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

Main Report

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 full report should be referenced as follows:

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

Bovolo C. I., Parkin G., Wagner T. (2009) *Initial Assessment of the Climate of Guyana and the Region with a Focus on Iwokrama, Main Report.* School of Civil Engineering & Geosciences, Newcastle University, Newcastle upon Tyne, UK

Bovolo C. I., Parkin G., Wagner T. (2009) *Initial Assessment of the Climate of Guyana and the Region with a Focus on Iwokrama, Part A Appendices – Data Availability.* School of Civil Engineering & Geosciences, Newcastle University, Newcastle upon Tyne, UK

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.* 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.* School of Civil Engineering & Geosciences, Newcastle University, Newcastle upon Tyne, UK

Acknowledgements

I would like to express sincere appreciation for the support received from all individuals and organisations contacted for this project.
Please see Appendix A1 for all individuals and organisations gratefully acknowledged.

Summary

This report presents a brief summary of the initial findings from a 4-month pilot project funded by the Commonwealth Secretariat to collate and analyse climate/hydrology data related to the Iwokrama International Centre for Rainforest Conservation and Development, Guyana.

Part A of this report involves the identification and collation of climate/hydrology data for Iwokrama and the surrounding regions in order to establish a baseline for all scientific studies involving climate and climate change, and assessment of data availability, quality and gaps in order to guide future monitoring and data collection programmes.

Part B, involves a brief basic analysis of the observed data to put Iwokrama's climate into a local, regional and global context and a brief overview of model simulations of future climate for the area.

This study is a comprehensive attempt to collate and review climate data for Guyana and the surrounding regions. The project has provided a valuable opportunity to establish relationships with a network of all the major data providers in the region. All of the main data sources are thought to have been identified, and some available data sets have been acquired. Some data are not readily available in a format that can be used for analysis, yet despite problems with data quantity and quality some of the outcomes from Part A and Part B have already been used to inform the design of a proposed hydrometeorological monitoring network for Iwokrama.

The key findings from Part A are that:

- Some long, if not always continuous, historical records are available electronically (one dating from 1892) which are extremely valuable in establishing long-term trends.
- The available climate and hydrology data sets have significant gaps in historical records, problems in data quality, and gaps in the spatial data coverage, and there remain substantial records that have potential high value that have not yet been processed into digital form.
- Due to the quality of the datasets, further assessment and processing is required before a full integrated analysis of the regional climate can be carried out.

The key findings from Part B are that:

- The study is regionally important for establishing an overview of spatial and temporal climate trends in the region. More research is needed however to fully understand the influences of the Equatorial Trough, the El-Niño Southern Oscillation and other regional influences on the area, and there remains an outstanding need for further analytical studies on the data.
- Iwokrama is located in a key geographical position in Guyana useful for investigating the climatic transition zone between the coastal area and savannah in the south. It is vital to understand the fate of the savannah and the neighbouring rainforests in relation to global warming.
- Global Circulation Models are currently unable to simulate current and therefore future climates in the equatorial regions well. Simulations of precipitation and its variability are particularly poor however the models agree that, in Guyana, temperatures are likely to increase in the future, particularly in the interior.

The recommendations arising from this study are that there is a need for further work beyond the scope of this pilot project on:

- training and capacity building, which is considered as a key priority to ensure that hydrometeorological data collection and analysis in Guyana is carried out to international standards (a clear and substantial need for this has been identified in previous studies by other organisations, but not yet resolved).
- processing the historical data sets to complete the available digital records, including digitising paper records, gap filling, and data quality assessments.

- integrated analyses of historical and future climate data using fully quality-controlled historical data sets (monthly and annual trends, spatial data analysis, comparison of climate model data with observations, and assessment of climate model outputs for future climates).
- installation of hydrometeorological equipment and long-term monitoring in the interior of Guyana
- specific climatic and hydrological data analyses, which will enable questions related to the broader science and business aspects of Iwokrama to be addressed. These would be based on modelling approaches such as downscaling climate model outputs and hydrological modelling, to address issues including the role of global climate patterns in regional drought and flood frequencies, analysis of the role of water in driving changes in ecosystem services such as soil quality and biodiversity, assessments of vulnerability of managed forests to climate extremes, and assessments of the significance of Guyanan forests to the water cycle and climate resilience of the Amazon basin.

Final Report

This report presents a brief summary of the initial findings from a short 4-month pilot project funded by the Commonwealth Secretariat, to collate and analyse climate and hydrology data related to the Iwokrama International Centre for Rainforest Conservation and Development, Guyana.

The report is split into two parts, Part A deals with data availability and Part B with a brief analysis of the data and climate change. A short report on hydrological modelling is also provided separately but is not discussed in this report.

PART A – Data Availability

1 Introduction

Part A of this report involves the identification and collation of climate/hydrology data for Iwokrama and the surrounding regions in order to establish a baseline for all scientific studies involving climate and climate change, and the analysis of data gaps and quality. Part A does not cover the actual analysis of the data which is covered in Part B of this report. Data sources include reports, publications, historical records and electronic databases including data available on the internet, covering the following areas:

- Climate data for Iwokrama, Guyana and the surrounding regions (including observed precipitation and temperature time series and modelled future climate scenarios)
- Hydrology data for rivers in and around Iwokrama (including discharge time series, rating curves, flood-peaks and extents, water quality, sediment discharge)
- Physical environment data (including ground surface topography (e.g. Digital Elevation Models), river network (including digital maps, river profiles and cross-sections), vegetation cover maps and properties, soil type distributions and properties, geology maps).

This report deals with (1) data (gathering strategy, providers, and availability), (2) gap analyses, and (3) key conclusions and recommendations. More detailed information on the specific aspects is compiled in the Part A Appendices.

2 Data

Gathering Strategy: Data has been gathered using personal contacts and web-searches. Iwokrama-related individuals and the Iwokrama International Centre itself have also helped in providing contact names and introductions to people and organisations. Initial communications often revealed further potential data sources or contacts. Two ‘field-visits’ enabled face-to-face contact with key organisations and people and were instrumental in procuring data (which was not always in electronic formats) and in establishing good-will and rapport with contributors.

<u>Field-visit 1:</u> 7th to 22nd March 2009.

The first field-visit entailed meeting staff at the Iwokrama International Centre Georgetown Office and field-station (13-16th March), establishing face-to-face contact with regional and local organisations and following data-trails. Visits were made to various organisations in Georgetown, Guyana, the University of the West Indies St Augustine campus in Trinidad and Cave Hill Campus in Barbados, plus the Caribbean Institute for Meteorology & Hydrology (Barbados).

<u>Field-visit 2:</u> 25th April to 10th May 2009.

The second field-visit enabled follow up appointments to be made, in particular to organisations which had promised data during the fist visit. New contacts were also made with individuals who were unavailable during the first visit. Participation at the first Iwokrama Science Committee Meeting (28-29th April) enabled some initial findings to be presented to the group. A visit to Iwokrama field-station (1st to 4th May) enabled further discussions to take place with field-staff and potential sites for installing new climate and hydrological monitoring stations were identified with colleagues from Newcastle University (Geoff Parkin and Tom Wagner). Details of the two field-visits are provided in Appendix A1.

Providers: Relevant global climate datasets have been identified and secured free of charge from CRU, BADC, NCDC GHCN and TRMM. Other available datasets include ERA40 and NCEP/NCAR data. Outside of Guyana, organisations such as the Caribbean Institute for Meteorology and Hydrology (Barbados), Caribbean Community Climate Change Centre (Belize), Météo-France, the National Meteorology Institute of Suriname and others have regional climate records. Datasets are provided under certain licensing restrictions. Within Guyana, HydroMet as part of the Ministry of Agriculture is the main organisation responsible for collecting, processing and storing hydrometeorological data within the country although other organisations such as GuySuCo (the sugar corporation) also maintain their own records. Limited data for Iwokrama is available through the IIC. Organisations contacted for data are listed in Appendix A2.

Availability: Available climate data include observed precipitation and temperature time series and modelled future climate scenarios. Hydrology and other physical environment data related to Iwokrama have been collated from initial site surveys and project data such as the Guiana Shield Initiative. Data assimilated include digital maps of topography, geology, soil type and vegetation data and properties. The collated data has already proved valuable in designing and setup the new climate and hydrology monitoring program for Iwokrama to be installed in autumn 2009. A full list of data that has been identified as existing (whether or not it is readily available in electronic format or is of appropriate quality) is given in Appendix A3. It has been noted in Appendix A3, Tables 1-4 whether this data has been collated or not.

3 Gap analysis and other data issues

3.1 Climate data

3.1.1 Climate records for the wider region

<u>Data sets:</u> Global climate data sets are available in monthly formats only and are generally the best, most accessible or most long-term records available within each country. Records have the benefit of having been checked and standardised for quality, format and location information. Global climate dataset providers, however, do not always have access to all data within specific countries, and coverage of Guyana in the global datasets is poor and for neighbouring countries is adequate but not substantial.

Despite lack of adequate coverage, the available records do provide a solid overview of the climate in the region. Global datasets of observations are also used as the basis for driving and testing global climate models (GCMs). They therefore give an indication of the quality, quantity and spatial distribution of the forcing data used within the models and provide a reference of the potential performance of the GCMs for the region.

Licensing issues: Several data providers exist, all with different licensing restrictions. Data is usually free for academic use but is not allowed to be distributed further without prior consent from the provider or without separate application by the interested party. Future research strategies therefore need to take licensing issues into account.

3.1.2 Climate records for Guyana

Spatial coverage: HydroMet have a network of 147 current and/or historical rainfall gauges across Guyana plus 5 weather stations. The distribution of the existing rainfall stations is uneven, mainly due to uneven population distribution and inaccessibility issues, especially in the interior of the country. 90% of the population live on the coastal plain where several gauges are located but there are gaps in especially in the interior. The World Meteorological Organisation (WMO) recommends that countries have at least a minimum hydrological/climatological network consisting of the minimum number of monitoring stations necessary to initiate planning for the economic development of water resources. The density of stations for a minimum network depends on the type of climatic zone, areal and seasonal variation in rainfall and population density. Six types of physiographic regions have been defined which should be adjusted to reflect the actual socio-economic and physio-climatic conditions of the country. Following WMO guidelines on numbers of rain gauges needed to cover an area, only the coastal regions in Guyana currently have an adequate rain gauge network, and the interior region is inadequately covered. There are two automatic weather stations on the coast so evaporation stations are adequately represented whilst the one in the interior does not provide sufficient coverage.

One key outcome and recommendation of this survey is the urgent demand to bring the climatological network in Guyana up to minimum WMO recommendations. Several new rain gauges and weather stations need to be installed to be consistent with international standards, particularly in the interior, and these should at minimum be a combination of standard and recording gauges.

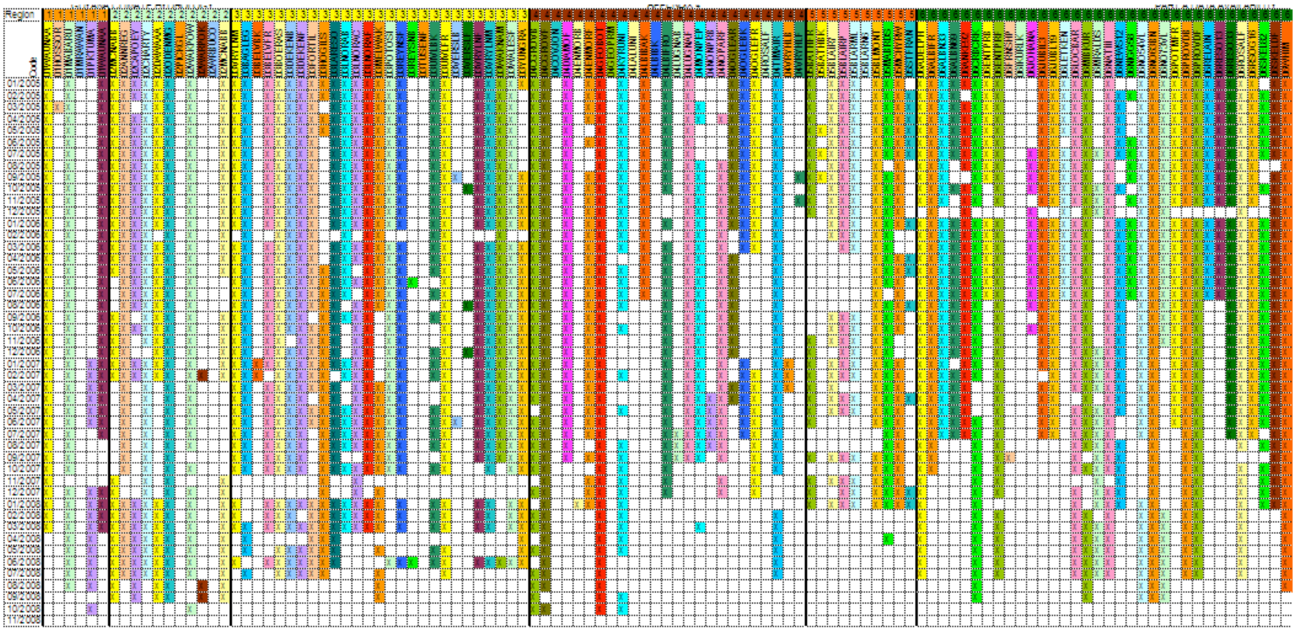

Figure 1 - Sample from Appendix A4 of data (coloured strips) and gaps (white) in the historical rainfall records. Months are listed on the left-hand axis (Jan 2005 to Oct 2008). Names for precipitation stations in regions 1 to 6 are listed horizontally at the top and are separated by vertical black lines. A month is only listed if present in HydroMet's database.

Temporal coverage: Rain gauges are usually of the standard type and require manual daily or monthly measurements. Very few gauges record measurements at the sub-daily level. It is particularly important to have fine resolution measurements of rainfall and other variables across Guyana to assess and measure intense, short-duration rainfall which provides information on the intensity, distribution and duration of precipitation. This type of data is particularly useful for assessing and quantifying extreme events.

It is known from old paper reports that records prior to 1970 are usually of better continuity than the more recent ones which have significant discontinuities especially in the 1980s and 1990s. However it is mainly records dating from 1974 that have been digitised and are available electronically. Some older records have also been digitised but of these longer-term rainfall records, none are totally continuous. Gaps in the records are particularly noticeable around Christmas and other holiday periods. A sample of the historical data records showing data gaps is shown in Figure 1.

Paper records: HydroMet have an archive which contains several older, and in most cases, hand-written records which require digitising. These paper records may be lost if not committed to digital form in the near future. Long-term records are of obvious benefit for establishing long-term climatic trends, however HydroMet do not have the staff resources to digitise all of these records at present but this is clearly a priority that needs further action without delay.

Data quality: There are some issues to consider with the quality of climate records. Firstly measurements may have originally been recorded wrongly (for example in the wrong units), either through human error, or through the use of incorrect or inaccurate measuring equipment, and secondly data may have been digitised incorrectly. There is evidence of both forms of errors.

Furthermore, rainfall gauge geographical locations require regular control, as some are clearly incorrect (digitally plotting in the sea), and the height of the gauges above sea-level are also lacking, so no account can be taken of differences in the data due to the effects of elevation.

3.1.3 Climate records for Iwokrama

Data sets: Old records show the existence of 4 rainfall stations around Iwokrama (Annai, Apoteri, Kurupukari and Surama) although not all data is available electronically. Data may have been lost or require digitising. Data has been collected at the Iwokrama field station, although records are fairly short and have several gaps.

3.2 Hydrology data

Hydrology data for the major rivers in Guyana exist in the form of discharge data and gauge heights at various gauging stations and miscellaneous sites however very few other data exist for example for water quality or sediment discharge. Furthermore, no data exists for smaller rivers or tributaries. Old reports indicate the existence of data for rivers around Iwokrama however this data has not yet been identified by HydroMet and it is not known if this data exists electronically. Hydrology data for Iwokrama rivers are therefore presently unavailable.

3.3 Physical environment data

Digital Elevation Model data in the form of SAR imagery is available for Iwokrama under the Guiana Shield Initiative project. Data generated from the TerraSar-X radar is particularly relevant in humid tropical areas as the radar is able to penetrate cloud cover. The radar will not penetrate totally through the canopy cover however, so although the data is useful for tracking deforestation, it is not suitable for applications such as hydrological modelling which require ground elevation data. Digital maps of the river network, roads, vegetation and soil cover are also available however all maps require quality control as they are all currently slightly offset from each other and require realignment.

Basic properties for vegetation and soil cover are available through the original Iwokrama site survey, N.A.R.I. and through Tropenbos reports (of a field-site next to Iwokrama), however these data are not sufficient for hydrological modelling and further soil collection and analysis would be required to carry out appropriate hydrological simulations.

4 Conclusions

The key conclusions from Part A are as follows.

- Good quality regional climate data sets have been obtained from global monthly data archives on the internet. Some long, if not always continuous, historical daily records of climate data available electronically.
- The available climate data sets for Guyana usually have significant gaps in the historical records, may have problems in data quality and self-consistency, have several gaps in the spatial data coverage, and there remain substantial records that have potential high value that have not yet been processed into digital form. Nevertheless, some long, if not always continuous, historical records have been digitised and are available electronically (one dating from 1892) which are extremely valuable in establishing long-term trends.
- Hydrology and physical environmental data sets are incomplete, sometimes inconsistent, and of variable quality.
- The survey so far has shown that there is considerable potential for valuable climatic research to be carried out of interest to international research communities focusing on tropical forests and climate from the local scale of the Iwokrama reserve up to the regional scale. However, due to the quality of the datasets, further quality assessments and processing is required before a full integrated analysis of the regional climate can be carried out. Furthermore, additional site specific monitoring and data collection is required before any hydrological modelling can be carried out.

5 Key recommendations

Key recommendations from Part A of this study are as follows:

- **Demand for capacity building and training in Guyana**
  HydroMet and other research and monitoring institutions in the country require trained professional staff to operate and maintain the network of rain gauges and weather stations and to manage, analyse and process the data produced, however they have both a shortage of staff resources and a shortage of qualified staff. There is, therefore, a clear demand for training and capacity building to ensure that hydrometeorological data collection and analysis is carried out to international standards in the future. Basic hydro-meteorology theory and practical courses are required initially, but longer-term provision for training and capacity building needs to be developed.

- **Processing of historical data sets**
  Old paper records need to be digitised as soon as possible and the quality checking of existing records needs to be carried out, including cross-checking between data sets, gap-filling, checking the locations, elevations and condition of existing gauges.

- **Additional instrumentation**
  There is a need for more automatic rain gauges and weather stations, especially in the less populous, forested interior where the spatial coverage of climate monitoring equipment is particularly poor. In particular, information is needed to characterise the transition zone between the coastal zone influenced by the inter-tropical convergence zone which experiences two wet seasons a year, and the inland area experiencing a more continental type climate and one wet season. First activities in this direction are planned for the forest of Iwokrama through IDB resources.

Importantly, provision needs to be made for long-term upkeep of installed equipment. The WMO recommends that stations in the basic network should be operated for at least 10 years, to obtain satisfactory information on mean value of observed parameters and on their temporal variations. Automatic and possibly solar-powered instrumentation would be less labour intensive, and would help to reduce reliance upon human data collection and processing.

PART B – Climate Overview

1 Introduction

Part B of this report involves a brief analysis of regional and local climate data in and around Guyana. It does not report the data sources or gaps, which are given in Part A of this report. In the low elevation tropics, the annual temperature range is not very large and precipitation is usually used as the basis for differentiating seasons. Part B therefore only deals with a brief overview of the spatial and temporal distribution of precipitation and does not cover an analysis of temperature or other climate variables such as wind or sunshine hours due to the short timescale of this pilot project. It is stressed that only a brief overview of the data is given and no attempts are made to conduct full detailed analyses of the data. There remains an outstanding need for analytical studies on the available climate data.

Hydrometeorological records are needed to examine and understand past and current climates and to place them into a local, regional and global context and as a basis for understanding the water resources of the area. Interpretation of these records for the tropics is especially important for helping to understand the complex relationships which exist between the climate and rainforests. Rainforests generate water through evapotranspiration which helps drive atmospheric wind circulation and keep the land cool. These forests are however threatened by deforestation and climate change which may lead to decreased evapotranspiration thereby reducing precipitation and leading to increases in temperature but further studies are required to understand the complex relationships. The IPCC 2007 Climate Change Report[1] states that "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."

This report covers an overview of (1) the climate of Guyana and the region, (2) temporal and spatial precipitation distributions in Guyana and Iwokrama, (3) a summary of climate change in Guyana and the region and (4) key conclusions and recommendations. More detailed information on specific aspects is compiled in the Part B Appendices.

2 Climate of Guyana and the region

The climate in the area is controlled by seasonal shifts in the Equatorial Trough which brings heavy rain to the region. The Equatorial Trough moves north during May to July to a position approximately 7° N and southwards during November to January placing it well over the Amazon basin.

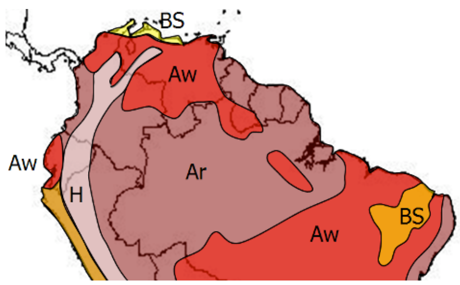

Figure 1 – Trewartha Classification system for the northern part of South America (after [2]). Aw = Tropical Wet and Dry; Ar = Tropical Wet; BS = Steppe or Semiarid climates; H = Highland climate

[1] IPCC-Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp. Chapter 11 (Regional Climate projections): Section 11.6 (South and Central America).

[2] Trewartha Modification of the Koppen Classification system *in* An Introduction to Climate 5th ed., by Glenn T Trewartha and Lyle H Horn. 1980 McGraw-Hill Inc.

In general terms, much of the Amazon Basin and coastal portions of the Guianas are classified 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[2] (see Figure 1). 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. This region is likely to experience increased temperatures in the future, as mentioned in the section below on climate change. The fate of this savannah belt and its potential expansion, either towards the coast or into the Amazon basin or both, in response to the increasing temperatures in the region due to climate change, needs to be investigated in order to assess the potential impacts on the local and regional climate and the impacts on neighbouring rainforests, including Iwokrama.

In detail, coastal regions of Guyana and Suriname have two rainy seasons, French Guiana has one long-rainy season and a short dry season and southern areas of Guyana and the Guiana Highlands in Venezuela and northern Brazil have a more continental type climate with one dry and one wet season distributed more evenly throughout the year.

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[3]. This is also the case in the Savannah region and in mountain areas over 1000 m[4]. Generally, forested areas are marked by hotter days and cooler nights. Temperature has not been analysed in this report.

3 Precipitation in Guyana

Precipitation in Guyana is spatially and temporally very variable and is influenced by the seasonal movement of the Equatorial Trough and the El-Niño Southern Oscillation (ENSO).

Guyana's coastal areas experience two wet and two dry seasons a year. Major rainfall peaks occur in June and December and relatively dry periods occur in March and September. The two-peak rainfall pattern is observed over regions 1 to 6 along the coast. Monthly precipitation averages show that these regions receive differing amounts of rainfall in September and October with coastal regions in the southeast receiving less rainfall than in the north during this time. Similar rainfall patterns occur inland in regions 7 and 10 which are set back but parallel to the coast. Region 8 on the north of Iwokrama receives the highest rainfall in Guyana whilst region 9 on the south the least. The savannah region in region 9 experiences only one dry season and one wet season.

The Southern Oscillation Index (SOI) is a measure of ENSO. Positive numbers indicate a La-Niña event whilst negative numbers indicate El-Niño events. In general, ENSO appears to have a strong influence on annual rainfall totals in Guyana with more rainfall occurring in La-Niña years and less during El-Niño events. Figure 2 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,

[3] Ramraj R. 2003 Chapter IV – Climate, *in: Guyana: Population, Environment, Economic Activities*. 1st Edition, USA Battleground Printing Publishing, p63-86. ISBN 0-9728295-0.4
[4] The Climate of Northern South America. Snow JW. *in* World Survey of Climatology Volume 12: Climates of Central and South America, edited by Schwerdtfeger W. Elsevier 1976

there has been a general trend towards very pronounced El-Niño events. Figure 2 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 regional climate in Guyana. 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 assessing the possible future of the rainforest in a progressively warming climate. There is therefore, a clear demand for further monitoring and research.

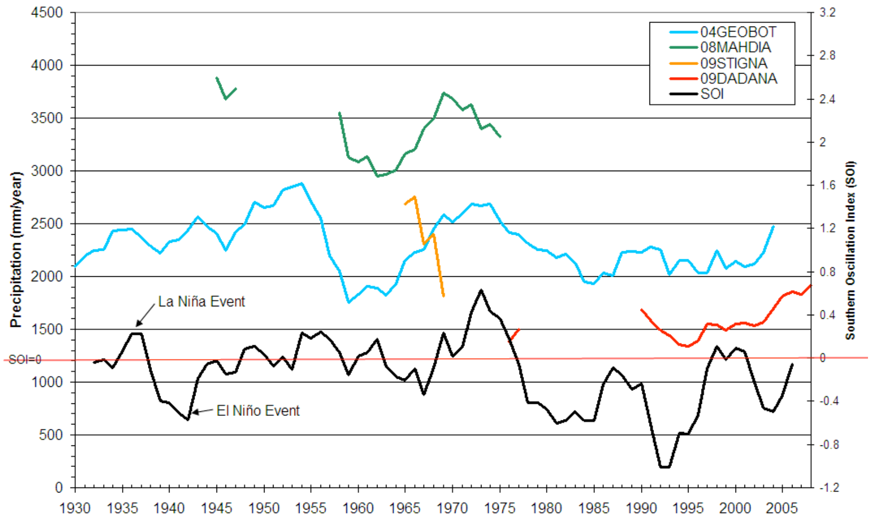

Figure 2 – 5-year annual average Southern Oscillation Index (SOI, bold black) compared with 5-year annual precipitation observations for stations in Guyana: Georgetown (04GEOBOT, blue) on the coast, Mahdia (08MAHDIA) in the rainforested interior north of Iwokrama (green), and St. Ignatius (09STIGNA) and Dadanawa (09DADANA) in the Savannah (red and orange) south of Iwokrama.

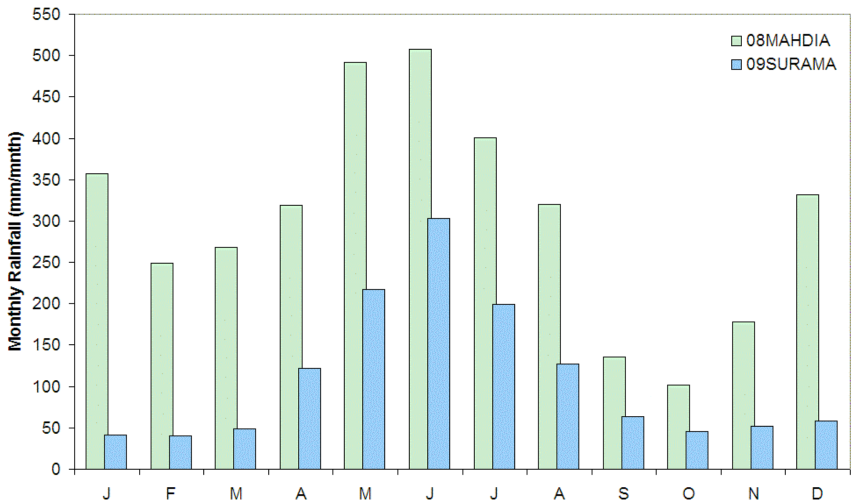

Figure 3 – Comparison between average monthly rainfall distribution for Mahdia (08MAHDIA) in the rainforested interior north of Iwokrama (green) and for Surama (09SURAMA) south of Iwokrama (blue).

Iwokrama is 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 (see Figure 3). To overcome the identified gaps in observed data a from the interior rainforest and savannah areas a new climate and hydrology monitoring program is being imitated 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 and types of vegetation (covering rainforest at the Iwokrama Research Centre to savannah at Bina Hills). 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.

4 Climate change

According to the UNDP Climate Change Country Profiles[5], mean annual rainfall along the Guyana coast 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.

According to the IPCC Working Group 1 Report[1] based on an ensemble of 22 General Circulation Models, 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.

According to the UNDP Climate Change Country Profiles for Guyana[5], model simulations of temperature change over Guyana tend to agree with each other and project increases in temperature by 0.9 to 3.3 °C by the 2060s and 1.4 to 5.0 °C by the 2090s. Simulations of precipitation, however, vary and projected changes vary between -34% to +20%. Furthermore, models show wide disagreement in projected changes in frequency of El Niño events.

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 important 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. 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[1]. Changes in these processes will affect the region considerably. Feedbacks between carbon cycle and dynamic vegetation 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.

Regional climate models are still being developed and tested for Guyana. It should be noted that although GCMs and RCMs can be used to model the 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 any 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 assessments of future climates on just on one model, but to take account of several model outputs through an ensemble.

[5] McSweeny C., New M., Lizano G. UNDP Climate change country profiles – Guyana, from http://country-profiles.geog.ox.ac.uk

Lastly, it is important to be aware of which future scenarios or ensemble of scenarios the models have been run for.

5 Conclusions

The key conclusions from Part B are as follows.

- This is the most recent study to collate and analyse rainfall data not just for Georgetown, Guyana but for the whole of Guyana and the wider region. The participation and collaboration of the HydroMeteorological Services for Guyana, Suriname and French Guiana demonstrate the regional importance of the research. More research is however urgently needed to fully understand the influences of the Equatorial Trough, the El-Niño Southern Oscillation and other regional influences on the area, and there remains an outstanding need for further analytical studies on the data.
- The equatorial rainforests in the Guianas and Amazon are intimately linked with the climate of the area and more research is needed to understand how the rainforests generate and buffer climate. Deforestation is likely to lead to reduced precipitation and increased temperatures and the effects could be felt regionally if not globally.
- Brief analyses of precipitation data for Guyana and the wider region indicate that Iwokrama is located in a key geographical location to investigate the changes taking place between the coastal climate influenced by the Equatorial Trough and the savannah region experiencing a more continental type climate. It is vital to understand the fate of the savannah and the neighbouring rainforests in relation to global warming. Any potential expansion of the savannah, currently restricted to the southern region of Guyana, towards the coast or further south into Amazonia are likely to have an immediate impact on both the regional climate and the rainforest.
- Global Circulation Models are currently unable to simulate current and therefore future climates in the equatorial regions well. Simulations of precipitation and its variability are particularly poor for Guyana, but models agree that temperature is likely to increase in the future, particularly in the interior.

6 Key recommendations

Key recommendations from Part B of this study are as follows:

- **Understanding the current climate**

  A fully integrated analysis of historical, present and future climate data is only possible once the historical datasets have been fully quality-controlled. It was only possible within the scope of this pilot study to make an initial overview of the precipitation data so it is recommended that a more detailed analysis of spatial and temporal trends be made on all the available data including temperature. Analyses should include monthly, seasonal and annual means, variances, skewnesses, proportion of dry days and spatial and auto-correlations. The identification and analysis of the impacts of major climatic influences such as El Niño (droughts) on Guyana's climate should also be made and short and long-term climatic cycles should be identified.

  More analyses also need to be conducted on the effects of altitude, aspect and other environmental factors as well as spatial correlations between sites. For example, as there is a lack of data for the forested interior of Guyana, it may be possible to use data from Suriname or French Guiana to infill or predict missing values if these are well correlated.

A fully quality-controlled historical data set would be of significant value to the international climate science community, as it would allow improved comparison of climate model data with observations, and would support the specific research goals of Iwokrama.

- **Understanding the impacts of future climate on tropical rainforests**
  Understanding the two-way relationships between tropical rainforests and climate, and the influence of forest management on these relationships, is central to Iwokrama's mission. Specific research is required to enable questions related to the broader science and business aspects of Iwokrama to be addressed, using the analyses of the quality-controlled historical climatic data sets together with new data arising from monitoring programmes at Iwokrama.