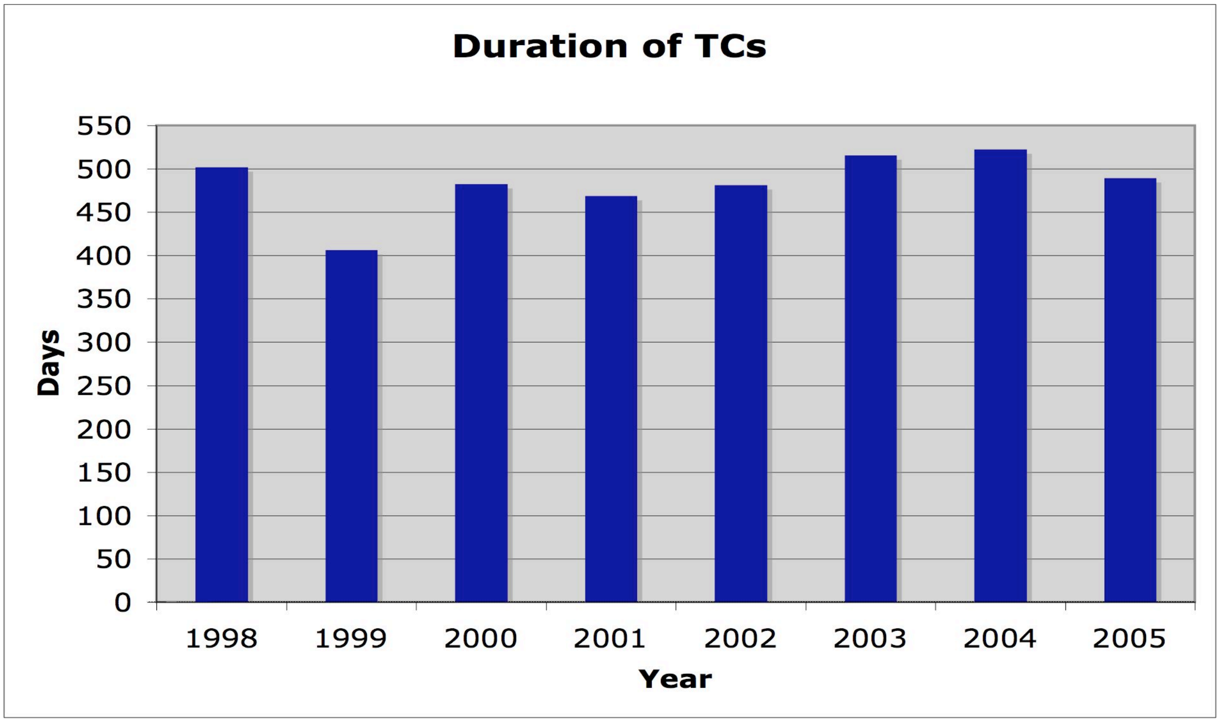


Figure 4

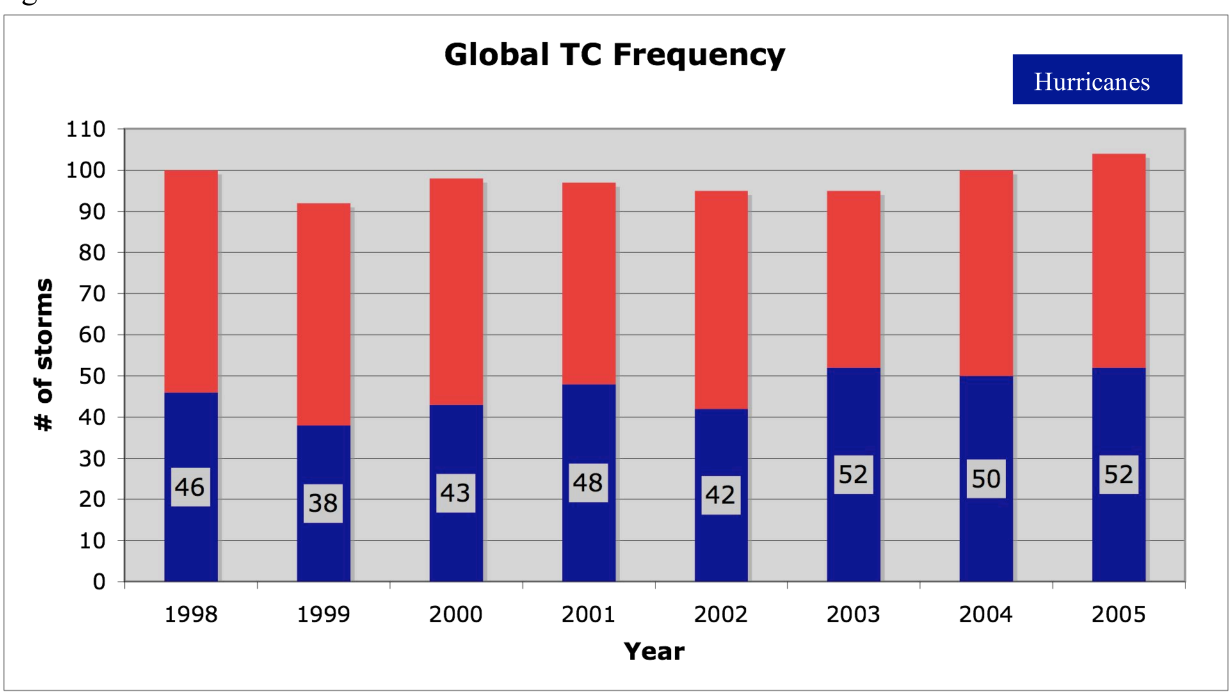


Figure 5

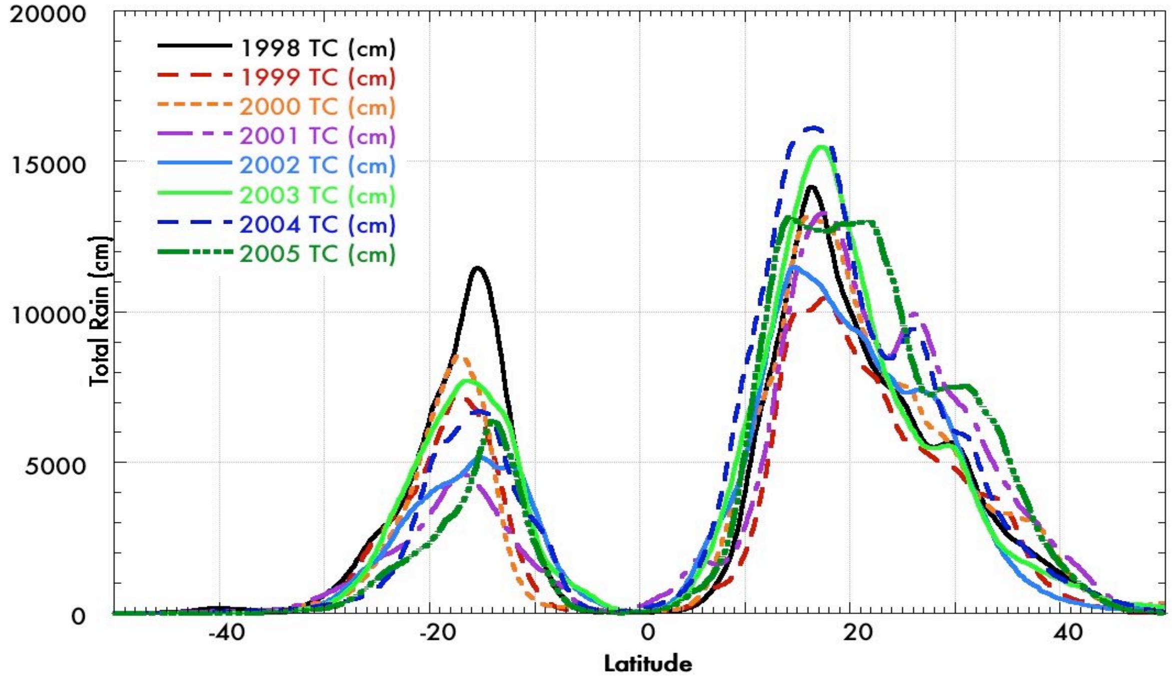
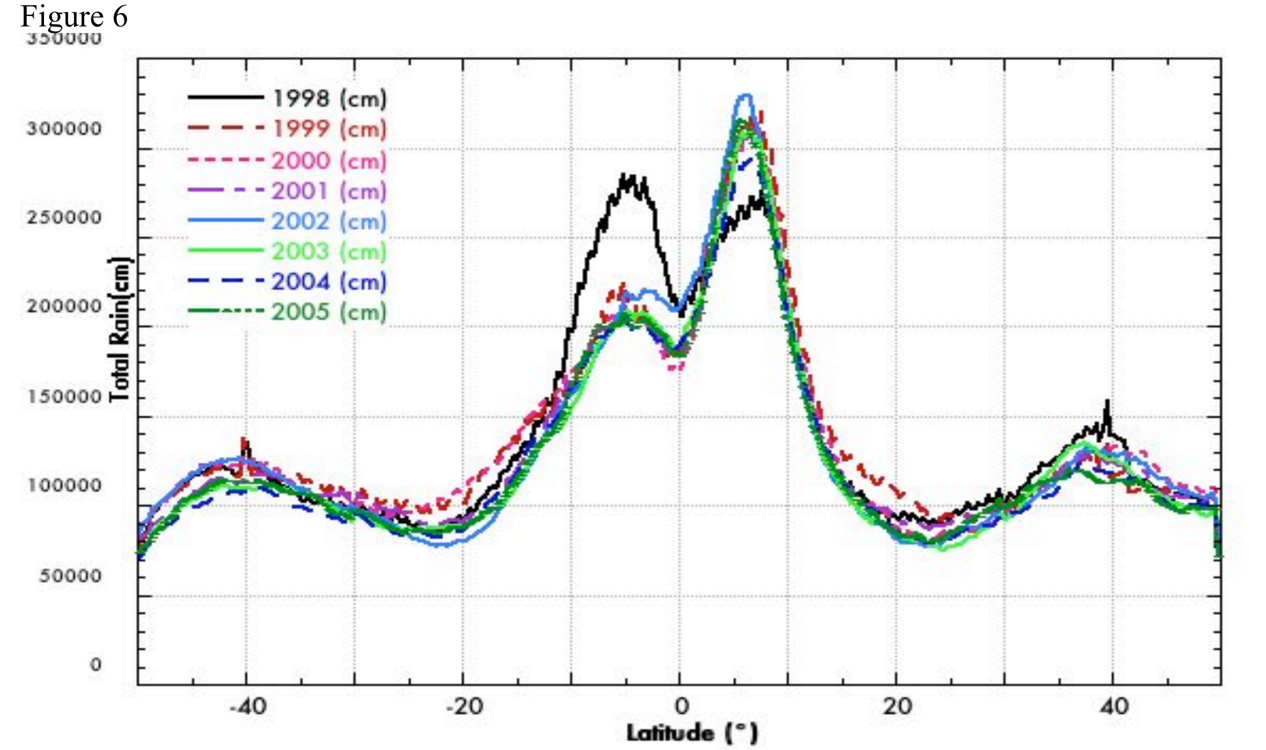
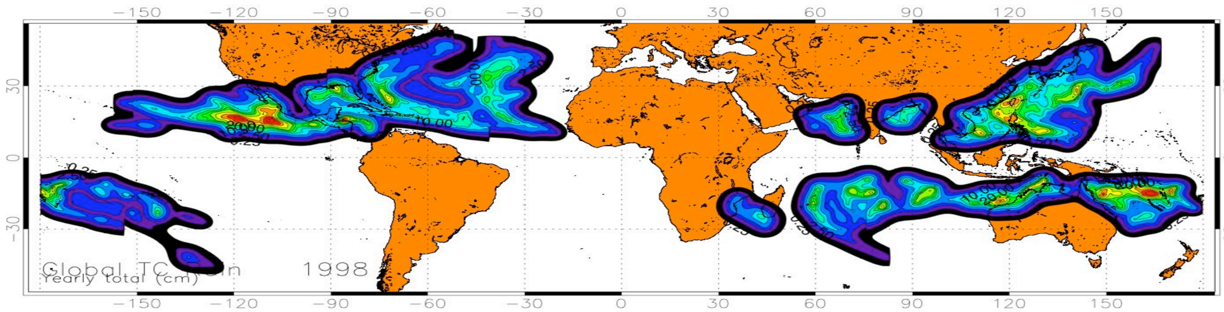
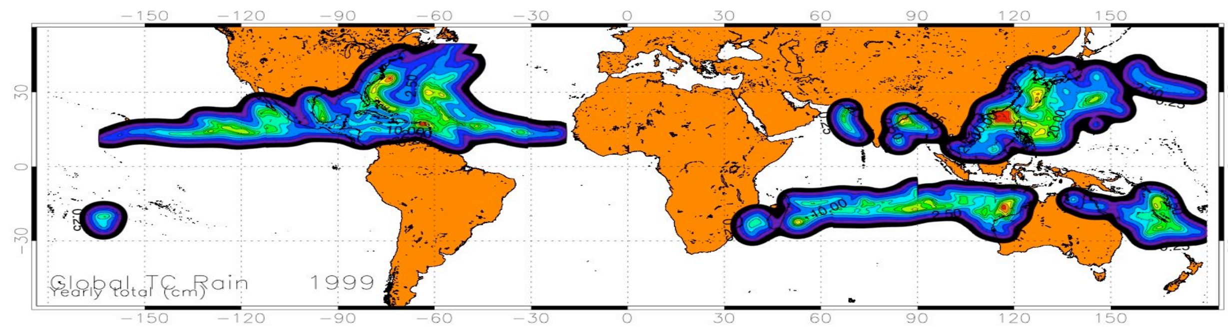


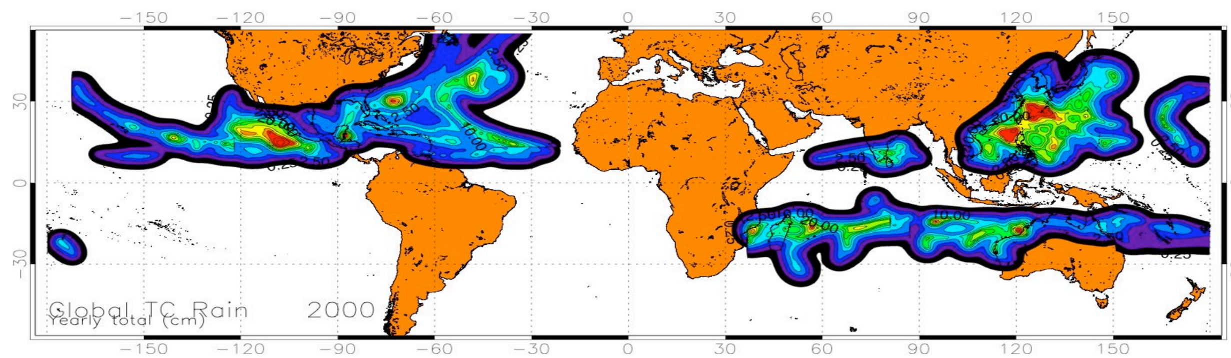
Figure 6

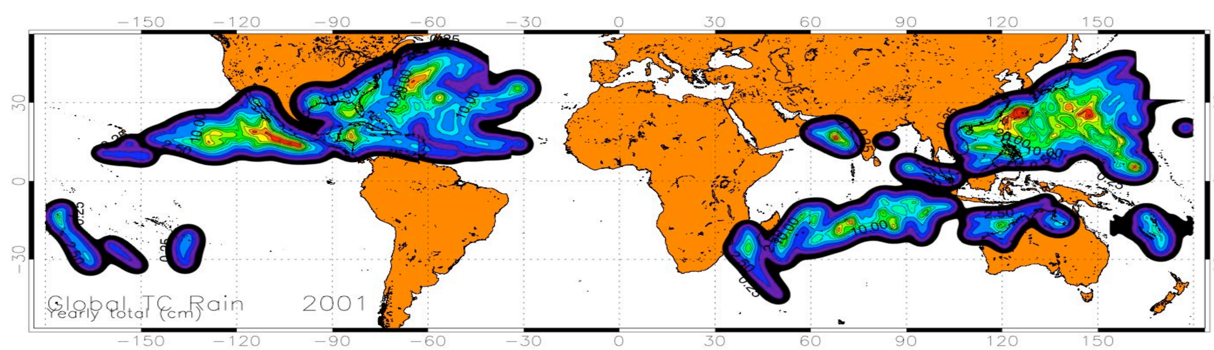


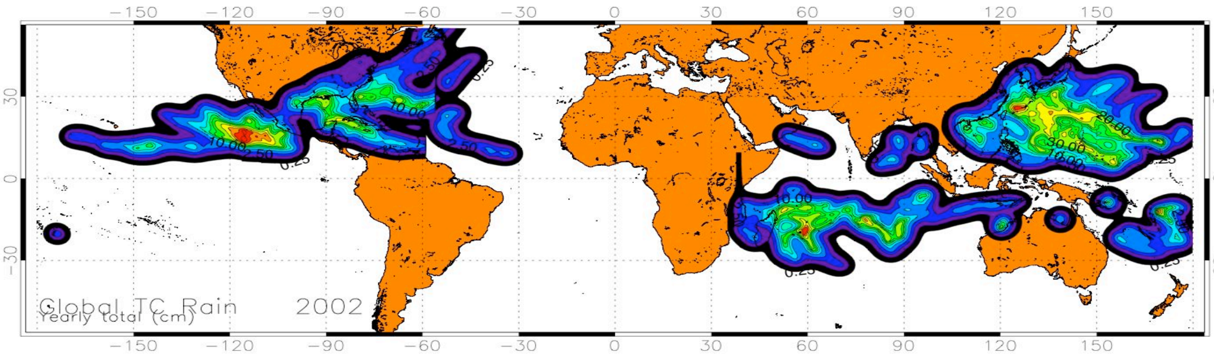
R-CLIPER/ TC rain Images

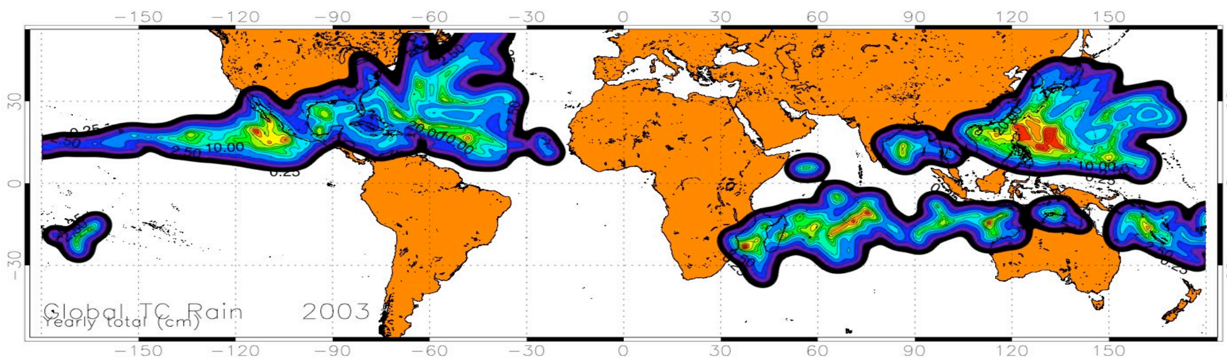


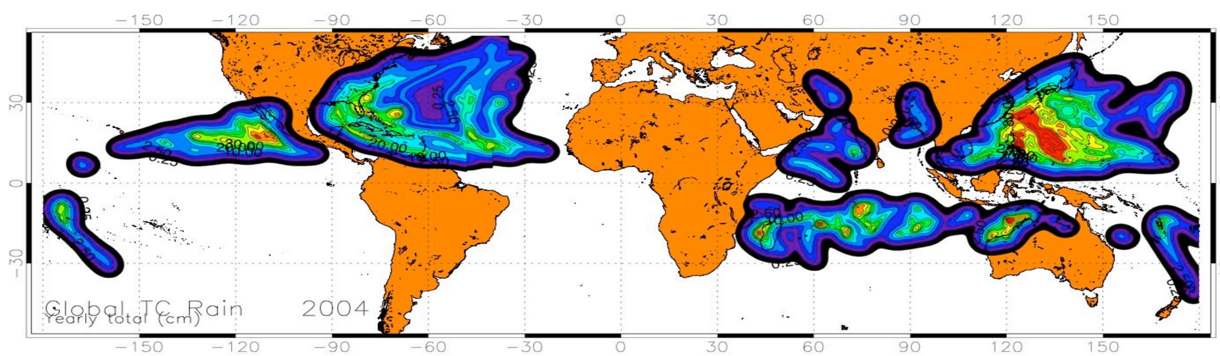


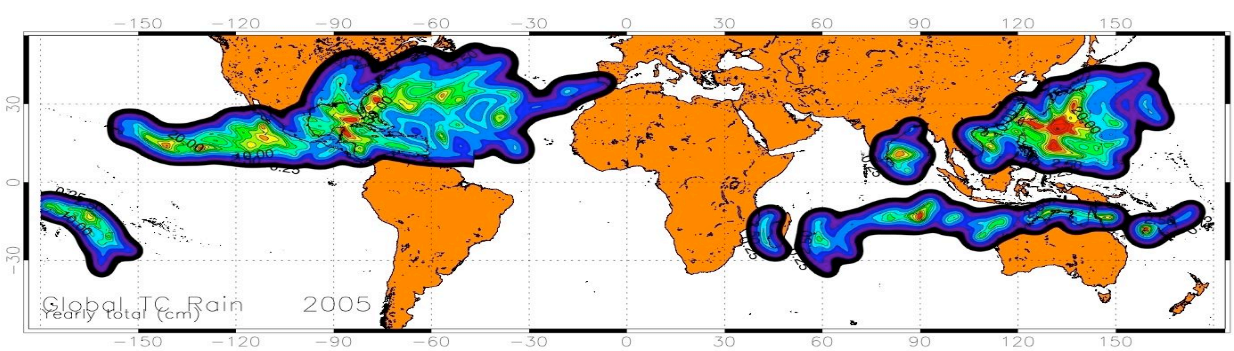





Global TC Rain 2002
Yearly total (cm)

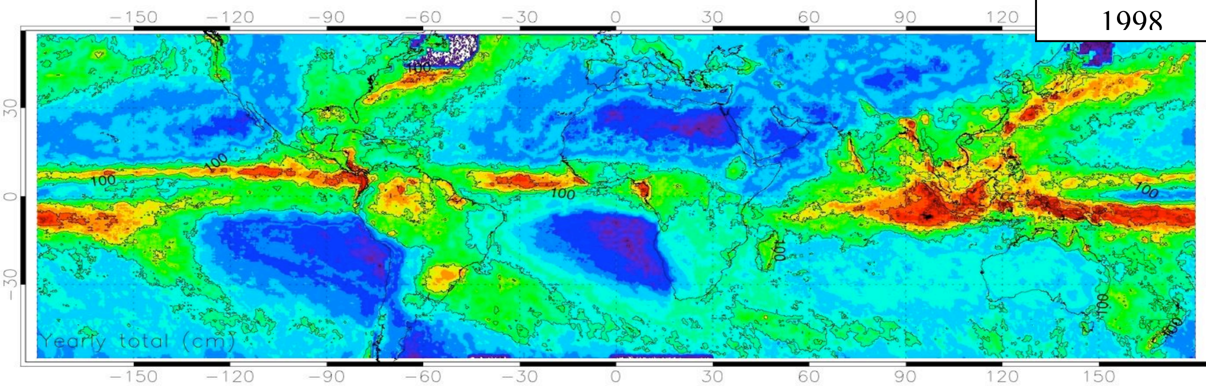

Global TC Rain 2003
Yearly total (cm)

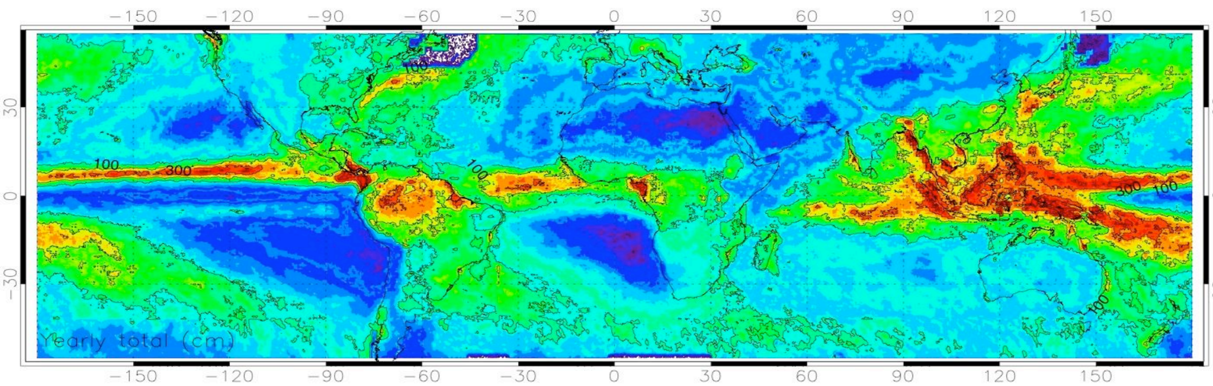

Global TC Rain 2004
Yearly total (cm)

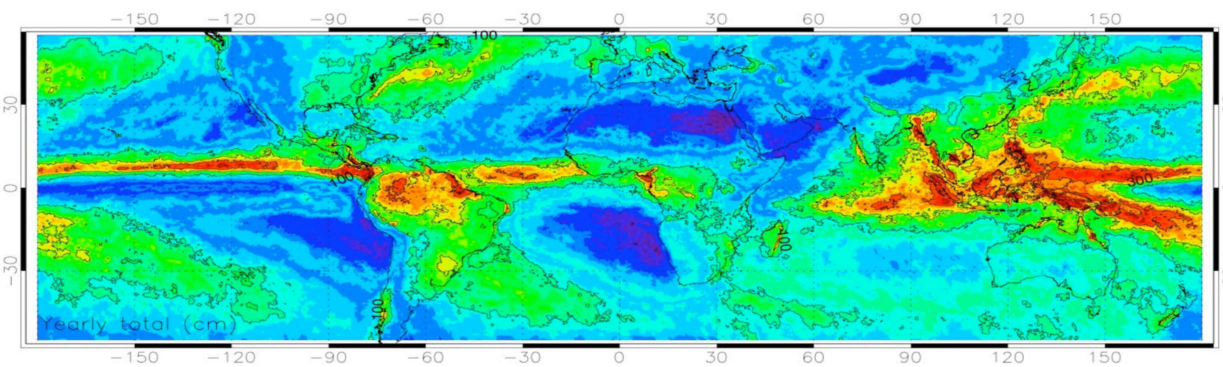

Global TC Rain 2005
Yearly total (cm)

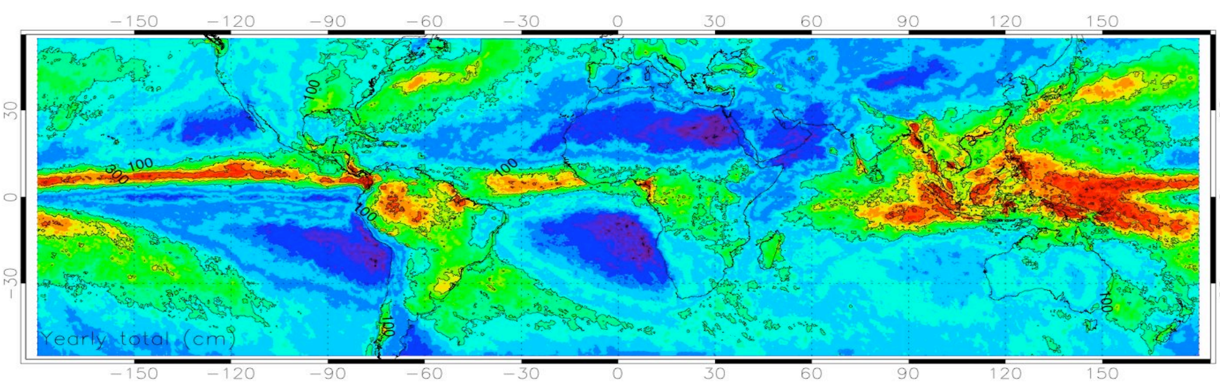
3B43/ Global rain Images

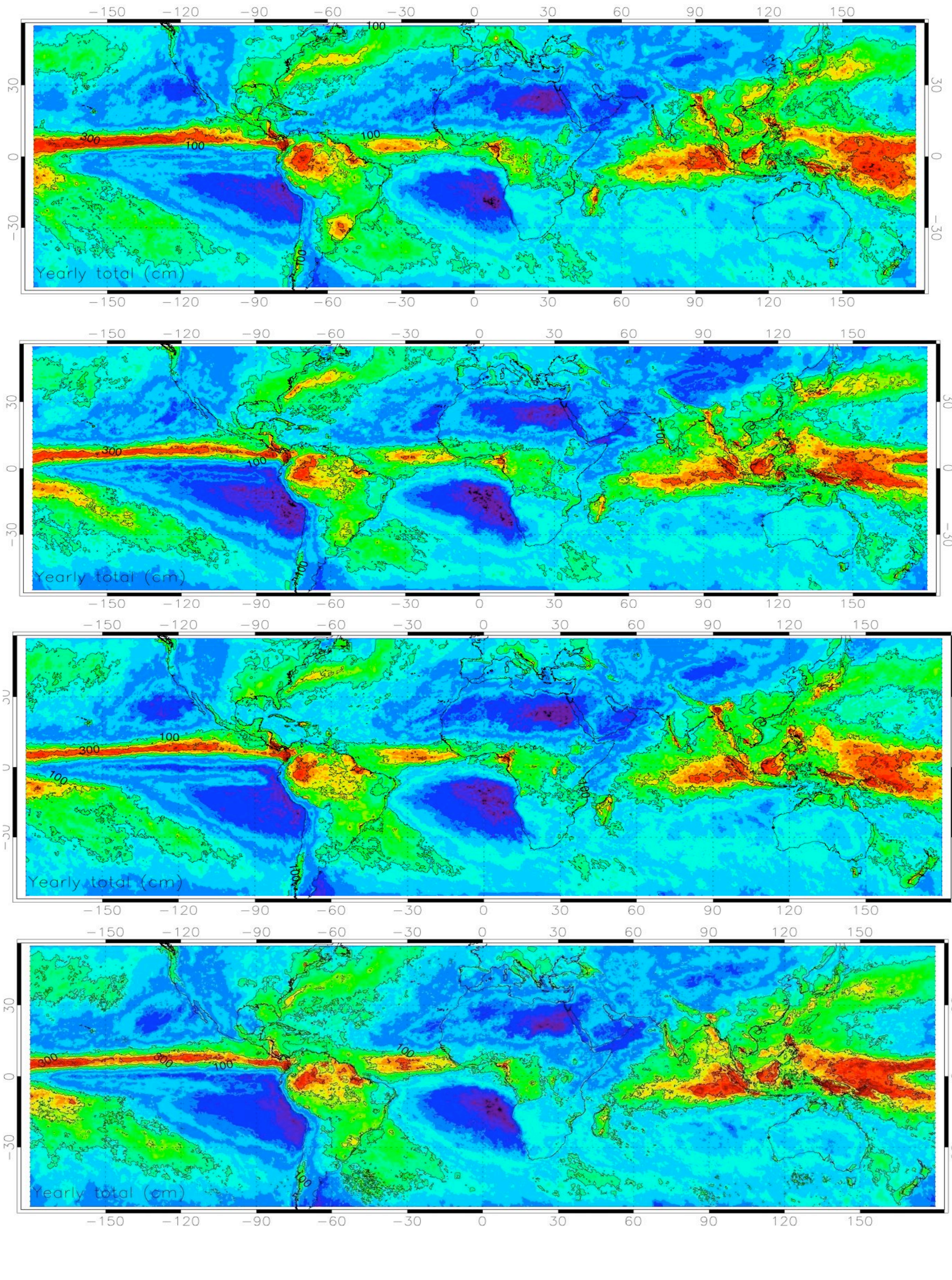
1998

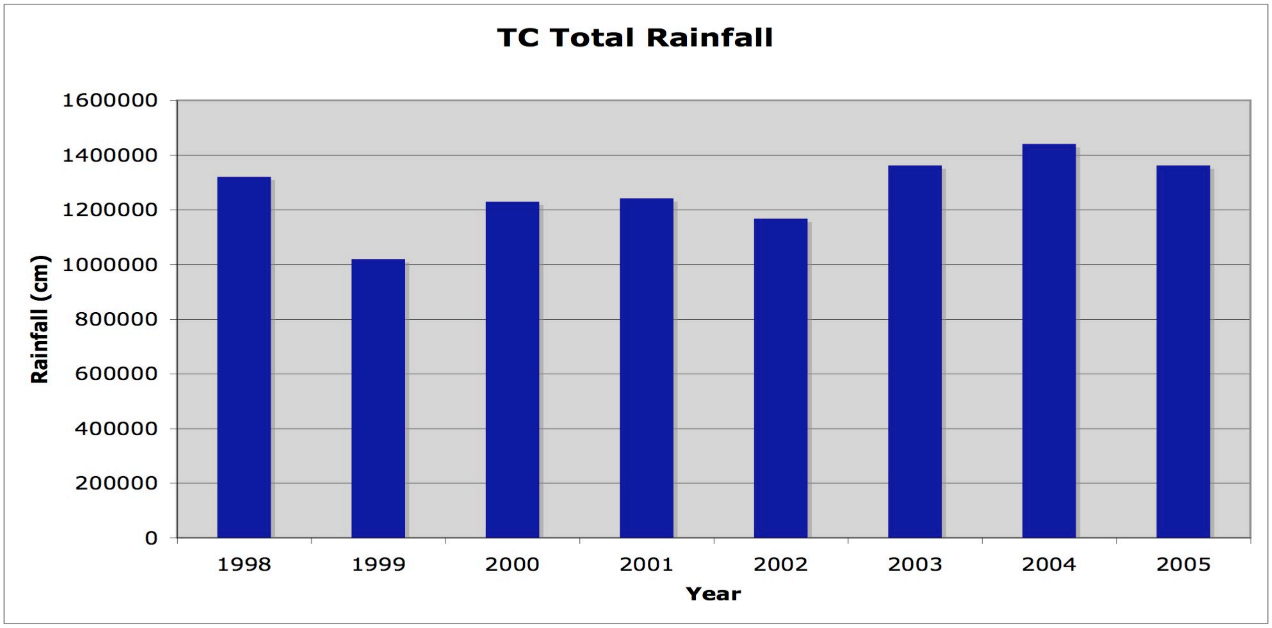


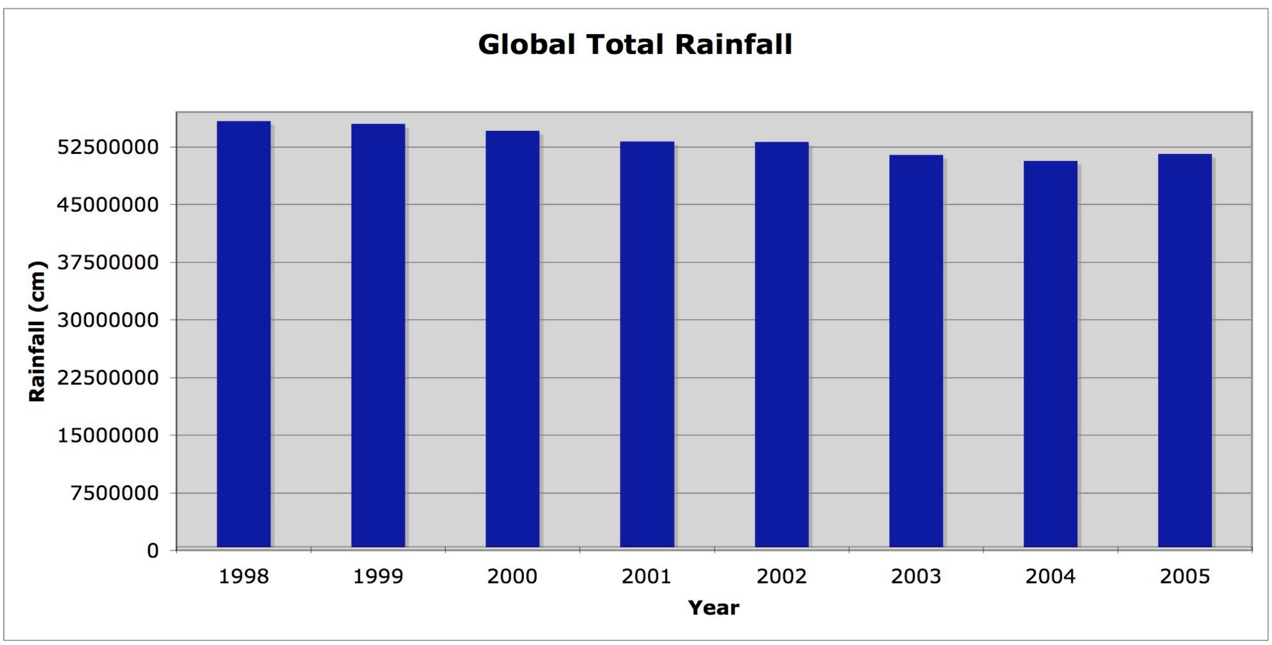







Yearly total (cm)
Yearly total (cm)
Yearly total (cm)
Yearly total (cm)


TC Total Rainfall
Rainfall (cm)
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
1998
1999
2000
2001
2002
2003
2004
2005
Year


Global Total Rainfall
Rainfall (cm)
52500000
45000000
37500000
30000000
22500000
15000000
7500000
0
1998
1999
2000
2001
2002
2003
2004
2005
Year