IMPORTANCE OF THE TROPICAL RAIN FOREST AS AN ATMOSPHERIC MOISTURE SOURCE

B A MONTENY

O.R.S.T.O.M. - Bioclimatology,
Ecologie Végétale, Faculté des Sciences, Université de Paris XI, 91405 ORSAY, France

ABSTRACT

This paper is part of a study on land surface processes at the forest-atmosphere interface. Tropical forests evapotranspirations were calculated knowing the solar energy and rain distributions, soil water storage and the plant characteristics. Atmospheric water vapor originating from these forests are found to be 60 to 75 % of the total rainfall. The recycling of water evaporated from the tropical forest is very important : water vapour is driven northward by southwesterlies inside the continent where it is then reprecipitated.
Deforestation, on a large scale, has induced modifications in the global land surface processes: more sensible heat is transferred to the atmosphere due to the evolution of the physical and biological characteristics of the soil-plant interface.

Keywords: tropical rain forest, land surface processes, energy exchanges, evapotranspiration rates, water budget, deforestation.

1. INTRODUCTION

Tropical rain forests, generally located around the equator in relation to oceanic and orographic effects, are characterized by heavy rains (1600 to 3000 mm per year), high humidity and an average temperature of 26°C. At the present time, these land surfaces are continuously being deforested for agricultural purpose, in order to feed the increasing human population (mean annual increase : 4%). On the Ivory Coast the deforestation by human activities represents an annual rate of 323,000 ha per year since 1973 (1), or a total of 35% of the Ivorian rain forest area. The geographical situation of the Ivorian tropical rain forest and the sites where this work has been conducted are presented in figure 1.

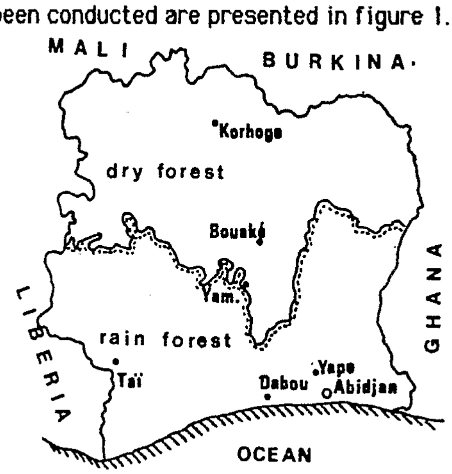

Fig. 1 : Geographical distribution of the tropical rain forest in Ivory Coast and the studied sites in the forest area.

These land surface modifications affect the soil-plant-atmospheric interactions. The land surface processes, which depend on the nature of the surface and their biological characteristics for the equilibrium state, influence such atmospheric parameters as water vapour content and air temperature. In turn, they alter the equilibrium state of the vegetated surfaces.

The first part of this paper presents a short analysis of the land surface processes: radiation budget and energy exchanges at the vegetation-atmosphere interface. From the results obtained on two forested surfaces in the southern part of Ivory Coast, the calculations of the annual water budget gives an estimate of the amount of the rainwater turnover by forest stands and agricultural land surfaces. The discussion is focused on the vegetated surface alterations which introduce some irreversible modifications in the land surface processes and their possible impact on rain in the northern region of West Africa.

2. BASIC FORMULATION

Net radiation Rn is of great importance in the evaluation of radiative land surface characteristics. It is a balance between the incident, reflected and emitted radiations upon a surface and it is written as:

$$Rg - Rr + Ra - Rt = Rn$$

where Rg: total shortwave radiation; Rr: surface reflected shorwave radiation; Ra and Rt: longwave radiation emitted by the sky and the surface respectively. Two terms, Rr and Rt are dependent upon the radiative properties of the biological system and the canopy characteristics. But, in humid tropical areas, variation in the reflected shortwave radiation is the only factor which influences net radiation values (2) for well covered land.

This net absorbed energy, Rn, is partitioned at the interface between different heat transfer processes expressed in the following simplified energy budget:

$$Rn = H + LETR + G \quad Wm^{-2}$$

where H: sensible heat flux; LETR: latent heat flux and G: ground heat flux. Net photosynthesis and stored heat by the forest volume can be neglected. The energy budget-Bowen ratio method was used to partition the available energy between LETR and H in the case of the rubber forest system while Rn and G are measured by a net radiometer and a soil heat fluxmeter respectively (3). In the case of the rain forest, evapotranspiration rate has been measured by the water balance method which is expressed as follow:

$$P - D - R + dS = ETR \quad mm/week$$

where P : precipitation; D: percolation; R : runoff; dS : change in soil moisture storage; ETR actual evapotranspiration rate. Although dew deposition on the canopy leaves is an important water supply during the dry season in the forest region, it was not measured in this study. Changes in the soil moisture storage were measured with a neutron probe (4) in conjunction with P, D, and R measured by classical methods. These povide an estimation of the tropical rain forest evapotranspiration values (ETR).

3. RESULTS AND DISCUSSION

In the tropics, net radiation measurements at a vegetated interface are not usually available even though they are of primary interest. However, based on some measurements, net radiation can be derived from the total solar radiation Rg or sunshine duration which are more readely available. Table I gives the regression relationship obtained between Rg and Rn. Tropical rain forests, rubber and oilpalm forests have higher regression coefficients than all other vegetative surface, most likely due to low reflectivity (Rr/Rg) and weak thermal fluxes (see b values).

TABLE I : Relationship between the solar radiation Rg and the net radiation Rn for different vegetated surfaces at canopies level. (sources of the data are indicated in parantheses).

plant surface	Rr/Rg	Rn = aRg + b ($W.m^{-2}$)			
	%	a	b	r	n
amazonian forest(5)	12	.86	-35		
thailand forest (6)	12	.87	-25	0.99	
Puerto Rico forest(7)	12	.72			
rubber forest (3) (wet air)	14	.72	-0.4	0.98	282
rubber forest(3) (dry air)	14	.78	-50	0.98	113
oil palm forest (8)	13	.71	-22	0.98	135
wet herbaceous surfaces					
Panicum maximum (8)	19	.74	-37	0.98	184
rice (9)	18	.71	-5	0.99	165
Paspalum (8)	20	.66	-6	0.99	155
crop surfaces					
pueraria (8)	22	.66	-3	0.99	141
pineapple (10)	19	.62	4	0.97	
casava: high density	18	.64	-9	0.99	96
low density	18	.66	-18	0.99	96
soil					
bare soil : dry	23	.64	-42	0.98	150
: wet	12	.73	-5	0.97	27
fallow field	21	.58	-36	0.96	42
savana burn soil	9	.54	-42	0.97	26

Figure 2 presents the relations between latent heat fluxes and the net radiation for a rubber forest canopy. The regression coefficient (slope of the relations in fig. 2) varies depending on foliage age and soil water availability. It appears as expected that water vapour exchanges LETR and its evolution are time dependent via the impact of two phenomena: the aging foliage and a strong feedback due to plant reaction to changing climatic and soil factors (11).

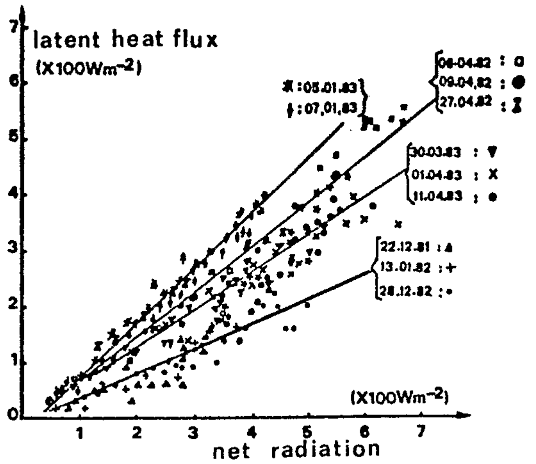

Figure 2 : Relationship between latent heat flux and net radiation for a rubber forest.

In the case of the rain forest, the evapotranspiration rates (ETR) vary from 2 to 6 mm per day, depending on solar energy and stored soil water. An analysis of the layering of the underground forest biomass showed that roots less than 5mm thick are found at 2 to 3 m depth, allowing the trees to extract 160 to 200 mm of available soil water in the case of the rain forest (4) and 230 to 250 in the case of the rubber forest (3). Another major factor which influences the water vapour exchanges is the rain intercepted by the the forest canopy (leaf area index between 6.5 and 8.2 (13)). The capacity of water storage on the leaf forest canopy can range from 11 to 39% of the rainfall (12) depending upon the rain duration and intensity.

To evaluate the forest evapotranspiration rates for practical uses, certain amounts of basic information (climate and plant responses) are needed. In considering the equilibrium evapotranspiration rate ETo as the first term of the Penman equation and comparing it with the measured values of the actual evapotranspiration rates, it gives a ratio " C" = ETR/ETo called crop coefficient which characterizes the importance of stomatal regulation to soil water content or meteorological factors (11;15).

Priestley and Taylor (14) found that this coefficient C had a value near 1.26 for a number of well watered plant covers. Table II presents the values of C attributed to a rubber and a tropical rain forest on the same sandy soils formed of tertiary continental sediments.

TABLE II : Mean Values of "C" measured for the rubber forest and the tropical rain forest.

month	rubber forest		rain forest	
	soil water *	C	soil water*	C
D.J.	60 to 120	.4< C<.6		
F. rubber trees are leafless				
D.J.F.			40 to 100	.4<C<0.7
			100to160	.7<C<1.1
M.A.M.	120to200	.8<C<1.1	100to180	.8<C<1.2
J.J.A.	>200	.9<C<1.1	>180	.9<C<1.2
S.O.	120to200	.8<C<0.9	100to180	.8<C<1.1
N.D.	>200	.5<C<0.9	>180	.8<C<1.2
D.J.dry air	120to200	1.0<C<1.3	100to180	.7<C<1.3

* fraction of available water in the root zone (mm)

The higher values of the coefficient C for forests are related to the amount of rain interception by the leaves . Another influencing element is that growth of new leaves is not synchronized because of the varied species heterogeneity in the tropical rain forest. This factor does not occur in homogeneous forest such as rubber trees which remain leafless for 3 to 4 weeks.

4. MODELLING FOREST WATER CONSUMPTION

The evapotranspiration rates of the tropical rain forests and of the rubber forest have been evaluated by the following equation (14):

$$ETR = C\ [\Delta/\Delta+\gamma]\ [(Rn - G)/L] \quad mm/d$$

knowing the incoming solar radiation and the rain quantities, the soil water availability, soil water capacity, the foliage interception and the variation of the coefficient C which is dependent on the previous factors. Table III summarizes the results of rain water transfer to the atmosphere by the forest at different locations in the ivorian tropical forest zone.

The two years we have studied show a different annual rain distribution : 1980 had 2 rainy seasons between march and november whereas in 1982, the equivalent of 75% of the annual rains fell between april 15 and july 15 , particularly in the southern part of the forest area (Dabou).

The tropical rain forest injects the equivalent of 63 to 74% of the annual rain fall as water vapour into the atmosphere (table III). The same conclusion has been found with the amazonian forest (16). The importance of the recycling depends on the annual rain distribution. The driving force of the global water cycling is the water vapour advection from the nearby ocean which is precipitated over land.

TABLE III : Estimation of the annual evapotranspiration rates for different vegetated surfaces.

year	vegetation	rain mm	C ETo mm	CETo/Rain
1969 -1971	Equat.forest BANCO (4)	1800	1195	0.66
1971 -1973	Equat.forest YAPO (4)	1950	1425	0.73
1980				
TAI	Equat.forest	2066	1313	0,63
	fallow field+crop	2066	821	0.30
	crop cover(4months)	629	374	0.59
YAM	Equat.forest	1382	1025	0.74
	fallow field+crop	1382	764	0.55
	crop cover(4months)	571	384	0.67
DABOU	rubber forest	1135	1126	0.99*
	fallow field+crop	1135	664	0.58
	crop cover(4months)	581	346	0.60
1982				
TAI	Equat.forest	1714	1257	0.73
	fallow field+crop	1714	788	0.46
	crop cover(4months)	803	328	0.60
YAM	Equat.forest	990	1026	1.13*
	fallow field+crop	990	762	0.76
	crop cover (4months)	514	433	0.84
DABOU	Equat.forest	2242	1007	0.44
	fallow field+crop	2242	525	0.23
	crop cover (4months)	1802	378	0.21

* soil moisture participated in the water exchanges from year to the next.

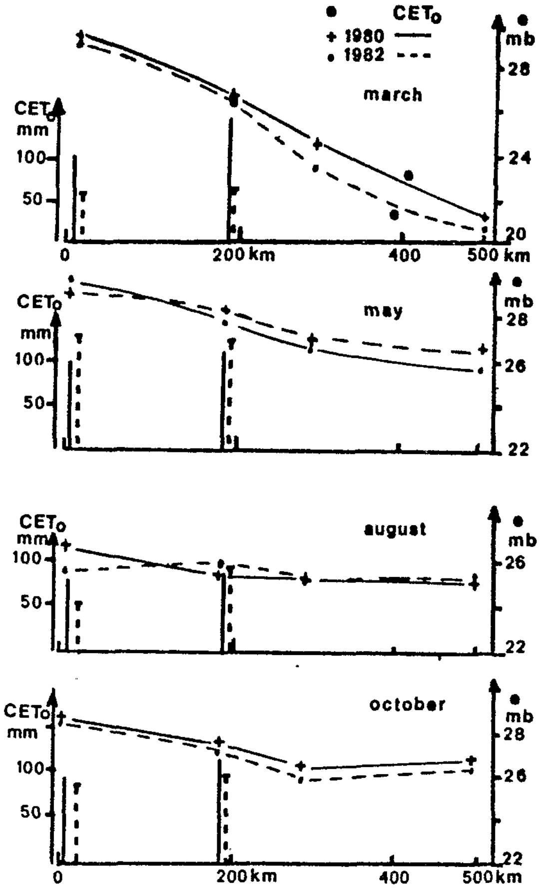

Fig. 3. Evolution of the atmospheric vapour pressure and the forest evapotranspiration rates as a fonction of the distance from the Bay of Guinea coast for different months during 1980 and 1982.

The regional recycling of this precipitated water depends on the vegetated land surface which acts as a water source for the atmosphere. The forests transfer the equivalent of more than 65 % of the annual rainfall, while annual crops exchange less water vapour into the air: the reduction is 40 to 60 % of the total forest amount. Owing to the large forest evapotranspiration rates, the depletion of the atmospheric water vapour content by precipitation above land is quite low from april to november.

Figure 3 shows the evolution of the mean monthly atmospheric vapour pressure (e) near the coast, at the forest savana border (Yamoussoukro, 190 km from the coast) and more in the north of Ivory Coast (Korhogo, 500 km from the coast) in relation to the monthly forest evapotranspiration rates (CETo in mm).

The tropical rain forest accounts for a large turnover of the precipitated water back to the atmosphere. This moisture which contribues to the formation of clouds will reprecipitate mostly in the northern regions in relation to the general atmospheric circulation. From an annual water budget over Ivory Coast which takes into account the global amount of advected water vapour from the ocean and the total amount of measured rainfall, LAGLAIRE (17) concludes that advected oceanic moisture represents only 33 % of the total rainfall and so that 67 % comes from the forest evapotranspiration. This agrees with our calculations

Modifying the land surface covers will induce changes in the partition of heat transfer and in the intensity of the exchange processes. The differences between latent and sensible heat are locally significant due to the mosaic vegetative covers. (Table IV).

Table IV : The partitioning of the net radiation Rn into sensible heat H, latent heat LETR and ground heat G fluxes (Wm^{-2}) over different vegetated surfaces after deforestation

surfaces	Rn	LETR	LETR/Rn	H	H/LETR	G
rice crop						
1*	548	431	.78	90	.21	28
2*	506	311	.61	170	.55	25
casava crop						
1*	352	292	.82	18	.26	52
2*	316	181	.57	70	.39	65
short grass						
1*	450	385	.86	55	.14	17
2*	575	380	.66	190	.33	27
bare soil						
	430	52	.12	236	4.54	142

1* well watered crop
2* water stress crop

The reduction in the evapotranspiration rates LETR observed on different vegetated surfaces is linked with the importance of the ramified root system which extracts the soil water. Root systems of annual plants generally grow in the first 50 to 70 cm soil layer; the consequence being that the soil water content of this layer is rapidly depleted. This reduces water vapour exchanges which increases sensible heat transfer and affects the air temperature. If deforestation occurs on a large scale by fire and by human activities as is the case for the moment, regional water balance will be modified: evapotranspiration rates will drop due to a change of plant characteristics and to an increase of water runoff on non protected soil surface. Reduction in the atmospheric water vapour content and increase in air temperature could affect the rain distribution over West Africa in relation to the perturbed general atmospheric circulation.

5. CONCLUSIONS

In the tropical regions, important physionomical changes of the rain forest are occurring due to the conversion into agriculturally exploitable lands to satisfy the growing population. Large forest area are being converted slowly to savana systems. This modification affects the radiation budget and the energy partition. In relation to plant surface characteristics, the ratio Rn/Rg drops from 0.86 for forests to 0.62 for annual plant covers, reduction in relation with the increase of the reflected and emitted radiations by the crop surfaces. With less absorbed energy, water vapor exchanges with the atmosphere by the vegetated surfaces decrease. This reduction is accentuated by the rapidly depleting water in the soil layer exploited by the annual plant root system. The annual water transfer by crop surfaces represents 50 to 60 % of the annual moisture amount tranfer from forests to the atmosphere. An increase of sensible heat, which affects the air temperature and in some cases the soil temperature, is associated with this reduction of water recycling. These effects could induce a weakness in the southern hemispheric tradewinds which are the main source of moisture influx. The results would be a decrease of rainfall over forested areas and a drastic reduction of reprecipitated water above savana regions, mostly in the north, leading to the desertification processes.

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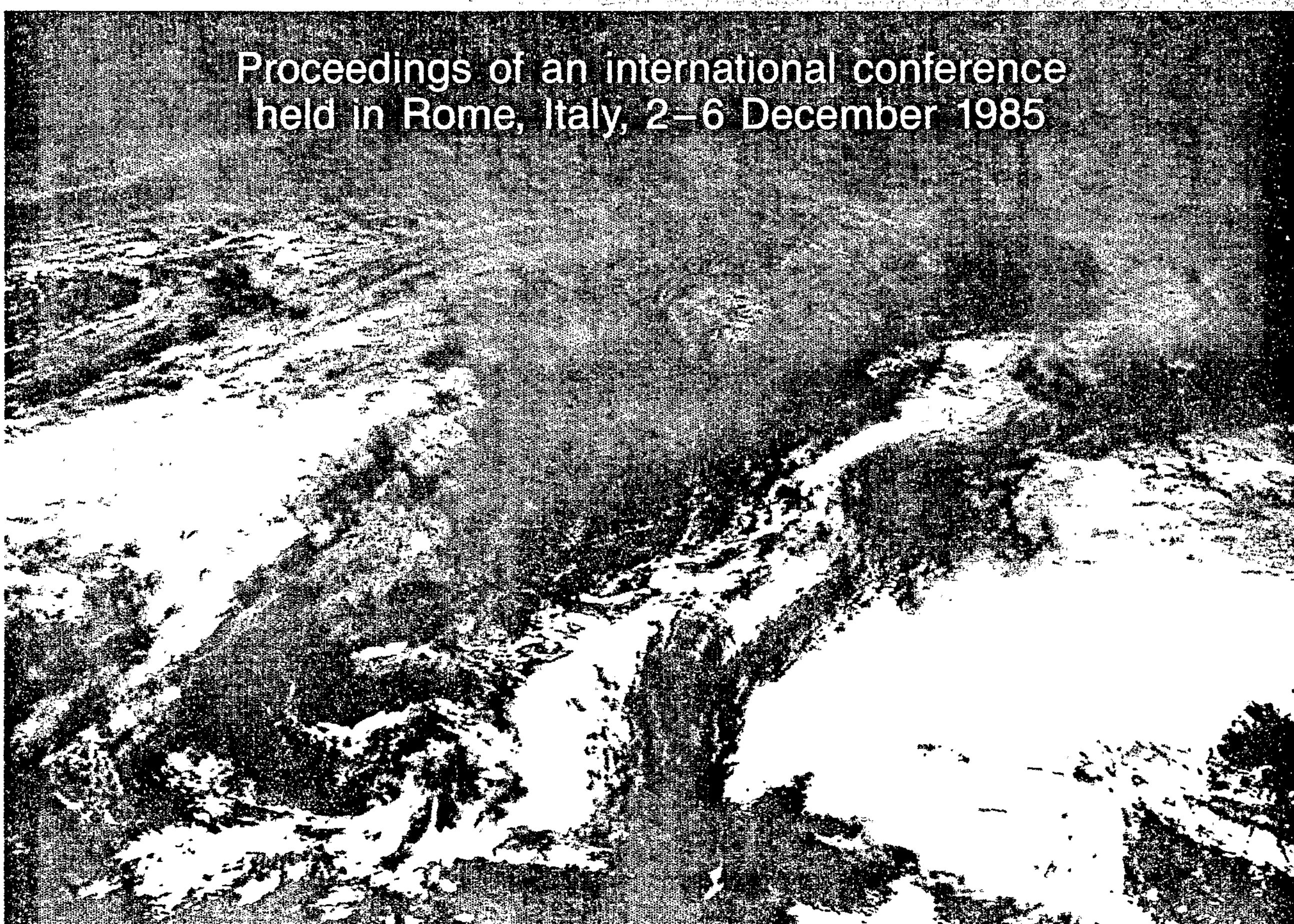

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