P3.17 ASSESSMENT OF PCM RESULTS FOR PREDICTIONS OF CLIMATE CHANGES IN THE CARIBBEAN

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1. Introduction

The Caribbean region is located along a relative tropical stripe land free, where the Tropical Atlantic and Pacific equatorial influence the interannual variability of its rainy season.

Giannini et al. (2001) established that the North Atlantic subtropical High SLP center (NAH), which is called Bermuda-Azores High, modulates the Caribbean rainfall on an interannual timescale. Close to the coasts the tradewinds strengthening cause an upwelling increase and a slight evaporation and cooling of the surface water (Knaff, 1998).

Taylor et al (2002) ascertained that the Caribbean rainfall season has a bimodal nature, where the initial peak of this season, called early rainfall season (ERS), begins in May and it extends until July, with a brief dry period in July. The second half of the overall rainy season or late rainfall season spans from August to November.

Taylor (1998) and Giannini et al. (2000) showed that a strong relationship exists between the early season and the El Niño event. Chen et al. (2002) established that the ERS anomalies are influenced implicitly by the wintertime Pacific anomalies by means of the influence it has over the sea surface temperature anomalies (SSTAs) on the North Tropical Atlantic (NTA) during the spring months. On the other hand, Taylor (2002) has established that a strong La Niña event generally leads to a drier than normal early rainy season. Chen et al (1997) is suggesting that the La Niña phenomenon favors dry Caribbean conditions when it develops during the early rainy season. Enfield and Alfaro (1999) showed that a warm tropical Atlantic-cool Tropical Pacific scenario had a tendency to enhance the rainfall amount over the Caribbean basin and Central America.

The comparison between the precipitation climatology (24-year average) -based in the CPC-merged analysis- and the precipitation that occurred in the years corresponding to the La Niña phenomenon showed that the ERS was affected by this event, causing a dry ERS (figure 1). The 1998 is a year in which a dry early season and La Niña event coincided and when rainfall began to subside in April continuing until the end of the early rainy season.

According to Arkin et al. (1998), the La Niña teleconnection between the equatorial Pacific, the Atlantic, and the Caribbean Sea, causes a diminished vertical wind shear via a weakening of the subtropical low-level jet, and therefore an increase in the precipitation amount over the Caribbean basin, when all NTA SSTs are above the threshold of convection.

Knaff (1999), using observed data, established the principal factors that enhance Caribbean rainfall and the development of hurricanes. They are: low surface pressure, low vertical wind shear, lower convective stability, and warmer NTA SSTs, being the NTA SSTs the main factor of the early season precipitation occurrence. Giannini et al. (2001), Chen et al. (2002) and Kingtse et al. (2001) defined the vertical wind shear as the difference between the wind speed in the upper troposphere, 250 mb, and wind in the lower troposphere, 850 mb.

During the late season, after the NTA reaches the SST criteria (SSTs of the NTA above 26.5°C), the atmosphere become the principal modulator of the thermal convection throughout the vertical wind shear of the horizontal wind, according to Taylor et al. (2002).

In this work we will investigate these climatology trends for the Caribbean region as defined by the regional precipitation, SSTs, and dry advection. The analysis will use the observed regional data and simulated information from outputs of Global Circulation Models (GCMs). The analysis provides a tool to assess the ability of GCMs to predict the regional climatological trends in this subtropical region.

2. Global model description and methodology

2.1 Global Circulation Model

PCM model version 1, used in this research, is a fully coupled, global climate model, comprised of the NCAR Community Climate Model version 3 (CCM3) with a T42 resolution (~2.8^{o} latitude and longitude) and 18 vertical levels (hybrid sigma coordinate), the Los Alamos National Laboratory Parallel Ocean Program (POP), whose resolution, on average, is 0.6 degree, and about ½ degrees near the Equator, with 32 vertical layers in the Ocean, the Sea ice model from the Naval Postgraduate School with 25 km x 25 km (0.25

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resolution degree) over the artic ocean, and the land surface biophysics model which runs with T42 resolution (Dai et al. 2004, Washington et al. 2000, and Weatherly et al. 2000).

Smith et al. (2002) has shown that POP uses an orthogonal curvilinear coordinate system. A semi-analytic dipole grid is constructed where the northern pole is in North America and the southern hemisphere is a Mercator grid with a pole exactly over the South Pole. The ocean model was initialized with assimilated observed data conditions from 1995 instead of performing traditional runs (Dai et al. 2003 and Barnett et al. 2003)

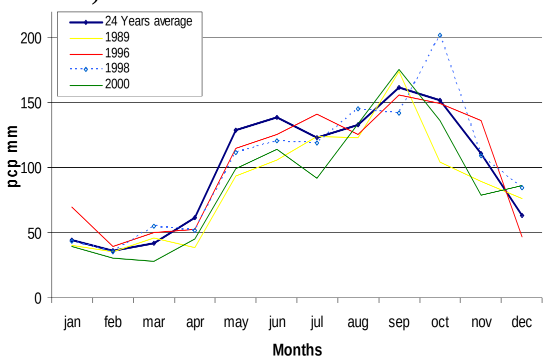

Figure 1. Comparison between the precipitation climatology and the years during the development of the La Niña event. The Caribbean area was defined as 8.75°N-25.25°N and 88.75°W-58.75°W.

2.2 Methodology

The validation of the PCM global model under present conditions is performed in this research. First a climatology analysis is developed to determine the long term average condition of the Caribbean basin. The second analysis consists of determining the deviation of the PCM global model, under the B06.46 experiment to 1998, with respect to the Caribbean climatology, as a consequence of the natural atmospheric and oceanic variables variation. Finally a comparison between the 1998 ERS observed and simulated conditions are carried out.

The Caribbean region is segmented in three periods, the dry season which correspond to December-April, and the wet season that includes the months of May-November (Taylor et al. 2002, Giannini et al. 2001, and Taylor 1999). Within the wet season the presence of a brief dryer period in July allows a division into an early and late rainfall season. The main development area (MDA) for this analysis purposes is defined as 7.5°N – 30°N and 95°W – 52.5°W. The National Center for Environmental Prediction (NCEP) reanalysis data, which has 2.5 degree of resolution over a regular grid, is used to calculate the climatology conditions of the Caribbean region. The CCM3 output -with T42 resolution- is first used to calculate the geopotential height and relative humidity and then, using the spline methods, the interpolation from the hybrid sigma-pressure 18 vertical levels to the standard 17 levels was performed. Next, a spatial interpolation, using the bicubic methods, is performed from T42 to 2.5° resolutions.

The SSTs from the POP model needs to be interpolated from a very irregular grid to a regular grid of 1 degree of resolution. The AMIP observed SSTs data is also interpolated to one-degree resolution.

The Climate Prediction Center (CPC) merged analysis uses gauge observations and satellite estimations. As in the previous case with SSTs, the rainfall data is interpolated from CPC (2.5 degree of resolution) to PCM resolution, to then compute the long-term conditions.

The calculation of the moisture advection is performed computing the dot product between the moist-air mass mixing ratio gradient and the velocity field. To calculate and display the horizontal distribution of moist or dry advection at a certain level (e.g. 850mb), the advection term is computed.

To determine the stability of the atmosphere, the dry adiabatic lapse rate or the moist adiabatic lapse rate is compared with the temperature vertical profile of the ambient air. The vertical temperature profile is computed as an average over the entire Caribbean basin. The level of condensation is considered at 800 mb level, where the dry and moist adiabatic lapse rate intersects.

3. Long Term Average Conditions

The climatology SSTs field shows that a relative warm surface ocean locates in the western and central MDR, which reach the leeward Greater Antilles. The western MDR has SSTs with 0.5 to 1°C above the threshold for convection, while from middle MDR to Lesser Antilles and the middle northern MDR boundary range from 26.5 to 27°C. A cool surface Ocean dominate the Gulf of Mexico, reaching values up to 8°C below the threshold, close to the southern coast of the Unites State (see figure 4b). The MDR area is relatively dry during this month with values of accumulated precipitation below 40 mm, with the exception of Dominican Republic, which has a wetter area. Its surroundings reach values between 60 to 120 mm. The updrafts around Central America together with the warm pool close to its seashore cause a considerable precipitation with a rainfall amount similar to Dominican Republic. The Gulf of Mexico essentially is a zone that presents greater rainfall amount than the Caribbean area (60 to 120 mm), as shown in figures 2b, c and d. In accordance with the potential virtual temperature criteria, the entire Caribbean basin has a stable atmosphere behavior, from the surface to the level of condensation. Above the level of condensation the atmosphere is unstable (figures 2e).

In the ERS, the warm pool with 0.5 and 1°C above 26.5°C is placed farther from the Windward Islands (Greater and Lesser Antilles). The western and north-central MDR area has a warm pool (among 28 to 28.5°C) where the SSTs values reach the Windward Islands, favoring the convective development. The other part of the Caribbean region, the Gulf of Mexico, shows fundamentally SSTs between 1 and 2°C above the threshold for convection (see figure 3a). During this season the atmosphere continues stratified with a stable atmosphere near the ground and a more intense unstable atmosphere at higher elevations (figure 2d). The MDR shows wide areas with accumulated rainfall amount between 60 to 120 mm. A strong warm pool placed close to Central America predominates over the dry advection to enhance the rainfall amount up to 200 mm as maximum. The vertical wind shear over this area has weak values leaving an obstruction to the precipitation development. The Gulf of Mexico has 60 to 120 mm of accumulated rainfall over its complete area, agreeing with the warmer pool place in this season (the moisture advection and weak vertical shear superimposed), see figures 3b, c and d.

The strong warm pool that arose in the first rainfall season, and that was placed near Cuba, kept up its values between 28.5 and 29.5°C. However in the late rainfall season it covers a greater area, expanding toward Windward Greater Antilles and Central America. The Gulf of Mexico in this period shows a stronger warm pool than the previous season, almost entirely controlled by the SSTs between 1.5 to 2°C above the threshold for convection (see figure 4a). The areas where the vertical wind shear weakened, the rainfall amount increased in both MDR and Gulf of Mexico, reaching ranges as high as 120 to 200 mm. The updrafts around Central America together with a weak vertical wind shear and sustained by a strong warm pool cause a substantial precipitation (figure 4b, c and d). The atmosphere state (stability/unstability) in this season is similar than the early rainfall season (see figure 2d).

4. 1998 Caribbean Season Simulated by PCM

The PCM SST field reproduces an intense cold ocean Caribbean basin in the dry season. Along the northern South America the SSTs have values that range from 20.5 to 22.5°C. The cool surface ocean water that reach values greater 8°C below the threshold for convection is located in the Gulf of Mexico, close to the southern coast of the US (see figure 5a). Otherwise, PCM computer-generated a wetter MDR, where the higher rainfall amount is located close to the Yucatan Peninsula, Guatemala and Honduras (between 60 and 120 mm). The lesser cool pool along with the water vapor concentration over these areas cause a greater rainfall amount. The South America Caribbean coast shows a dry area, with lesser than 40 mm of rainfall amount, influenced by the cooler SSTs although a moisture advection and a zero vertical wind shear are present. The coolest warm pool located over the Gulf of Mexico is responsible for a dry basin, predominating even over the moisture advection (see figures 5b, c and d). The computer-generated atmosphere shows a good agreement with the climatologic stability of the atmosphere into the boundary layer. Above the level of condensation up to approximately 633 mb level the atmosphere continues to be a stable, which is unlike the long term average characteristic. From this pressure level up, the atmosphere becomes unstable (see figure 5e).

In the ERS a warm pool around Cuba and the island of Bahamas appears for the first time with the SSTs varying between 26.5 and 27°C. A warm pool lag is simulated in the month of June, in contrast with the typical Caribbean behavior where the warm pool is present during the entire year in the middle MDR (Caribbean Sea). At the same time in the Gulf of Mexico an incipient small warms pool begins to appear (see figure 6a). With respect to the previous season the precipitation increased, where the areas with greater rainfall amount were mainly regulated by the moisture advection simulated by CCM3 and for SSTs computed by POP. The area that has the highest SST presents the greatest rainfall amount demonstrating its strong influence in the precipitation. Relative stronger vertical wind shear (with respect to the middle Caribbean Sea) and low SSTs produced the necessary conditions to get lower rainfall amounts near the northern South America seashore. In the Gulf of Mexico the SSTs and the moisture advection influence the precipitation increase (see figure 6b, c and d). The stable atmosphere as in the climatologic case is close to the ground in the boundary layer, while above the level of condensation an unstable atmosphere is simulated (see figure 5e).

In the late rainfall season a wide warm pool, with SSTs as high as 28.5°C, is generated. The stronger warm pool during the simulated year covers almost the entire Caribbean basin, with exception of the southern MDR, where upwelling reduces its intensity (SST reach 24.5°C as lower value). The warm pool with values between 1 and 2.5°C above the threshold for convection covers almost completely the Gulf of Mexico (see figure 7a).

In the areas where the SSTs were intense the rainfall

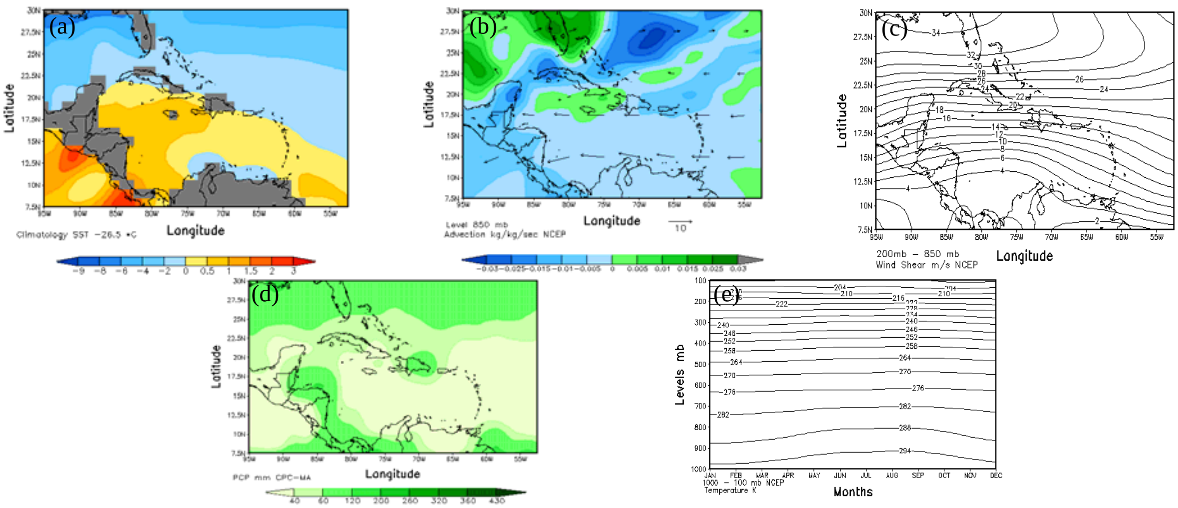

Figure 2. Dry season climatology from NCEP-data. (a) SST above (positives values) or below (negatives values) of the threshold for convection (26.5^{0}C), (b) Moisture/Dry advection, (c) Vertical wind shear with contours of 2 m/s, (d) accumulated rainfall amount from CPC- Merged Analysis, and (e) Vertical temperature in Kelvin.

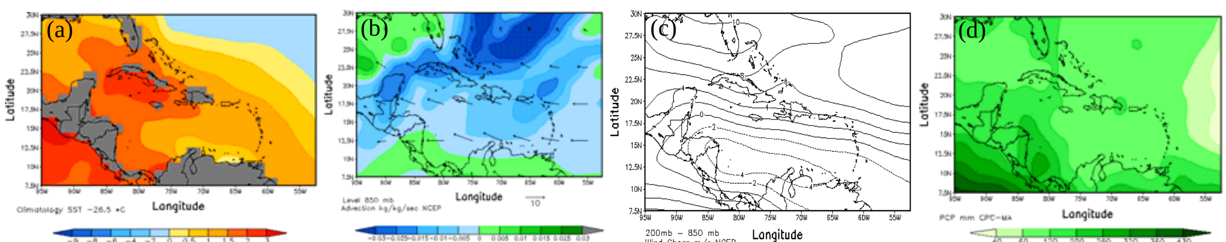

Figure 3. Early rainfall Season Climatology. (a) SST – 26.5^{0}C, (b) Moisture/Dry advection, (c) Vertical wind shear with contours of 2 m/s, and (e) Accumulated precipitation.

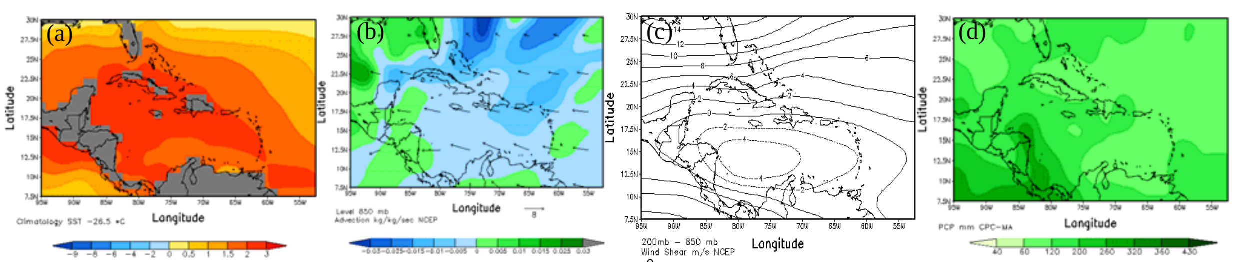

Figure 4. Late rainfall season Climatology. (a) SST – 26.5^{0}C, (b) Moisture/Dry advection, (c) Vertical wind shear with contours of 2 m/s, and (d) Accumulated precipitation.

amount increased between 120 to 260 mm for both the MDR and the Gulf of Mexico. The moisture advection also causes a precipitation enhancement in the Gulf of Mexico (see figures 7b, c and d). The atmosphere continues divided in a stable and an unstable state to the lower atmosphere and the region above the level of convection, respectively (figure 5e).

5. Annual variability and interactions between the atmospheric variables and SST

The variability of the vertical wind shear, the moisture/dry advection, the SSTs, the rainfall amount and the water vapor mass mixing ratio are averaged over the complete Caribbean basin. These variables are analyzed in the following paragraphs.

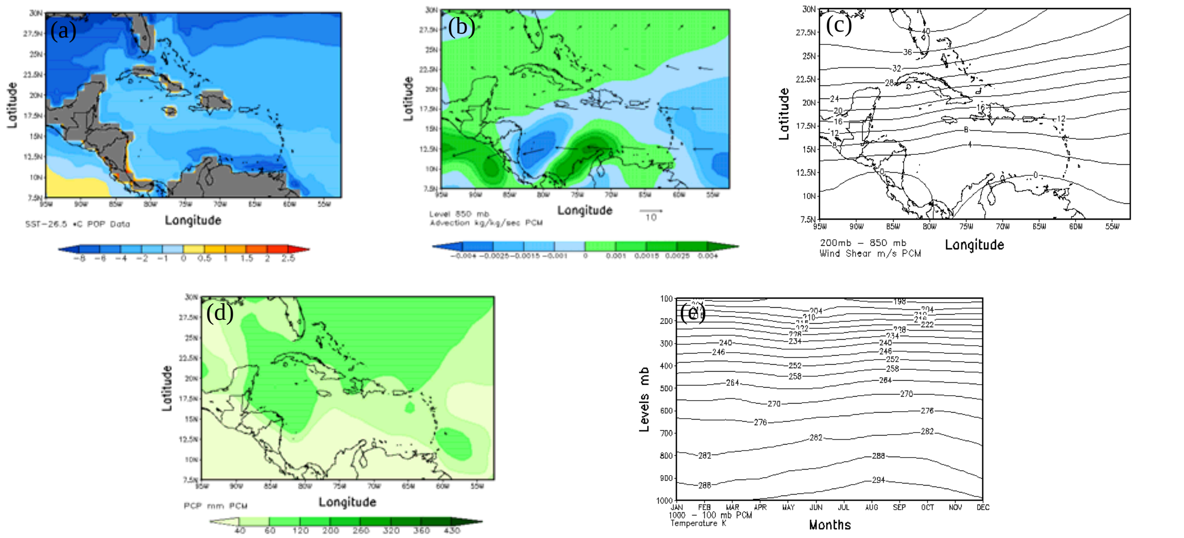

Figure 5. Simulated dry season by PCM, computed from the CCM3 and POP ocean model. The variables are (a) SST – 26.5^{0}C, (b) Moisture/Dry advection, (c) Vertical wind shear with contours of 4 m/s, (d) accumulated rainfall amount from CCM3, and (e) Vertical temperature in Kelvin.

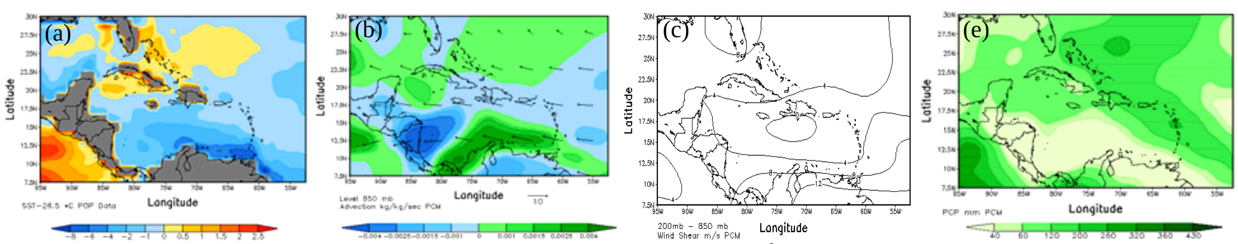

Figure 6. Simulated early rainfall season by PCM. (a) SST – 26.5^{0}C, (b) Moisture/Dry advection, (c) Vertical wind shear with contours of 4 m/s, and (d) Accumulated precipitation.

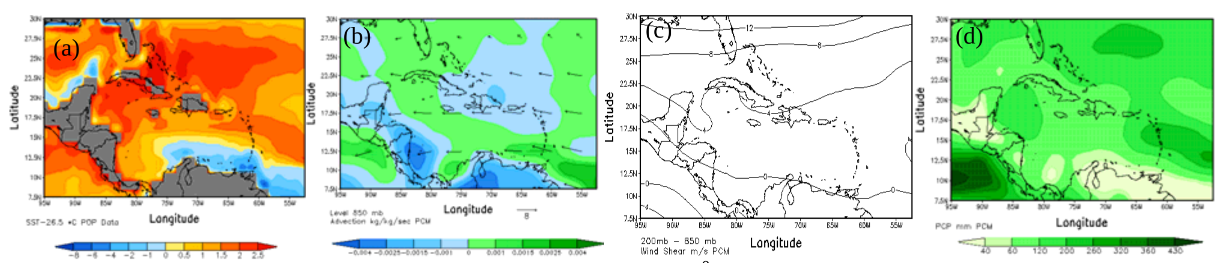

Figure 7. Simulated late rainfall season by PCM. (a) SST – 26.5^{0}C, (b) Moisture/Dry advection, (c) Vertical wind shear with contours of 4 m/s, and (d) Accumulated precipitation.

In the dry season the slight reinforcing of the vertical wind shear along with the weakening of the moisture advection indicated the little influence of these variables, in contrast with the SSTs influence. During the early rainfall season, the influence of the SSTs over the rainfall amount in the Caribbean basin is clearly observed. To the end of this period the vertical wind shear shows its influence decreasing the rainfall amount. In the entire late rainfall season, the rainfall amount follows the variations of the vertical wind shear (in absolute values) and of the SSTs. During the entire year the rainfall amount variability follows the tendency of the water vapor mass mixing ratio (see figure 8a). PCM global model computed a vertical wind shear shift, where the maximum peak is placed in the month of January. At the same time, the moisture/dry advection also shows a shift, placing in this case the maximum seasonal peak in the month of March. The simulated rainfall amount is influenced by the SSTs during almost all year, except from February to April, into the dry season. Within this time range the weak vertical wind shear along with the moisture advection influenced the precipitation increase while from March to April a strong vertical wind shear caused a decrease in rainfall. The early rainfall season is controlled by the simulated SSTs, and also favored by the weakening vertical wind shear. In the late rainfall season the SSTs show a good correlation with precipitation, similar to the vertical wind shear. From September to October the dry advection also play an important role (see figure 8b).

PCM predicts a greater precipitation than the climatology during the dry season, except for the month of April which is characterized by an underestimation of the rainfall amount, while in the late rainfall season PCM predicts lower precipitation than the climatology, except in the month of August. The maximum peak of simulated precipitation is shifted to the month of August, in contrast with the usual time in the month of September (see figure 13).

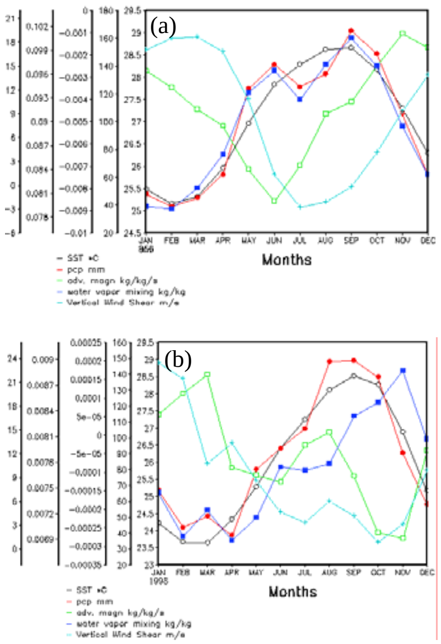

Figure 8. Monthly variability of oceanic and atmospheric variables SSTs, precipitation, moisture/dry advection, water vapor mass mixing ratio, and vertical wind shear from (a) Long term average conditions, (b) Simulated by PCM global model. The order of the ranges on the plots follows the order of the variables into the legend.

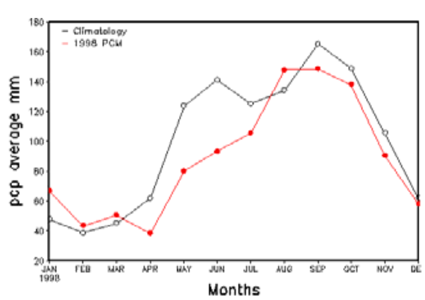

Figure 9. Monthly variability of precipitation between the climatology of the Caribbean basin and 1998 as simulated by PCM.

6. La Niña phenomena development during the early rainfall season, 1998

In 1998, in contrast with its normal development, two phenomena that had a strong impact on the climate over the NTA were in transition from one to the other: the El Niño, diminishing in its phase El Niño +1 year and the La Niña event, taking place in May, at the beginning of the ERS.

The Equatorial ITCZ during the early rainfall season reached negative SSTAs between -1 to -2°C and positive anomalies of up to 2 to 3°C along the South American Pacific coastline, depicting the presence of a warm pool during the decaying stages of the 1997-1998 El Niño events and the arising of the La Niña phenomenon (see figure 10a). In the NTA, the SSTs positive anomalies were present almost everywhere, with values in the 0.6-0.8^{0}C range over the eastern and southern MDR. The island of Puerto Rico and its surroundings had stronger SSTAs, getting values between 1 and 1.5°C. Negatives anomalies of SSTs were present essentially over the Yucatan Peninsula, as seen in figure 10b. In addition to the SSTAs influences, the dry advection along with a relative strong vertical wind shear plays an important role to cause a dry area as detected in Cuba, Bahamas Islands and northern Lesser Antilles area (see figure 10c). In the Gulf of Mexico the presence of moisture advection and vertical wind shear magnitude with values able to support the thermal convection (< 8 m/s), kept a similar rain production that in the MDR (no shown here).

The ocean model predicts negative SSTAs of approximately -5°C along the ITCZ during the dry season, and simulates small areas with positives anomalies which reach 5°C, close to the northern South America Pacific coast. In the next season, the early rainfall season, the cool water area retreat along the ITCZ but with approximately -5°C (average of the complete ERS), as is shown in figure 11a, while in the late rainfall season, this area along of the ITCZ retreats more. Therefore it can be concluded that the ocean model was unable to capture the onset of the La Niña phenomenon.

On the other basin, the NTA, although a warm pool is placed over Cuba and the Bahamas Islands, negative SSTAs cover these areas, but less intensive than MDR where a cooler pool is controlling the climate (figure 11b). The accumulated precipitation predicted by the model for the entire area shows values less than those observed during this month, mainly regulated by the negative SSTAs and sustained by the vertical wind shear and moisture/dry advection simulated by CCM3. Dry advection and strong negative SSTAs produce the necessary conditions to get lower rainfall amounts near the Central America seashore. The Gulf of Mexico is also controlled by negative SSTAs, which along with the moisture advection and vertical wind shear sustain the precipitation increase (see figures 5b, c and d).

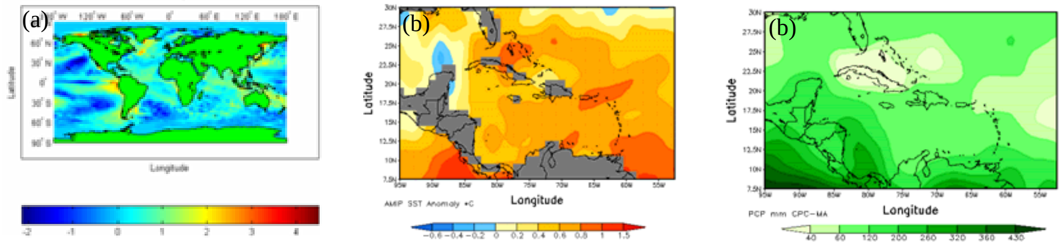

Figure 10. ERS to 1998, showing the variables (a) SSTAs to global scale, (b) SSTAs over the Tropical Atlantic and the Caribbean basin, and (e) CPC-merged analysis-gauge.

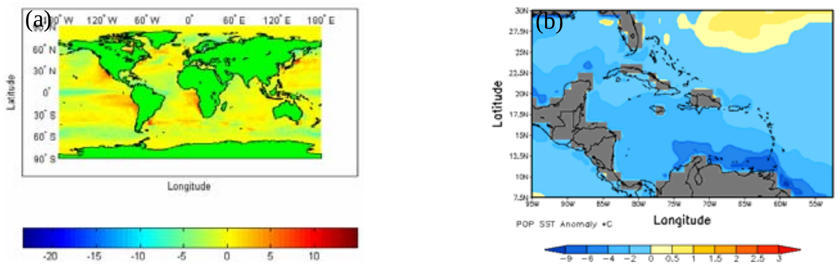

Figure 11. POP simulated ocean data to dry season, (a) SSTs to global scale, (b) SSTAs in the Caribbean basin.

7. Summary and conclusions

The climatology of the early rainfall and of the dry seasons and of the Caribbean was analyzed in this work using observed synoptic data and outputs of a GCM. The region is characterized by low mean SSTs influence over the precipitation, with respect to the spatial distribution. It was found from climatological data that the the monthly variability of the SSTs affects the precipitation variability in contrast with the SSTs spatial distribution. In the ERS the spread or retreats of the NTA warm pools is followed by the areas with greater rainfall amount. The monthly variability of the SSTs shows its strong influence over the rainfall amount, where only at the end of this season the vertical shear causes a decrease of the precipitation. In the late rainfall season the rain production increased, where the areas with greater rainfall amount correspond with the warmer pools. The vertical wind shear in the same way weakened just over the areas with greater precipitation. Observing the monthly variability, the SSTs and the vertical wind shear cause the variability of the precipitation.

These processes were analyzed in light of the GCM PCM with the objective of assessing the accuracy of the regional outputs. The ocean model of the PC, POP, underpredicted the SSTs in the dry season simulating a cool pool. The monthly variability simulated by CCM3 and POP global models show that the precipitation evolution was irregular, decreasing in February along with the SSTs and increasing in March where a strong weakening of the wind shear took place. In the ERS the SST is underpredicted for both regions the main development and the Gulf of Mexico. The moisture advection and the weak wind shear along with the SSTs enhance the rainfall amount. The monthly variability of this rainy season shows the influence of these variables. In the late rainfall season the warmest pool is simulated by the POP model, which range from 2 to 2.5°C above the threshold for convection, and it is close to the climatology warm ocean water. The prognostic precipitation is placed over the areas with warmer surface water, while the simulated monthly variability of the SSTs is followed by the rain production. The vertical wind shear is an important factor in the rain variability during the late rainfall season. The vertical profile of the temperature simulated by PCM has a closer behavior with the climatologic temperature vertical profile.

In 1998, La Niña began to develop at the beginning of the rainy season of the Caribbean basin and it extended throughout the year. La Niña affected the rainfall amounts during the early rainy season, causing a dry season.

The POP ocean model underpredicted the cooling of the Pacific ITCZ during the rainfall season and showed a different behavior of the negative SSTAs. The progressive retreat of the cool area over the ITCZ during the complete year is in disagreement with the span of cool area over the ITCZ. Everything indicated that the POP ocean model was unable to capture the onset of the La Niña phenomenon. In the middle MDR the simulated dry advection along with stronger negative SSTAs produces the necessary conditions to decrease the rain production. In the Gulf of Mexico, under the PCM scenario, the SSTAs were less negative and along with the weaker vertical wind shear and stronger moisture advection caused more rain production. Basically, the NCEP reanalysis data and

PCM output agreed in the influence of the vertical wind shear and the SSTAs on precipitation.

In conclusion, the PCM global model simulated a Caribbean region with greater moisture advection in contrast to the climatology characteristic. The SSTs simulated have influence in the spatial distribution of the precipitation, while in the temporal evolution the vertical wind shear influenced. POP ocean model predicted a warm pool lagged, which appeared in June. The POP ocean model shows a lag in the arising of the positive SSTAs. It is in stark contrast with the positive SSTAs shown by the observed data. Because the POP ocean model is a climatologic model and initialized with assimilated SSTs data from 1995 along with atmospheric variables derived from historic runs, it is expected that the model does not detect events that arise abruptly such as La Niña phenomenon.

Acknowledgments. This work was partially supported by the NASA EPSCOR Grant# NCC5-595. We acknowledge the Oak Ridge National Laboratory, Computer Science and Mathematics Division for the assistance and support in providing the appropriate PCM outputs at six hours intervals.

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