On the Future Climate of Belize- projections of a 20 km grid size atmospheric general circulation model.

Dennis Gonguez
Meteorologist
National Meteorological and Hydrological Service of Belize

ABSTRACT

This paper presents climate projections for Belize based on the output of a single global atmospheric circulation model. The 20-kilometer grid size model was developed at the Meteorological Research Institute of the Japan Meteorological Agency and was run on their Earth Simulator supercomputer. Model performance evaluations based on data for Belize are presented in this paper. Qualitative future changes in two climatic variables- temperature and rainfall are also presented. Using this model, significant objectively based inferences can be made on the future climate of Belize.

1. INTRODUCTION

Numerical simulation of future changes in climatic variables presents probably the most singularly daunting task in creating a 21st century global climatology. Even more challenging is predicting future climate changes with adequate detail and on a small spatial scale such as the islands of the Caribbean or even a larger geographical area like Belize. This research focuses on climate predictions for Belize derived from a 20 km grid super high resolution Atmospheric Global Circulation Model (AGCM) developed at the Meteorological Research Institute (MRI) of the Japan Meteorological Agency (JMA). The author of this paper spent four weeks as a visiting scientist in Tsukuba, Japan studying the AGCM's outputs and evaluating the model's performance in the Caribbean.

No one single climate model should be used to make adaptation and mitigation plans or strategies as pertaining to climate change. However, the results of this simulation provide one likely scenario for the future climate of Belize. The results should therefore be given more than a cursory glance but instead looked at as a serious and possibly real climate scenario with just as egregious implications on the livelihood and economy of Belize.

The first section of this paper is an overview of the features of the AGCM and the Earth Simulator supercomputer on which this global model was run. This is followed by the section dealing with the evaluation of the model performance using data from select stations around the country of Belize. In the third section projections for the future climate of Belize are presented as generated by the 20-km AGCM. Next the important topic of model uncertainty is briefly but topically discussed. The final section is the summary and conclusions.

Corresponding author's address: Dennis S. Gonguez, National Meteorological Service of Belize, Philip Goldson International Airport, Ladyville Belize, Central America.
E-mail: DGonguez@hydromet.gov.bz

2. MODEL CHARACTERISTICS

The 20-km grid of the AGCM has a horizontal spectral truncation of TL959. This corresponds to 20 km horizontal grid spacing. The vertical resolution consists of 60 sigma layers with a 0.1 hPa being top level. The time integration is accelerated by introducing a semi-Lagrangian scheme (Yoshimura and Matsumura 2005). On the Earth Simulator. supercomputer it takes 4 hours of real time to perform one month's integration with a time step of 6 minutes (i.e. ΔT= 6 min). The cumulus convective parameterization scheme is a prognostic Arakawa-Schubert (Randall and Pan 1993). Further features of this AGCM can be found in more detail at http://www.es.jamstec.go.jp/esc/images/annualreport2003/pdf/project/chapter1/1-07aoki.pdf.

The present climate was simulated using observed climatological sea surface temperature (SST) average from 1982 through 1993. The change in SST between the present (1979-1998, 20 year mean) and the future (2080-2099, 20 year mean) were obtained from a climate change simulation performed with the MRI's Coupled GCM2.3. This change was based on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenario (SRES) A1B (IPCC 2000). The future simulation using the 20 km AGCM was done with the assumption of concentrations of greenhouse gas and aerosol emissions having values in 2090 as those specified by SRES A1B. Then, the model was integrated for ten-year period each by forcing the SSTs as the lower boundary condition.

3. MODEL PERFORMANCE EVALUATIONS

Evaluation of the AGCM's performance was done by comparing the present climate as simulated by the model with the actual 12-year climatological data for the same 1982 to 1993 period. Average monthly and daily temperatures were used from strategically chosen stations around the country of Belize. Continuity of data was the main criterion for choosing these stations. In the instances where there were large amounts of missing data the climatological period was shifted to reduce the effects of the missing data. However, the same length of time (12 years) was maintained.

With a horizontal resolution of 20 km from north to south across Belize is covered by 13 grid boxes. From east to west at its widest point the country takes up 5 grid boxes.

4. PERFORMANCE EVALUATIONS

Method

As stated in the above chapter model climatology (designated AJ) is compared with observations taken from the same time period as AJ. This forms the basis for assessing model performance.

i. Philip Goldson International Airport. PGIA (Latitude 17.5 °N, Longitude 88.3 ° W, elevation above mean sea level= 5 meters)

a. Precipitation

As shown in Figure 1 a comparison between the AJ and the monthly averages reveals that from February through November the model over predicts precipitation quantities. A qualitative assessment depicts that the model picks up on the bi-modal distribution of rainfall.

However, the modal points were temporally displaced one month too early and the other a month too late for the second rainfall peak. The rising and descending limbs were readily noticeable marking the start and end of the rainy season. The two peak values in the AJ data are 9.5 and 9.4 respectively. The change between peak values and the minimum in September is 1 mm/day. This compares to an average 30 mm accumulation for any particular month. So this change can be considered legitimate and outside the realm of noise in the model output.

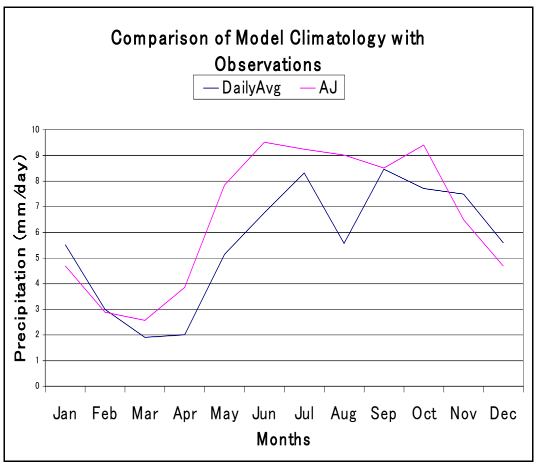

Figure 1. Comparison of model climatology with rainfall observations for period 1982-1993 at Philip Goldson International Airport (PGIA)

The commencement and conclusion of the rainy season are well resolved by the model.

Adjustments can be done to correct for the amplitude (quantity) and phase (time) differences.

It can be concluded then that the model performance in resolving the bi-modal rainfall was acceptable. However, it overestimates precipitation quantities.

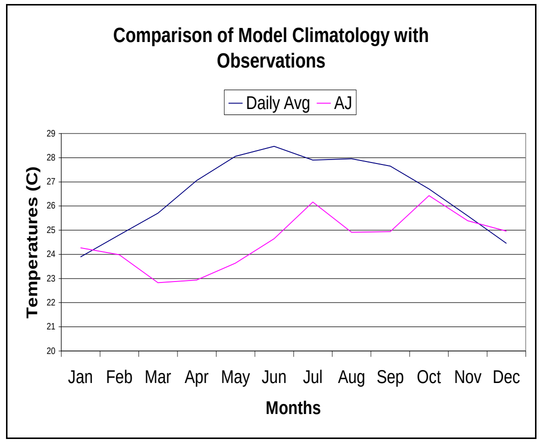

Figure 2. Comparison of model climatology with temperature observations for the period 1982-1993 at the Philip Goldson International Airport (PGIA).

The AGCM climatology (AJ) in Figure 2 shows very little similarity to the observations from the same time period. As a result, no correction factor could be applied to account for the amplitude and phase differences between the two plots. The AJ plot reveals that with the exception of January and December all the other months were much cooler than the observations. The coolest month at this particular station according to the model is March.

Model performance could be considered poor in regards to temperature at this particular station

ii. Belmopan BMP (Latitude 17.25° N, Longitude 88.77º W. elevation above mean sea level= 90 meters).

a. Precipitation

The two peaks in rainfall occurring in June and late August were very subtly resolved, if at all, in the model climatology. In reality a gentle decline was depicted during the months of June all the way through to December. During the peak of the dry season (March to May) AJ values are substantially greater than the observations. Also note that during the wet months (June through

October) the model resolves significantly less rainfall than observed.

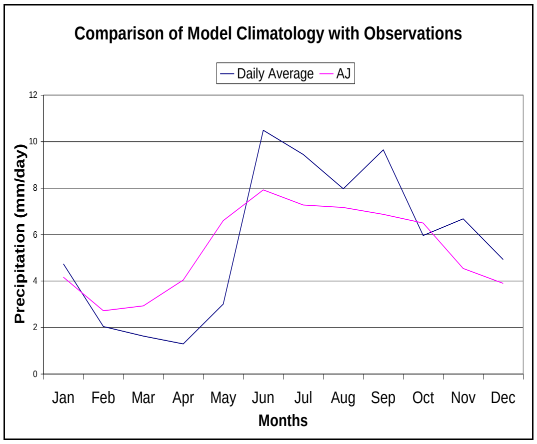

Figure 3. Comparison of model climatology with rainfall observations for the period 1982-1993 at Belmopan (BMP)

Once again the model climatology (Figure 4) showed cooler temperatures as compared with the observations. On average AJ was about 2 to 3 °C cooler than actual climatology with as much as a 4 °C difference observed in April. The model places a temperature maximum in July when in reality the hottest month is May. As shown by the observation.

Of note, though, are the similarities in the form of the AJ plots in Figures 2 and 4 even though the data were collected from two different grid points.

In this study additional temperature evaluations were not included for stations other than the previously two mentioned stationed as performance appeared well below acceptable standards. The errors were random and corrections or adjustments would not have improved the output.

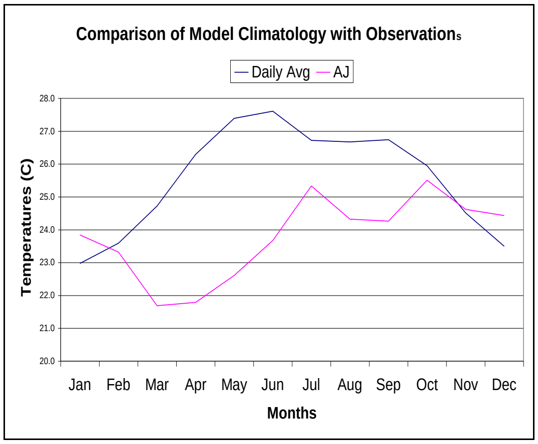

Figure 4. Comparison of model climatology with temperature observations for the period 1982-1993. at Belmopan (BMP).

iii. Central Farm CFarm (Latitude 17.2° N, Longitude 89.0º W long, elevation above mean sea level= 90 m)

a. Precipitation

The observations of daily rainfall also reveal the bimodal nature of the precipitation with a peak in July and another in November. (Figure 5) This is also borne out in the model climatology.

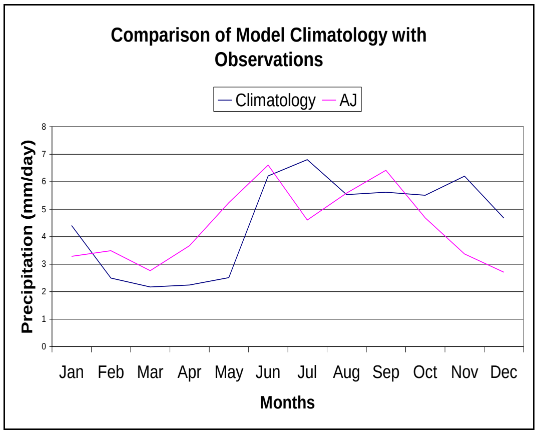

Figure 5. Comparison of model climatology with rainfall observations for the period 1982-1993 at Central Farm (CFarm)

However the AJ plot places the first peak a month earlier and the second two months earlier than the observations. Such phase displacement can easily be adjusted.

iv. Libertad Lib (Latitude 18.28° N Longitude 88.47°W.elevation above mean sea level= 12.0 meters.)

Precipitation

Model climatology for the first nine months of the year resolves higher precipitation amounts as compared to the actual climatology.

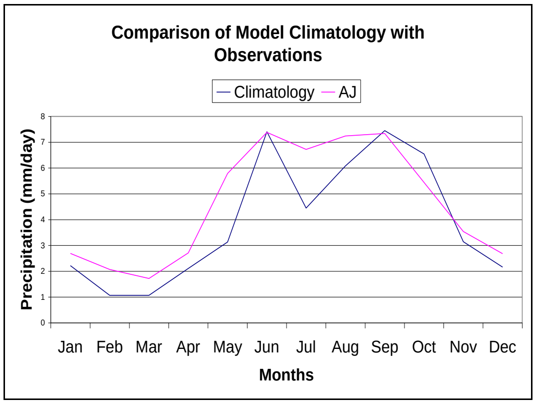

Figure 6. Comparison of model climatology with rainfall observations at Libertad (Lib).

Although two peaks in the rainfall are picked up by the model the dry spell in August is not as distinct as in the observations. However, applying a correction factor to AJ would bring this trough closer to the actual climatology.

v. Big Falls South BFallsS (Latitude 16.26°N, Longitude 88.78°W, elevation above mean sea level= 20 meters.)

Precipitation

Performance could be rated as poor for this station pertaining to precipitation.

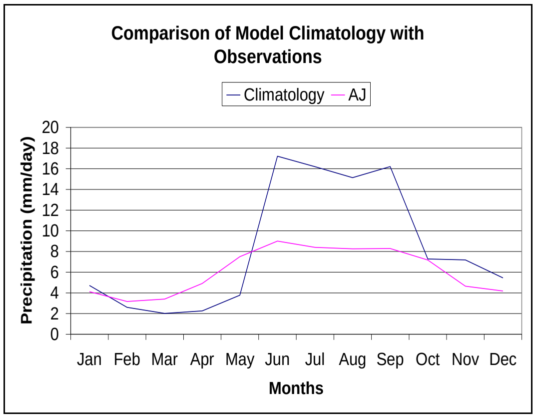

Figure 7. Comparison of model climatology (1982-1993) with rainfall observations (1966-1981) at Big Falls South (BFallsS).

Due to unavailability of data the period 1966-1981 which covers some 16 years had to be used for the comparison with the model climatology. The difference in length and time intervals could account for some of the discrepancy between the observations and AJ. However, armed with the knowledge that the southern parts of the country receives substantially more precipitation than depicted by AJ in Figure 7 then it is a safe assumption that the model is underestimating rainfall amounts at this station.

vi. Tower Hill THill (Latitude 18.03 ºN, Longitude 88.6 ºW, elevation above mean sea level= 13 meters)

Except for the overestimation of precipitation quantities from January to September model performance at this station could be deemed excellent.

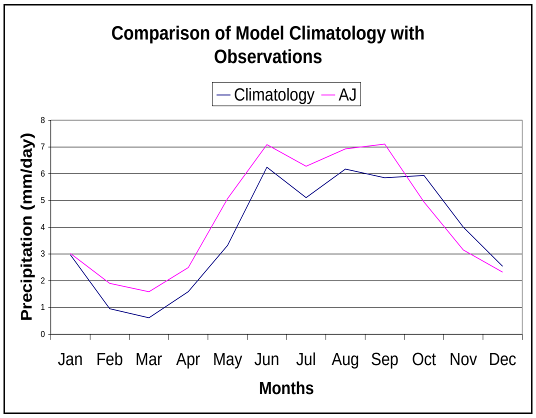

Figure 8. Comparison of model climatology with rainfall observations for the period 1982-1993 at Tower Hill (THill)

From the above figure it can be seen that the start of the rainy season in June and the plateau in August to November are both resolved by the model.. The AJ plot bears a close resemblance to the plot of observations.

vii. Melinda Forest Station (MFS) Latitude 16.6 ºN. Longitude 88.3 ºW, elevation above mean sea level= 30 m)

There was a persistent overestimation of rainfall rates for the greater portion of the year. Only the months of November and December showed any consistency in the resolution of precipitation.

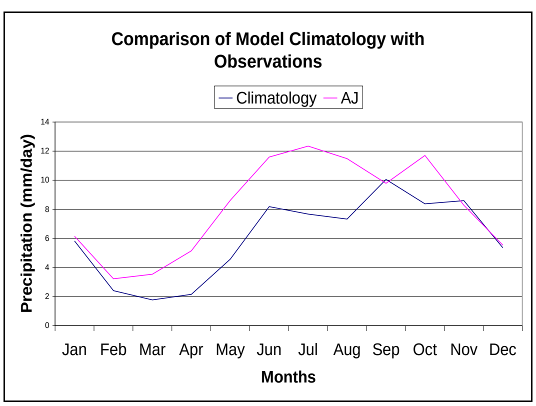

Figure 9. Comparison of model climatology with rainfall at Melinda Forest Station (MFS)

The climatological period used for comparison with the model climatology was from 1984 to 1999. The use of this period may have also introduced some differences between actual observations and AJ.

Given altitude considerations locations where station locations were at low elevations (less than 20 m above mean sea level) showed better results in the temperature performance evaluations. This is clearly shown by comparisons between performance at Towerhill (elevation 13 m) as compared with Belmopan (elevation 90 m) or even Big Falls South (elevation 20 m) as examples. It can be concluded that the 20 km AGCM performs better where over low, unchanging topography.

Another source of errors could have evolved from the comparison of point observations with averaged values representing a grid box. This matter will be discussed later in the section dealing with model uncertainty.

5. PROJECTIONS FOR THE FUTURE CLIMATE

In this section the future state of climate variables (designated AK) as simulated by the AGCM is presented. This covers the period 2080 to 2099 (20 years). However, before venturing into the probable future state of the climate of Belize a review of the present climatic conditions is required and even more so, prudent.

Average annual rainfall values in Belize vary from 1500 mm (60 inches) in the north to 3,800 mm (150 inches) in the south. The greater portion of this latter amount is orograhically induced. There is a marked wet and dry season with a transitional cool period from November to February during which an average of twelve cold fronts cross the country. The dry season runs from

February to April and even to the mid May at which time the rainy season begins in the south. By mid June the rains would have spread to the north. A brief two week cessation or lull in the rains usually occurs in August showing up in most precipitation data as the characteristic bimodal peaks. About 60% of the total annual rainfall occurs during this rainy season.

The average maximum temperature for the country considered on a whole is around 29 ºC and the low 21 °C. Diurnal temperature ranges in the interior are much greater than along coastal areas basically due to the effects of the sea breeze. Some coastal areas see high temperatures 4 to 6 ºC cooler than inland. In the summer months this variation can be significantly greater. The coldest month on average is February.

a. Future Temperature Change:

Figures 10 through 21 represent the future average monthly surface temperature changes over Central America, the western Caribbean and Belize as generated by the 20 km atmospheric general circulation model.

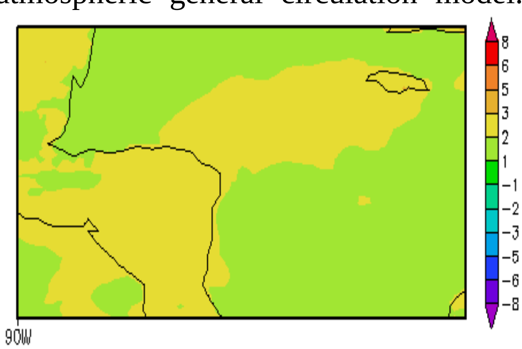

Figure 10. January Projected Temperature change

These changes are computed by the difference between AK and AJ i.e. (AK-AJ).

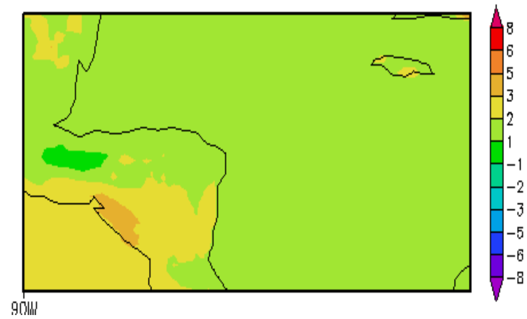

Figure 11. February Projected Temperature Change

It is clearly shown that all months from January through May are projected to be warmer and as much as 2 to 3 ºC warmer at some places in January and May.

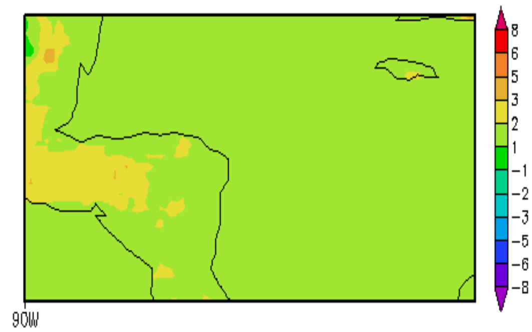

Figure 12. March Projected Temperature Change

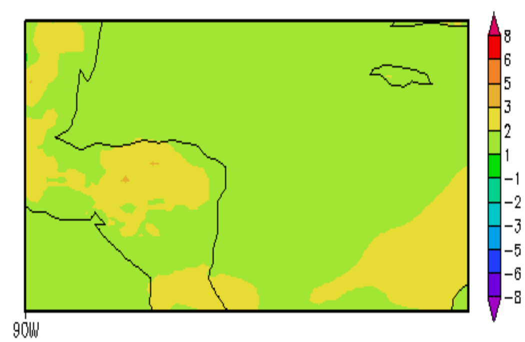

Figure 13 April Projected Temperature Change

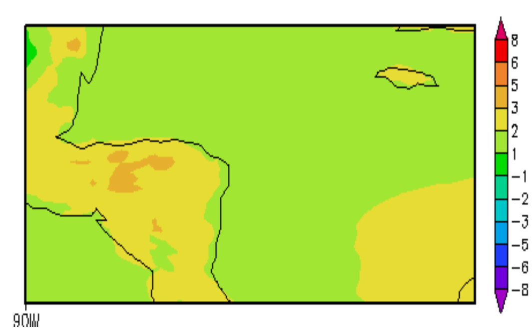

Figure 14. May Projected Temperature Change

During the months of June and July (See Figures 15 and 16) temperatures appear to be cooler by about 1 to 2 °C but more so in June as compared to the following month.

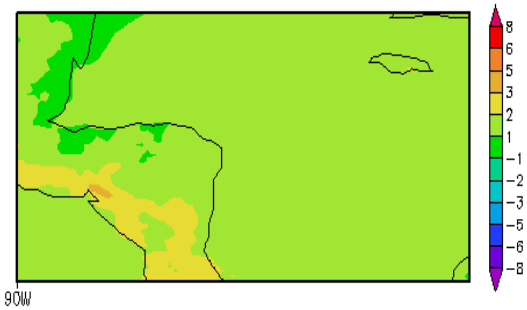

Figure 15. June Projected Temperature Change

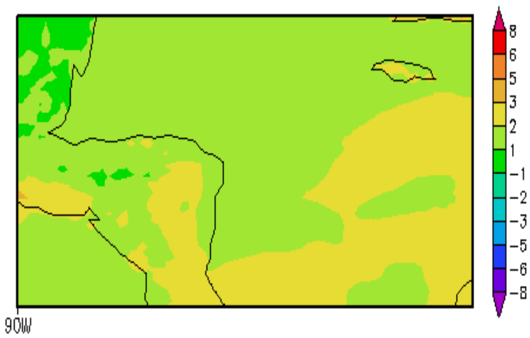

Figure 16. July Projected Temperature Change

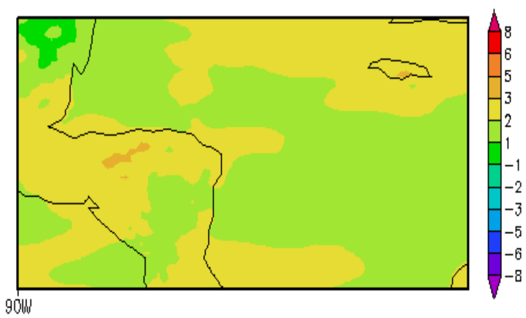

Figure 17. August Projected Temperature Change

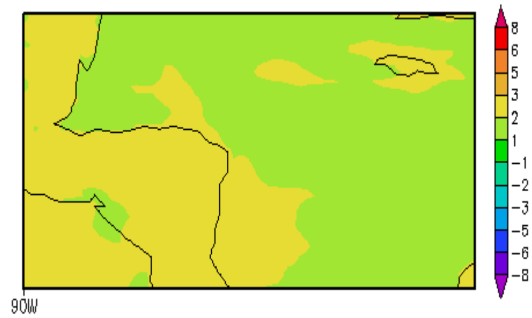

Figure 18. September Temperature Change

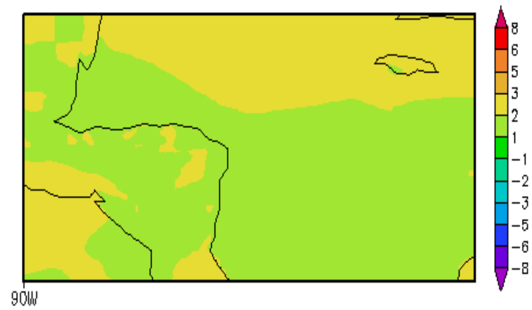

Figure 19. October Projected Temperature Change

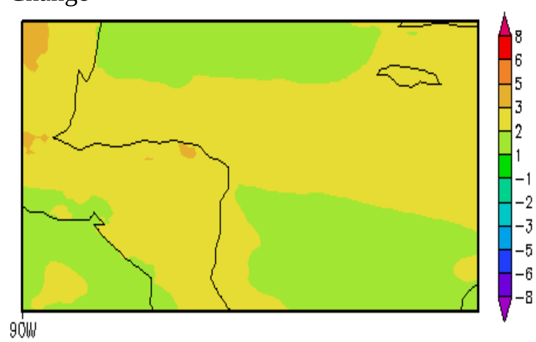

Figure 20. November Projected Temperature Change

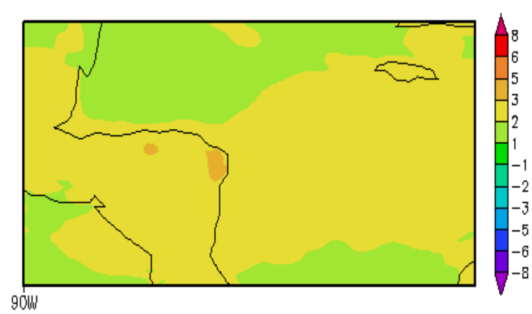

Figure 21. December Projected Temperature Change

The remainder of the year is projected to be warmer than climatology. The winter transitional months of November and

December are projected to be some 2 to 3 ºC warmer. Overall a warmer pattern is being forecast by the 20 km global model for the period 2080 to 2099.

b. Future Precipitation Changes

Figures 22 to 33 show the projected average daily precipitation (mm/day) changes as generated by the 20 km global circulation model.

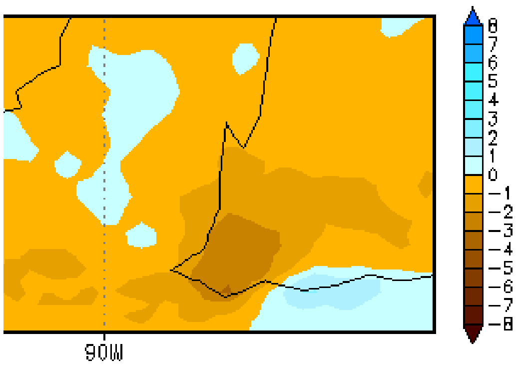

Figure 22. January Projected Precipitation Change

January (Figure 22 above) is projected to show a deficit with up to 1 to 2 mm/day over southern sections of the country.

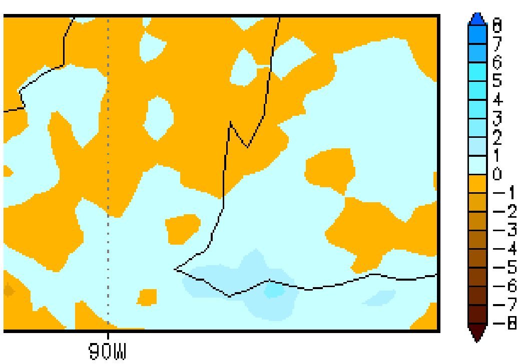

Figure 23. February Projected Precipitation Change

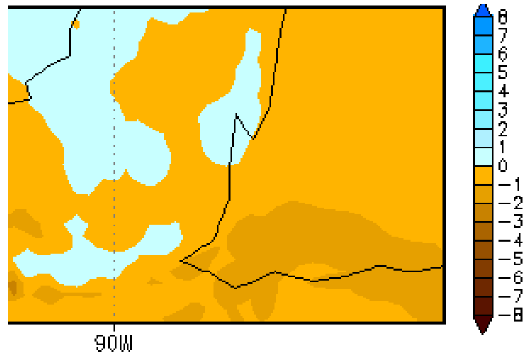

Figure 24. March Projected Precipitation Change

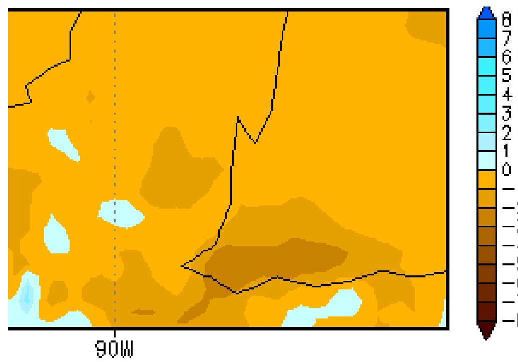

Figure 25. April Projected Precipitation Change

Considering figures 22 to 25 it can be inferred that the heart of the dry season will be drier as compared to present day.

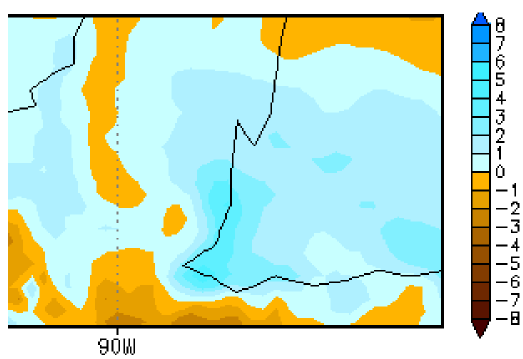

Figure 26. May Projected Precipitation Change

In the month of May as shown in Figure 26 there are predictions of 3 to 4 mm/day increases in precipitation in the south and 1 to 2 mm/day surplus elsewhere.

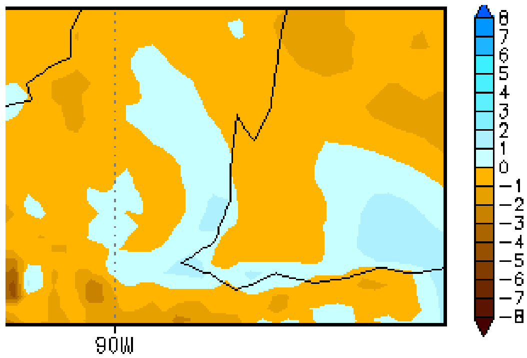

Figure 27. June Projected Precipitation Change

Considering now the heart of the rainy season, June (Figure 27 above) is the only month showing any significant surplus in rainfall. All other months in the peak of the rainy season show deficits except for the interior parts of the mainland in October (Figure 31). So the implication then is for a drier rainy season as shown in Figures 28 through 31.

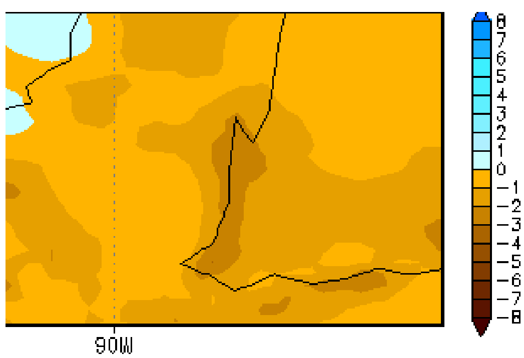

Figure 28. July Projected Precipitation Change

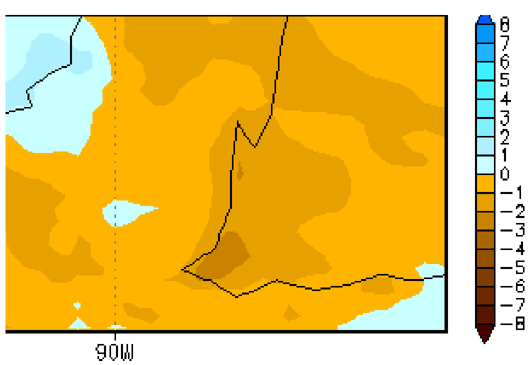

Figure 29.August Projected Precipitation Change

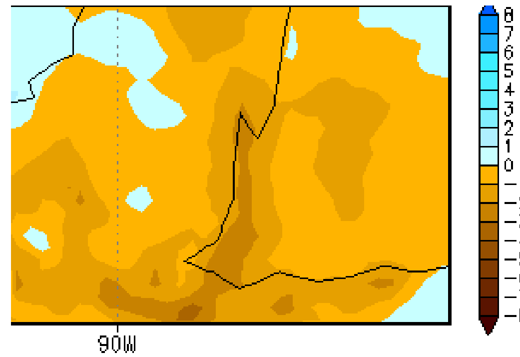

Figure 30. September Projected Precipitation Change

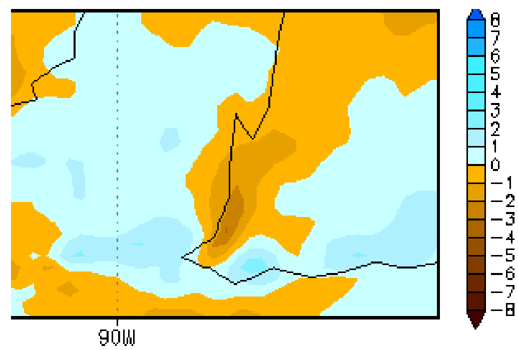

Figure 31. October Projected Precipitation Change

October, November and December are early transitional months leading into the dry season. However, these months were simulated to be wetter than normal as shown in Figure 31, 32 and 33.

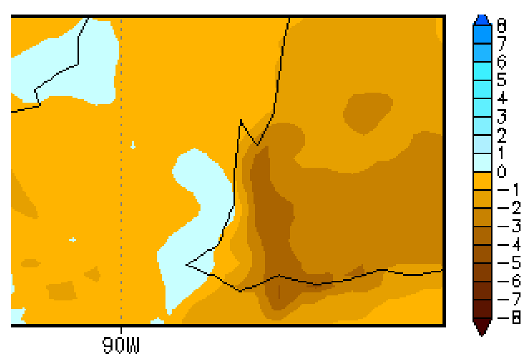

Figure 32. November Projected Precipitation Change

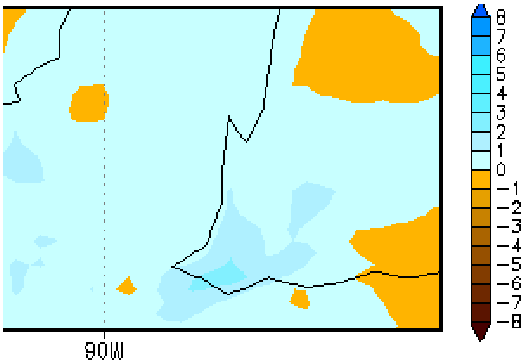

Figure 33. December Projected Precipitation Change

In summary, then, it can be inferred from the simulations that near the end of this century both the dry and wet seasons could be drier than normal. The early part of the winter or transitional period is projected to be wetter than average.

Attempts were made at completing phase and amplitude adjustments to account for the systematic biases when present in some of the model climatology (AJ). These were then applied to adjust the model projections (AK). The phase and amplitude adjustments displayed negative effects on the AK variables.

7. Model Projections and Change (2088- to 2099)

a) Precipitation

This section deals with unadjusted model climatology and forecasts along with the change in a couple variables at select stations. Future changes in rainfall pattern for the Philip Goldson International Airport (Figure 34) show negative changes for most of the year with May being the only month in which rainfall was forecast to increase.

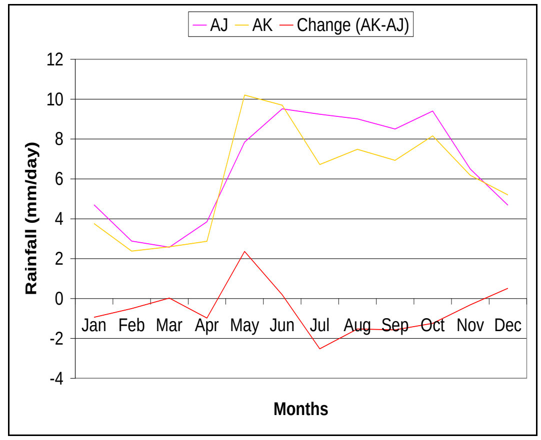

Figure 34. Future Changes in Rainfall at Philip Goldson International Airport (PGIA).

Belmopan's projected rainfall (Figure 35 below) depicts the same trend with the largest increase also occurring in May.

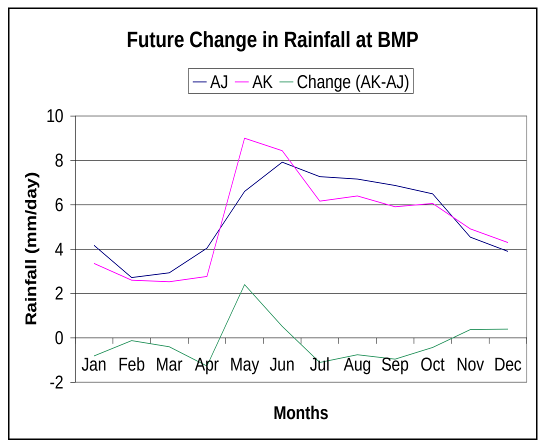

Figure 35. Future Changes in Rainfall at Belmopan (BMP)

At Central Farm (Figure 36) once again the projected rainfall shows the same pattern as BMP and PGIA. However, the change is much less exaggerated.

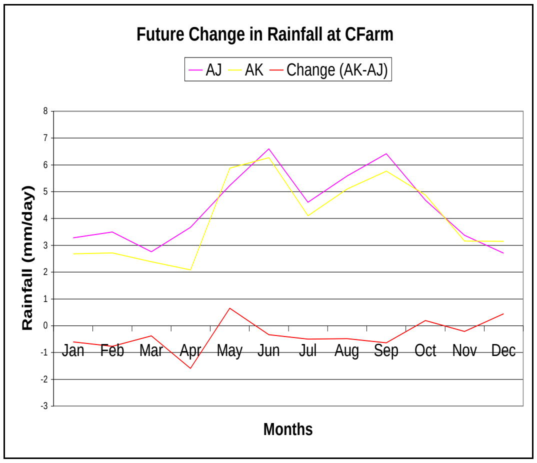

Figure 36. Projected Change in Rainfall at Central Farm (CFarm)

b) Average daily temperatures

At PGIA projections are for a warmer climate with the largest change coming in August and September.

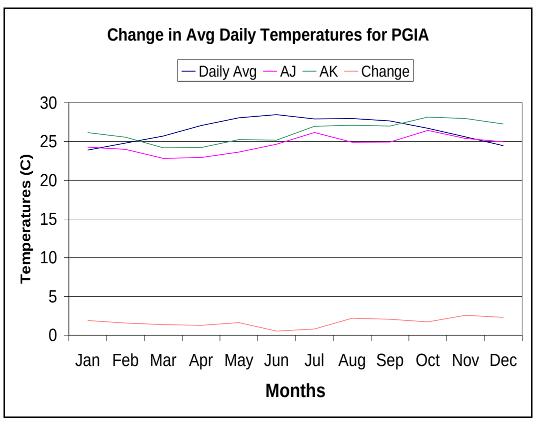

Figure 37. Future Change in Temperature for Philip Goldson International Airport (PGIA)

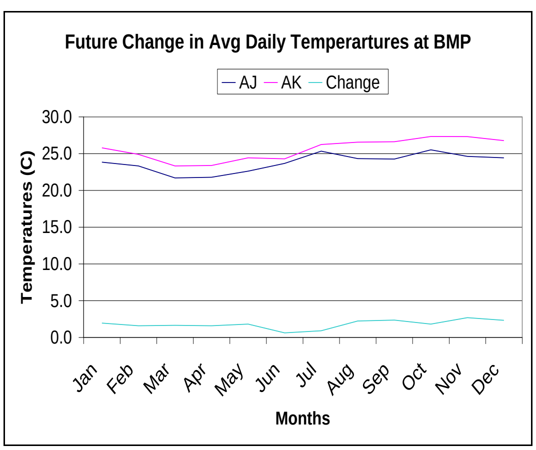

Figure 38. Future Change in Temperature for Belmopan (BMP)

The figure above showing future temperature changes at Belmopan also follows the same trend as in Figure 37. Based strictly on unadjusted model output indications are that the future climate at couple select localities will be warmer but drier.

c) Consecutive Dry Days (CDD)

The variable Consecutive Dry Days (CDD) is defined as the maximum number of consecutive days with less than 1mm/day precipitation occurring in a particular year..

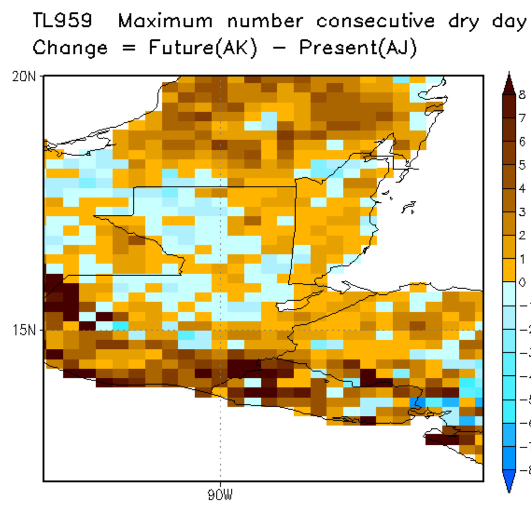

Figure 39. Change Consecutive Dry Days (CDD)

For more than three quarters of the country there is an increase in consecutive dry days. In the drier north and northwest there are negative changes in CCDs. The implication or connotation of this could be wetter conditions. Such an occurrence adverse impacts on the sugar cane productions which are mainly concentrated in that area.

d) Special Case Study:

April was chosen as a special case for consideration of the effects of the changes in maximum and minimum temperatures on the average temperatures for that particular month.

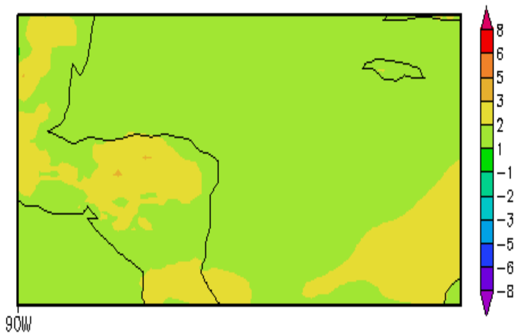

Figure 40. April Change in Average Temperatures.

As shown in figure 40 above, average daytime temperatures near the latter part of this century are projected to increase some 1 to 2 °C over almost all portions of Belize. Some parts of the country will see decreases in the maximum temperatures as depicted in figure 41 below.

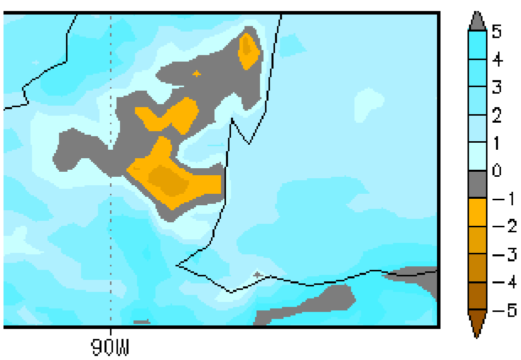

Figure 41. April Maximum Temperature Change

Minimum temperatures, on the other hand, were simulated to increase by 3 to 4 °C over almost all sections of the country. (See figure 42.)

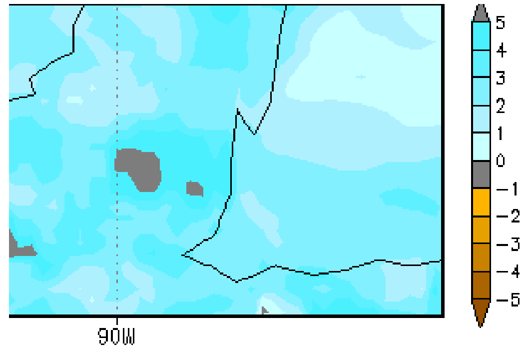

Figure 42. April Change in Minimum Temperatures

Table 1 below shows the change in average, maximum and minimum temperatures for the period 2080 to 2099 for select locations around Belize. Station names are as was used earlier in this paper. Overall there is a projected increase in average temperature greater than 1 °C at all these stations. Meanwhile at some localities the maximum temperature changes are negative while others were positive with magnitude as much as 3 °C.

Table 1. Change in Average, Maximum and Minimum Temperatures for the month of April:

Station	T_{avg} Change	T_{max} Change	T_{min} Change
PGIA	+1.3	-0.6	+4.4
C Farm	+1.7	-2.6	+4.7
BMP	+1.6	-1.8	+4.3
THill	+1.5	+1.5	+2.8
BFallsS	+1.7	+3.0	+2.6

All locations show positive minimum temperature changes-. Some of these changes are almost 5 °C in magnitude. Noting that average daily temperatures are computed by the simple formula $T_{avg} = ½ (T_{max} + T_{min})$ then it can be concluded that the change in average daily temperatures in April towards the end of this century will be largely attributed to increasing minimum temperatures rather than increasing maximum temperatures. This makes for much warmer nights in the future. This is only one example and other months could also show similar trends.

8. MODEL UNCERTAINTY

No one single climate model should be used as guidance for planning adaptation strategies for alleviate the effects of climate change. This is because of the inherent uncertainties in all climate models. In this section the description of some of the uncertainties in climate models are addressed.

There are two types of uncertainties. When a parameter or observation value is not known precisely this constitutes statistical uncertainty. On the other hand, when relationships between variables may not have been correctly identified then it is classified as structural uncertainty This type of uncertainty is more difficult to assess and can only be done to some extent by comparison of models with observations (as was done earlier in this paper) or comparing models with each other. The level of confidence in a model is the degree of belief that the model is accurate. It is determined by a combination of the amount of evidence and the degree of consensus in the interpretation of that evidence.

Also limitations in the observing network have to be taken into account when considering uncertainties in observed climate change. Perceived negligible but persistent errors in climate data can extremely significant effects on inferences being derived from them.

As spatial averaging scales decrease the variance of climate parameters also increases. At regional scales this makes the determination of trends or systematic patterns even more uncertain. Determination of trends in extremes in such variables as precipitation is made even more uncertain by greater spatial and temporal variance.

In this paper performance evaluations were done by comparing observations from a point with a specific grid box value. This grid box location corresponded to the closest latitude and longitude of that particular observation station.

9. CONCLUSIONS and ACKNOWLEDGEMENTS

Acknowledging MRI/JMA TL959L60 data

"We acknowledge the Kyosei4 modeling group for providing their data from the time-slice experiment performed on the Earth Simulator for analysis. The Kyosei4 project funded by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) is cooperatively conducted by the Meteorological Research Institute (MRI), the Japan Meteorological Agency (JMA) and Advanced Earth Science and Technology Organization (AESTO). "

REFERENCES

Randall, D and D.M. Pan (1993), Implementation of the Arakawa-Schubert cumulus parameterization with a prognostic closure, *Meteorological Monograph/The representation of cumulus convection in numerical models,* 46,145-150.

Yoshimura H. and T. Matsumura (2005), A Two-time Level Vertically Conservative semi-Lagrangian semi-implicit double Fourier Series AGCM, *Research Activities in Atmospheric and Ocean Modeling*, 35,3.27-28.