JP1.21 HOW THE CONGO BASIN DEFORESTATION AND THE EQUATORIAL MONSOONAL CIRCULATION INFLUENCE THE REGIONAL HYDROLOGICAL CYCLE

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1. INTRODUCTION

The Central African Equatorial region (CEA) which is composed mainly of the Congo Basin, has not received adequate attention in the field of climate research despite its crucial position as the third largest deep convection center in the world after the West Pacific warm pool region and the Amazon Basin. It is still the least endowed in terms of climate data collection (equipment) and experimental (field) research. More often West Africa, especially the Sahel region, East Africa and to a lesser extent Southern Africa are the subject of most African climate variability studies covered in literature. The CEA region therefore represents a notable gap in our understanding of some aspects of the tropical climate system, e.g. the influence of tropical land cover type on some climate parameters like rainfall and river runoff.

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This situation has led to large data gaps in a key climatic zone which make it difficult to address the global climatic situation in a more integrated manner. Recent trends like the use of models and modern data collection facilities e.g. satellites are desirable events for bridging the data gaps in the region.

Tropospheric heating resulting from deep convection within the Congo basin is one of the major driving forces of large scale circulation, especially over the tropics. In the last part of this study an attempt has been made to look at the relationship between the upper level (above 600 mb) wind patterns and the seasonal rainfall variability.

Paleoclimatological and sedimentary data in the mid-Holocene period indicate that the Sahara/Sahel region might have been much wetter and greener than is currently the case. Simulations from coupled biosphere–atmosphere models, e.g. ZonalBAM, show that changes in the land-cover type, possibly due to anthropogenic activities, could be largely responsible for the southward spread of the desert by about 5° in latitude from its early-Holocene boundaries (Irizarry-Ortiz et al, 2002).

Charney's hypothesis on the dynamics of deserts and droughts in the Sahel region (Charney, 1975) seems to lend credence to the southward spread of the Sahara due to anthropogenic activities. However, the Congo basin's resilience in precipitation and water yield goes against the grain in this case. The last chapter of this study suggests that the large scale circulation patterns as indicated by the upper level wind convergence and divergence might offer the negative feedback that steadies the rainfall regime over the basin.

1.1. LITERATURE REVIEW

The continuing global research on the biosphere-Atmosphere interactions can be traced back to the proposal by Charney (1975), whose work on the drought mechanisms of the Sahel focused on the role of land use changes in forcing the atmosphere. Since then a number of studies have been undertaken using general circulation models (GCM) with the purpose of understanding the environmental effects and climate alterations that might be associated with the continuous removal of tropical rainforests (Henderson-Sellers and Gornitz, 1984; Dickinson and Henderson-Sellers, 1986; Lean and Warrilow, 1989; Shukla et al., 1990; Nobre et al., 1991)

The earlier experiments used models with much lower spatial resolutions and were not able to represent the mosaic nature of the plant types on a single grid. Henderson-Sellers and Gornitz (1984) performed the first deforestation experiment using the Goddard Institute for space studies finite difference model which had a resolution of 8^0 latitude by 10^0 longitude. To mimic the change in vegetation from tropical forest to grassland, the albedo value was increased while the roughness length and soil moisture–holding capacity was reduced. A total area of 4.94 $x10^6$ square kilometers was deforested from the Amazonian Basin. A 10-year simulation was done and the last 5 years were then compared to the last 5 years of a 20-year control run.

Their results indicated no change in surface temperature, decreased rainfall (rainfall decreased by 0.6mm per day), decreased evaporation (0.4-0.5 mm per day), decreased cloud cover (5-15 %), increased planetary albedo (1-1.5%) and decreased soil moisture availability. They did not observe any significant regional or global scale effects.

Dickinson and Henderson-Sellers (1988) modeled tropical deforestation (Amazonian Basin) by changing several parameters in the Biosphere-Atmosphere Transfer Scheme (BATS) to represent the change from tropical moist forest to impoverished grassland. They used the National Centre for Atmospheric Research Community Climate Model (NCAR CCMOB) at a resolution of 4.5^0 by 7.5^0. They noted that seasonal pattern of precipitation was satisfactorily simulated but that the modeled precipitation was greater than observed in some parts of the study area. Their observations included a rainfall response that was noisy with no systematic regional change, an increase in surface and soil temperature (approximately 2K), decreased evaporation except in September and decreased canopy interception except in August.

Shukla et al's (1990) simulation was conducted with relatively high resolution in comparison to others as summarized in the report by Nobre et al (1991). Deforestation was modeled by changing a range of physical parameters in the SiB land-surface scheme (Sellers et al., 1986). They used the NMC GCM (spectral) model at R40 (1.8° X 2.8°) resolution (Sela, 1980: Kinter et al., 1988; Sato et al., 1989). The SST fields for the model were fixed at December values and cloudiness was prescribed from seasonal means.

The last few years have seen more improvements in model resolutions and in the mosaic representation of the various plant functional types. There have also been significant improvements in the land-surface schemes used in the coupled global circulation models. The advances on the land surface schemes tailored for use in General Circulation Models (GCMs) are mostly expansions on Dickinson et al (1984) BATS and Sellers et al (1986) Simple Biosphere Scheme (SiB).

More recent work on the influence of land cover change on the African climate have used more 'realistic' scenario for simulating the impacts by taking advantage of the improved computational capacity (Maynard and Royer, 2004). Where as the past studies needed 'complete' deforestation to be able to detect the model response to the land use change, current experiments can investigate less drastic perturbations like fractional decline of specific plant functional types. A couple of experiments have attempted to investigate the relationship between the surface energy budgets and both the atmospheric circulation and the hydrological cycle. Numaguti (1993) highlighted the role of evapotranspiration in the Hardley circulation dynamics by indicating that a small fractional change in evapotranspiration, as often occurs in deforestation experiments, could course large changes in the energy supply thereby resulting in significant modification to the meridional structure of the Hardley circulation. The possibility of large scale climate disturbances originating from the effects of tropical deforestation have also been investigated by Zhang et al (1996) , Sudd et al (1996) and Zeng et al (1996)

The role of soil moisture content in regulating the impact of tropical deforestation has also been receiving some attention. Osborne et al (2003) have shown that the introduction of freely draining soils in the tropics via the hydraulic parameters reduces significantly the climate sensitivity to vegetation and by implication to land use change. Eltahir and Gong's (1996) and Irizary-Ortiz et al (2002) have looked at the influence of deforestation on the West African Monsoon and have pointed out the positive correlation between the longitudinal temperature gradient and the strength of the monsoons.

The impact of tropical deforestation on hydroclimatic variables (e.g. precipitation, soil moisture, evaporation) in the Extratropical Regions have been shown in some studies to have very little statistical significance (Kirsten et al 2005).

Most of the studies mentioned above have focused on various elements of the climate parameters in diverse places within the tropics. This study focuses on the climatic parameters over the Congo basin and offers a unique view of the integrated influence of deforestation on the Central African Equatorial region. The study looks at the spatial and temporal variation of precipitation, evapotranspiration and runoff, i.e. the land surface components of the hydrological cycle, and the divergence/convergence of the upper levels winds over the basin in response to various levels of deforestation. The idea is to be able to identify the existence of a compensatory influx of water vapor at the upper levels following the reduction in local upward flux of moisture accompanying deforestation. The study is looking into the change in circulation pattern that might be inhibiting the positive feedback between deforestation and precipitation or the intensity of the hydrological cycle.

1.2. Deforestation in the Congo Basin

The Congo basin is located in the central and western region of the African Continent roughly within latitudes 10^oE- 30^o E and longitudes10^o S-

5^o N. The Congo basin forest has shown much resilience in size and water yield despite the clearly increasing trends of deforestation in the recent past. The basin is 3.4 million square kilometers in size and its water yield per unit river length is second only to the Amazonian basin, giving it a prominent position in the water stressed continent of Africa. The changing demography and socio economic issues in the region have a direct impact on the land use practices with accompanying climatic feedbacks. Deforestation is the most visible anthropogenic influence in the Congo basin currently.

For the period 1980-1990 the tropical forests of the world are estimated to have been disappearing at the rate of 17 million ha annually (Lanly et al., 1991). This figure is known to have increased to 20 million ha annually in the early 1990s (Lal, 1995). While the accuracy of these figures may be open to debate, there has been a deluge of publications giving specific and vivid descriptions of environmental changes wrought by deforestation (Proctor, 1989). These publications have lead many to automatically associate tropical deforestation with negative impacts like: lower rainfall; lower water yields from springs and streams; major floods; extreme sedimentation and hence the chocking of reservoirs and irrigation canals, etc.

Deforestation is defined as the clearing of large spaces in the natural forest, mostly through anthropogenic activities, as the expanding human populations seeks to exploit the forested areas for its own comfort and 'survival'. Forests can be cleared by occasional fires, cyclones, selective logging etc. Some of these disturbances are of intermediate intensity and the forest tends to recover after a relatively short while. This study is looking into the scenario where the forest is converted into grassland due to persistent logging for cultivation purposes or for settlement. This is therefore a long- term change where recovery might not happen for several decades.

Despite efforts by the international community to stem deforestation, it has to a large extent persisted, especially in areas like the African tropical forests where the quest for modern living styles are quickly encroaching together with the increase in population. The reasons for deforestation range from the need for more land for agriculture, livestock and habitat to commercialization of forest products for the manufacture of paper and other wood works. In Central Africa many landless people have been moving into the once forested areas and are quickly converting them into cultivated plots using simple slash and burn methods to create more space.

2. DATA AND METHODOLOGY

2.1 Model Description

The Community Climate System of Models (CCSM) is based on a framework that divides the climate system into various components, namely the ocean, atmosphere, land and sea-ice. Through a coupler different configurations of these components can be facilitated to allow for specific applications.

This study was performed using the Community Land Model (CLM3) coupled to the Community Climate Model (Cam3) the former being the land component while the latter is the atmospheric component of the CCSM group of models.

In this coupled (cam3/clm3) mode precipitation values and other parameters are delivered to the CLM3 module from the Cam3 module. CLM3 has one vegetation layer, ten soil layers and up to 5 snow layers depending on the snow depth

The input dataset needed for CAM3 include the initial state data, ozone boundary data and water vapor absorptivity and emissivity data. The initial dataset consists of the prognostic variables like zonal wind component, meridional wind component, temperature, specific humidity, surface pressure and cloud mass mixing ration among others. A climatological dataset of sea surface temperatures (SST) beginning from 1978 and containing 12 monthly time samples is read in by the ocean data model.

The major input in the land component (CLM3) is the dataset providing plant functional type and physiological constants. A default land surface dataset based on the International Geosphere-Biosphere Program (IGPB) classification is provided with the model. Modification of this dataset for the Congo basin is a major factor in this experiment. Other indices that define the land surface characteristics are the soil texture and soil color. A full description of the CLM3 and Cam3 can be obtained from 'The Technical Description of the Community Land Model (CLM)- Ncar Technical Note /Ncar TN-461 +STR, 2004" or from the CCSM website.

2.2 Methodology

The first step in this experiment is to find out how well the CAM3 model captures the temporal and spatial distribution of rainfall in the basin. To this end 15 stations monthly mean (observed) rainfall data in the Congo basin was plotted against the CAM3 simulated rainfall. The observed data was collected by Sharon Nicholson **(NCAR Data Support Section-1982-**Monthly African rainfall data)

The model overestimates the mean monthly precipitation for the 20 year period 1979-1988 when compared to the mean of observations from the 15 stations within the basin. The model however reproduces the seasonal variations of precipitation and more noticeably the bi-modal pattern of the equatorial region precipitation (figure 1). The overestimation of mean monthly rainfall by CAM3 is also visible in the spatial comparison between the observed (TRMM-GPCP-v2-Combined) MAM, JJA and OND and the model generated counterparts (Figures 2-7).

Statistical analysis of the spatial and temporal distribution of rainfall in the basin using Empirical Orthogonal Functions (EOFs) indicates a latitudinal shift in rainfall intensity in phase with the Inter-tropical Convergence Zone (figures8 & 9). The first mode explains 55 percent of the rainfall variability and is indicative of the predominance of the annual circle over any other phenomena in the rainfall pattern. The second mode (Figure 3) explains 13% of the variability and depicts a periodicity of roughly 3 years.

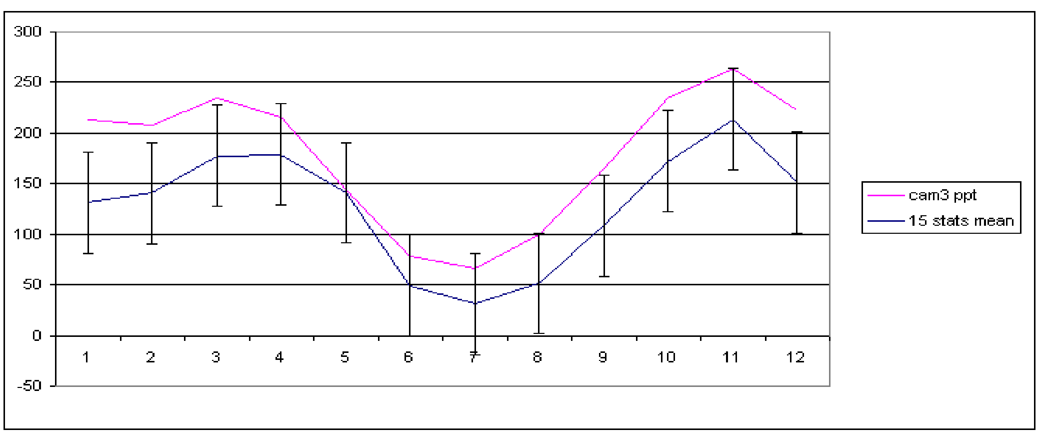


Figure 1. Seasonal variation of rainfall in the Congo Basin (model versus observation)

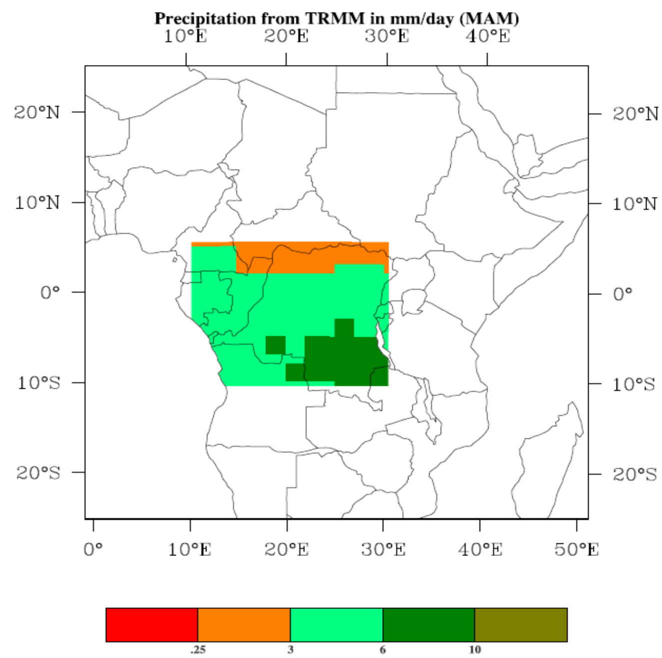


Figure 2. Global Monthly Merged precipitation (MAM) from the Global Precipitation Climatology Project (GPCP –v2-Combined)

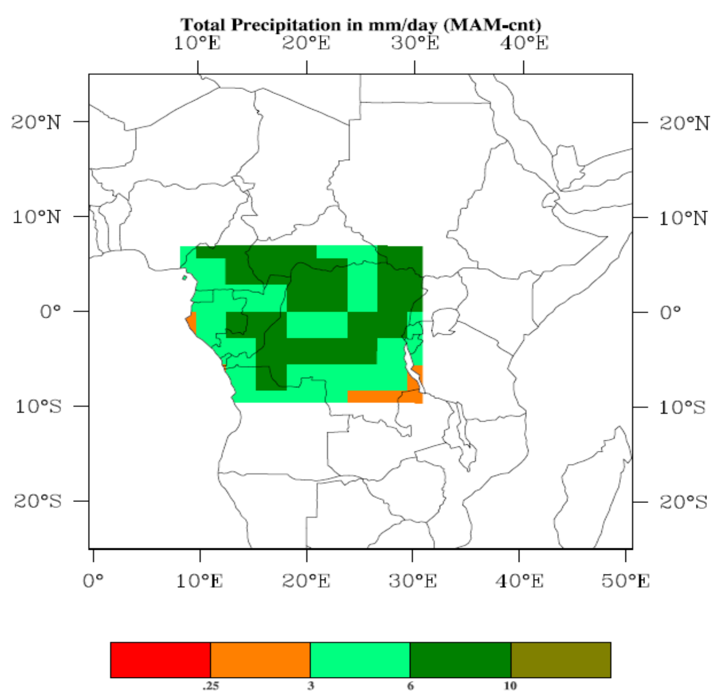


Figure 3. Cam3 (MAM) simulated precipitation

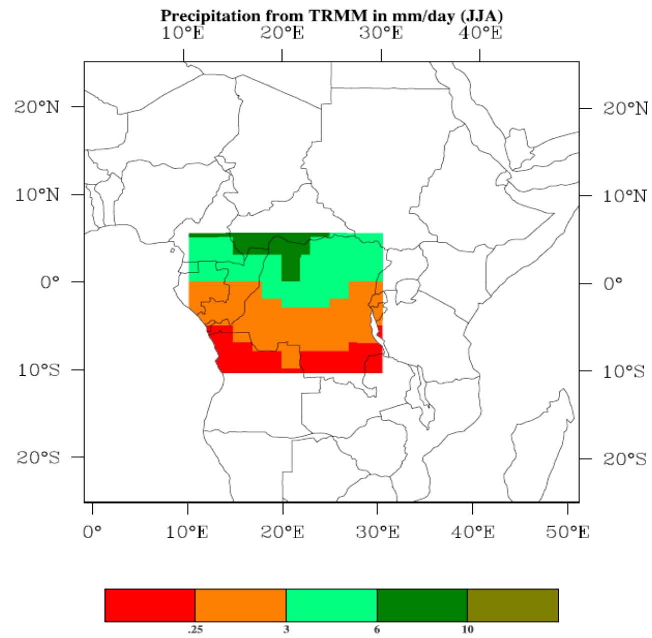


Figure 4. Global Monthly Merged precipitation (JJA) from the Global Precipitation Climatology Project (GPCP –v2-Combined)

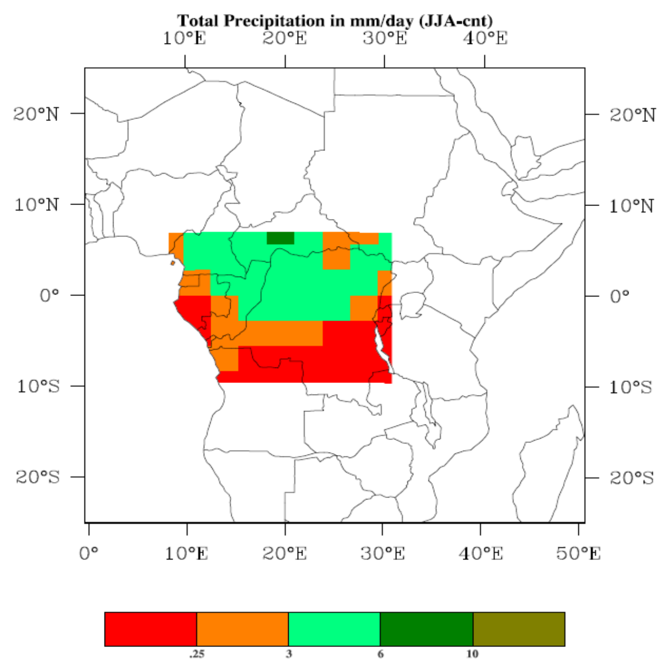


Figure 5. Cam3 (JJA) simulated precipitation

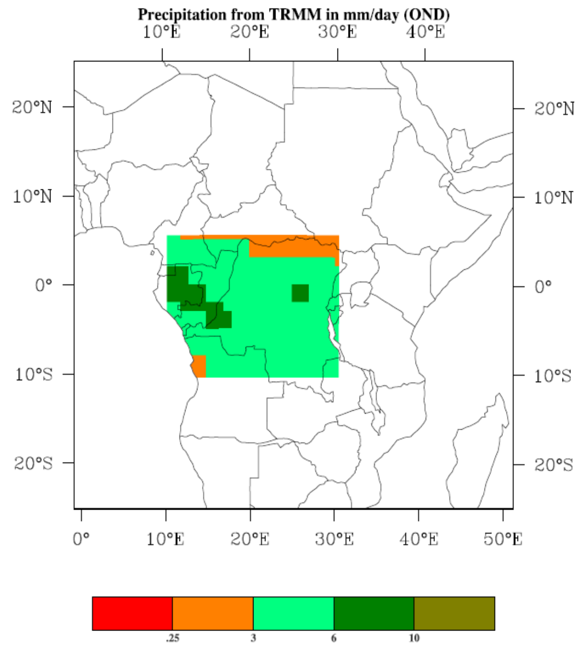


Figure 6. Global Monthly Merged precipitation (OND) from the Global Precipitation Climatology Project (GPCP –v2-Combined

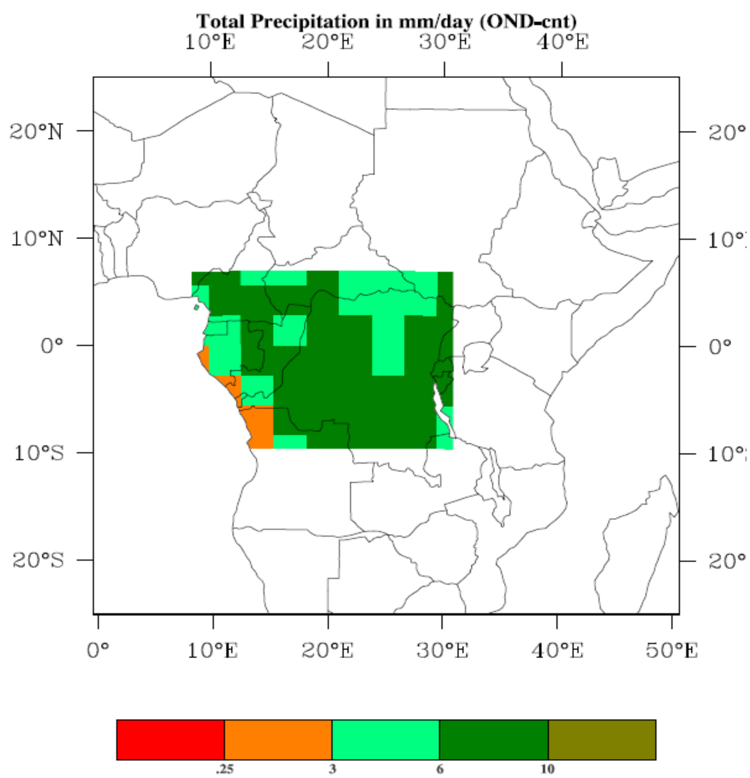
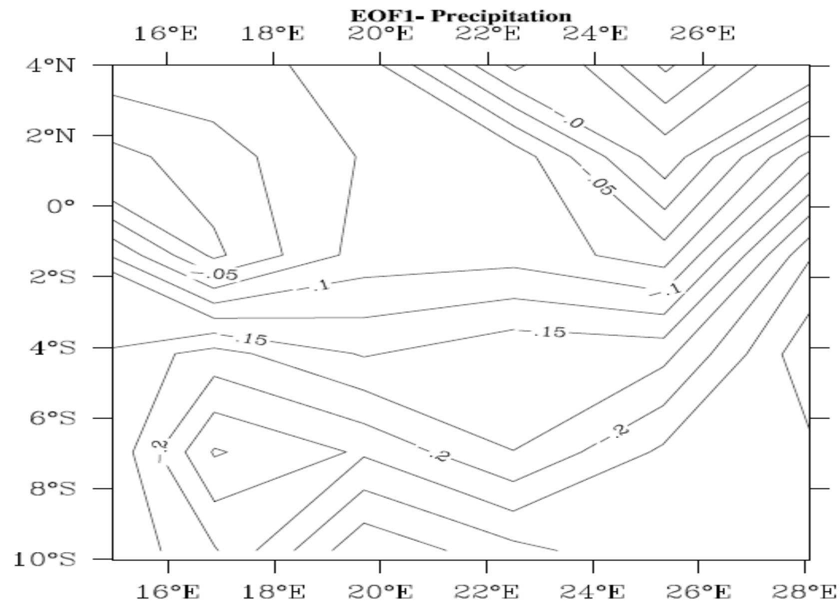
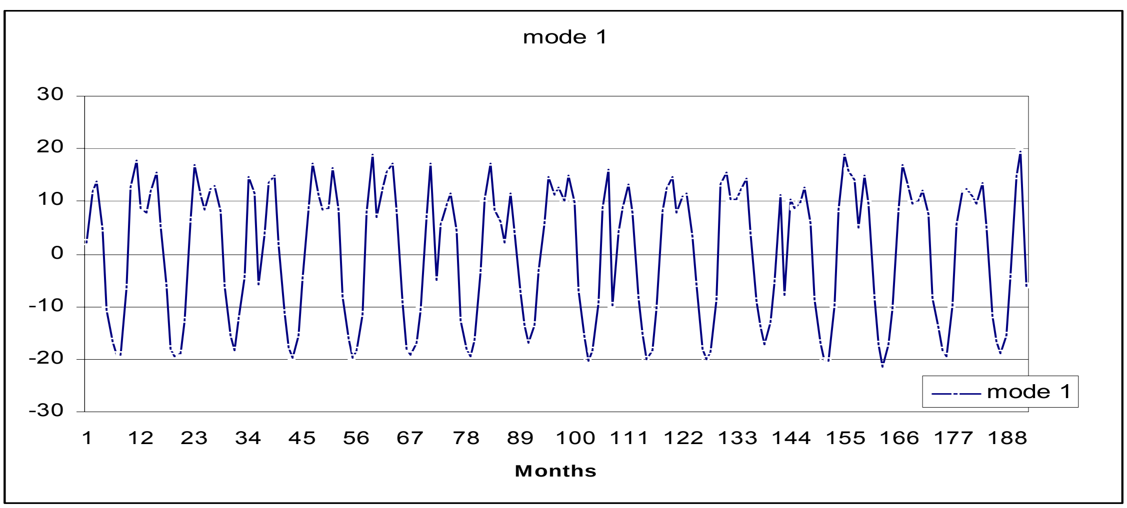


Figure 7. Cam3 (OND) simulated precipitation

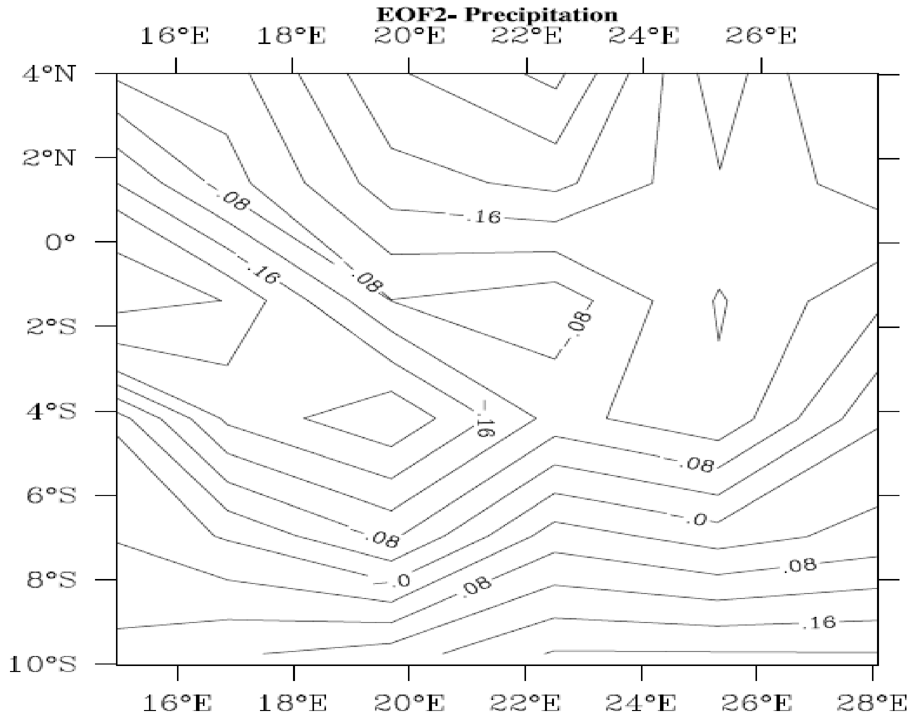


(a)

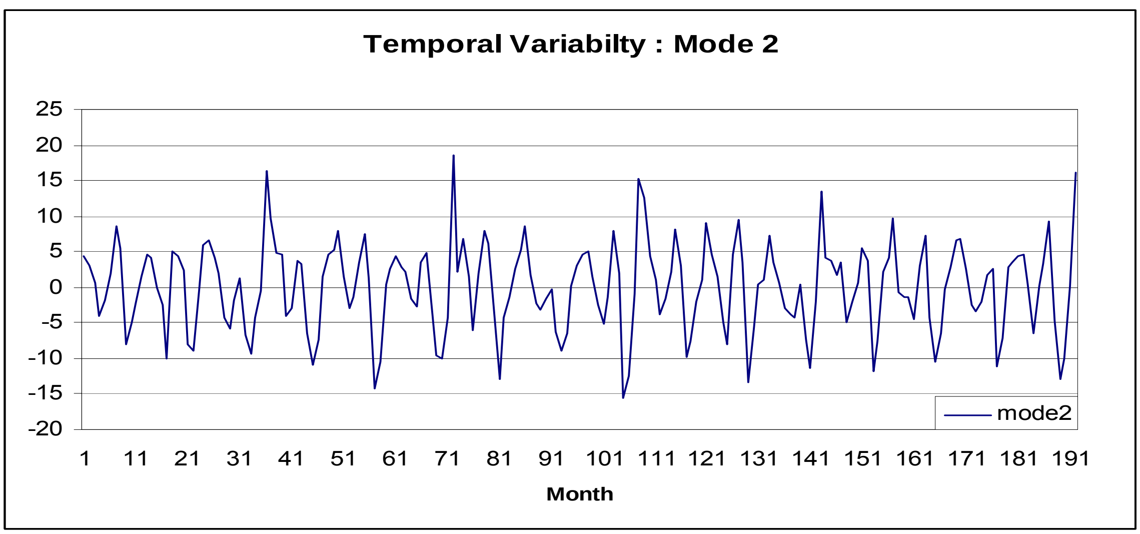


(b)

Figure 8. Spatial (a) and Temporal (b) distribution of the mode 1 (EOF's) for Congo Basin Cam3 PPT



(a)



(b)

Figure 9. Spatial (a) and Temporal (b) distribution of the mode 2 (EOF's) for Congo Basin Cam3 PPT

Experiments on the impact of deforestation of the Congo Basin on climatic parameters like precipitation, evaporation, river runoff etc. were performed by simulating three different scenarios, namely, high, medium and low deforestation

2.1. EXPERIMENT 1 (High Deforestation)

In this experiment the current (control) plant functional type using the International Geosphere-Bisophere Program's (IGBP) specifications is configured in the CLM3 as 44.5% broadleaf evergreen tropical trees, 14.4% Broadleaf deciduous tropical trees, 15% C3 Non-Arctic grass, 24% C4 grass, 1.7% corn and 12% Non-Vegetation (Figure 10). In the experiment this is altered to 96 % C4 grass, 2% C13 grass, 1 % corn and 1% broadleaf evergreen tropical trees (Figure 12) to mimic a long term permanent change of plant functional type and hence a change in the ecosystem of the Congo basin. The percentage of the vegetated portion of the grids occupied by the various plant functions types are shown in Figure 11 for the control case and Figure 13 for the highly deforested case. The effect of this change on the temporal distribution of precipitation and other parameters is shown in Figures 14-17. Student's t (distribution) test indicates the decrease in precipitation after high deforestation to be significant at the 95% confidence level. This is only a crude and provisional estimate of statistical significance since some of the assumptions in this test (e.g equal variance in the ensemble) are not strictly applicable to this experiment.

The runoff analysis includes comparison with results from the NASA/GISS model and the use of NCEP re-analysis data (Figure 19).

2.2. EXPERIMENT 2 (Medium Deforestation)

In this scenario the broadleaf deciduous tropical trees was completely wiped out but the evergreen was slightly reduced to 40% while the C4 grass, non-arctic grass and corn now covered 57%, 2% and 1% of the land surface respectively.

2.3. EXPERIMENT 3 (Low deforestation)

This scenario assumes almost equal size of land surface covered by the evergreen tropical trees, evergreen deciduous trees, C4 grass and c3 non arctic grass type i.e. at 25 % each.

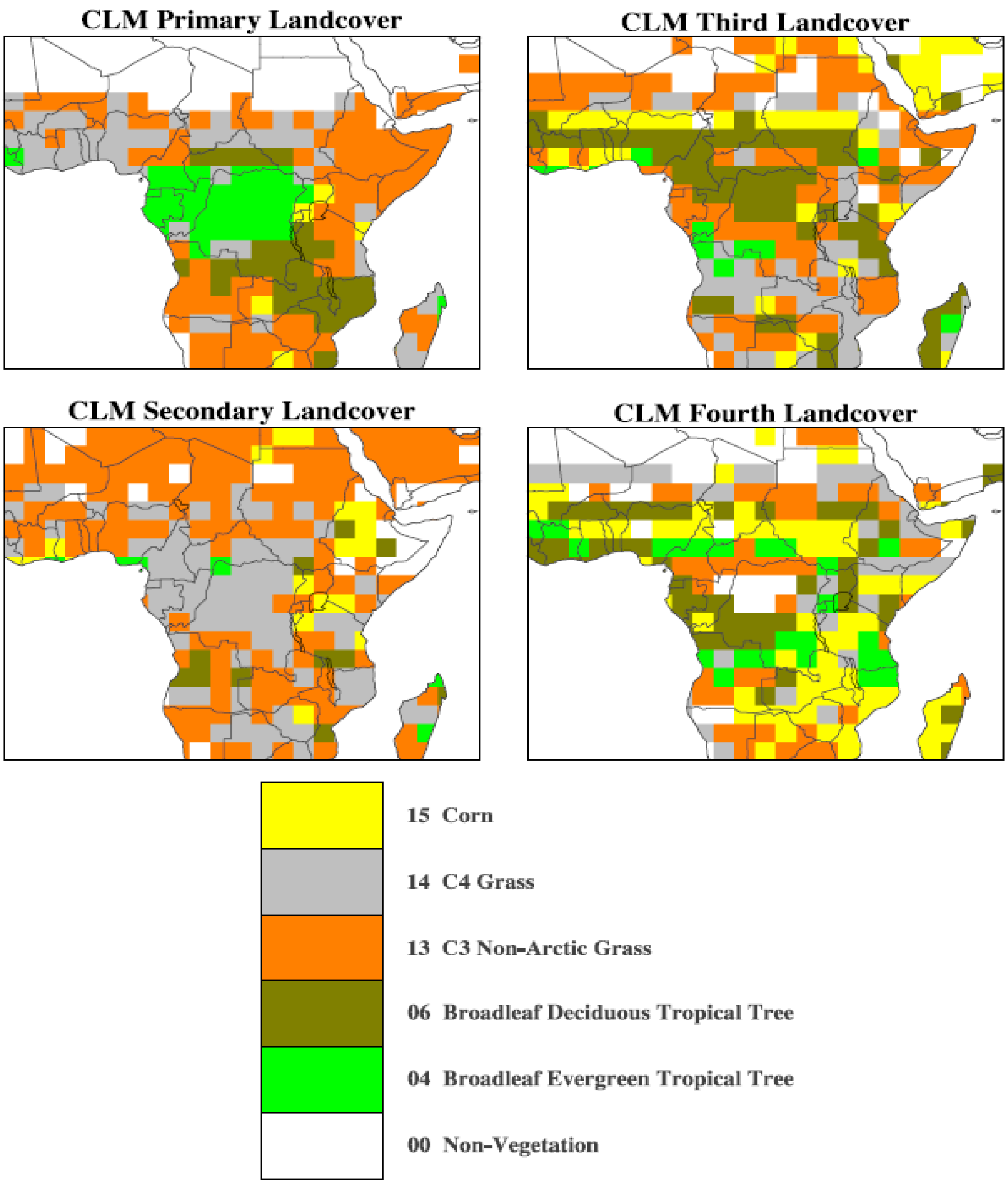


Figure 10. Current configuration of the plant functional type over the Congo Basin- IGBP specifications

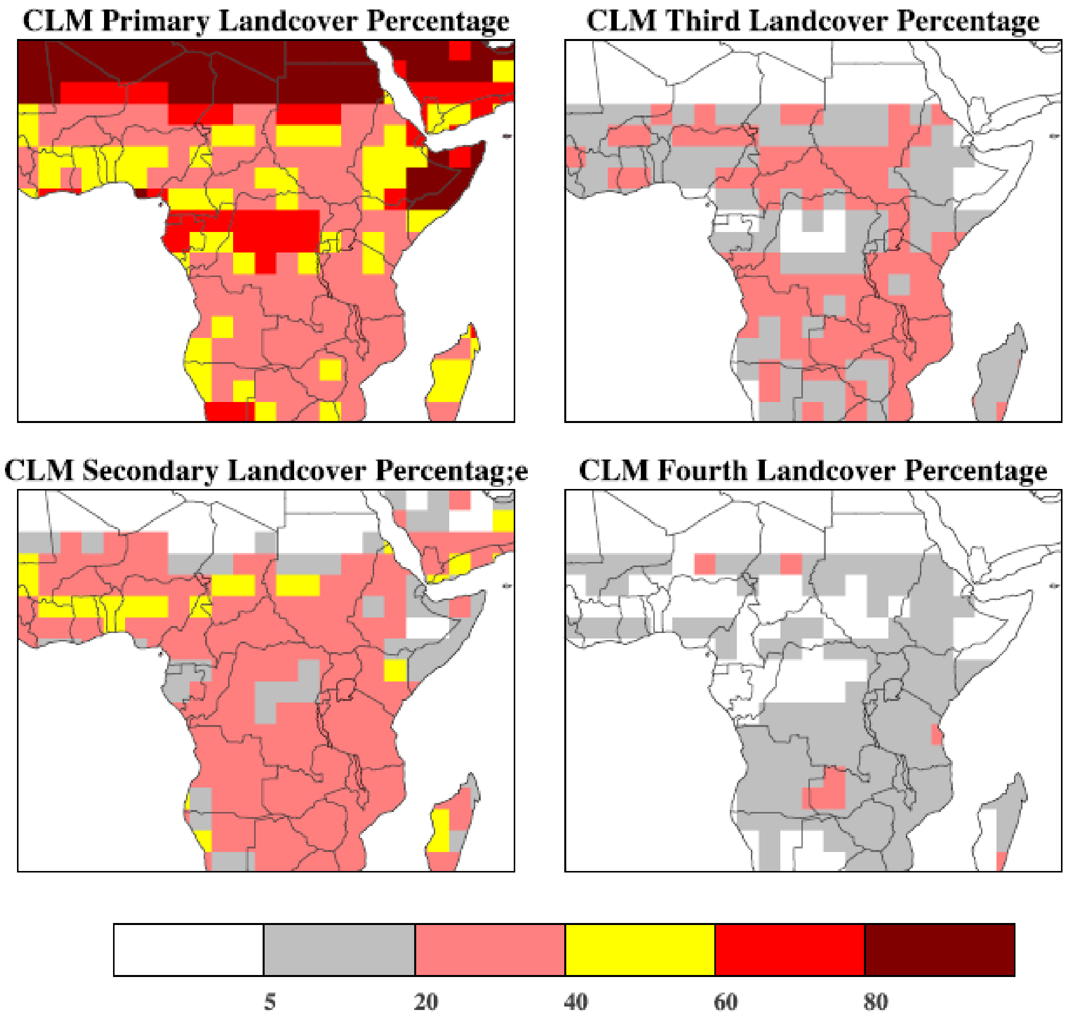


Figure 11. Percentage of the vegetated portion of the grid covered by the 4 plant functional types

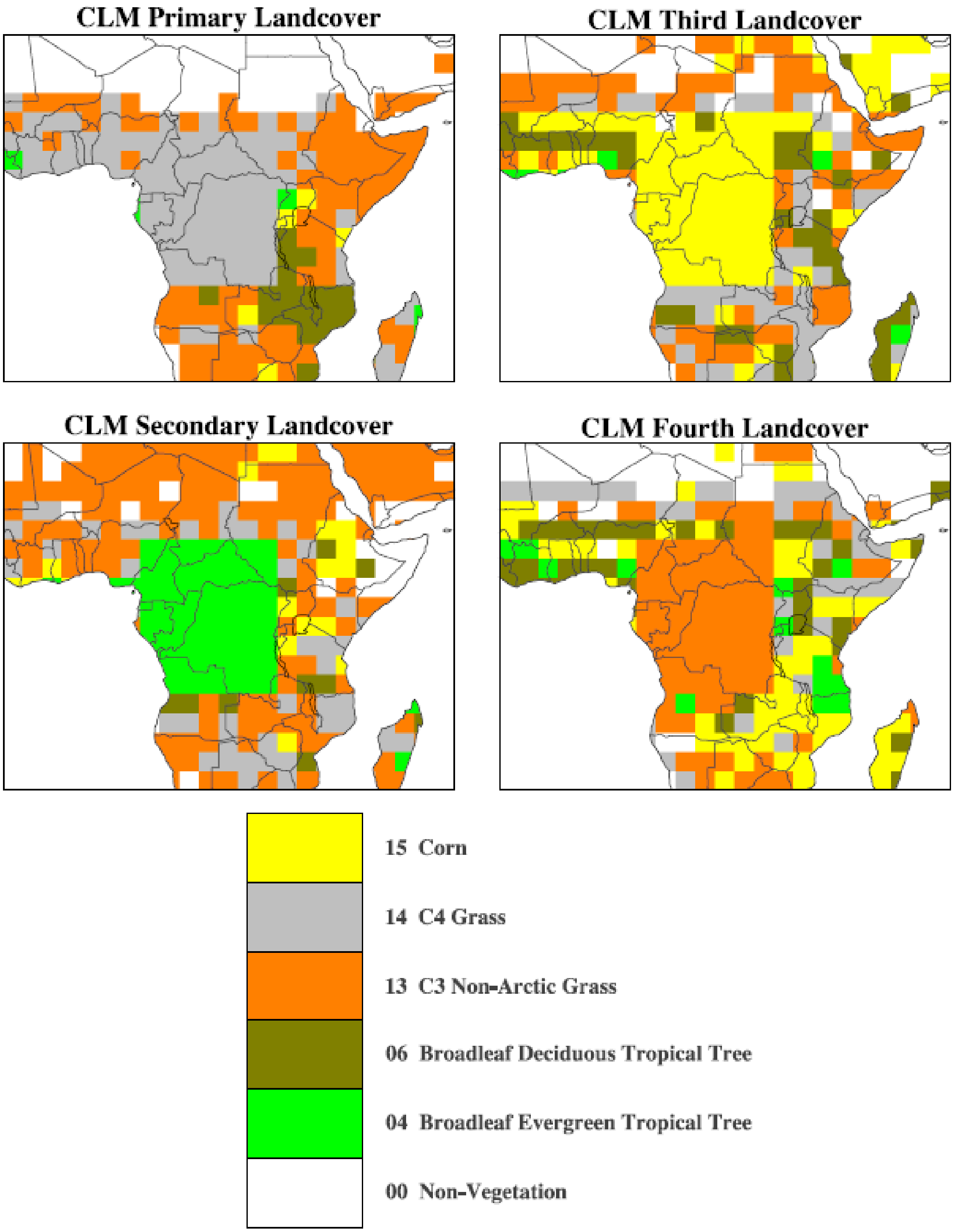


Figure 12. Reconfigured plant functional types mimicking high deforestation.

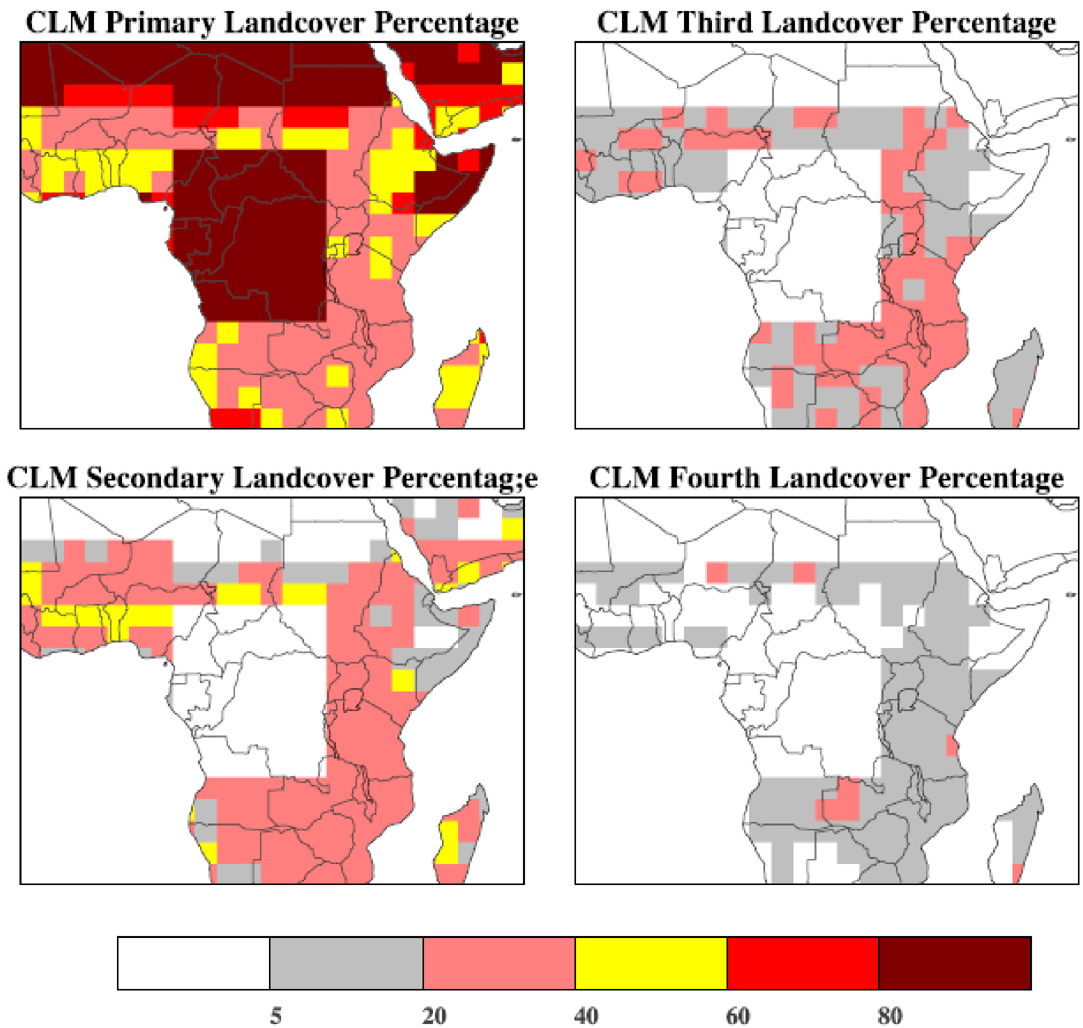


Figure 13. Percentage of the vegetated portion of the grid covered by the 4 plant functional types in the high deforestation experiment

3. The impact of deforestation (i.e. experiment 1) on various climatic parameters.

(i) **Precipitation**

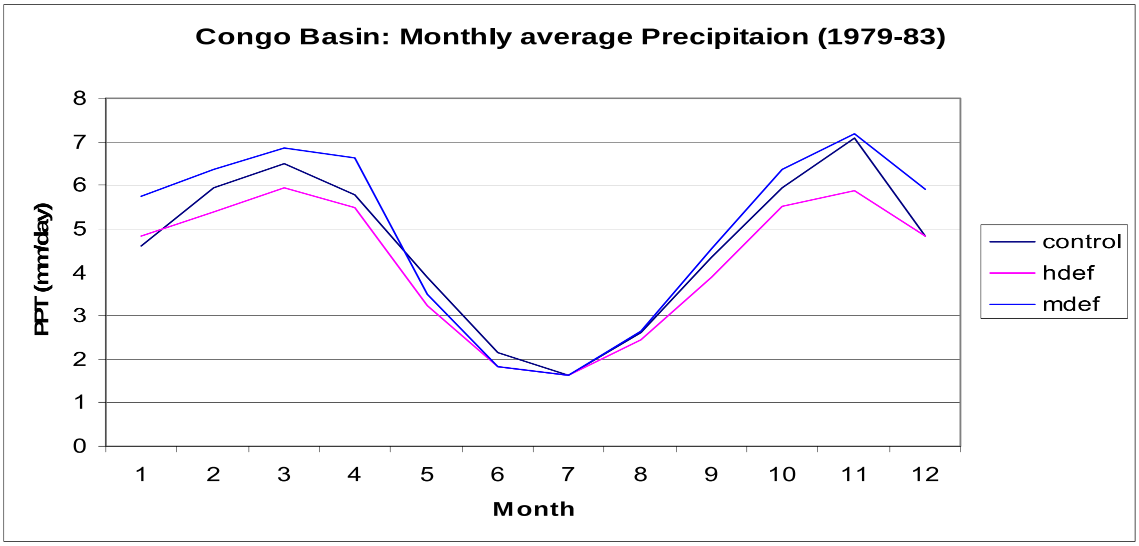


Figure 14. River Congo precipitation simulated by the Cam3 module under the control, high and medium deforestation (hdef->high deforestation; mdef->medium deforestation)

(ii) Evapotranspiration

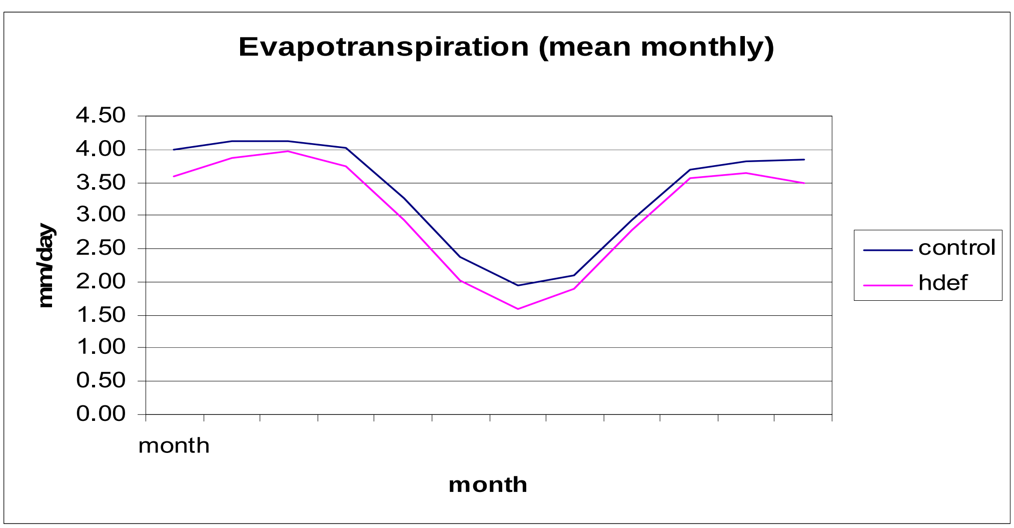


Figure 15. Cam3 simulation of evapotranspiration-monthly average values (1979-1983)

(iii) Sensible heat flux

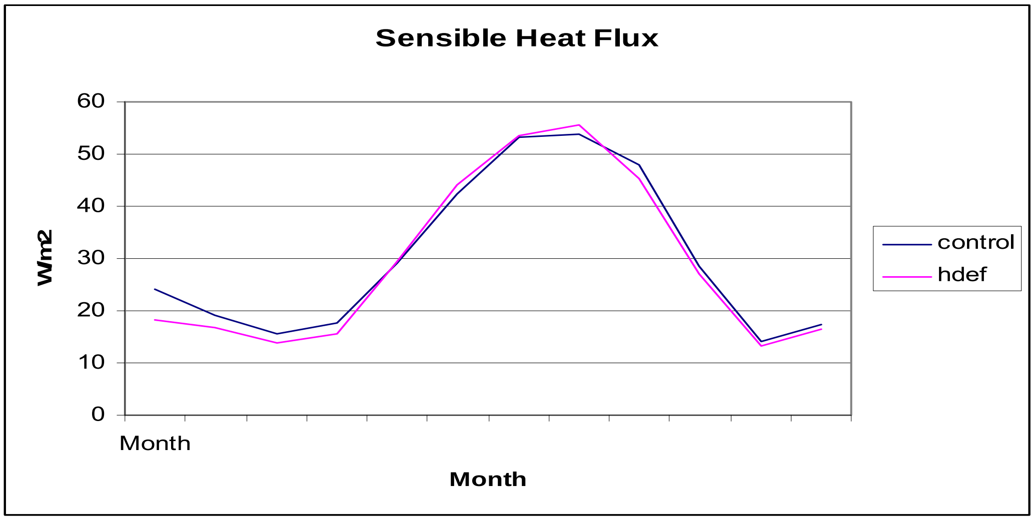


Figure 16. Cam3 simulation of sensible heat flux-monthly average values (1979-1983)

(iv) Latent heat flux

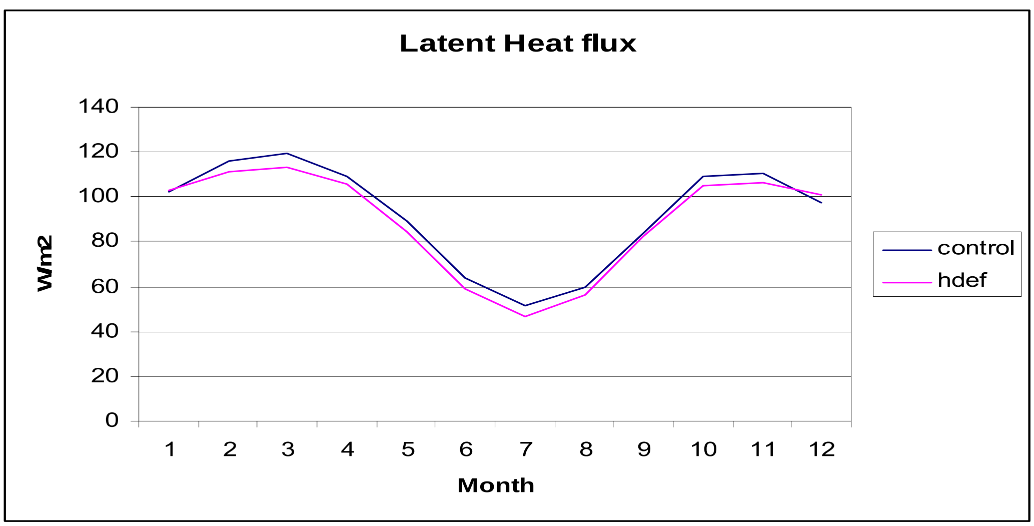


Figure 17. Cam3 simulation of Latent heat flux-monthly average values (1979-1983)

3.1. Simulation of the River Congo Runoff using Cam3/Clm3 coupled model

Runoff simulations using the coupled Cam3/Clm3 models for the station shown in Figure 18 are as plotted in Figure 19.

The River Transfer Module (RTM) highly over estimates the discharge (by up to a factor of 3) during the rainfall months of March-May (MAM) and almost doubles the discharge during the other rainfall period of OND. It underestimates the runoff during the drier months of JJA. Considering its size as the second largest river in the world (after Amazon) in terms of water yield) it is important that the rate of its freshwater discharge into the Ocean be correctly modeled if its impact on the coastal ocean water properties e.g salinity, temperature, density etc and hence on the local ocean-land -atmosphere interactions is to be correctly determined.

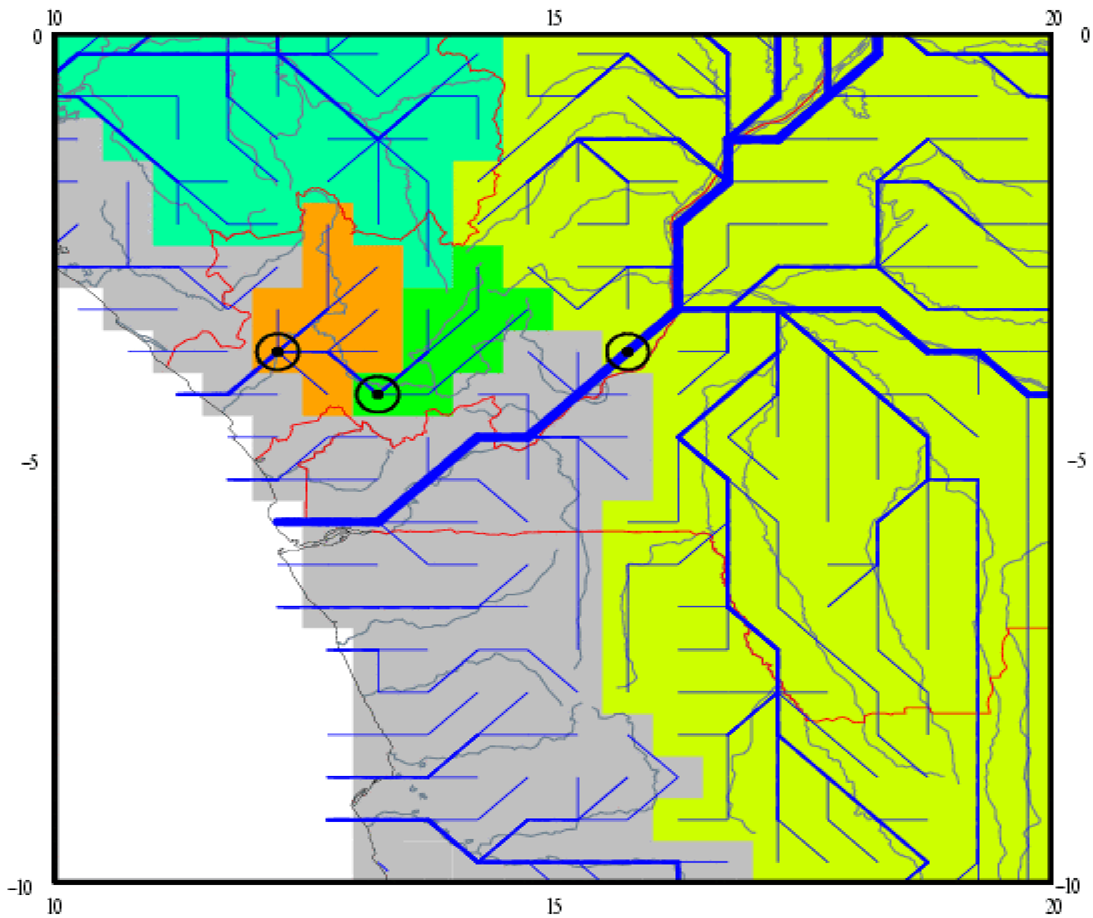


Figure 18. Congo River- gauging station located at Kinshasha (4.3^0 S,15^0 E)- from Global Runoff Data Center.

(i) **River Runoff**

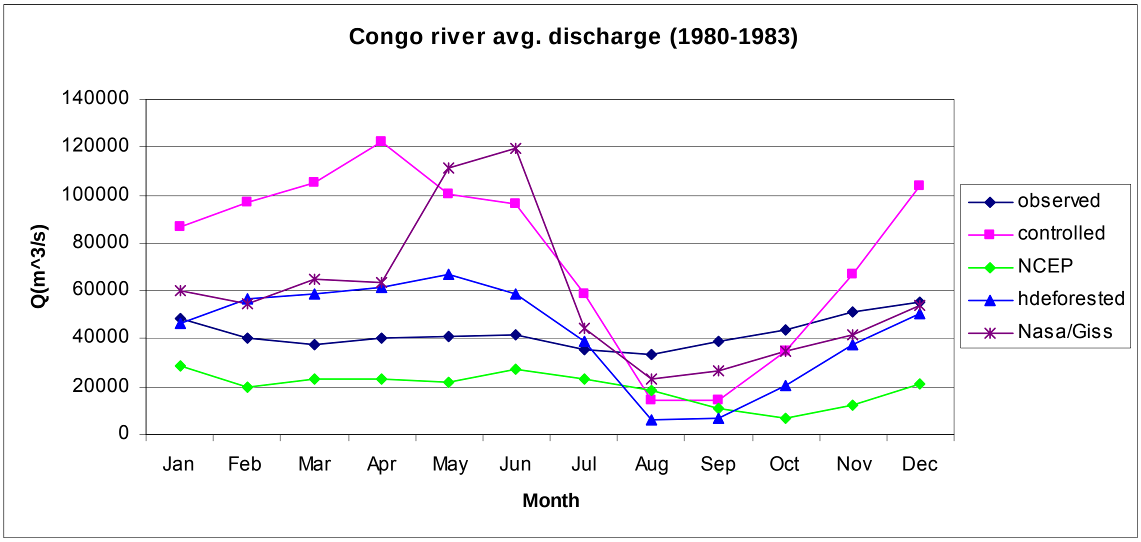


Figure 19. River Congo discharge curves for the Cam3/Clm3 control run, Cam3/Clm3 highly deforested scenario, NCEP data (offline Clm3run), Nasa,/Giss Model and observations data from the International Research Institute (IRI)

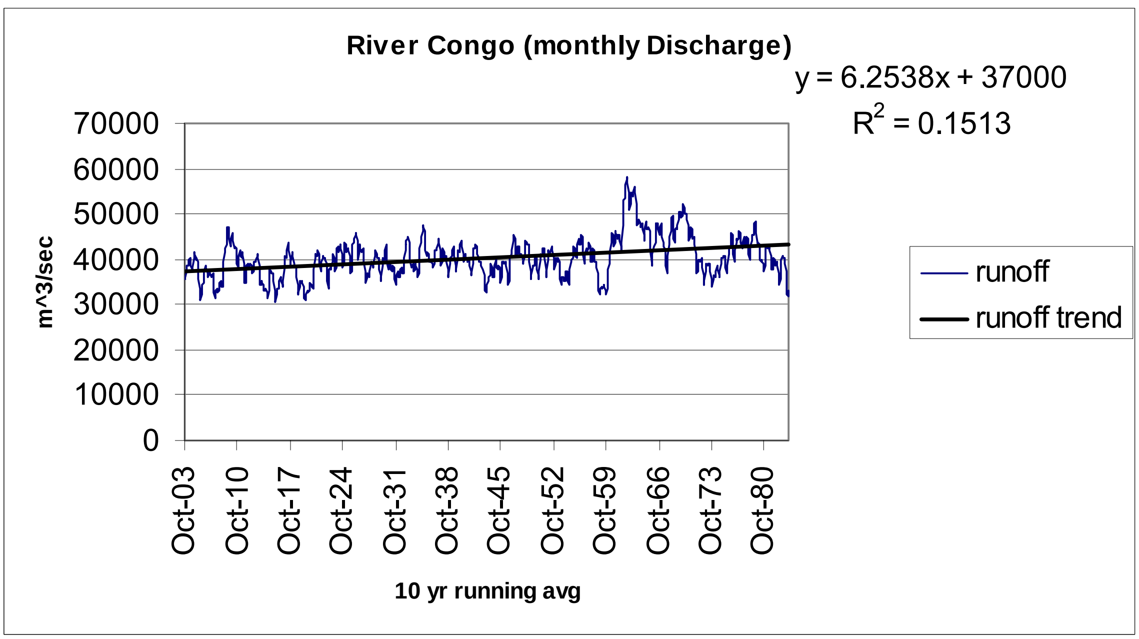


Figure 20. Time series runoff data (1903-1980) – Data obtained from Institute of International Climate Research (IRI).

Errors in the calculation of freshwater inflows into the ocean are subsequently transferred to other parameters through the ocean module coupling.

A water balance study of the Congo Basin using a 5 year period precipitation and evapotranspiration simulation from Cam3 leads to an average runoff/discharge (about 40E3 m3/s) that closely approximates to the average of the observed time series runoff data, 1903-1980, (figure 20) obtained from the Institute of International Climate Research (IRI). The realization of a balance between model precipitation, evaporation and observed runoff data calls for further investigation into the performance of the RTM in this particular watershed. An offline run of the CLM3 using the NCEP-reanalysis data results in a better simulation of the runoff variability even though it underestimates the river discharge (figure 19).

. The terrestrial water balance is given by the equation

$$S = P - E - Ro - Rs \qquad (1)$$

Where

S= rate of storage of water

P= precipitation rate

E = Evaporation rate (includes evapotranspiration over land and sublimation over snow and ice)

Ro = Surface runoff

Rs = Subterranean runoff

For a large region like the Congo basin the net subterranean runoff is usually small and can be neglected to simplify the equation to the form

$$\{\overline{S}\} = \{\overline{P} - \overline{E}\} - \{\overline{Ro}\}, \qquad (2)$$

where the parenthesis { } and the bar (¯) indicate the spatial average values of the parameters over the whole region and a time average respectively. Over long periods of time and in large areas S becomes small in comparison to other terms and hence the equation reduces to

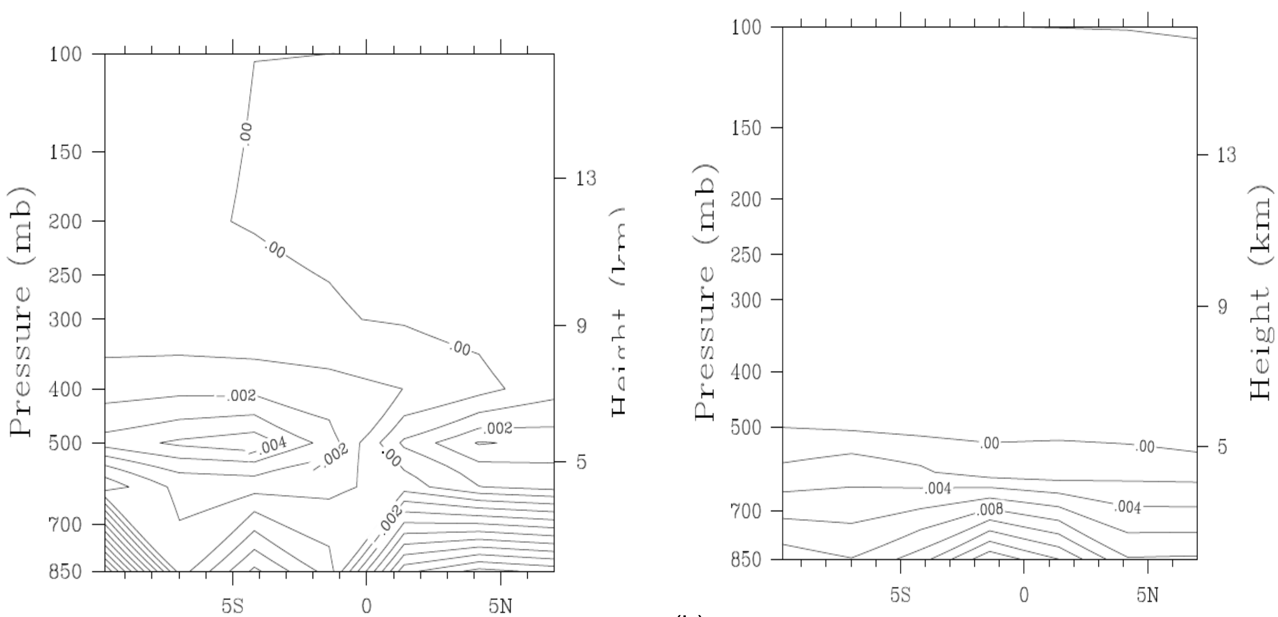
$$\{\overline{Ro}\} = \{\overline{P} - \overline{E}\} \qquad (3)$$

The model results for the right hand parameters of equation 3 for the 5 year period 1979-1983 are in good agreement with the observed values of runoff, Ro.

4. Perturbations in the Atmosphere

4.1. Vapor Transport

A contour plot of the meridional transport of water vapor (Figure 21) indicate a northward transfer of water vapor (from the oceans) during the drier months of JJA and a reversal of the flow (at a reduced magnitudes) during the wetter OND season. This is consistent with the theory of divergence and convergence of water vapor to balance the budget of the atmospheric portion of the hydrological cycle



(a) (b)

Figure 21. Meridional water vapor transport for (a) OND and (b) JJA

4.2. Dynamical theory of Monsoonal Circulations in the tropics

The dynamical theories of thermally direct, zonally symmetrical circulations in the tropical atmosphere has been studied by various researchers including Held and Hou (1980), Lindzen and Hou (1988), Plumb and Hou (1992), and Emmanuel et al (1994). A summary of their findings is that below a certain threshold value of thermal forcing the atmosphere maintains a steady state of thermal equilibrium with no meridional flow. Beyond this threshold value of thermal forcing the equilibrium breaks down and a meridional circulation is initiated. The subtropical thermal forcing can be distinctively described for dry and moist atmospheres. Plumb and Hou (1992) described it for a dry atmosphere by specifying the distribution of equilibrium temperature. For a moist atmosphere Eltahir and Ngong (1996) a quasi–equilibrium balance between moist convection and large scale radiative forcing and hence a uniform vertical distribution of saturation entropy is assumed. The moist atmosphere assumption is even more appropriate for the Congo Basin relative to the Sahel region and is therefore used in this study. Depending on the distribution of entropy, either of two possible regimes may dominate the dynamics of tropical atmosphere: a radiative-convective equilibrium regime or an angular momentum conserving regime (Plumb and Hou 1992).

The thermal wind can be expressed by (for a zonally symmetric atmosphere)

$$\frac{\partial u}{\partial p} = \frac{1}{f}\frac{\partial \alpha}{\partial y}, \qquad (1)$$

where u is zonal wind and p is pressure, f is the coriolis parameter, α is specific volume and y is the meridional distance. Using Maxwell's theory we have

$$\left(\frac{\partial \alpha}{\partial y}\right) = \left(\frac{\partial \alpha}{\partial s}\right)_p \frac{\partial s*}{\partial y} = \left(\frac{\partial T}{\partial p}\right)_{S*} \frac{\partial s*}{\partial y} \qquad (2)$$

where s* is saturation entropy and is given by s* = $C_p \ln(\theta_{e^*})$. Cp is the specific heat capacity at constant pressure and θ_{e^*} is the equivalent potential temperature of air saturated at the same pressure and temperature. Integrating eqn. (1) from the surface (u=zero) to the tropopause under the assumption of a moist adiabatic lapse rate we have

$$u_t = -\frac{1}{f}\left(T_o - T_t\right)\frac{\partial s_b}{\partial y}, \qquad (3)$$

where u_t and T_t are wind and temperature at the tropopause, T_o is the surface temperature and s_b (~s*) is the boundary layer entropy.

The absolute vorticity at the tropopause is given by

$$\eta_t = f - \left(\frac{\partial u_t}{\partial y}\right) \qquad (4)$$

$$\text{->}\ \eta_t = f + \frac{\partial}{\partial y}\left(\frac{1}{f}\left(T_0 - T_t\right)\frac{\partial s_b}{\partial y}\right) \qquad (5)$$

Equation (5) indicates the relationship between absolute vorticity at the tropopause and the meridional distribution of boundary layer entropy. The distribution of entropy will thus dictate which of the two possible regimes will dominate the tropical atmosphere. Either a radiative –convective equilibrium regime or an angular momentum conserving regime (Plumb and Hou, 1992) will prevail depending on the sign of the absolute vorticity in relation to the coriolis parameter. A radiative-convective equilibrium regime should prevail if the absolute vorticity at the tropopause has the same sign as the coriolis parameter f. This condition implies

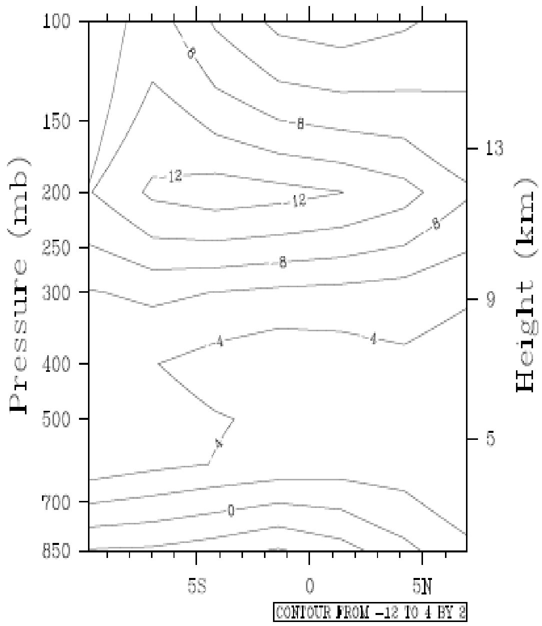
$$1 + \frac{1}{f^2}\frac{\partial}{\partial y}\left((T_0 - T_t)\frac{\partial S_b}{\partial y}\right) - \frac{\beta}{f^3}(T_0 - T_t)\frac{\partial S_b}{\partial y} > 0 \qquad (6)$$

where β is $\partial f / \partial y$. This derivation assumes a geostrophic wind approximation (not very appropriate for near equatorial regions. Under the assumption of a gradient wind balance a similar set of equations can be derived i.e.

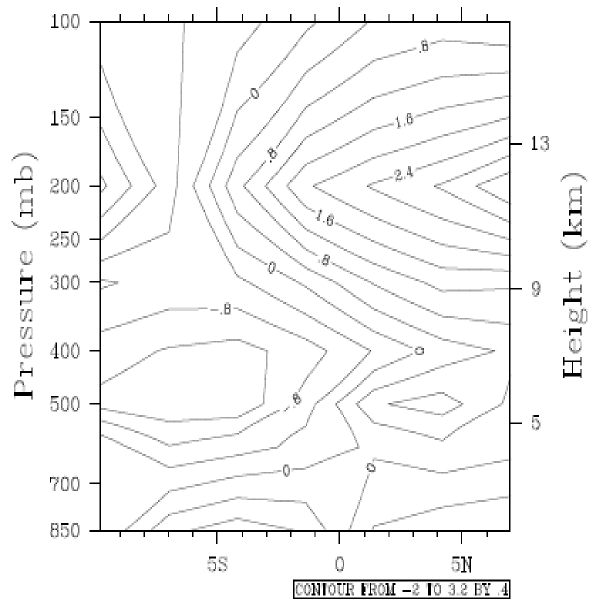
$$\left(\frac{\partial}{\partial \varphi}\left[\frac{\cos^3\varphi}{\sin\varphi}\left(T_0 - T_t\right)\frac{\partial S_b}{\partial \varphi}\right]\right) + 4\Omega^2 a^2 \cos^3\varphi \sin\varphi > 0, \qquad (7)$$

where φ is latitude and Ω is the angular velocity of the earth. When the absolute vorticity gets close to zero or when condition (6) or (7) is violated then the angular momentum conserving regime is predominant and a meridional (monsoon) circulation is initiated.

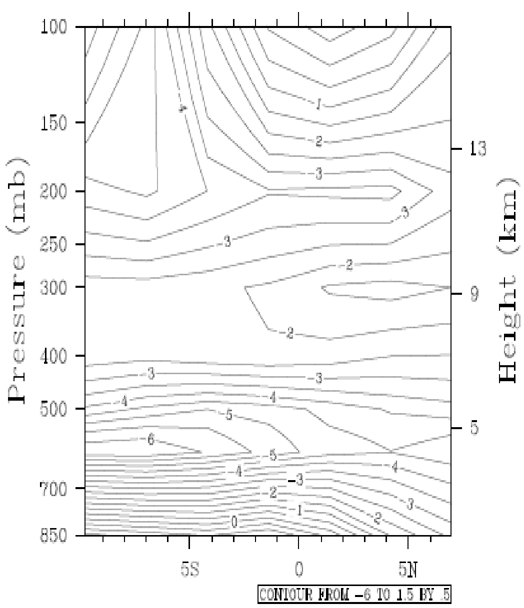
Equation (6) indicates that the gradient and the second derivative of the meridional distribution of boundary-layer entropy control the threshold levels which trigger the monsoonal circulation. A zero absolute vorticity in the upper troposphere is therefore indicative of the presence of monsoon circulation. If this theory holds then the monsoon type of circulation over the Congo Basin should be sensitive to natural or anthropogenic perturbations (e.g. deforestation) that may impact the meridional gradient of boundary layer entropy. A comparison of the OND zonal and meridional wind velocities for the relatively wetter 1980 and drier 1981 is shown in Figure 22 below. The zonal wind at the upper levels (about 200mb) is seen to be stronger for the wetter year (1980) than for the drier year(1981). The differences in meridional wind velocities between the two years are harder to detect but a keen observation reveals that the wind velocity contours are slightly more packed in the case of the wetter year



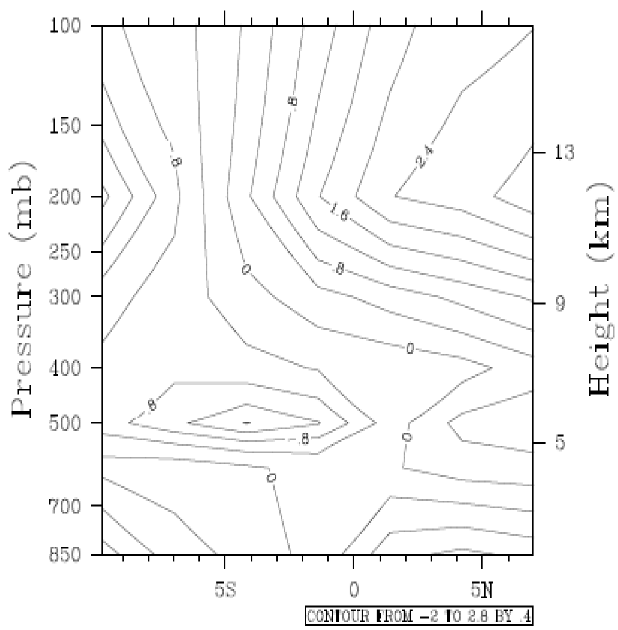
(a)



(b)



(c)



(d)

Figure 22. Average wind velocity (m/s) for OND at the 20^0E meridional cross section (a) zonal velocity for 1980, (b) meridional velocity for 1980, (c) zonal velocity for 1981 and (d) meridional velocity for 1981

4.3. Factors that influence the boundary Layer Entropy

Several factors and phenomena over land, ocean and the atmosphere can have some influence on the meridional gradient of boundary layer entropy. For coastal locations like the Congo Basin, the entropy fluxes from both the ocean and land surfaces can play very significant roles in modifying the boundary layer entropy via various physical processes like convective cloud formation, radiative cooling, variability in sea surface temperature (SST) and land cover changes Eltahir and Gong (1996) proposed a land-atmosphere-ocean interaction (Figure 23) using the arguments from the dynamic theory discussed in section 4.2 which graphically sums the concept of the theory. Barring dramatic changes in the other factors that influence the meridional gradient of boundary layer entropy, the interplay between the influences of SST and land cover changes on precipitation is as summarized in Figure 24

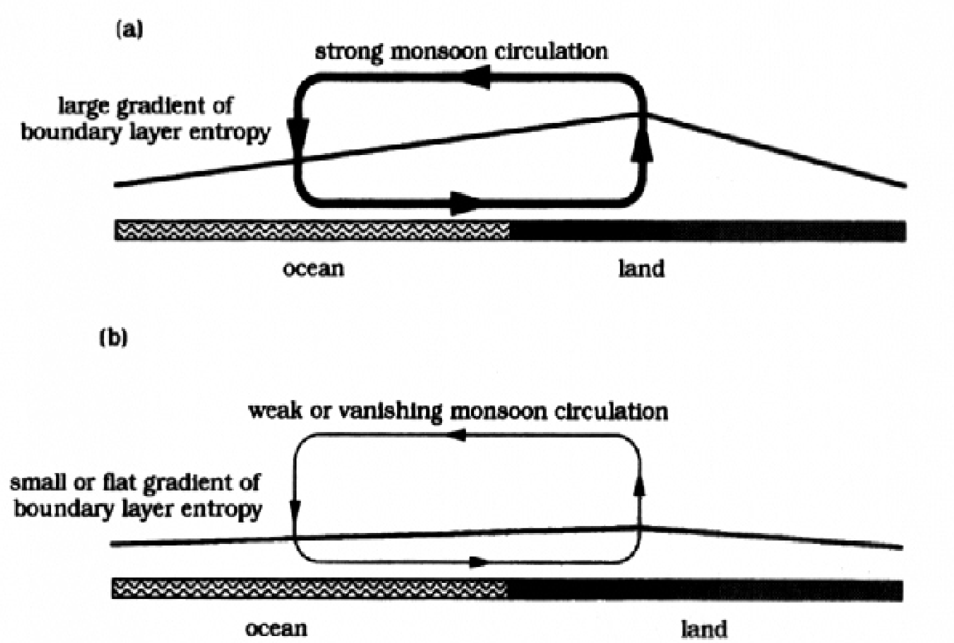


Figure 23. Schematic of the proposed land –atmosphere –ocean interaction over West Africa (Eltahir and Gong-1996)

5. Discussion and Conclusions

This study has re-emphasized the already known couplings between the land, ocean and atmospheric processes that influence climate in any region of the globe. The Community Climate System of Models (CCSM) is therefore a very useful tool in the analysis of these interactions because of its modular structure that allow coupling of the various earth system processes.

However there is need for continued fine tuning of the model to accurately simulate some of the major climatic parameters e.g. rainfall in the tropics. Even though the CCSM does a good job in simulating the magnitude and seasonal variation of Congo Basin precipitation, there is room for improvement in the spatial distribution of precipitation and more accuracy in the high rainfall months of OND and MAM. River runoff simulation is not to the acceptable level (despite the mitigating factor of low model resolution) yet and the weak point seems to be the River Transfer Model (RTM) embedded in the CLM3, since the water balance (budget) study for the 5 year period (1979-1983) is in close agreement with the observed runoff.

Though model simulations indicate reduction of precipitation with increasing deforestation the observations do not indicate any significant feedbacks. Possible explanations include the fact that deforestation has mostly been on the peripheral boundaries of the basin and not as idealistic as in the experiment. Another possibility is the stabilizing effect of the atmospheric dynamical theory explained in section 4.2 which hypothesizes that the monsoons are strengthened or weakened by any perturbations (natural or anthropogenic) that influence the boundary layer entropy. Improved understanding and simulation of the hydroclimatic parameters of large basins like the Congo hinge on further modifications of the global circulation models like the CCSM both in terms of model resolution and parameterization schemes. Such modifications will result in model outputs that will be very useful in decision making and policy formulations in the management of water resources for such large basins

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