

Using reanalysis data to establish the precipitation and temperature regime of data poor areas: the Guianas of South America

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Abstract

The Inter-Tropical Convergence Zone has a large influence on the climate of the Guianas, bringing twice yearly rainfall to coastal areas but only a single wet season inland. The climatic transition zone corresponds with the boundary between rainforest and savannah type vegetation. The El-Niño Southern Oscillation (ENSO) also affects the area, with El-Niño conditions bringing drought to coastal areas and possibly an opposite effect inland. Generally however, the climate of the Guianas is poorly understood because observed historical climate datasets are generally sparse and of low quality. Furthermore, simulations from Global Climate Models disagree about whether the region will become wetter or dryer, although most agree that temperature is likely to increase in the future. It is, therefore, important to establish a baseline climate for the region so that the impacts of landuse change and climate change and the complex relationships existing between climate, vegetation and water cycling interactions can be understood. To overcome the limitations in the inadequate observational data, we make use of the ECMWF ERA40 reanalysis dataset for the period 1957–2002 at ~125 km² (1.125) resolution, giving a spatially consistent climate for the region based on historical data. Mean differences (biases) and annual average spatial correlations are examined between modelled ERA40 and observed time series, comparing the seasonal cycles and the yearly and monthly time series. Results show that reanalysis precipitation and temperature for the region compare favourably with areally averaged observations where available, although ERA40 underestimates precipitation in some zones of higher elevation. Once validated, ERA-40 is used to determine the precipitation and temperature regime of the Guianas. Grid-cell by grid-cell analysis provides a complete picture of spatial patterns of averaged monthly precipitation and its high variability across the area, vital for establishing a basis from which to compare any future effects of climate change. This is the first comprehensive study of the recent historical climate and its variability in this area.

Introduction

The Guianas (consisting of Guyana, Suriname and French Guiana) on the northern rim of Amazonia hold some of the world's most intact rainforests. These are home to several Amerindian communities, are biologically highly diverse, have key functions in the carbon cycle and are vital for the regulation of the local and regional climate: trees return water to the atmosphere through the process of evapotranspiration helping to generate rain over vast distances; 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 (Lean and Warrilow, 1989; Shukla *et al.*, 1990; Dickinson and Kennedy, 1992; Hoffmann and Jackson, 2000). Although considerable efforts have been made to study the hydrology and climate of the neighbouring Amazon basin (e.g. Avissar *et al.*, 2002; Marengo, 2006) comparatively little research has focused specifically on the Guianas (notable exceptions include Tropenbos International and the Guiana Shield Initiative project).

Accurate, complete and long-term meteorological records are needed to examine and understand past and current climates and to place them into a local, regional and global context. Through the analysis of climate observations, spatial and temporal climate trends can be discerned and global and local scale climate drivers can be identified, helping to establish and predict climate variability and change. Meteorological 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. The rainforests are, however, threatened by deforestation and climate change. Deforestation generally leads to decreased evapotranspiration thereby reducing precipitation and increasing temperatures (see IPCC, 2007 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 (IPCC, 2007). More research is needed to ascertain the potential climatic and hydrological

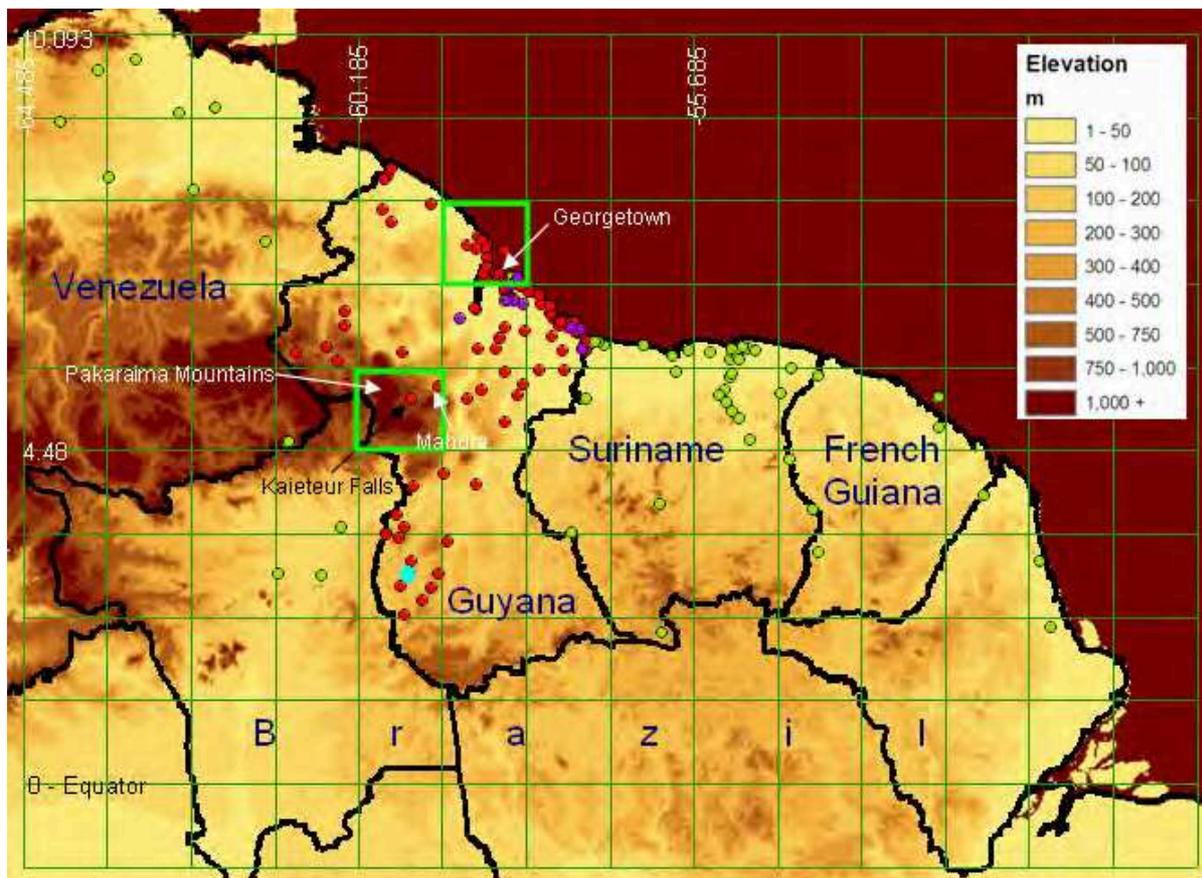


Figure 1 Digital Elevation Model (DEM) and raingauge locations in the Guianas. DEM is from the USGS Earth Resources Observation and Science (EROS) Centre. The DEM is overlain with country boundaries and locations of raingauges in Guyana and the surrounding land area. Points in red are data from HydroMet (Guyana), points in purple are from the Guyana Sugar Corporation (Guyana) and points in green are from the Climatic Research Unit (CRU) database. Points in Suriname were also obtained from the Suriname Meteorological Service. Dadanawa Ranch is highlighted in pale blue. The ERA-40 re-analysis grid is superimposed and the Georgetown and Madhia grid cells discussed below are highlighted.

impacts that land-use changes would have, both locally and regionally. These changes need to be compared against established baselines.

We have collated climate data for Guyana and accessed international datasets for Venezuela, Suriname and French Guiana (Figure 1) (Bovolo *et al.*, 2009). Analysis of the data reveals that although some long daily historical datasets exist, observations are mainly located along the coast and a large data gap exists inland in the Guianas and in northern Brazil. Densities of weather stations and raingauges in this area are well below the recommended WMO standards (Bovolo *et al.*, 2009) and timeseries from individual stations have several gaps and data quality issues. Basic (and at times hand-drawn) precipitation maps for the region are based on these limited datasets (Persaud and Persaud, 1995; Nurmohamed *et al.*, 2007) and are therefore highly sensitive to interpolation methods. Furthermore, country specific datasets are generally used only for the country of interest, neglecting the regional context, whilst maps of the wider region (such as for South America as a whole) are based on only a few timeseries. Up-to-date climatic maps of the region using all available datasets are therefore urgently required.

Aside from the regions' large areas of rainforest, a band of savannah-type vegetation extends from the Venezuelan highlands (Baruch, 2005) into the southern third of Guyana. Unlike on the southern margin of the Amazon basin, the savannah-rainforest boundary in the Guianas is particularly abrupt. The reason for this abruptness is currently unknown but is potentially due to specific combinations of climate, landscape (soil, topography) and fire (Frost, 1968; Sinah, 1968; Hills, 1969; Medina and Silva, 1990). This

rainforest-boundary is envisaged to be particularly susceptible to changes due for example to climate change, deforestation, mining or agriculture (Baruch, 2005). It is important, therefore, to establish a baseline climate for the region, from which the impacts of any future environmental change may be compared.

Here we make use of the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-40 reanalysis dataset for the period 1957–2002 at a $\sim 125 \text{ km}^2$ (1.125°) resolution to examine the climate of the Guianas in detail. Mean differences (biases) and annual average spatial correlations are examined between modelled ERA40 and observed time series comparing the seasonal cycles and the yearly, monthly and monthly anomaly time series. Once validated, the ERA-40 data is used to derive a fine resolution regional climate of the area.

Brief overview of climate in the Guianas

The principal factors controlling the climate around northern South America are the subtropical high-pressure zones over the South Atlantic and South Pacific and their seasonal shifts in position. These determine both the large-scale patterns of wind circulation and the location of the Inter-Tropical Convergence Zone (ITCZ), a band of rising air movement and relatively low pressure where the trade winds of both hemispheres converge. The ITCZ moves north during May–July to a position approximately 7°N and southwards during Nov–Jan, placing it well over the Amazon and bringing with it prolonged, heavy rainfall. The seasonal movement

of the ITCZ results in particularly high spatial variability in precipitation over the area; for example, the Guyana coast exhibits two wet seasons whilst inland Guyana exhibits only one wet season.

Guyana's climate is influenced not only 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. An analysis of ENSO activity on precipitation in Georgetown was conducted by Wardlaw *et al.* (2007). The authors concluded that a La Niña event most likely results in significantly higher than normal precipitation, whilst an El-Niño event most likely results in drought conditions. The most significant influences of ENSO were found to 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.

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. Figure 2 shows 5-year average annual rainfall totals for select precipitation stations in Guyana (Georgetown on the coast, Mahdia in the rainforested interior north of Iwokrama, and two stations in the Savannah south of Iwokrama) compared with a 5-year averaged annual SOI index from the Climatic Research Unit (CRU) at the University of East Anglia, UK. Visually, ENSO appears to have a strong influence on annual rainfall totals. For example, rainfall in Georgetown and Mahdia appear to decrease during the 5-year averaged SOI La-Niña events of 1946, 1959 and 1985 and increase during the 5-year averaged El-Niño

events of 1973 and 1998, suggesting La-Niña events favour wetter conditions in line with the results of Wardlaw *et al.* (2007). On the other hand, the limited datasets suggest that the savannah areas to the south-west of Guyana may have an opposing trend. 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.

Global Climate Models (GCMs) indicate that all of Central and South America is likely to warm during this century (IPCC, 2007), with continental regions, such as inner Amazonia, warming the most. However, inter-model temperature ranges are large for this area, making it difficult to establish actual amounts. It is also uncertain how annual and seasonal precipitation may change, particularly over northern South America, as models for this area do not agree. Most GCMs 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 and 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 (IPCC, 2007). Feedbacks between carbon cycles 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 CO². 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 these vary considerably for the tropics (see IPCC, 2007 and references therein).

For Guyana, the UNDP Climate Change Country

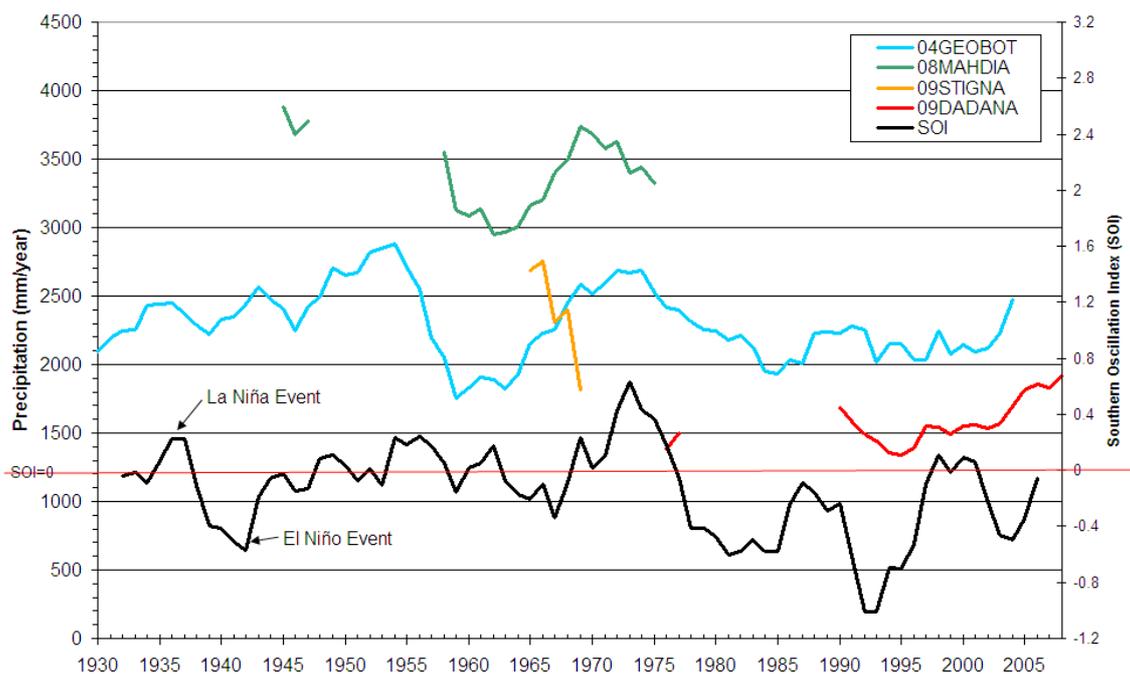


Figure 2 5-year annual average Southern Oscillation Index (SOI) compared with 5-year annual precipitation data for stations in Guyana: Georgetown (04GEOBOT, blue) on the coast, Mahdia (08MAHDIA) in the rainforested interior north of Iwokrama (green), and St. Ignatius (09STIGNA) and Dadanawa (09DADANA)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

Profiles (McSweeney *et al.*, 2009) suggest that ensembles of GCMs project wide changes in precipitation for Guyana with projected future precipitation for the region varying between -34% to $+20\%$. Furthermore, models show a 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 the SRES report (Nakićenović *et al.*, 2000), 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. 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.

The discussion above suggests that it is becoming increasingly important to understand the processes taking place in the region. Observations can help establish spatial and temporal trends and help to identify climatic drivers but where observations are not available, other methods of analysing the current climate need to be considered. Reanalysis datasets provide the best means of deriving a spatially consistent climate in areas where observations are lacking.

Method

Precipitation and temperature observations for Guyana were collated. These have been kindly provided by the HydroMeteorological Service of Guyana (HydroMet), the Guyana Sugar Corporation (GuySuCo) and Dadanawa Ranch, whilst data for the region have been kindly provided by the Suriname Meteorological Office and CRU. The collated observations were checked for obvious errors and then the daily precipitation datasets were aggregated to monthly and annual levels, taking into account data which were recorded as being aggregated over several days. On several occasions it was impossible to ascertain if values recorded as zero signified actual values or missing data so some precipitation observations may be slightly underestimated. Aggregated monthly datasets of precipitation were only used for further analysis if data for all days within that month were present; likewise yearly datasets were only used if all monthly datasets were present. As temperature does not vary considerably day to day, aggregated temperature datasets at the monthly or annual level were accepted if over 75% of data were present. Although these datasets give an idea of the current precipitation and temperature regime, they cannot be used to establish past climatic trends without further analysis for discontinuities; nevertheless, as the only datasets available, they give a valuable insight into the climate of the area.

Reanalysis datasets derive from modified operational weather forecast and analysis models. The ECMWF ERA-40 re-analysis dataset (Uppala *et al.*, 2005) takes as input global observations of available atmosphere and surface conditions for the period September 1957 to August 2002 and provides as output a spatially consistent global climate including analyses of temperature and other atmospheric variables and short range forecast accumulation data such as precipitation, on an N80 reduced Gaussian grid (where the number of longitudinal grid points decreases from 320 grid points around the Equator to 18 near the poles). The grid has a spatial resolution of $\sim 1.125^\circ$ at the Equator. As technological advances generate new datasets, these become available for input to the model. These new datasets further constrain the simulations causing some apparent discontinuities. As such, it

is usual practice to analyse ERA-40 outputs in the following time periods: 1958–2001 (all data), 1958–1972 (pre-satellite), 1973–1986 (satellite) and 1987–2001 (advanced satellite) (Betts *et al.*, 2005).

Unlike for temperature, precipitation observations are not assimilated into the ERA-40 model as input. Consequently, output analyses of ERA40 temperature are expected to be more robust than for model forecasts of precipitation. Precipitation outputs are therefore considered to be a good test of model performance (Bolisovich *et al.*, 2008).

Precipitation (in the form of separate large-scale and convective components) and 2 m temperature at the 6-hour resolution for the complete years 1958 to 2001 were extracted from the datasets and accumulated to monthly and annual levels. Data were then analysed for all years and for each epoch in turn. For validation purposes, ERA-40 data were also compared against observations. Observations taken at a point should not be directly compared with model data averaged over a grid cell however, unless observations are representative of the area. Where possible therefore, multi-site observations of precipitation with more than 75% of data between the relevant time periods were arithmetically averaged over a grid cell to derive a mean precipitation for that grid. Unfortunately, a lack of data meant that it was not possible to average multiple temperature observations within an individual grid cell as usually only single site observations were available in a cell. However, as average monthly temperatures in the Guianas do not vary significantly, single site temperature observations are considered to be spatially representative where elevation does not vary considerably over the grid cell. Comparisons of the mean differences (biases) and annual average spatial correlations between modelled ERA40 and the mean observed time series (where available), comparing the seasonal cycles (monthly averages for each month, Jan-Dec) and the yearly (1958–2001) and monthly (1958–2001) time series, are made below.

Results

Table 1 and Figure 3 compare statistics for temperature and precipitation observations against the equivalent ERA-40 dataset. For the Georgetown grid cell on the coast (Figure 1), where one good quality temperature and several good quality long precipitation datasets are available to provide a grid-cell mean, the ERA-40 simulations match observations relatively well. For temperature, ERA-40 is well correlated against the single-site observation with correlations of 0.75 at the annual level, 0.78 at the monthly level and 0.92 for monthly averages and with only a slight positive bias of around 0.4 °C in all cases. For precipitation, ERA-40 is also relatively well correlated with observations with a correlation of 0.4 at the annual level, 0.7 at the monthly level and 0.94 for monthly averages, with a positive bias of 700 mm/year or around 220 mm/month. This is also the case in other areas along the coast where multiple good quality datasets are available.

Inland, few observations are available (data not shown here). Nevertheless, where these are available, simulated temperature again fares well against observations, with overall cross-correlations over 0.4 and biases of less than 1 °C with data not allowing trends of either positive or negative biases to be discerned. Inland, annual precipitation correlations between ERA-40 and observations are of the order of 0.2 to 0.4 whilst monthly correlations are between 0.4 and 0.8 with generally negative biases of the order of 300 mm/year or 100 mm/month. As mentioned above, simulated temperature outputs are expected to be more robust than those for precipitation. However, as very few temperature observations from the Guianas have been actually used as

Table 1 Comparison of statistics for yearly, monthly and monthly averaged mean precipitation and temperature timeseries from ERA-40 compared with arithmetically averaged observations (Obs) where available for model grid cells over Georgetown and Mahdia (see Figure 1 for locations) for the period 1958-2001.

		Georgetown Cell				Mahdia Cell	
		Temperature (°C)		Precipitation (mm)		Precipitation (mm)	
		ERA 40	Obs	ERA 40	Obs	ERA 40	Obs
Annual	Average	27.4	27.0	2687	1977	1772	3453
	Bias		0.4		709		-1681
	Variance	0.06	0.15	237959	237649	119770	662617
	Skewness	0.14	0.39	0.34	0.60	0.57	1.85
	+1 hr auto correlation	0.33	0.58	0.41	0.46	0.35	-0.20
	Cross-correlation		0.75		0.42		0.37
Monthly	Average	27.4	26.9	224	188	145	288
	Bias		0.5		36		-142
	Variance	0.34	0.45	8608	16478	5229	33750
	Skewness	0.08	0.26	0.90	0.92	0.67	0.91
	+1 hr auto correlation	0.76	0.69	0.50	0.41	0.62	0.47
	Cross-correlation		0.78		0.69		0.53
Monthly Averages	Average	27.4	27.0	223	162	147	288
	Bias		0.4		61		-140
	Variance	0.26	0.21	3818	5599	3674	15004
	Skewness	0.08	0.34	0.39	0.17	0.54	-0.03
	+1 hr auto correlation	0.75	0.60	0.51	0.55	0.81	0.67
	Cross correlation		0.92		0.94		0.72

input to the ERA-40 model, these results are considered to be particularly good.

Areas where ERA-40 simulations do not compare well with observations include areas of high elevation such as to the north-east of Mount Roraima on the Guyana-Brazil-Venezuela border and in central Suriname (see Figure 1). From existing datasets, these areas appear to have particularly high precipitation levels compared with their immediate surroundings, but this is not captured by the model probably because the spatial extent of high elevation area is below the resolution of the ERA-40 grid cell. Table 1 and Figure 3 compare simulated and observed datasets for Mahdia (Figure 1). Nearby Kaieteur Falls (for which no datasets were available for the period of interest) also has particularly high precipitation levels. This is probably caused by orographic uplift of moisture-laden air from the onshore winds related to the Inter-Tropical Convergence Zone.

Figure 4 shows the average ERA-40 daily precipitation for northern South America. Spatially ERA-40 precipitation compares favourably with existing precipitation maps for Guyana and Suriname (not shown). From Figure 2 A, it can be seen that in Guyana a high precipitation zone along the coast (red) leads to a slightly drier but still very wet zone (green and brown) inland. A drier zone (blue) just south of the Guyana-Brazil-Venezuela borders corresponds with the savannah type vegetation. From the ERA-40 data, it appears that this dry area fluctuates over time (Figure 2 B, C and D), however, as few observations exist for this area, this is particularly difficult to validate. Nevertheless, these changing precipitation patterns could impact the location of the rainforest-savannah boundary. Particularly strong droughts or wet periods could therefore have a particularly noticeable effect on the vegetation distribution of the region.

ERA-40 yearly and monthly average precipitation are shown in Figure 5 and Figure 6 for each land-based ERA-40 grid-cell given in Figure 1. Figure 5 shows that ERA-40 yearly time-series across the region show relatively little annual variability although spurious peaks (particularly high or particularly low precipitation) occur in small clusters of cells. Further analysis of the data suggests that these peaks

occur in the wet-season months so are probably related to the water-balance equation within the model and should be discounted. Figure 6 shows the spatial variation of monthly averaged precipitation across the region. It can be seen that coastal areas exhibit two wet seasons a year, peaking in June and December, whilst inland, only one wet season occurs in May-June. Coastal areas of Brazil and French Guiana lack a primary dry season and November to July is particularly wet. The diagram also shows the onsets and lengths of the dry and wet seasons, useful for establishing growing seasons.

Conclusion

The ITCZ and ENSO have a strong effect on the Guianas but there is a general lack of understanding of the climatic drivers and processes taking place in general in the tropics so that the effect of ENSO on the region has not been fully understood and Global Climate Models are not able to reproduce the current regional climate well. Future climate simulations for Guyana generally agree that temperature is likely to increase but disagree in terms of future projected precipitation which is simulated to decrease or increase anywhere between -34% to +20% (McSweeney *et al.*, 2009). The climate of the Guianas is spatially particularly highly variable yet few studies have examined the climate of this region in detail. This is mainly due to climate observations being sparse and having many gaps in the timeseries, making it difficult to derive a meaningful baseline climate for the region. However, such a baseline is required so that the impacts of future land-use changes or climate changes can be established. In particular, the complex relationship between climate, forest and water cycling needs to be understood in greater depth as it is envisaged that the savannah-rainforest boundary will be particularly susceptible to environmental change.

Reanalysis data, such as the ECMWF ERA-40 dataset, provide a spatially consistent modelled climate dataset useful in data-poor areas once validated for the area of interest. Here, we have compared ERA-40 modelled data against observations and find that ERA-40 is satisfactorily

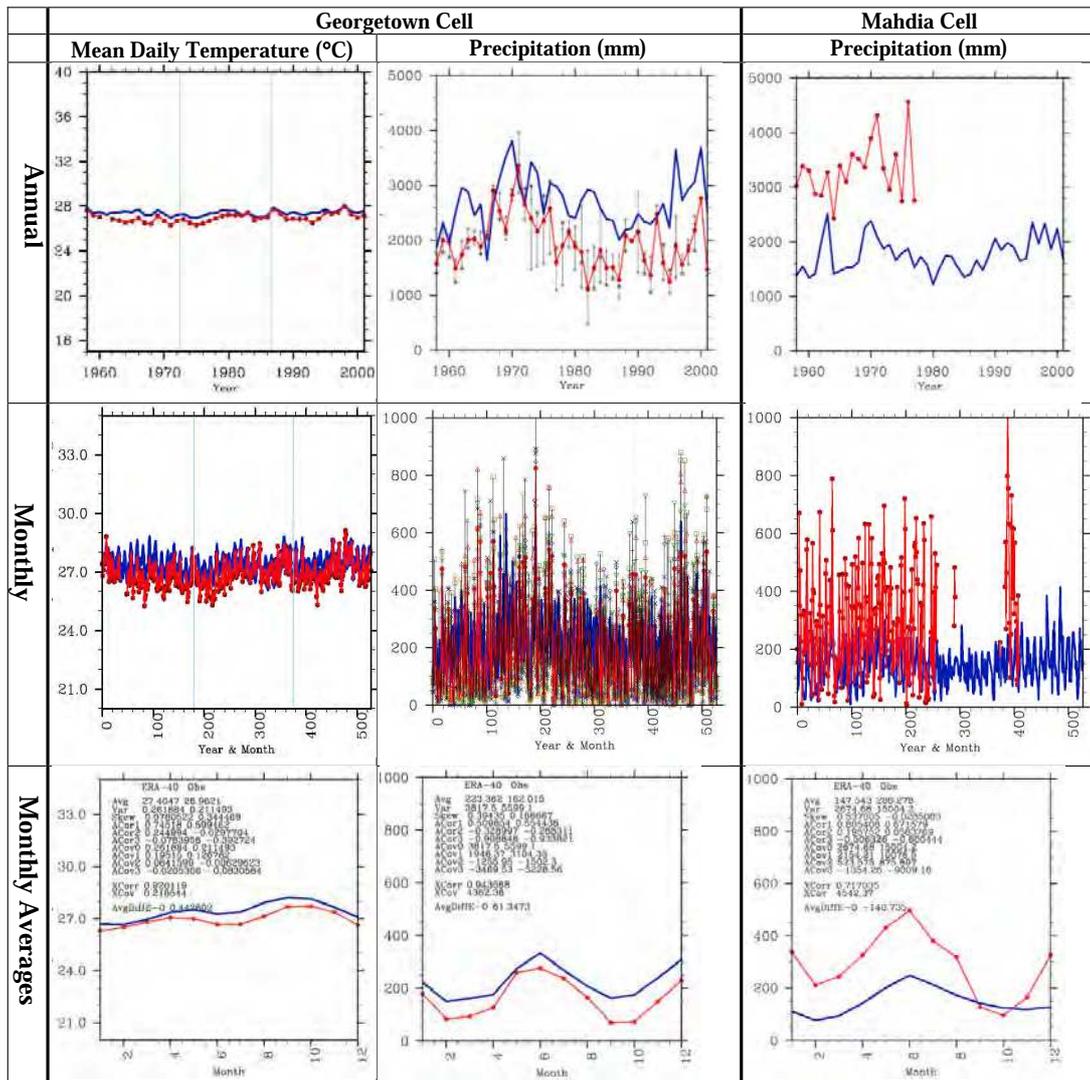


Figure 3 Comparison of yearly, monthly and monthly averaged mean precipitation and temperature timeseries from ERA-40 compared with arithmetically averaged observations (obs) where available for model grid cells over Georgetown and Mahdia (see Figure 1 for locations) for the period 1958-2001. Comparisons are only made between equivalent data but are shown for all ERA-40 data for yearly and monthly timeseries only.

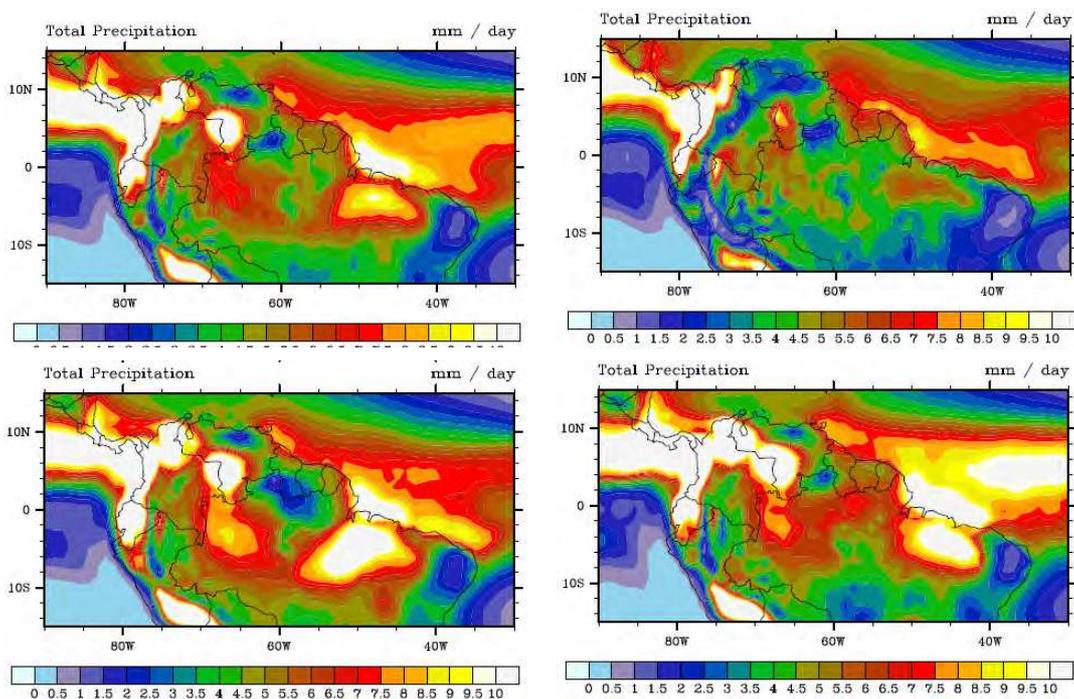


Figure 4 ERA-40 re-analysis average daily precipitation (mm/day) for (A) for 1958-2001, (B) 1958-1972, (C) 1973-1986 and (D) 1987-2001 for northern South America. Precipitation between 1973-1986 was particularly low (blue) for the Savannah zone in Southern Guyana compared with other years (C) whilst 1987-2001 was particularly wet (red) (D).

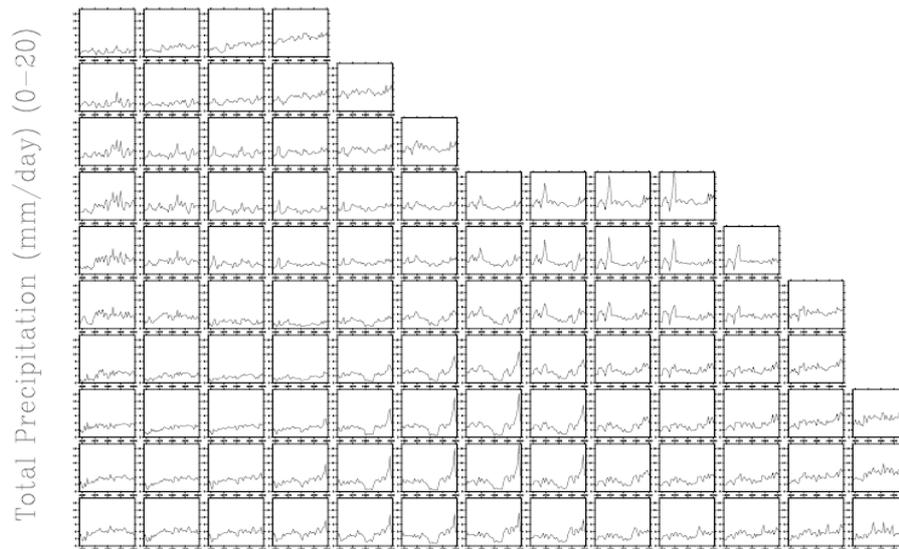


Figure 5 Spatial distribution of ERA-40 yearly precipitation (mm) for 1958–2001 for land-based grid cells shown in Figure 1.

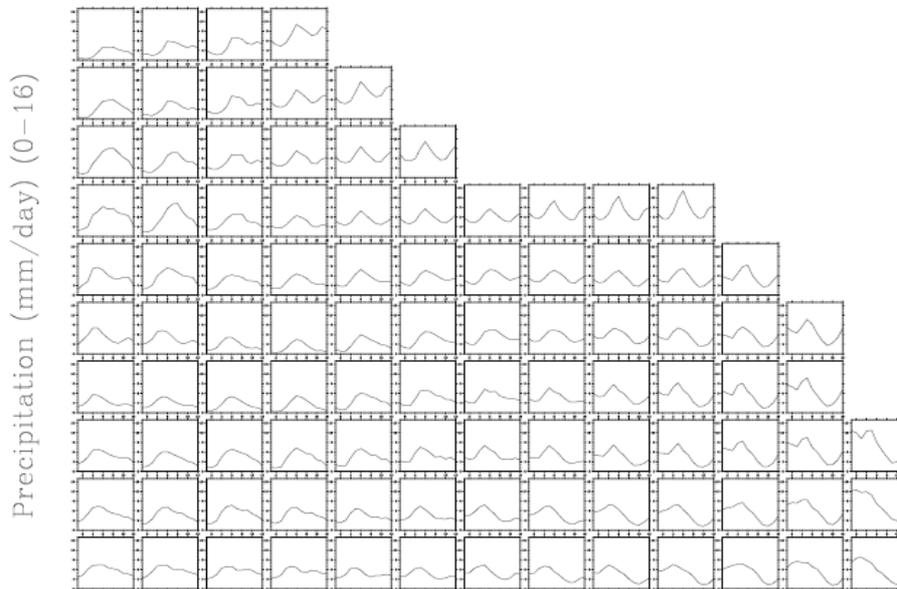


Figure 6 Spatial distribution of ERA-40 monthly average precipitation (Jan - Dec) for 1958-2001 for land-based grid cells shown in Figure 1.

correlated with observations on the annual and monthly time scales, particularly for temperature. ERA-40 temperature is slightly positively biased on the coast and whilst precipitation is also positively biased on the coast, it is negatively biased inland. ERA-40 precipitation on the annual scale produces some erroneous peaks but monthly averaged data provide the best results.

We have therefore used the monthly averaged ERA-40 data to derive the seasonal distribution of precipitation across the region on a grid-cell by grid-cell basis. The graphs are particularly valuable for establishing the onset of wet- and dry- periods across the region, useful for delineating growing seasons. Figure 6 shows a complete picture of the highly variable precipitation found across the region, vital for establishing a basis from which to compare any future effects of climate change.

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