Initial Assessment of the Climate of Guyana and the Region with a Focus on Iwokrama

Part B Appendices – Climate Overview

A 4 month pilot study supported by the Commonwealth Secretariat in collaboration with the Iwokrama International Centre for Rainforest Conservation and Development

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The report has 4 sections. If referencing individual sections only, please reference these as follows (the current section is highlighted in bold):

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Bovolo C. I., Parkin G., Wagner T. (2009) *Initial Assessment of the Climate of Guyana and the Region with a Focus on Iwokrama, Part B Appendices – Climate Overview.* Report produced for the Commonwealth Secretariat. School of Civil Engineering & Geosciences, Newcastle University, Newcastle upon Tyne, UK

Parkin G., Bovolo C. I., Wagner T. (2009) *Initial Assessment of the Climate of Guyana and the Region with a Focus on Iwokrama – Hydrological Monitoring & Modelling Strategy.* Report produced for the Commonwealth Secretariat. School of Civil Engineering & Geosciences, Newcastle University, Newcastle upon Tyne, UK

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APPENDIX B1: The Climate of Guyana and the Region

1 Introduction

The Appendix should be read in conjunction with the full report.

In the low elevation tropics, the annual range of temperature is not very large. As rainfall has the most variation, it is therefore used as the basis for differentiating seasons. The following analysis therefore concentrates on rainfall. Furthermore, this study concentrates only the best available datasets. It must be stressed that only a brief overview of the data is given. No attempt is made to conduct a full detailed analysis of the data. There remains an outstanding need for analytical studies on the spatial and temporal aspects of the regions' rainfall. One key recommendation for further work involves further analyses of all the available data.

2 The importance of hydro-meteorological data collection in the tropics

Accurate, complete and long-term hydrometeorological records are needed in order to examine and understand past and current climates and to place them into a local, regional and global context. Through the analysis of climate and hydrology observations, spatial and temporal climate trends can be discerned and global and local scale climate drivers can be identified helping us to establish and predict climate variability and change.

Hydrological and climatological observations also form the basis for understanding a country's water resources, including the assessment of water quantity, quality and spatial and temporal distributions and the ability to supply actual or foreseeable demands in the context of floods or droughts.

Hydrometeorological observations are especially important in the tropics where rainforests cover large areas of land and where further studies on the complex relationships between climate, forests and water cycling are required. Trees return water to the atmosphere through the process of evapotranspiration helping to generate rain over vast distances [25]. Up to half the rainfall in the Amazon basin is generated by the rainforest [25]. The process of cloud formation above the rainforests releases energy as latent heat which helps drive the atmospheric wind circulation and the clouds themselves reflect incoming sunlight, shading the land and helping to reduce surface temperature.

The rainforests are however, threatened by deforestation and climate change and more research is needed to ascertain the potential climatic and hydrological impacts these changes would have both locally and regionally. Deforestation generally leads to decreased evapotranspiration thereby reducing precipitation and increasing temperatures [see 20 and references therein]. In the Amazon, however, rainfall has been increasing during the last few decades despite deforestation. Increased rainfall in this case has been linked to large-scale changes in atmospheric convergence which counters the effects of deforestation thereby showing the complexities of the forest-atmosphere interactions [20].

"The future of the rainforest is not only of vital ecological importance, but also central to the future evolution of the global carbon cycle and as a driver of regional climate change" [20].

3 Geography of the Guianas

The Guianas, consisting of Guyana (~215 000 km^2), Suriname (~163 800 km^2) and French Guiana (~91 000 km^2) are located north to east along the northeast coast-line of upper South America and cover an area approximately 62° to 52° W and 8° and 1° N between the Amazon basin (Brazil) in the south and the Orinoco basin (Venezuela) in the north-west (see Figure 1).

The Guianas have a coastal strip 10 to 60 km wide, where most of the population live consisting mainly of mangrove swamps and rain forests. In Guyana, some areas have been cleared for agricultural use, mainly sugar plantations and are maintained by a system of drainage canals. Slightly more inland is mainly open tropical rainforest whilst the interior is typically covered in dense rainforest. The southern third of Guyana between the Rupununi River and the Brazilian border is Savannah grass land, as is the southwest of Suriname.

The Guiana Shield is a Precambrian geological formation spanning all of the Guianas and most of the northern parts of the Amazon basin in Venezuela, Brazil and Colombia. The highest elevation table-top mountains are called the Guiana Highlands and are the source of some of the most spectacular waterfalls including Kaieteur Falls in Guyana and Angel Falls in Venezuela. The highest point is Mt Roraima (2810 m high) on the eastern slope of the Guiana Shield, bordering Guyana, Venezuela and Brazil. Most of the Guianas however, have a relatively low elevation of less than 200 m although in Suriname, the south-central highlands rise up to about 1000 m and form the catchment divide between Suriname's border rivers whilst in French Guiana, the highest points are the Tumac-Humac Mountains on the Brazilian frontier and some small mountainous areas in the west-central area.

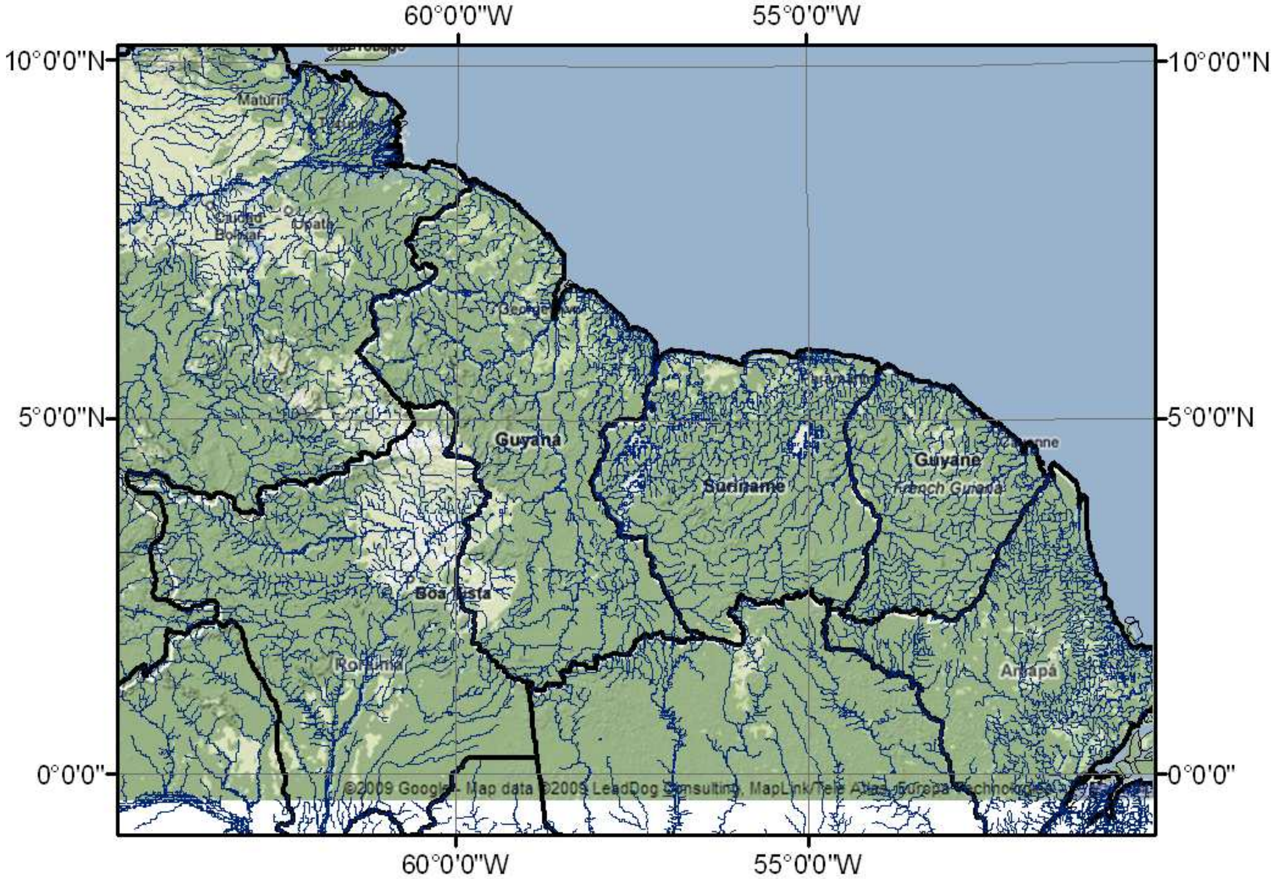

Figure 1 – Geographical location and river network of the Guianas.

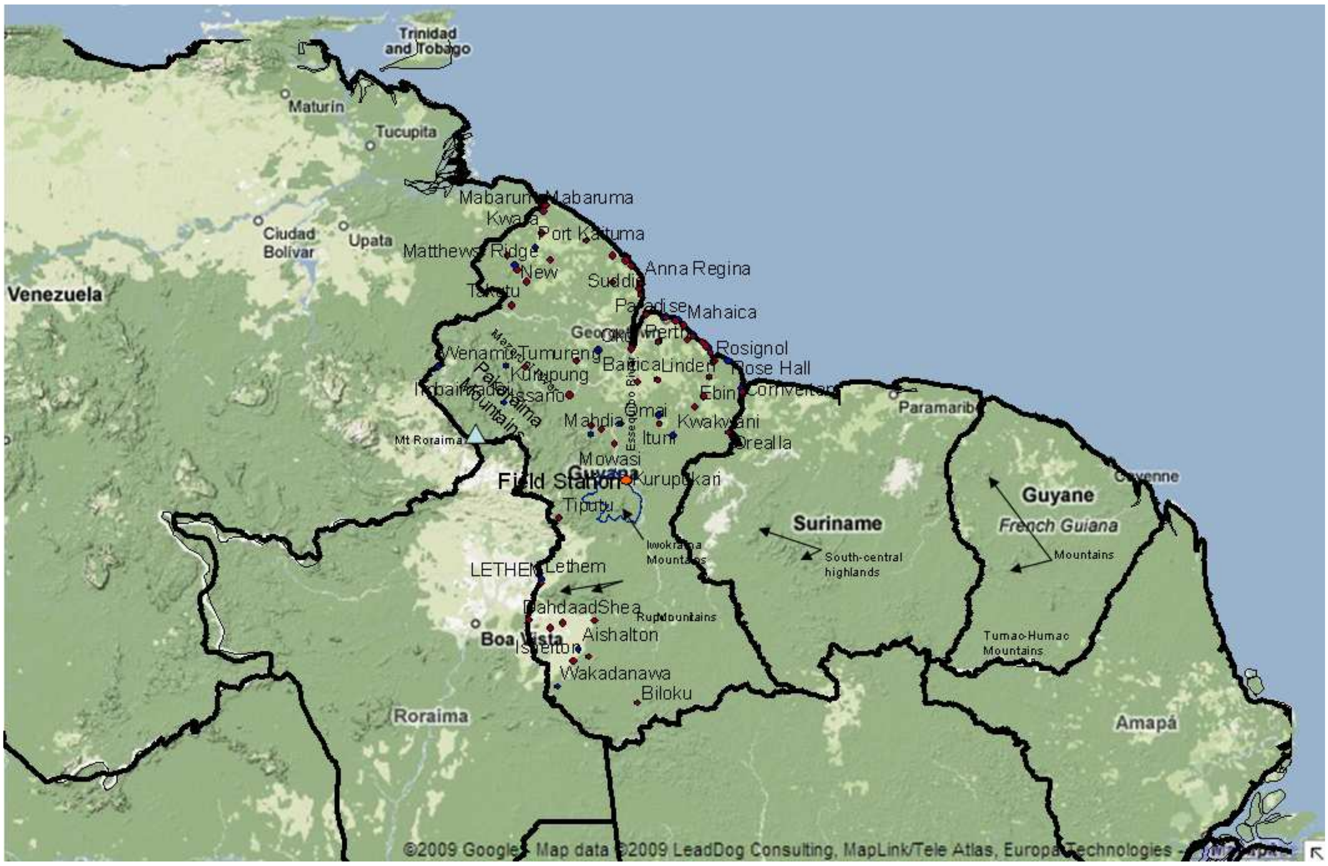

Figure 2 – Topographical relief and points of interest in the Guianas and surrounding region

4 Current Climate

4.1 The climate of northern South America

4.1.1 Overview

Based on the Trewartha Modification of the Koppen Classification system [3], much of the Amazon Basin and coastal portions of the Guianas classify as having a Tropical Wet climate (Ar) with a uniformly high average monthly temperature and heavy annual precipitation distributed throughout the year, so that there is either no dry season or at most two dry months (classified as having less than 60 mm average precipitation). A drier Tropical Wet-Dry (or Savannah) climatic region (Aw) separates the Guyana coast from the upper Amazon Basin. This area has a smaller total precipitation than the Tropical Wet climate zone and annual rainfall is less well distributed throughout the year. The wet season is shorter and the dry season longer with a more severe drought (see Figure 3).

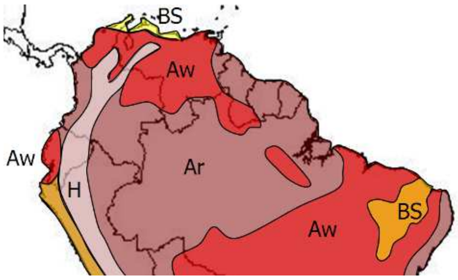

Figure 3 – Trewartha Classification system for the northern part of South America (after [4]). Aw = Tropical Wet and Dry; Ar = Tropical Wet; BS = Steppe or Semiarid climates; H = Highland climate

The principal factor controlling the climate around northern South America is the subtropical high-pressure zones over the South Atlantic and South Pacific and their seasonal shifts in position. These determine both large-scale patterns of wind circulation and the location of the cloud and rain-bearing Equatorial Trough [9]. The Equatorial Trough is a latitudinal zonal belt of rising air movement and relatively low pressure (rising up to 3000 m [8]) where the trade winds of both hemispheres converge between the subtropical highs of the northern and southern hemispheres [9]. The Equatorial Trough is sometimes referred to as the Inter-Tropical Convergence Zone (ITCZ) when the trough’s time-averaged location or transient areas are described [7], or when the convergence of air masses is considered more relevant [8].

The seasonal movement of the Equatorial Trough, a zone about 1000 – 2000 km wide [7], is generally greater over land [8] and follows but lags the annual migration of the Sun bringing with it periods of prolonged, abundant precipitation. It moves north during May-July to a position approximately 7° N [5] and southwards during Nov-Jan placing it well over the Amazon [5] and can be seen over South America in Figure 4. It its absence, the trade-winds, always blowing towards the west, dominate.

When the Equatorial Trough is to the south, the subtropical high is strong over the Caribbean, northeast coast of Brazil, the Guianas and Venezuela north of the equator. The north-eastern trade-winds, forming around the southern edge of the subtropical high pressure cell in the North Atlantic, generally bring reduced rainfall amounts to these areas, except in the mountainous interiors of Caribbean islands, where orographic uplift triggers instabilities and on the coastal areas of the Guianas from about 2° S to 9° N latitude, where the northeast trade winds are onshore [2, 5].

When the Equatorial Trough is to the north, the subtropical high weakens. Although rain in the Caribbean area is caused mainly by the passage of easterly waves or tropical cyclones at this time, rainfall in the southern Caribbean islands (Trinidad) and Guyana is still high [5].

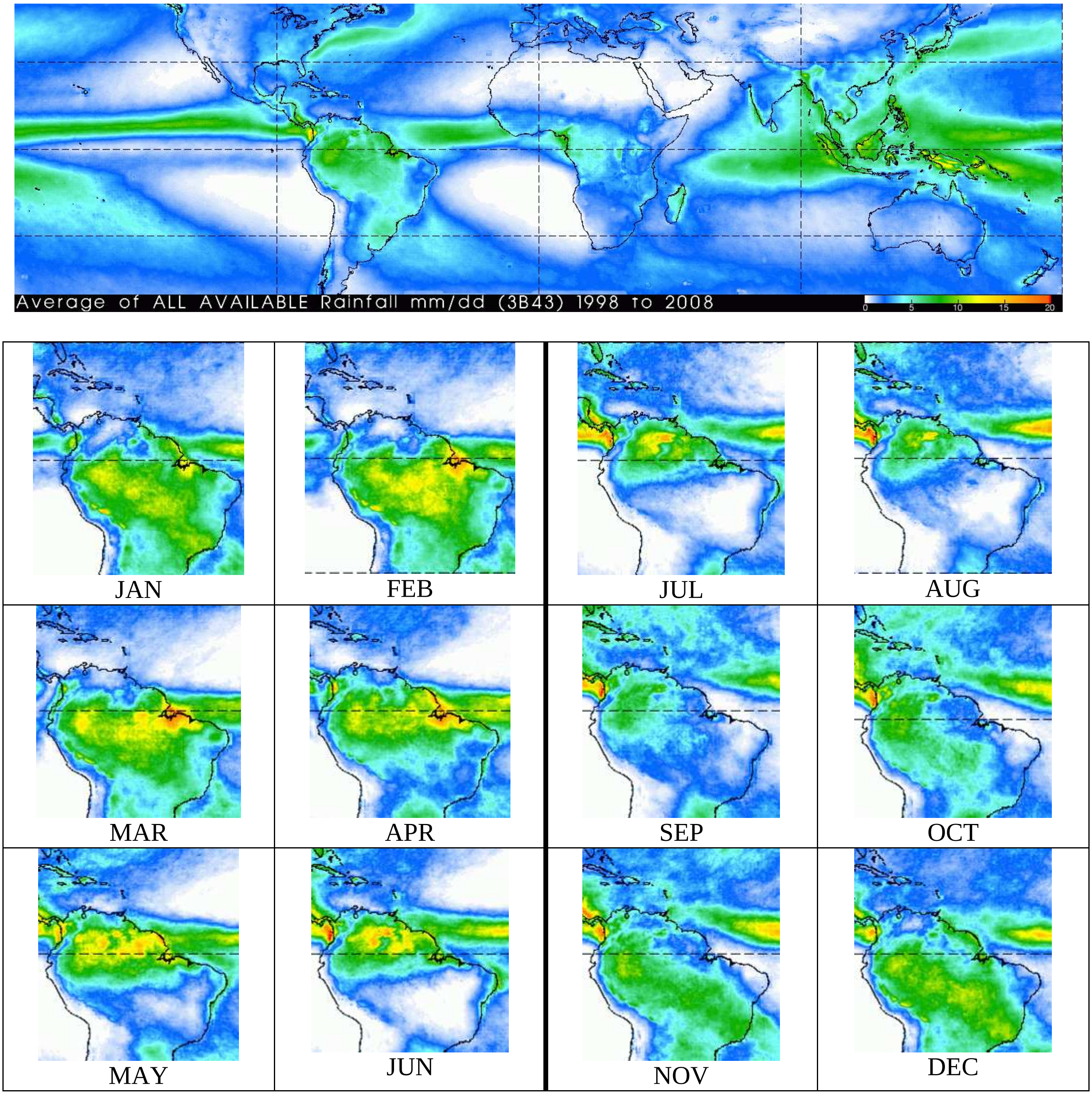

Figure 4 – Average of all available rainfall data from TRIMM and other sources (mm/day) data for 1998 to 2008 (see Dataset 6, Appendix A3). Also shown are monthly average rainfall amounts for northern South America for the same time periods (from NASA: http://trmm.gsfc.nasa.gov/trmm_rain/Events/trmm_climatology_3B43.html). The Equatorial Trough, shown by the zone of highest rainfall, is at its most northern position over land between May and July and its most southerly position between November and January. Graphs are arranged so that graphs for May and June can easily be compared to those for November and December.

4.1.2 New Data Analysis for Regional Precipitation

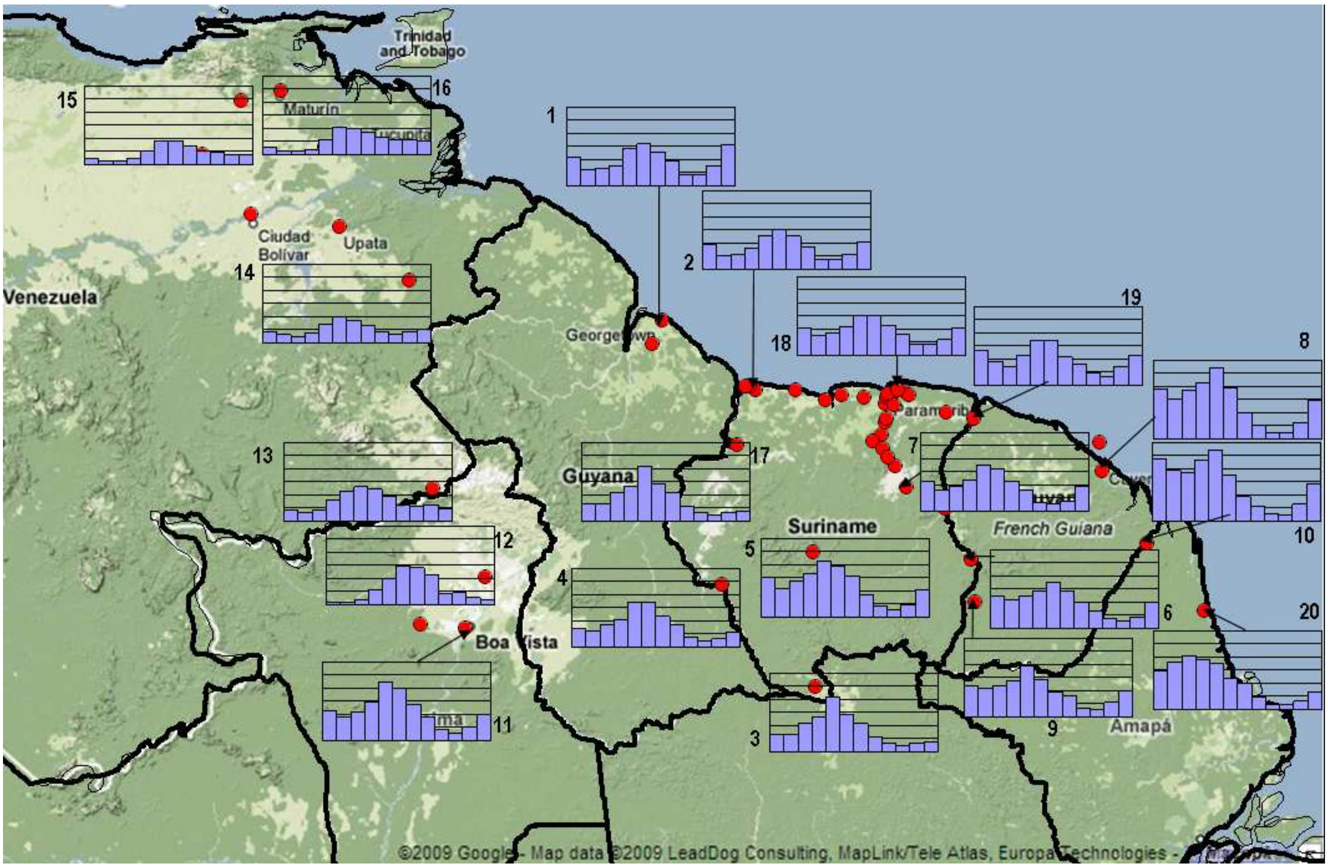

Figure 5 – Inset bar-charts show monthly precipitation (mm/month) (x-axis) for Jan-Dec (x-axis) for all available data for select sites based on data from CRU (dataset 1, Appendix A3). Each site is numbered and refers to Table 1. Vertical scales on bar-charts are from 0 to 600 mm with 100 mm increments. Background terrain from Google Maps.

Table 1 – Start and End years of precipitation data for various select stations shown in Figure 5 based on data from CRU (dataset 1, Appendix A3).

	Location	Elevation (m)	Start	End
1	Georgetown – Botanic Gardens, Guyana	6	1846	2006
2	Nickerie-Vliegveld, Suriname	-	1904	2000
3	Sipaliwini, Suriname	243	1961	1986
4	Coeronenie, Suriname	148	1961	1986
5	K-Tafelberg, Suriname	286	1961	1986
6	Benzdorp, Suriname	100	1905	1973
7	Dam, Suriname	35	1912	1970
8	Rochambeau, French Guiana	9	1847	2006
9	Maripasuula, French Guiana	104	1961	2006
10	Saint-Georges L'Oya, French Guiana	6	1961	2006
11	Boa Vista	74	1938	2006
12	Maloca do Contao, Brazil	100	1975	1992
13	Santa Elenta de Vaire, Venezuela	907	1940	2006
14	Tumeremo, Venezuela	104	1938	2006
15	El Tejero, Venezuela	240	1956	1990
16	Maturin, Venezuela	70	1921	2006
17	Apoera, Suriname	5	1914	1986
18	Cultuurtuin, Suriname	2	1847	1992
19	Saint Laurent, French Guiana	4	1961	2006
20	Macapa, Brazil	15	1954	2006

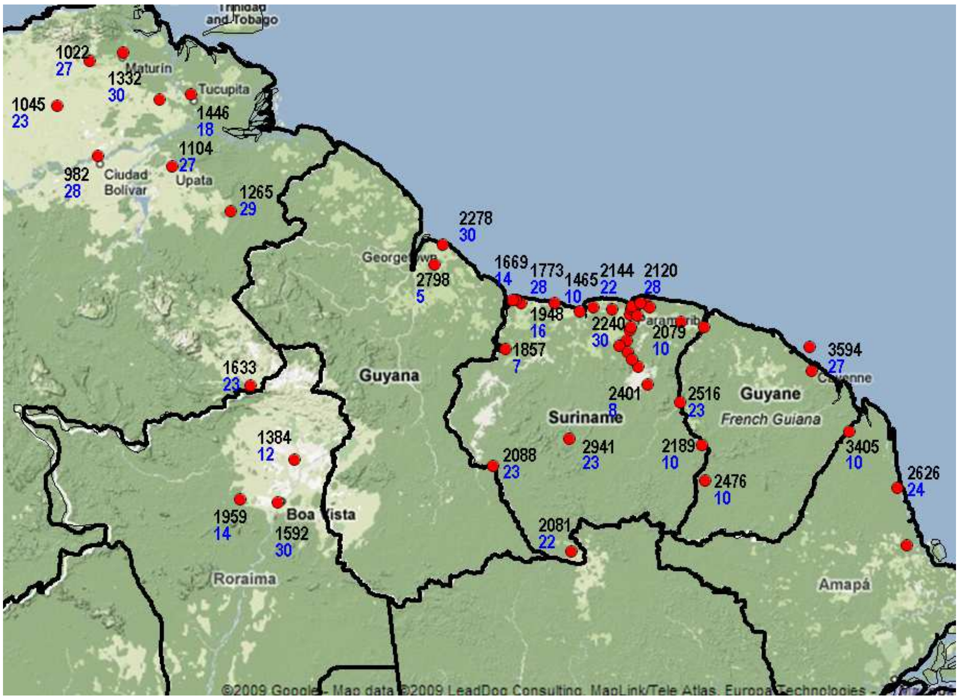

Figure 6 – Averaged annual rainfall amounts (mm/year) for the 30 year period from 1961 to 1990 for select sites based on data from CRU (dataset 1, Appendix A3). Numbers in blue refer to the number of years complete data were available within the 30 year period.

In the low elevation tropics, the annual range of temperature is not very large. As rainfall has the most variation, it is therefore used as the basis for differentiating seasons. The following analysis therefore concentrates on rainfall.

Precipitation

As can be seen from Figure 5, there are two wet-seasons in Georgetown (site 1, Figure 5), with the main peak centred on June (320 mm/month) and spanning April to August and a secondary peak centred in December (314 mm/month) and spanning January. The primary dry season (also distinguished further east in Suriname and French Guiana) is September and October and a secondary, more local, dry season occurs in February and March. This seasonal distinction is directly related to the passage of the ITCZ over the region with the zone of maximum convergence passing northwards during June [7] and southwards during December (the centre of the Equatorial Trough probably passes south in November, but the zone of maximum convergence takes place north of this [7]). The primary dry season is likely to be related to the South Atlantic trade winds, whilst the secondary dry season to those of the North Atlantic [7].

Similar two-peak rainfall patterns are found further east in Suriname. Sites 18 and 20 (Figure 5) show however, that peak monthly rainfall in the secondary rainy season begins a little earlier in May and June rather than in June as in Georgetown. Further east still, in French Guiana, peak monthly rainfall occurs in May. Here the rainy season brings much greater amounts of rainfall reaching 467 mm/month in May in Saint-Georges L'Oya (site 10). French Guiana lies approximately at the mean latitude of the Equatorial Trough (Figure 4) which oscillates over French Guiana twice annually in May and then again in late December and January. When the centre of the trough is to the south (Feb-April), the onshore trade winds are strong and the Equatorial Trough is still close enough to produce rain [7] so French Guiana lacks a secondary dry season. The wet season therefore stretches from November through to August, although the primary dry season (Sep-Oct) is maintained. In the primary dry season, less than 100 mm/month of rain falls across most of the Guianas. Desiccation, even in the inland rainforests can become quite extreme and forest fires can occur at this time.

In the savannah region in north-eastern Brazil (site 12), southern Guyana and southeast Suriname, the annual rainfall pattern also exhibits a single wet and a single dry season however the distribution is more typical of a continental climate with a wet season ranging from April to August and a dry season the rest of the year. During the wet season, the low plains are largely under water whilst in the long, dry season there may be airborne dust. This precipitation pattern is also found of the large, low areas of Venezuela, and in the Guyana Highlands (site 13, Figure 5).

Average annual rainfall for Georgetown, based on data for 1961-90 is 2278 mm/year (Figure 6). Moving east, rainfall totals appear to decrease slightly moving into Suriname then increase to similar levels as Georgetown near Cultuurtuin before increasing to above 3000 mm/year in French Guiana (Figure 6). Further inland, rainfall totals generally reduce further away from the coast, particularly in the Savannah region and Venezuela where rainfall can be as low as 982 mm/year in Ciudad Bolivar. Rainfall totals in the interior of Suriname and French Guiana appear to be around 2000-2500 mm/year (site 5, Figure 5).

Annual rainfall totals are shown for Guyana in Figure 7 where the long term average for Georgetown is 2304 mm/year, for Venezuela in Figure 8 where the average for all stations is 1221 mm/year, for Suriname in Figure 9 where annual average is 2169 mm/year, for French Guiana in Figure 10 where annual average is 2839 mm/year and for Brazil in Figure 11 where the annual average is 1913 mm/year. 11-year averages for all countries are compared in Figure 12.

Temperature

In the coastal regions of Guyana, Suriname and French Guiana, annual temperatures tend to be high, between 25 and 29 °C with small annual temperature variations between 1 and 2.5 °C. In Guyana, temperature maxima occur in April and October just after the equinoxes and generally the highest temperatures occur between 2pm and 3pm [11]. This is also the case in the Savannah region and in mountain areas over 1000 m [7]. Generally, forested areas are marked by hotter days and cooler nights. Temperature has not been analysed in this report.

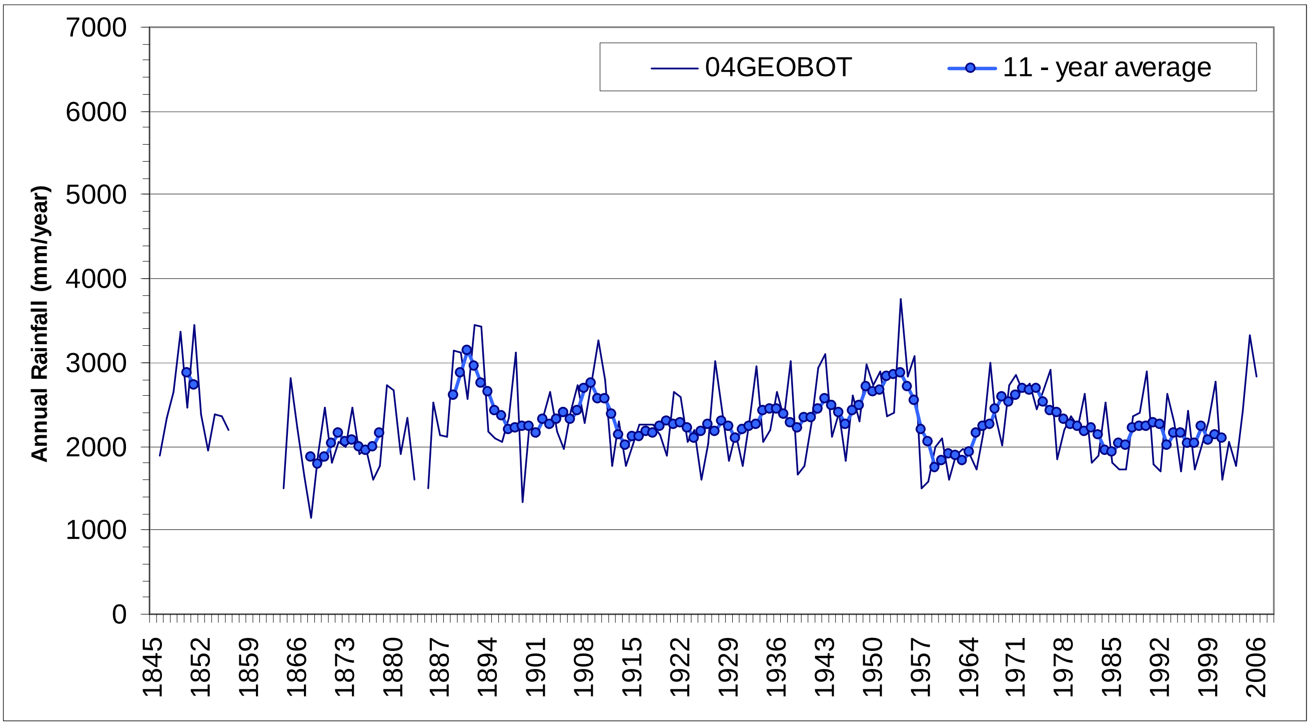

Figure 7 – Annual rainfall and 11 year-averages based on CRU data (dataset1, Appendix A3) (supplemented by HydroMet data, dataset 11, Appendix A3) for the Botanical Gardens in Georgetown, Guyana.

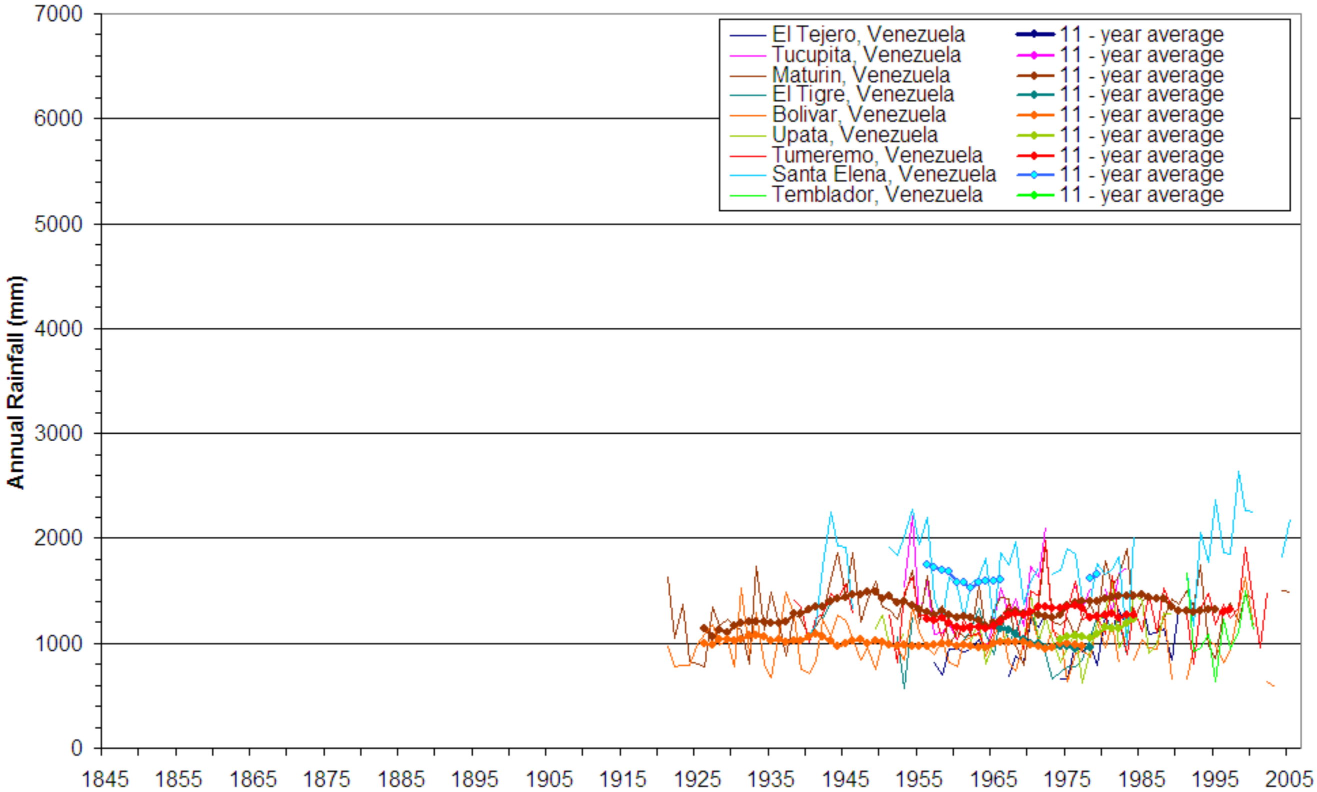

Figure 8 – Annual rainfall and 11 year-averages based on CRU data (dataset1, Appendix A3) for Venezuela

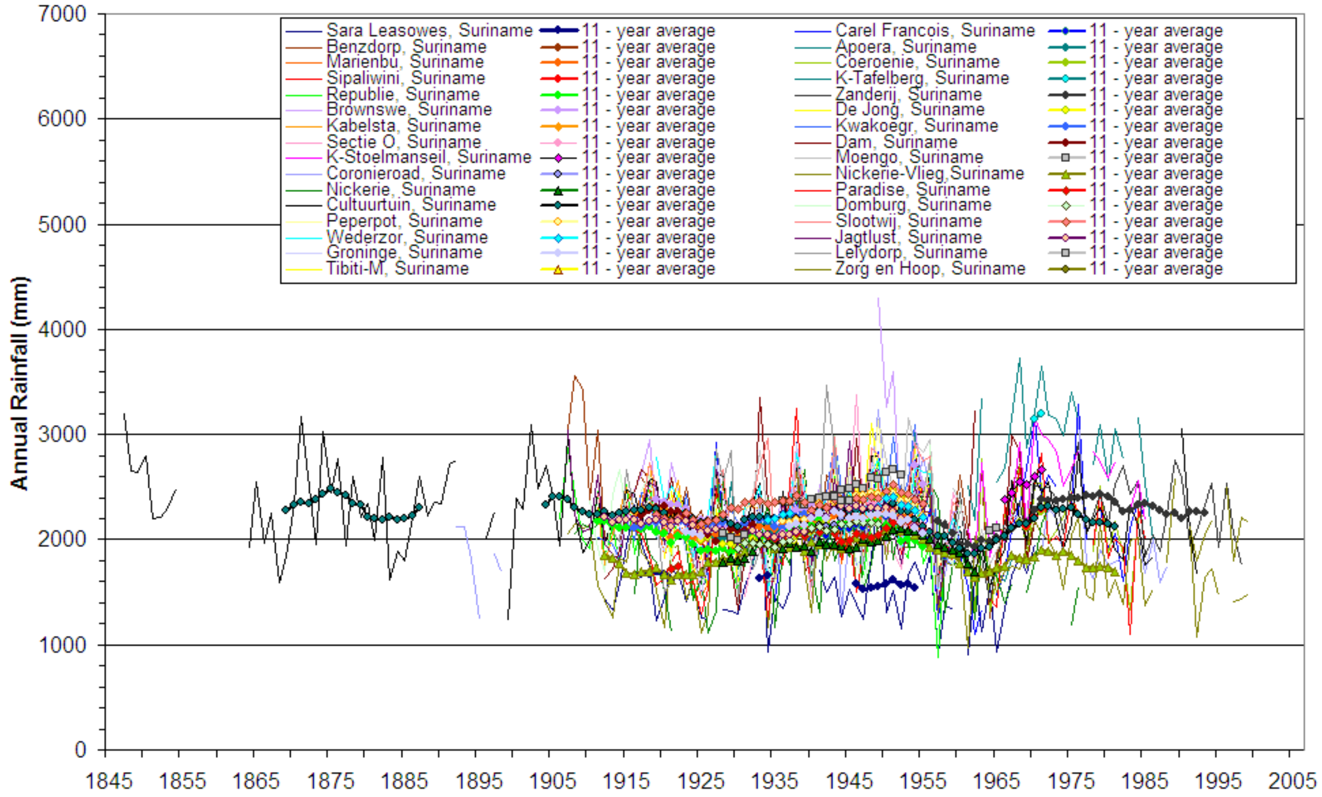

Figure 9 – Annual rainfall and 11 year-averages based on CRU data (dataset1, Appendix A3) for Suriname

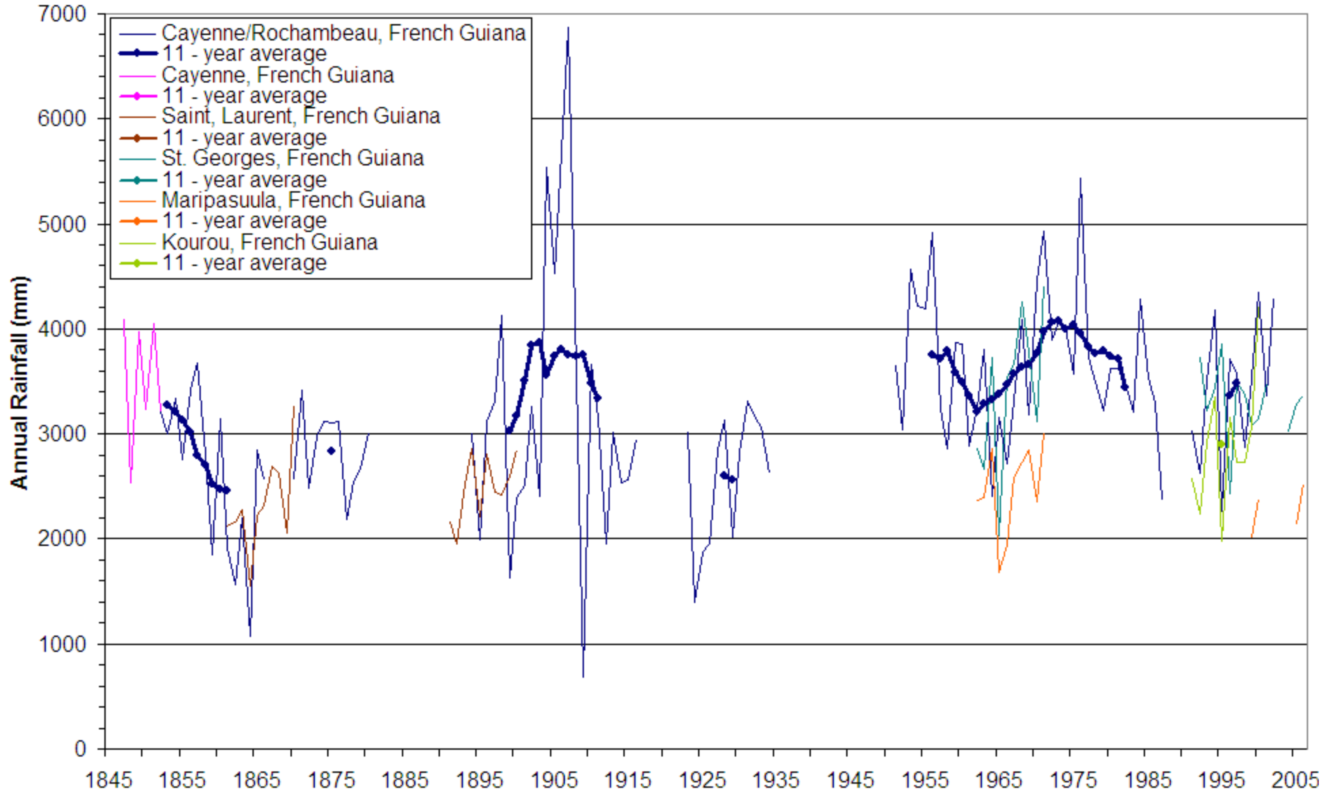

Figure 10 – Annual rainfall and 11 year-averages based on CRU data (dataset1, Appendix A3) for French Guiana

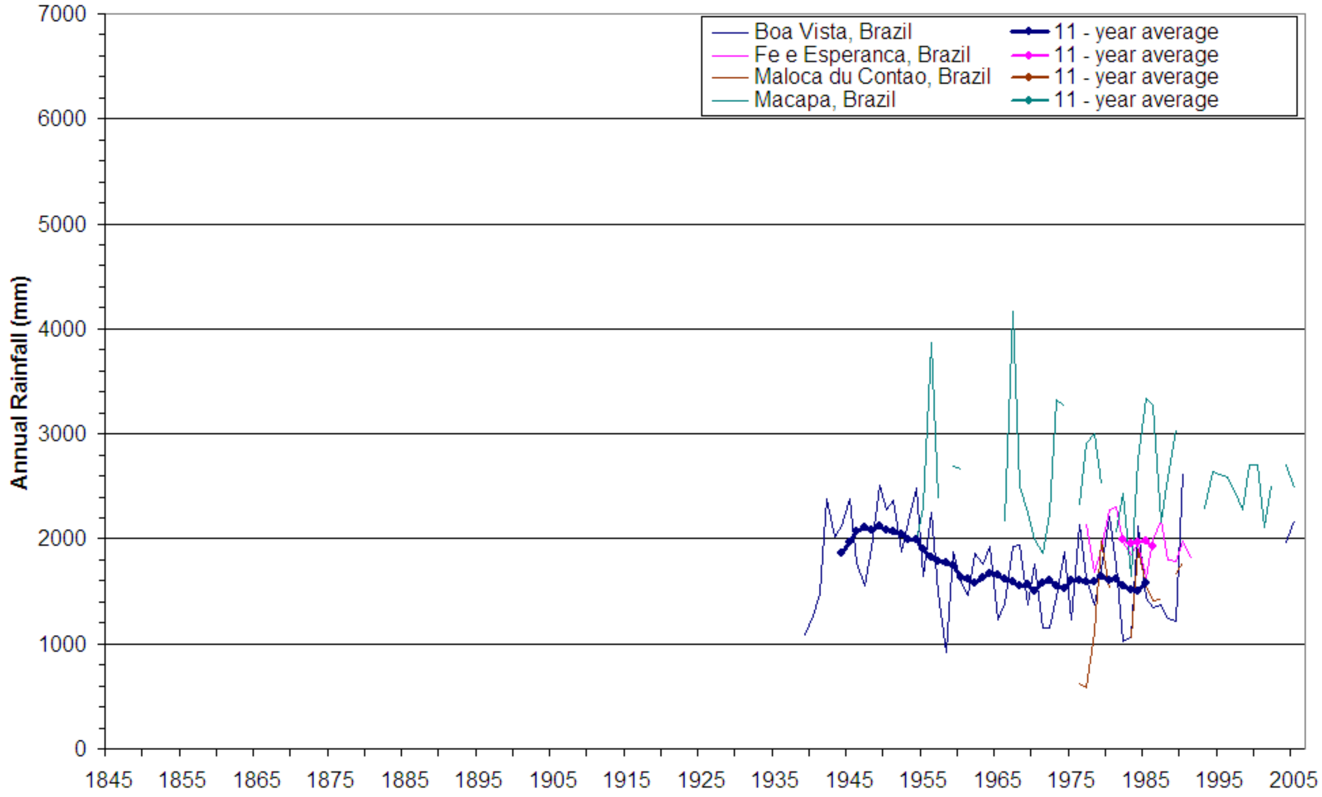

Figure 11 – Annual rainfall and 11 year-averages based on CRU data (dataset1, Appendix A3) for Brazil

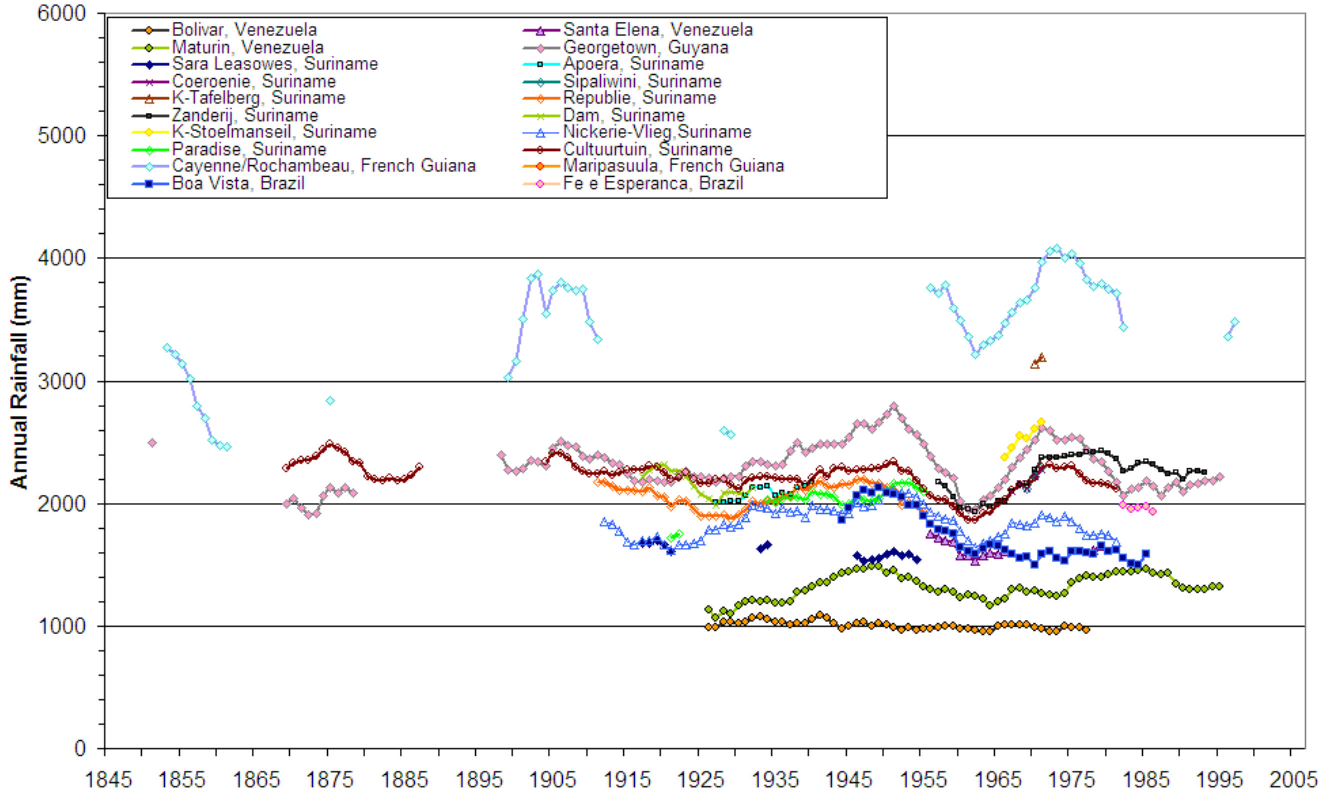

Figure 12 – Annual 11 year averages for select stations based on CRU data (dataset1, Appendix A3)

4.2 Precipitation in Guyana

4.2.1 Overview

Trewartha's modification of the Koppen Classification system [3], being necessarily general so as to classify all of the Earth's climates, does not therefore, detail Guyana's climate in fine resolution. According to Persaud & Persaud's 1995 rainfall classification map of Guyana [10], rainfall is spatially non uniform throughout the country (see Figure 13). The coastal region for example, is classified as having *wet coastal frontlands* (2438 - 2794 mm), *moderately dry coastal frontlands* (1778 – 2438 mm) and *very dry regions* (1397 -1778 mm) moving north to east across the coast. However, just inland there is a band of *moderately wet subcoast* (2184 -2794 mm), a *very wet region* (2794 – 3175 mm) and an *exceedingly wet region* (3175 – 4064 mm). Parallel to the coast but inland, the *wet region* dominates (2184 – 2794 mm) and rainfall increases to an *extremely wet region* (>4064 mm) over the Pakaraima Mountains towards the western central area. The Pakaraima Mountains are oriented perpendicular to the northeast trade winds accounting largely for the orographic nature of the rainfall there [11]. Moving south, the region becomes *moderately dry* with small areas in the very southwest being classed as the *Central Rupununi Savannahs* (< 1397 mm) before again becoming *very wet* on the Brazilian boarder. Annual precipitation maps for 1973 (Figure 14) show similar rainfall distributions considering both calendar (Jan-Dec) or water (Apr-Mar) years.

4.2.2 New Data Analysis for Precipitation in Guyana

As mentioned in the previous section, Guyana's coastal area experiences two wet and try dry seasons a year determined by the bi-annual passage of the Equatorial Trough over Guyana. Major rainfall peaks occur in June and December and relatively dry periods occur in March and September (see Figure 16).

In region 1, located furthest north, all the rainfall stations are located next to the coast. This is the case also in regions 2, 3, 4, 5 and 6 which run progressively north to southeast along the coast (see Figure 15). The two-peak rainfall pattern is noticeable in each case (see Figure 16). Monthly totals are roughly the same in each region except, most notably, during the primary dry season, September and October, where totals differ across the regions. In particular, stations in region 1 receive more rainfall during this time with 145 to 201 mm/month, whilst regions 2 and 3 receive 76 to 138 mm/month. Regions 4, 5 and 6 receive the least rainfall with 34 to 93 mm/month with the exception of 04TIMAIR, the international airport, which is located more inland along the Demerara River and receives 141-149 mm/month during this time. It is also noticeable that stations in regions 5 and 6 receive less rainfall overall, especially in May, June and July where the summer rainfall averages are the least recorded over all regions.

Monthly rainfall patterns for stations in regions 7 and 10 set further inland but parallel to the coast show similar distributions and monthly totals to each other with monthly totals in the primary dry season, September and October, ranging between 101 and 176 mm/month. Dry season averages are similar to those in regions 1-6 with the exception of station 07APAKWA which appears to receive more rainfall between December and April than all other regions except region 8. For example in February, 07APAKWA receives 177 mm/month rainfall in comparison with 85 to 100 mm/month for other stations in region 7, 85 to 121 mm/month in region 10 and 69 to 142 in regions 1-6. This station is located on the Mazaruni River, just north of the rising step of the Pakaraima Mountains, so may be influenced by effect of lift of the onshore tradewinds. 07KAMRNG and 07JAWLLA are located in the headwaters of the Mazaruni River in the valleys of the Pakaraima Mountains at about 500 m elevation. These two stations receive similar amounts of monthly rainfall but amounts here may actually be less then the neighbouring areas due to rain shadow effects from the surrounding mountains, particularly the Mt Kamakusa (1645 m), Mt Watabaru (926 m), Mt Ayangaik (1155 m) and Mt Tomasing (1067

m) all located in the north east, between the stations and the coast and hence the prevailing easterly onshore winds.

Further south, in region 8 rainfall totals recorded at the two stations are much higher than in any other region and reach 605 mm/month in May and 406 mm/month in December. 08MAHDIA (Mahdia) is located at approximately 90 m elevation whilst 08KAIETF (Kaiteur Falls) is in the Pakaraima Mountains at about 400 m elevation. Differences due to location or elevation appear to be more pronounced in the wet seasons (May-July and November-December) where rainfall amounts differ by over 75 mm than the other months where rainfall amounts differ by only 50 mm or less.

In region 9, it is apparent that the November to January rainy season, present in the rest of Guyana, is missing. Although rainfall in May to August is similar to other regions, rainfall in October to March is very low, usually less than 50 mm/month. Some areas, for example Karasabai (09KARSAB) located on the southern edge of the Pakaraima Mountains at about 150 m, receive only an average rainfall total of 697 mm/year. This is partly due to the rainshadow effects from the Watamung, Kwatamang and possibly Iwokrama mountains to the northeast. 09KUMUUU (Kumu village is actually located in near the Kanuku Mountains near Lethem, not in the centre of the region) receives the most rainfall in this region. This may be due to its location on or near the Kanuku Mountains. 09KARSAB and 09 KUMUUU both receive their peak rainfall in July whilst the majority of the other stations in this region receive peak rainfall in June. 09MOCOMO and 09LETHEM (near each other) receive maximum rainfall in May/June. As most stations are located relatively close to each other, this indicates that conditions vary substantially even across small areas.

Shaw [13] also noted that rainfall events in Guyana are highly variable both spatially and temporally and tend to be very localised. According to Shaw’s analysis based on data for 1947-1977 for 8 stations located along the coast, inter-station correlations are low and in some cases negative.

Figure 17 shows yearly precipitation totals and 5-year averages for the period 1930 to 2008 for select stations. It can be seen that long term annual data is not continuous and in most cases is sparse although records for 04GEOBOT and 06ROSALF are particularly good. Regions 1-4 are again quite similar having between about 2000 and 3000 mm of rainfall a year, but particular 5-year average annual trends differ between stations in each region. For example 01MRAWAN on the coast appears to receive less rainfall than 01PKTUMA which is slightly more inland; in region 2, 02CHARTY and 02PICKGL receive similar rainfall totals and slightly more than 02ANNREG and 02DENMG; most stations in region 3 have similar annual totals except 03ALESF which appears to have lower totals; and stations in region 4 differ by about 800 mm with maximum values inland. Regions 5 and 6 average about 2000 mm rain a year. 05BLMONT appears to receive more rain than 05BLAIR7 although stations are located in quite close proximity so the reason for this is unidentified.

Complete annual totals are very discontinuous and lacking for regions 7 to 10 although it can be seen that stations in region 8 receive rainfall totals averaging 3000 to 4000 mm/year whilst those in region 9 receive only around 1500 to 2500 mm/year.

4.2.2.1 El-Niño Southern Oscillation

Guyana’s climate is not only influenced by the oscillation of the Equatorial Trough, but also by processes such as the El-Niño Southern Oscillation (ENSO). ENSO results from cyclic warming and cooling of the surface of the central and eastern Pacific Ocean. The ocean there is colder than its equatorial position would suggest, due to various influences such as the trade winds and cold ocean currents and upwellings. When these influences weaken, the ocean heats up causing an El-Niño event whilst if these influences intensify, the ocean becomes cooler than normal causing a La-Niña event. The Southern Oscillation Index is a measure of the ENSO and is generated using a normalised sea level pressure difference between Darwin (north coast of Australia) and Tahiti (middle of the Pacific Ocean). Positive numbers indicate a La-Niña event whilst negative numbers indicate El-Niño events.

An SOI index from CRU [14] is compared with annual precipitation data for select stations for 1930-1950, 1950-1970, 1970-1990 and 1990-2010 in Figure 18, Figure 19, Figure 20 and Figure 21 respectively. 5-year average annual rainfall data is compared with the same select stations in Figure 22 and a simplified version is given in Figure 23. In general, ENSO appears to have a strong influence on annual rainfall totals. For example, rainfall appears to be greater during the 1937, 1996 and 1999-2000 La-Niña events and be less during the 1940-1941, 1982, 1987 and 1997 El-Niño events.

Figure 23 shows 5-year average annual rainfall totals for Georgetown on the coast, Mahdia in the rainforested interior north of Iwokrama, and two stations in the Savannah south of Iwokrama. Also shown are the 5-year averaged annual SOI values which suggest that since the 1970s, there has been a general trend towards very pronounced El-Niño events. Figure 23 shows that precipitation records for the rainforested interior and southern savannah regions are discontinuous compared with the long-term Georgetown record. Observations for the Mahdia and Georgetown are, however, fairly consistent with each other from about 1960 to 1975 following the global SOI record, but observations for the savannah show a potentially opposing trend during this period. Since the 1990s, observations seem to be relatively constant but either in or out of phase with the SOI thereby demonstrating the complexity of the interactions of ENSO with the climate. The complete absence of 5-year averaged precipitation totals from the rainforested interior from the mid-1970s precludes any further analyses of trends compared with coastal and savannah areas however understanding these relationships is crucial to understanding the possible future of the rainforest in a progressively warming climate. There is therefore, a clear demand for further monitoring and research.

An analysis of ENSO activity on precipitation in Georgetown was conducted by Wardlaw et al in 2007 [15]. The authors concluded that a La Niña event will most likely result in significantly higher than normal precipitation, whilst an El-Niño will most likely result in drought conditions. The most significant influences of ENSO occur in the November to December and October to January wet seasons. They also found that La Niña events resulted in increased precipitation in any season but particularly in November to December.

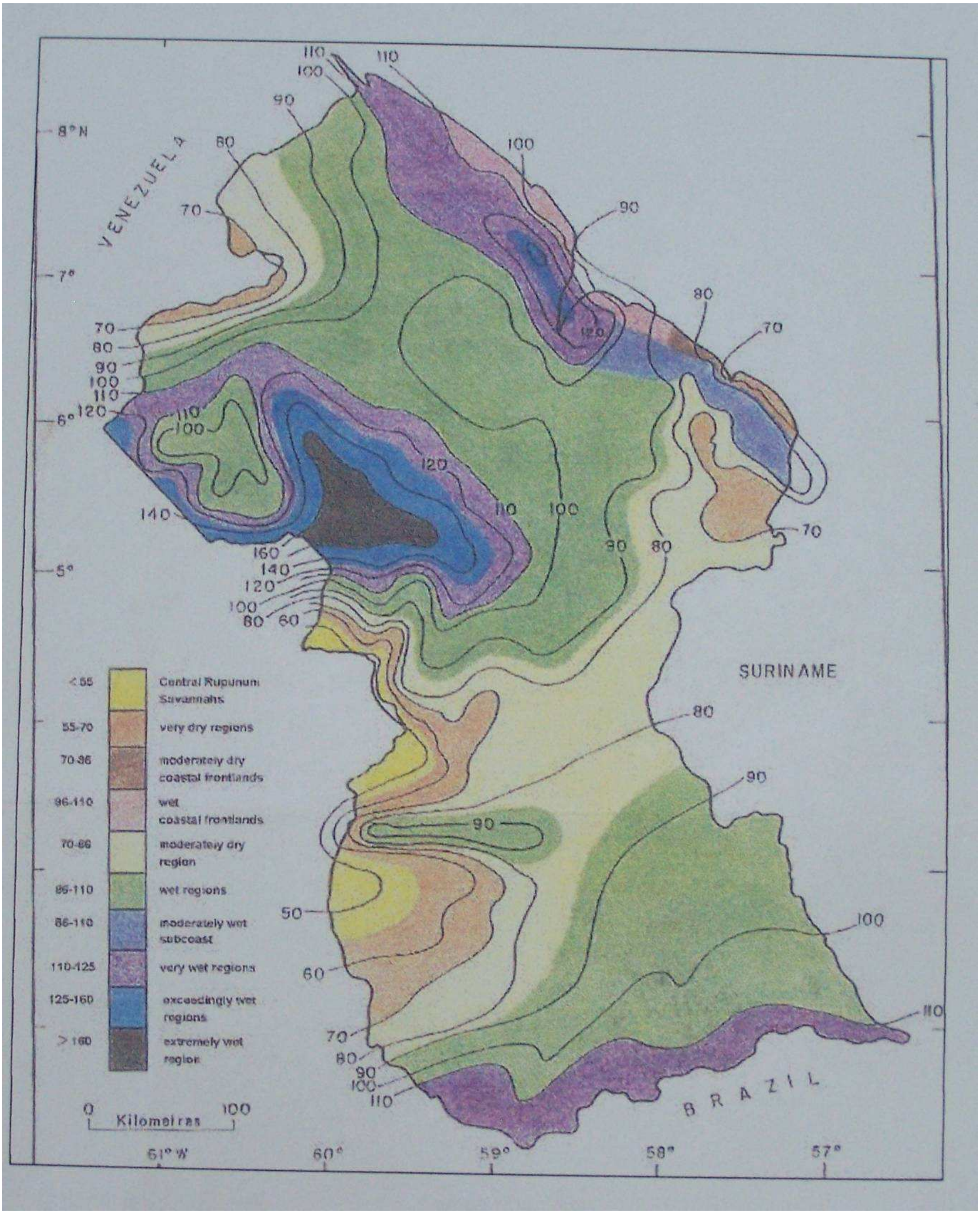

Figure 13 – Rainfall regions of Guyana (Persaud & Persaud, 1995) [10, 11]. Note rainfall units and contour intervals are in inches

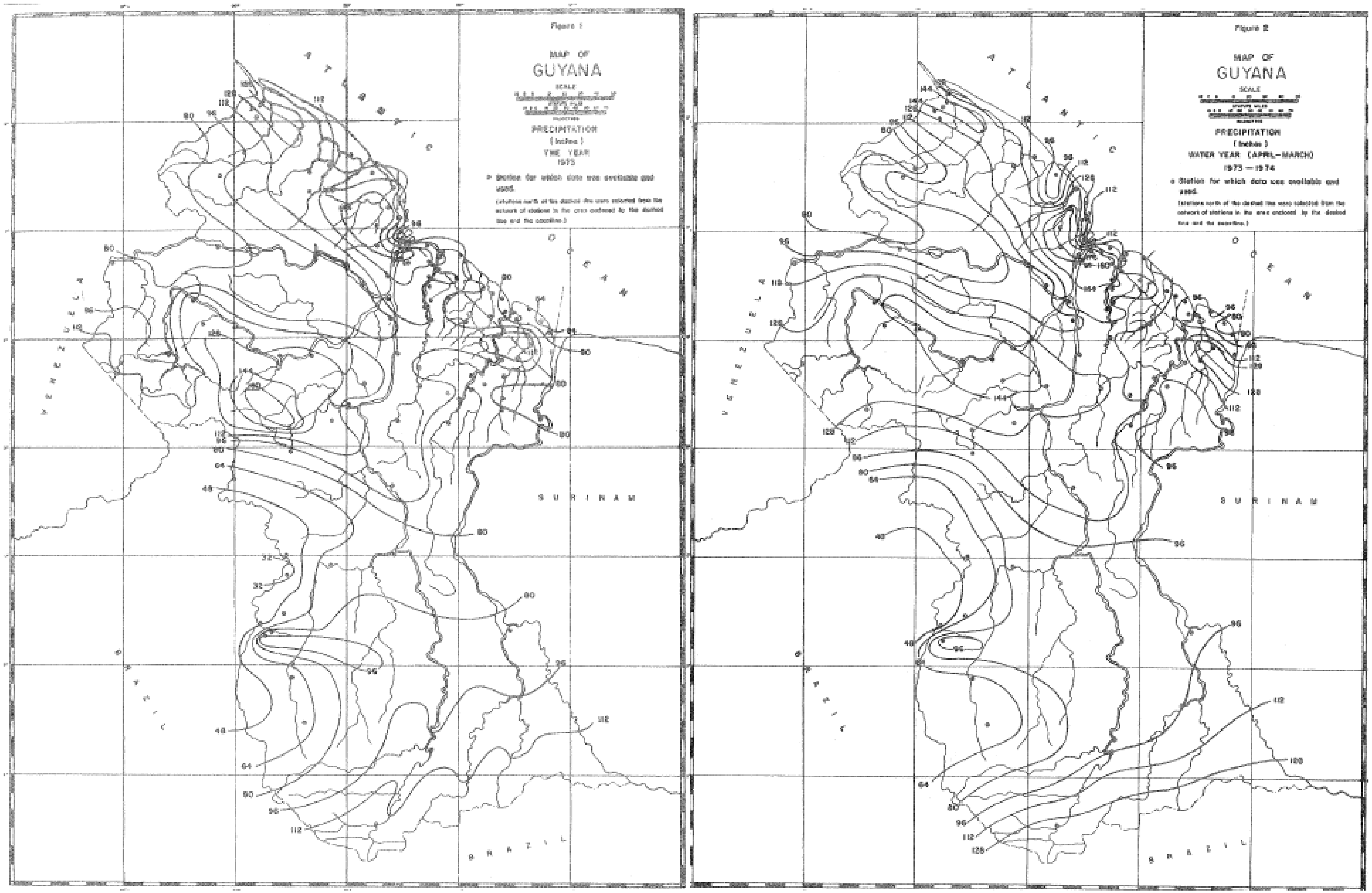

Figure 14 – Annual precipitation distribution maps for (left) 1973 (Jan-Dec) and (right) 1973-1974 (Apr-Mar) [from 12].

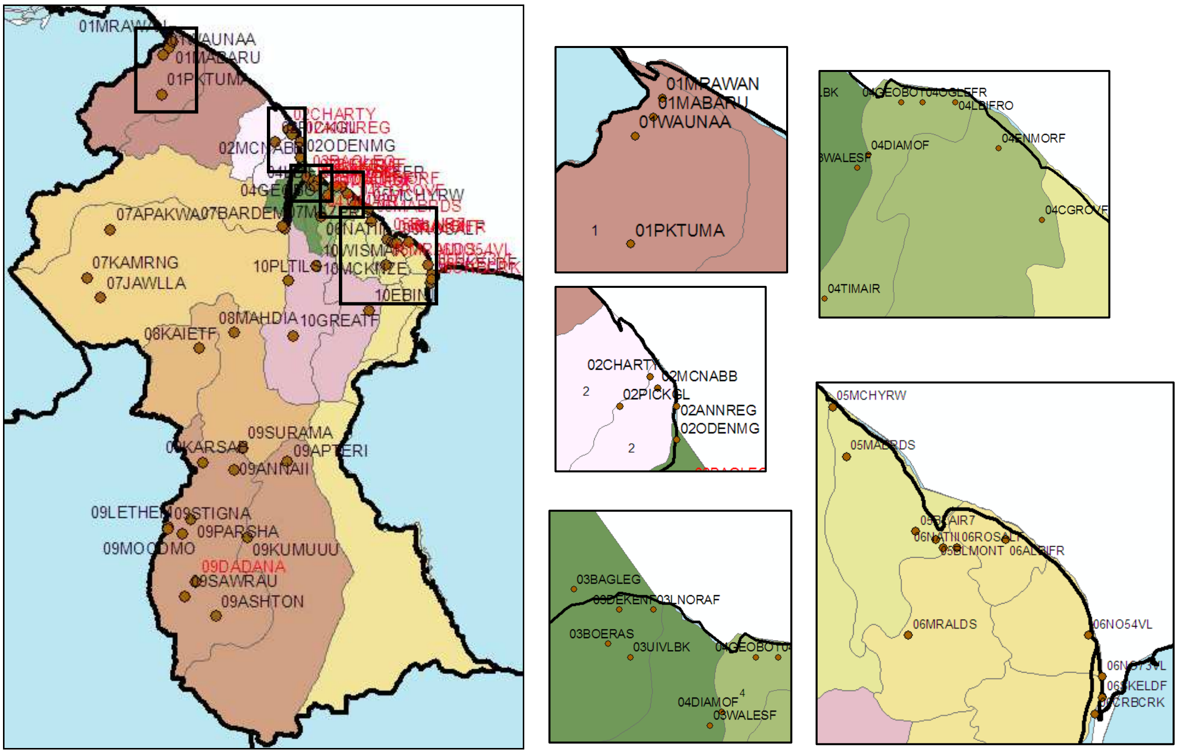

Figure 15 – Sites and station names of selected HydroMet precipitation gauges in Guyana. Boxed areas are shown in greater detail to the right.

Figure 16 – Monthly precipitation (mm/month) (y-axis) for Jan-Dec (x-axis) shown for the sites with most data for each Region in Guyana. Please refer to Table 5, Appendix 3 for site geographical coordinates. Note different y-scale for Region 8.

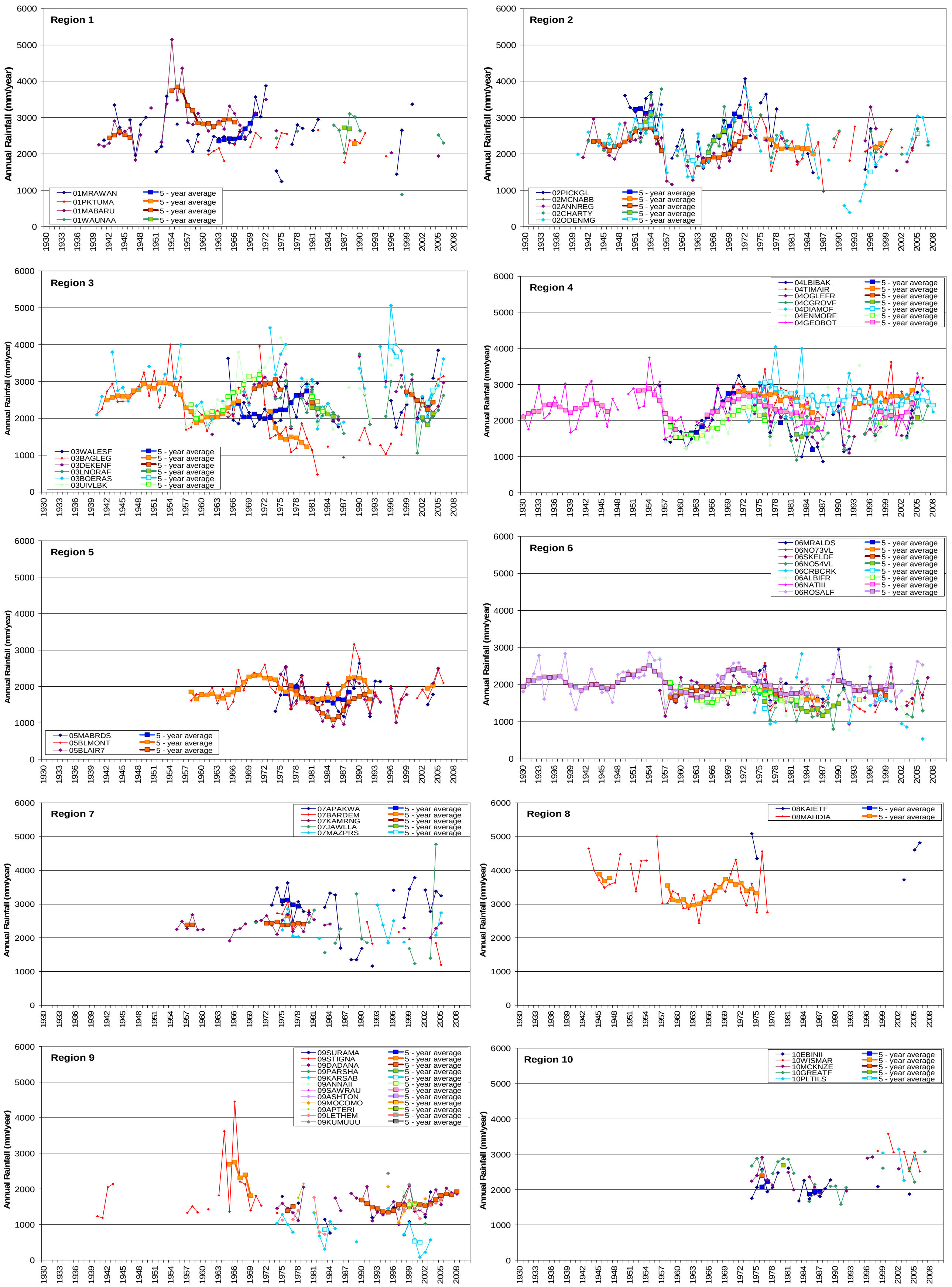

Figure 17 – Yearly precipitation totals and 5-year averages (mm/year) (y-axis) for 1930 to 2008 (x-axis) for sites with most data for each Region in Guyana (cross-reference with Figure 16). Only years with complete data are shown.

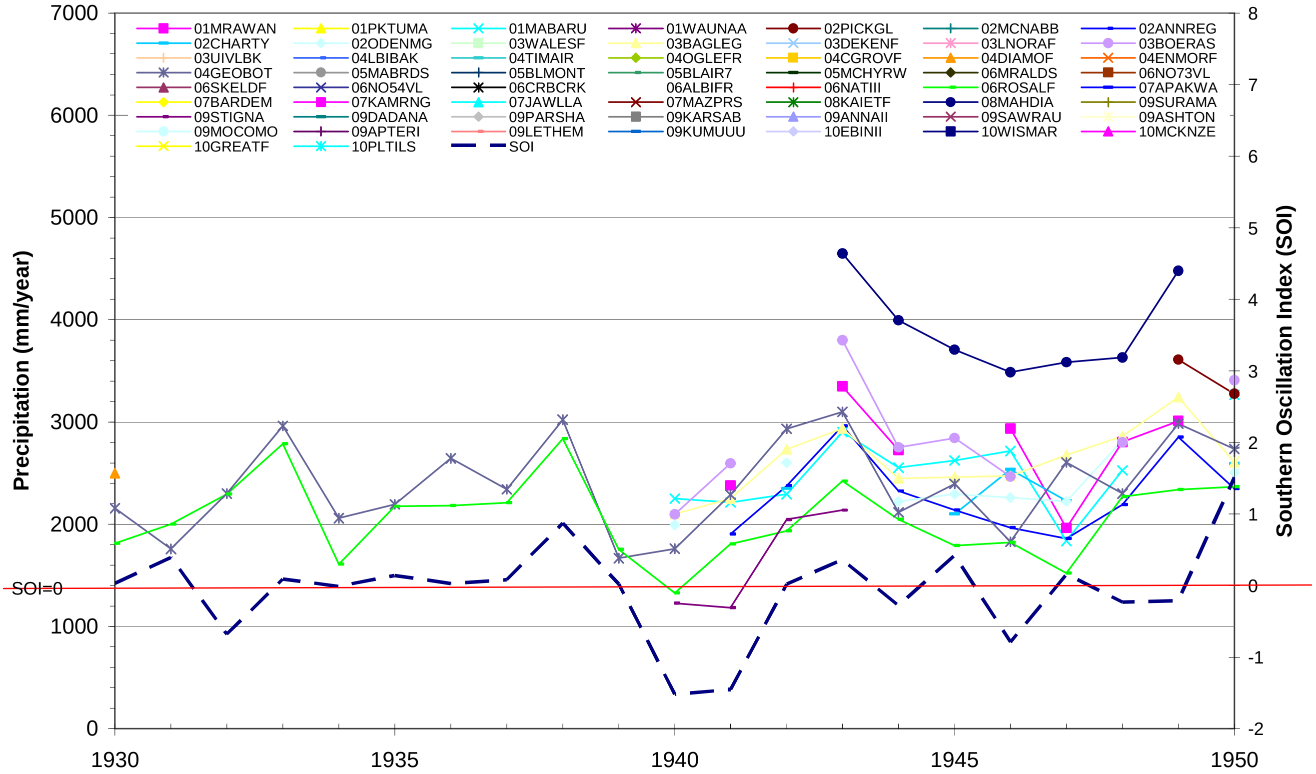

Figure 18 – Southern Oscillation Index (SOI) compared with annual precipitation data for select stations in Guyana for 1930 to 1950.

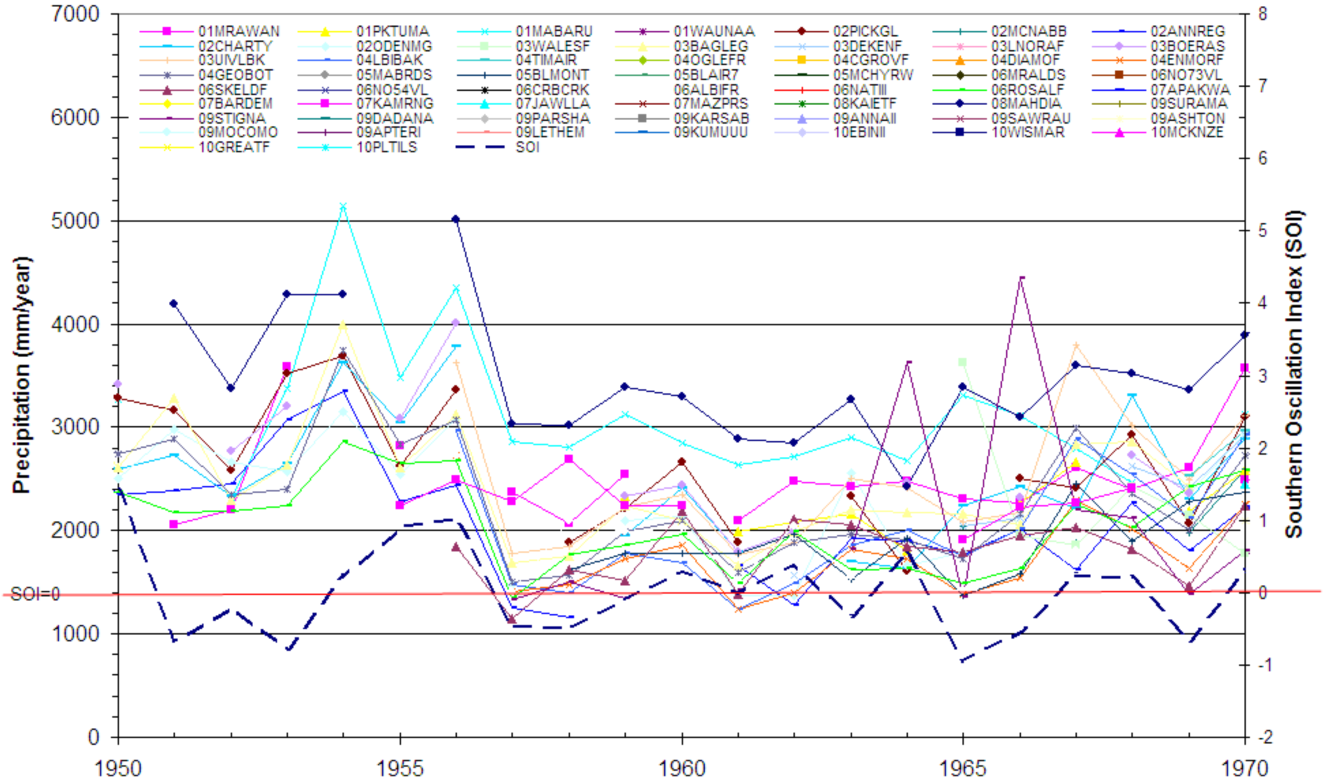

Figure 19 – Southern Oscillation Index (SOI) compared with annual precipitation data for select stations in Guyana for 1950 to 1970.

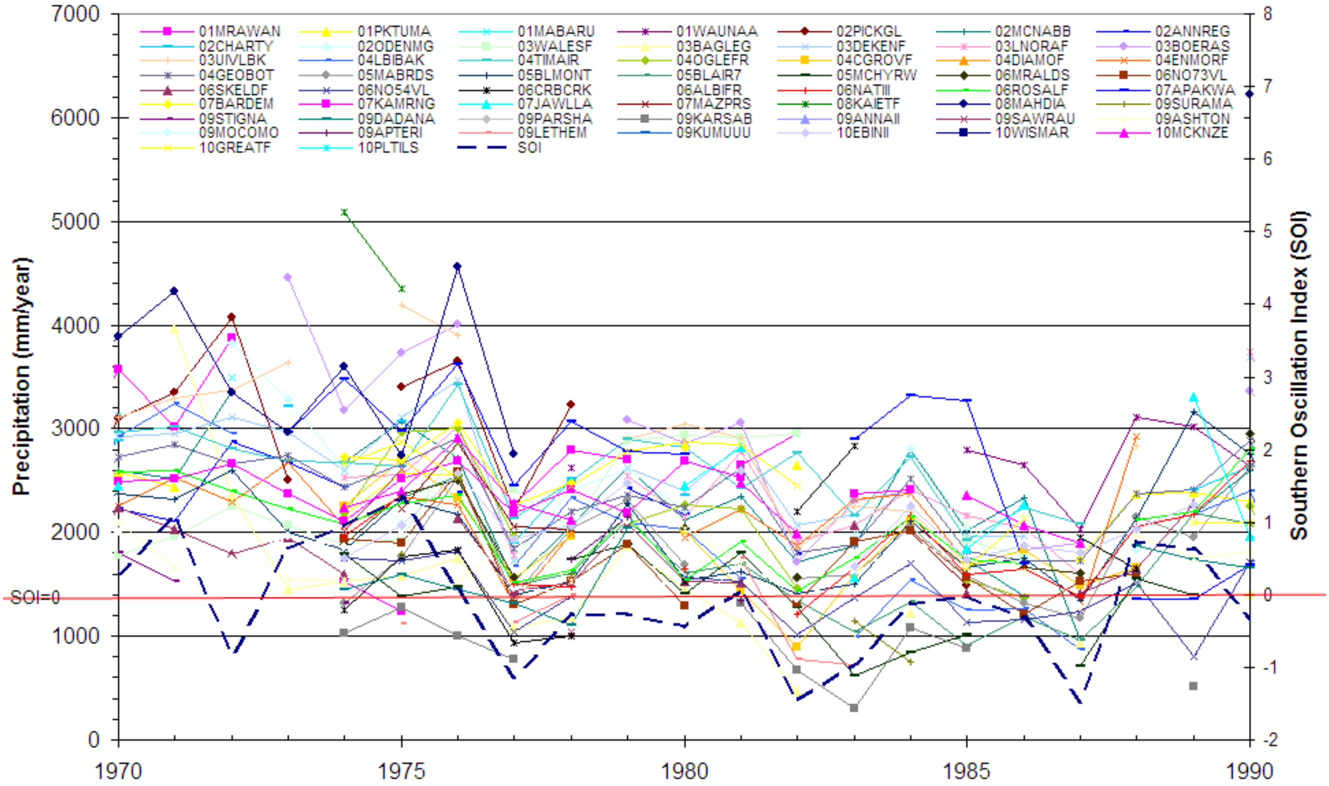

Figure 20 – Southern Oscillation Index (SOI) compared with annual precipitation data for select stations in Guyana for 1970 to 1990.

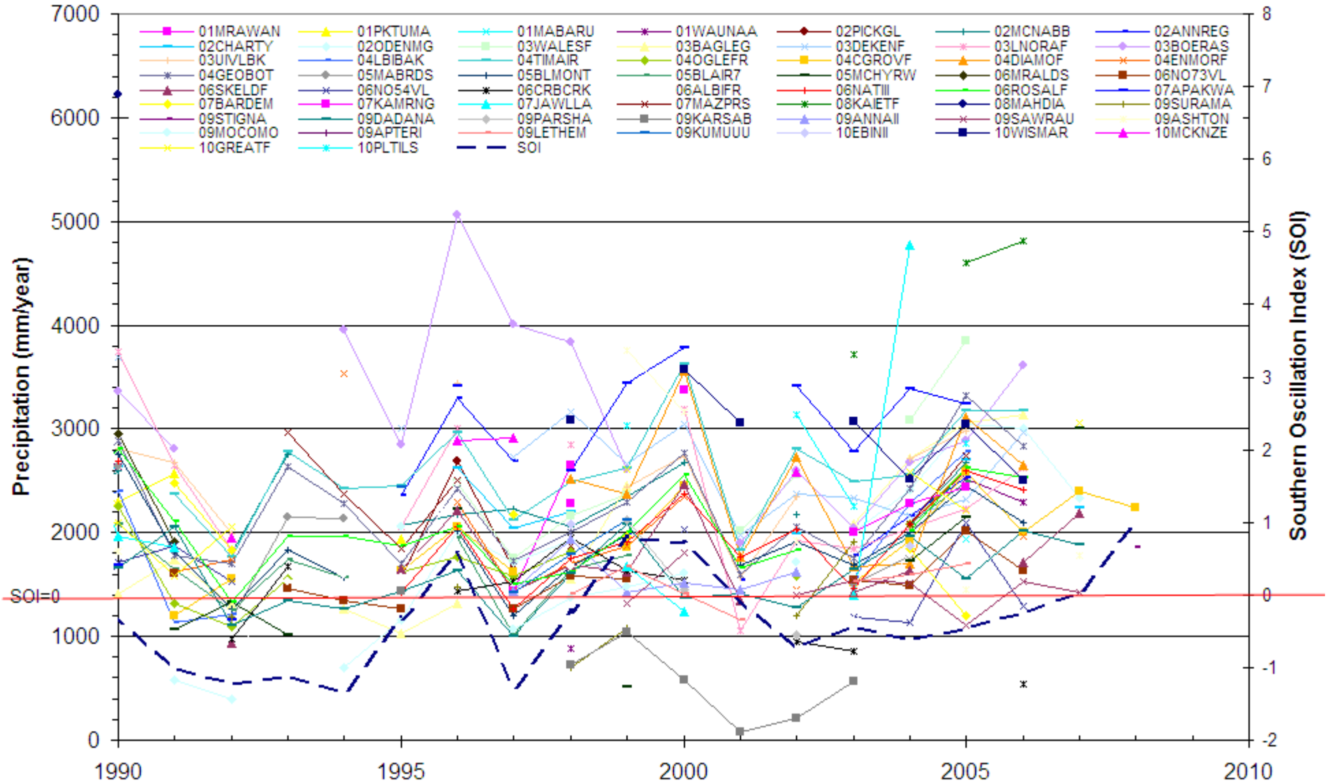

Figure 21 – Southern Oscillation Index (SOI) compared with annual precipitation data for select stations in Guyana for 1990 to 2010.

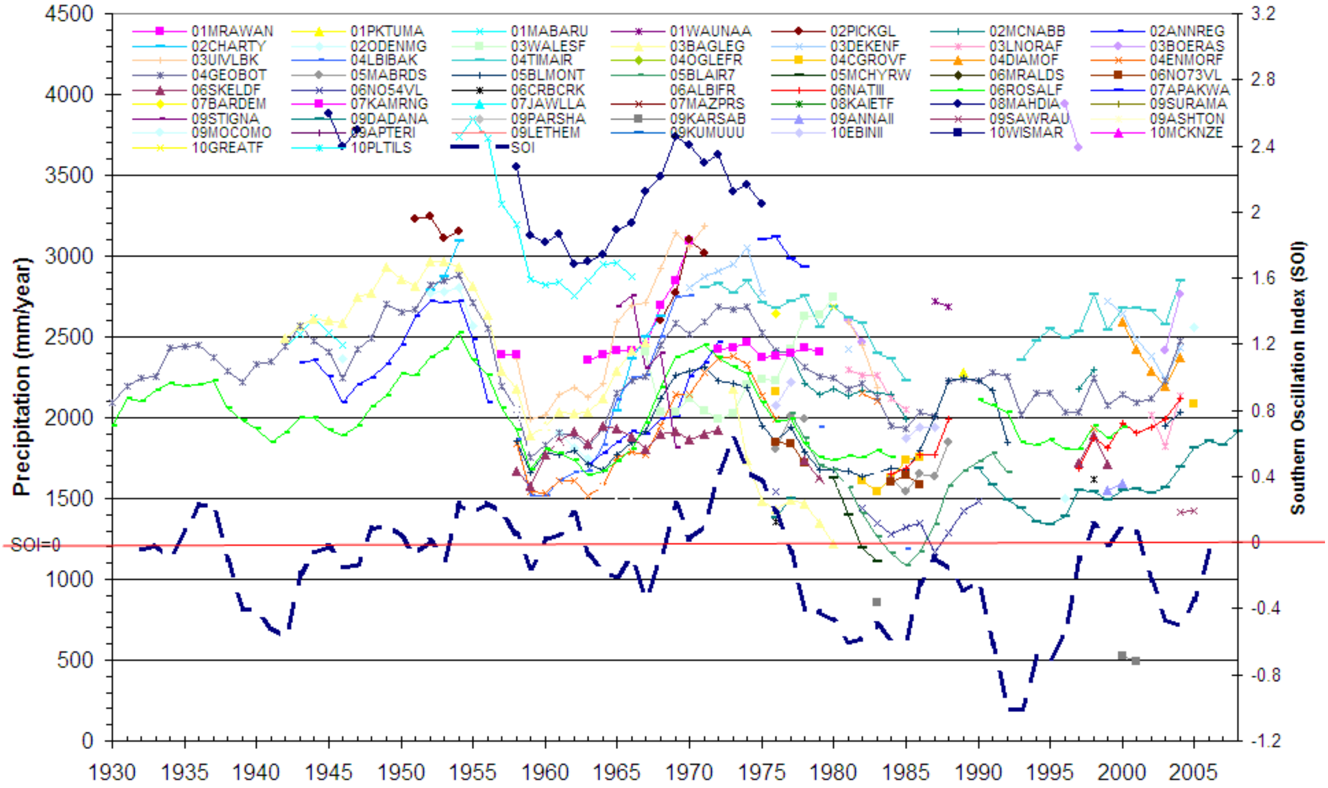

Figure 22 – 5-year annual average Southern Oscillation Index (SOI) compared with 5-year annual precipitation data for select stations in Guyana for 1930 to 2005.

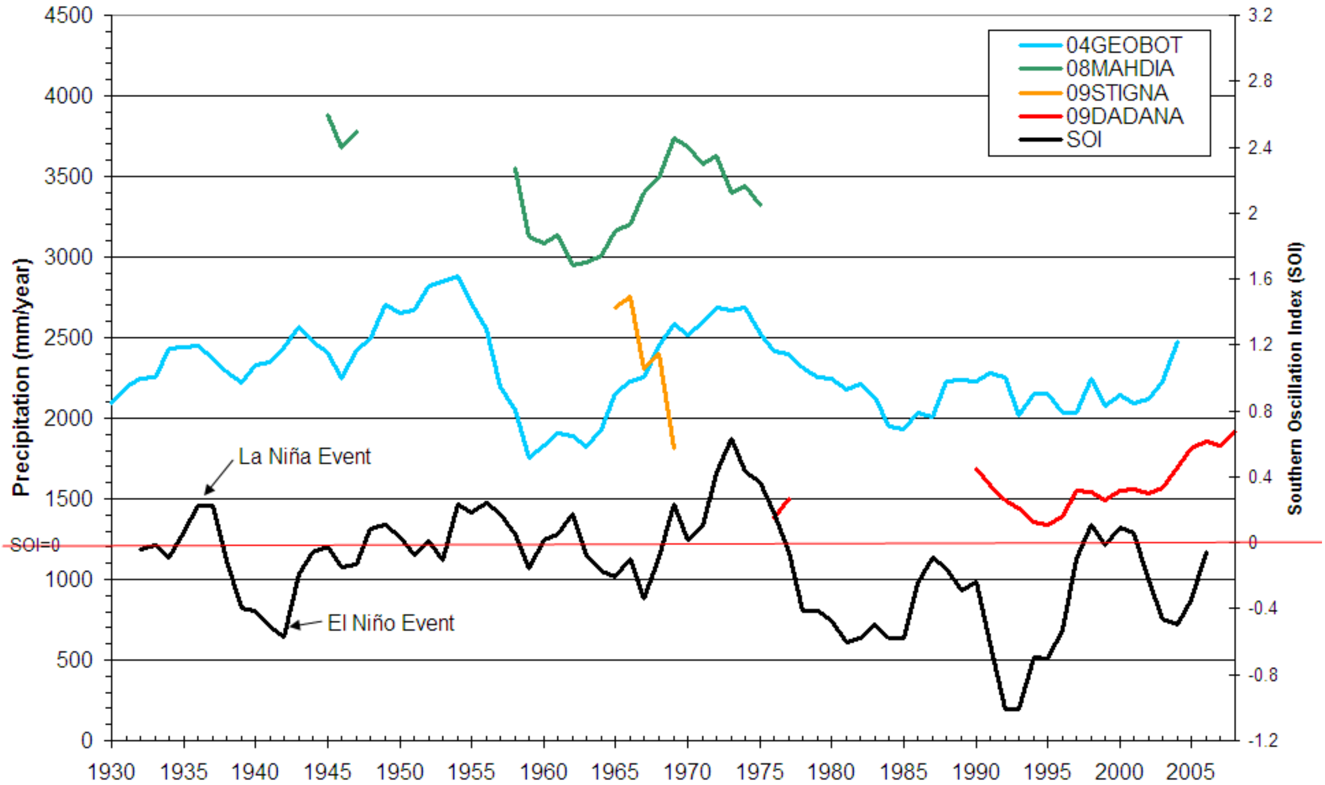

Figure 23 – Simplified diagram of 5-year annual average Southern Oscillation Index (SOI) compared with 5-year annual precipitation data for stations in Guyana: Georgetown (04GEOBOT, blue) on the coast, Mahdia (08MAHDIA) in the rainforested interior north of Iwokrama (green), and St. Ignatius (09STIGNA) and Dadanawa (09DADANA) in the Savannah south of Iwokrama

4.3 Precipitation at Iwokrama

4.3.1 Overview

The Iwokrama reserve lies between Mahdia (08MAHDIA) and Surama (09SURAMA) villages. As can be seen from Figure 24, rainfall at these two sites differs considerably. Mahdia in the north experiences two wet and two dry seasons with high rainfall totals, whilst Surama in the south experiences just one wet season and much lower rainfall amounts. Although records are not currently available, the original Iwokrama site survey reports [16] and [17] state that rainfall at Kurupukari on the north-east border of Iwokrama near the field-station for 1930-53 and 1970-74 show a bimodal rainfall pattern. Iwokrama is therefore located in a key geographical location to investigate the changes taking place between the coastal climate influenced by the Equatorial Trough and the Savannah climate experiencing a more continental type climate.

Although records are currently lacking, it is likely that rainfall distribution within the reserve is influenced by topography such as the Iwokrama Mountains through orographic lifting of moisture-laden air from the north-easterly trade-winds. Mountain slopes facing north east will receive more rainfall whilst leeward slopes would have reduced rainfall.

A new climate and hydrology monitoring program is being initiated in October 2009. The climate and hydrology network is designed to monitor in detail the climatic transition zone spanning Iwokrama along with the effects of elevation. Rivers will also be monitored to establish baseline hydrology data and to capture changes occurring due to the sustainable forestry operations taking place in Iwokrama.

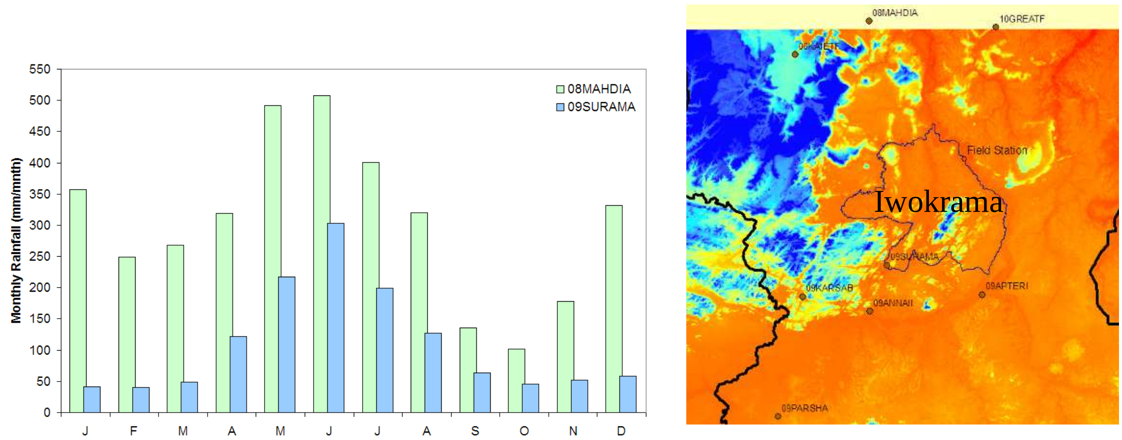

Figure 24 – Comparison between average monthly precipitation for Mahdia (north of Iwokrama, green) and Surama (south of Iwokrama, blue) (left). Relief map showing location of stations and Iwokrama (right). Blue is highest elevation, red lowest.

5 Future Climate

5.1 Introduction

General Circulation Models (GCMs) are mathematical models of the general circulation of the Earth's atmosphere or ocean and are based on well-established physical principles. Atmospheric and Oceanic GCMs are key modules of global climate models which also have additional components such as land-surface or sea ice models. Coupled Ocean-Atmosphere GCMs can be used to model the Earth's current climate and to project potential future climates under different scenarios. They have been demonstrated to reproduce the observed features of recent and past climate changes and there is considerable confidence that they provide credible quantitative estimates of future climate change particularly at continental and larger scales [22]. Estimates of future climate change are, however, more certain for particular variables such as temperature than for precipitation [22]. Recent improvements in the models have lead to them being able to simulate extreme events, such as hot or cold spells or intense rainfall, better and in the tropics, overall improvements have been made in the simulation of the spatial pattern and frequency of the ENSO. Criticisms of climatic modelling concern the lengths of the climatic records upon which they have been based or calibrated, validated and verified.

GCMs are run at a coarse spatial resolution (typically with horizontal scales of 300 km) and are therefore unable to provide data at sufficient spatial resolution to capture changes in climate across a region or small river catchment for example, particularly in areas of complex topography. As a result, GCMs cannot be used for local impact studies. Regional detail can, however, be obtained from statistical downscaling methods based on empirical regression relationships or simple interpolation, or from dynamical downscaling methods such as nesting high-resolution Regional Climate Models (RCMs) into GCMs (generally resolving features down to 50 km or less). (Please refer to Fowler et al 2007 [23], for a review of downscaling methods). Like GCMs, RCMs are full climate models and as such are physically based. They represent most, if not all of the processes, interactions and feedbacks between climate system components represented in GCMs.

Climate models simulate a "control" period or the current observed climate, usually taken to be 1961-1990, and various "future" periods, the potential future climates under various emissions scenarios, usually for the period 2071-2100. These "time-slices" represent a stationary climate over the 30-year period.

Various future scenarios have been developed in the Special Report on Emissions Scenarios (SRES) [19], each making use of different assumptions about future greenhouse gas emissions, land-use and socio-economic conditions. For example, the A1 scenario projects rapid economic growth with widespread use of new and efficient technologies. In this scenario global population reaches 9 billion by 2050 then declines. There are extensive cultural interactions worldwide. The A1B subset has a more balanced emphasis on all energy sources. The A2 scenario projects regionally oriented economic development with slower and more fragmented technological changes. In this scenario global population continuously increases. The B1 and B2 scenarios are more ecologically friendly.

It should be noted that although GCMs and RCMs can be used to model current and future climates, it is important to assess the model's skill at simulating the current climate of the particular region of interest before using the model for assessing the potential future climate change. Biases present in a model when simulating the current climate are likely to also be present in simulations of future climates and need to be taken into account when interpreting or downscaling results. It is also important to note that although different models are generally based on the same underlying principles, model outputs of future climate change can show very different directions of change leading to considerable uncertainty in the results. In order to take account of these uncertainties, it is best not to base an assessment of future climates on just on one model, but to take account of several model outputs through an ensemble. Lastly, it is important to be aware of which future scenarios or ensemble of scenarios the models have been run for.

5.2 Climate change in northern South America

According to the IPCC Working Group 1 Report and based on an ensemble of 22 GCMs [20], all of Central and South America is likely to warm during this century. The simulated warming is generally largest in the most continental regions, such as inner Amazonia but inter-model temperature ranges are large for this area making it difficult to establish actual amounts [20]. It is also uncertain how annual and seasonal precipitation may change particularly over northern South America as models for this area do not agree [20].

Most global climate models cannot reproduce the current regional climate over tropical regions well. Simulations of precipitation and its variability are particularly poor, especially over the Amazon. The rainforests are unique geographical features that shape the climate of the area, however there is a current lack of understanding of the processes taking place in this region, reflected in the outputs of the global circulation models [20]. The models tend to depict a relatively weak ITCZ which extends southward of its observed position and therefore tend to underestimate current rainfall in over the Amazon basin [20]. As mentioned in the previous sections, the Guianas are strongly influenced not only by the migration of the ITCZ but also by the ENSO. Changes in these processes will affect the region considerably. Feedbacks between carbon cycle and seasonal and dynamic vegetation properties are not included in the IPCC models; however separate studies have been conducted which suggest that the drying of the Amazon potentially contributes to acceleration of the rate of anthropogenic global warming by increasing CO_2. Furthermore it may be that tendencies towards an El Niño state would contribute to reduced rainfall and dieback of vegetation in the Amazon although this interpretation was based on just one model and as has been discussed, these vary considerably for the tropics [see 20 and references therein].

5.3 Climate change in Guyana

Current Climate Trends
According to the UNDP Climate Change Country Profiles [18], mean annual rainfall over coastal Guyana has increased at an average rate of 4.8 mm/month (2.7%) per decade and mean annual temperature has increased by 0.3 °C since 1960 an average rate of 0.07 °C per decade. This rate of warming is less rapid than the global average, however the increase in frequency of particularly hot days and nights has shown a significantly increasing trend since 1960 in every season. These are defined as the temperature below which 10% of days or nights are recorded in the current climate. The average number of hot days has increased by 93 days between 1960 and 2003 whilst the average number of hot nights has increased by 87. The frequency of cold days and nights has also decreased significantly since 1960 by about 37 days.

These observations are based on data from the Climatic Research Unit (CRU), the University of Delaware, Global Precipitation Climatology Centre (GPCC), NCEP and ERA40 data (please refer to Appendix 3 datasets 1, 3 and 4 for further information.

Future Climate
The UNDP Climate Change Country Profiles [18] future climate scenarios are based on a sub-set of 15 from the 22-member ensemble GCMs used by the Intergovernmental Panel on Climate Change (IPCC) for their fourth Assessment report (2007).

Based on these models the UNDP Climate Change Country Profiles [18] find that the ensemble of models project wide changes in precipitation for Guyana. Model projections vary between -34% to

+20%. Furthermore, models show wide disagreement in projected changes in frequency of El Niño events.

The models agree more for temperature. Temperature for Guyana is projected to increase by 0.9 to 3.3 °C by the 2060s and 1.4 to 5.0 °C by the 2090s. Under any particular emission scenario described by SRES report [19], the range of projections by the 2090s is 1.5-2.5 °C. The rate of warming is projected to be more rapid in the southern part of Guyana. Figure 25 shows the projected changes in temperature for the 2090s under the SRES A2 scenario.

All model projections also indicate an increase in the frequency of hot days and nights and decreases in the frequency of cold days and nights. In fact, the frequency of days and nights considered cold in the current climate are expected to become exceedingly rare and may not occur at all by the 2090s.

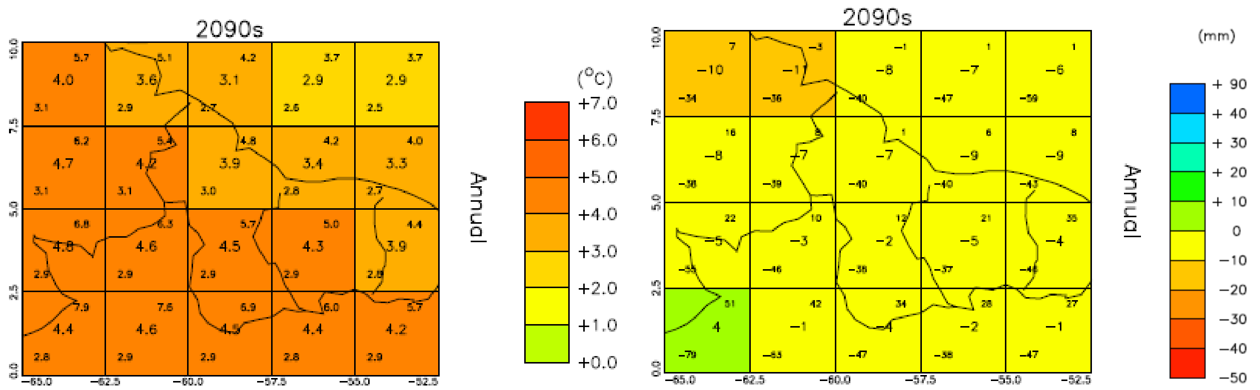

Figure 25 – Spatial pattern of projected change in mean annual temperature (left) and mean precipitation (right) for the 2090s for the SRES A2 scenario. All values are anomalies relative to the mean climate of 1970-1999. The model ensemble median, maximum and minimum is given in each cell in the centre, upper and lower corners respectively. From the UNDP Climate Change Country Profiles for Guyana [18].

Regional Climate Models (RCMs) are still being developed and tested for Guyana. Few studies exist and are usually constrained by short simulation lengths [20]. Studies in the skill of experimental downscaling of seasonal predictions over Brazil suggest however, that more realistic GCM forcings and improvements in the RCMs are needed whilst analyses of RCMs driven by Atmospheric GCMs suggest these types of simulations generally improve rainfall simulation in the tropics but that they could exacerbate dry bias and perpetuate the erroneous ITCZ over neighbouring ocean basins [see 20 and references therein].

The PRECIS Caribbean Climate Change Project is currently using the PRECIS RCM developed by the Hadley Centre, UK, to produce various future climate scenarios of the Caribbean region, including Guyana (see dataset 19, Appendix A3). These simulations are currently underway and results should be available soon. The PRECIS regional model and HadAM3P, the model that provides the default lateral boundary conditions are both based on the atmospheric component of the Hadley Centre's coupled climate model HadCM3. However, the HadCM3 model participating in the IPCC study, projects by far the largest reduction in annual rainfall over the Amazon (-21% for the A1B scenario) [20, 21]. Interpretations based on just one model are therefore to be used with caution.

An assessment of the potential impacts of climate change, a vulnerability assessment and potential mitigation measures for Guyana is available in the 1st National Communication Report [24].

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