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INTEGRATION OF THE SPATIO-TEMPORAL HETEROGENEITY OF ECOSYSTEMS TO IMPROVE THE HYDROLOGICAL FLUXES

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ABSTRACT

The soil water content is estimated using an hydrological model based on the radiometry surface temperature and some soil characteristics. The results are compared to the ground measurements and show a good fitting.

I. INTRODUCTION

In the arid and semi-arid regions, the real availability of water and its temporal repartition constitute usually the determinant factors of seasonal behavior of the vegetation. The funtionning of savanna's ecosystem depends strongly on temporal charactertistics of water's budget (Amram et al., 1994 [1], [2]).
The aim of this paper is to monitor the hydrological cycle at a regional scale. It is then necessary to develop a hydrological model with a limited number of parameters. Some of these parameters which vary in function with time can be derived from satellite measurements. The others can be obtained from maps. To estimate the water budget, an evapotranspiration is computed from land surface parametrization and the soil water content is modelized by a reservoir model.
The validation of the model at a regional scale must be done in a first step at a local scale.

II. STUDY AREA

The study area is the East supersite (2°42'E, 13°31') of the HAPEX-Sahel project.
The Sahel is the region where the annual precipitations are comprise between 100 and 600 mm. The rainy season goes from June to September with a maximum during August (Figure 1).

The vegetation is very sparse and covered a sandy soil. It is essentially composed by savannas (annual herbaceous). The vegetation cycle length is short (two or three months). It starts generally a few weeks after the begining of the precipitations.

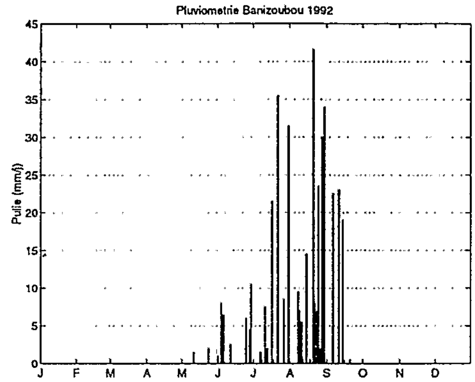

Figure 1: Daily precipitations of 1992 (Monteny).

III. BASIC CONCEPTS

The simplified hydrologic budget for a region can be written as:

$$P - Ev - R = \Delta S \tag{1}$$

where: P is the rain,
Ev is the evapotranspiration,
R is the runoff and
ΔS is the soil water content.

This is the basic equation of hydrology. Equation (1) is applicable to exercises of any degree of complexity and is therefore basic to the solution of all hydrologic problems. The difficulty in solving practical problems lies mainly in the inability to measure or estimate properly the various hydrological terms. For local studies, reliable estimates often are made but on the global scale quantification is usually crude. But for linking land surface processes to the atmospheric processes, it is important to modelize precisely the hydrologic process.

To modelize the soil water content, we use a model of tank (model CEQUEAU, developed at INRS- Eau - Quebec, Canada). It is a conceptual model which assimilates the water shed system to an assemblage of water tanks in series or in parallel. These tanks are filled according to conditionned laws by the part which is upstream from the system. And they empty out

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according to analytical laws which are particular to these tanks, and according to their level.

The differences which exist from a model to another is the number of variables, their link and the hypothesis done in the physical modelling.

Because the african regions are poor in data, we must use the physical models which are compatible with the data, it means which do not need non extracted parameters.

IV. LAND SURFACE PARAMETRIZATION

The land surface parametrization is based on the radiometric surface temperature. This temperature can be derived from satellite measurements (Kerr et al., 1992 [4]); for the validation of the model, we have used ground measurements of temperature. This radiometric temperature coupled with conventional meteorological information, is valuable for estimating the sahelian surface evaporation rate in order to parametrize the land surface water budget.

The radiometric surface temperature is the parameter which results from the eschange processes between the savanna surface and the atmosphere. This temperature is measured at spatial and temporal scales.

Many autors have proposed simplified relations between evaporation and the difference between the radiative temperature and the air temperature. Jackson et al. (1977[3]), Seguin et al. (1983 [6]) used instantaneous maximum temperatures values. Monteny et al. (1994 [5]) used integrated values between 11 h and 14 h.

The relation which will be used in this paper is the one built by Monteny et al., (1994 [5]). This relation has been established in three steps:

1- They have established a relation between remote sensing radiometric temperature (Trad), the air temperature (Ta) and the relative soil water content for the first 50 cm depth (S):

$$S/S_m = 1.22 - 0.081 \cdot \left(T_{rad} - T_a\right) \quad (R^2{=}0.83) \qquad (2)$$

where Sm is the field capacity.

2- A second relation was established between the evaporation fraction Ev/Eo (ratio between measured evaporation Ev and equilibrium evaporation Eo) and the relative soil water content (S):

$$E_v/E_o = 1.082 \cdot \left[1 - e^{\frac{-1.75 \cdot S/S_m}{1 - S/S_m}}\right] \quad (R^2{=}0.76) \qquad (3)$$

where Eo is the equilibrium evaporation.

This relation is a non linear as shown in the figure 2. The evaporation rate decreases when 35-40% of the total soil water is depleted in the root zone which increased the canopy surface resistance.

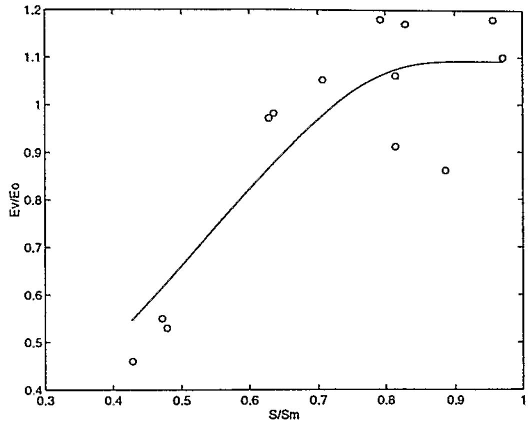

Figure 2: Relation between Ev/Eo and S/Sm.

3- The equilibrium evaporation (Eo) can be calculated from the Priesley-Taylor equation:

$$Eo = \frac{\Upsilon}{\Delta + \Upsilon} \cdot \frac{Rn - G}{L} \text{ (mm/day)} \qquad (4)$$

where: - γ is psycrometric constant,

- L heat latent of vaporization,

- Δ is the slope of saturation vapor pressure versus temperature curve at the air temperature, and

- the net radiation (Rn) and soil heat flux (G) are computed using linear relations between global radiation (Rg) and each of them.

Finaly, the parametrization of the savanna surface evaporation Ev, resulting from equations 2, 3, and 4, can be wrtitten as:

$$E_v = \frac{\Upsilon}{\Delta + \Upsilon} \cdot \frac{Rn - G}{L} \cdot 1.082 \cdot \left[1 - e^{\frac{-2.135 + 0.142 \cdot (T_{rad} - T_a)}{-0.22 + 0.081 \cdot (T_{rad} - T_a)}}\right] \qquad (5)$$

This relation leads to the evaluation of the daily surface evaporation rate.

A fairly good agreement is found between the measured and estimated evaporation rates as presented in the figure 3.

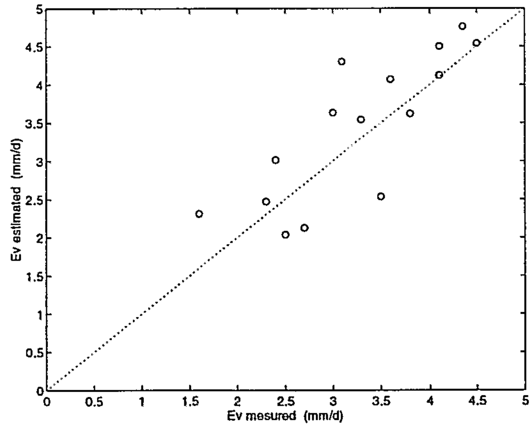

Figure 3: Comparison between Ev estimated and Ev measured.

V. WATER BALANCE ESTIMATION

Precipitation (P) is mesured by rain gauges located throughout the area. The estimation of evapotranspiration (Ev) lies on the method described above.

The runoff is considered equal to zero. This is true for this region at the scale of one kilometer (resolution of AVHRR data). For this work, the reservoir is partitioned in two layers: the first 0 - 50 cm, the second greater than 50 cm. The measurement of soil water content has been realized on the first layer. The field capacity (Sm) is taken at 55 mm.

The estimation of the soil water content (S) computed by the model is shown in figure 4.

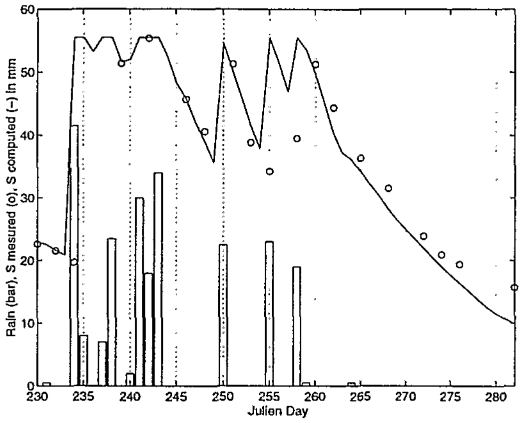

Figure 4: Temporal evolution of computed soil water content (line) and its measurement (circle) (mm/day).
The histogram is the daily rain (mm/day).

The observation of these results show a well temporal fitting between the model and the ground measurements. We note some important difference between the two values but in each case, we can explain it by the fact that measurements have been done before the rain. The model takes into account the daily rainfall before computing the soil water content.

After the end of the rainy season, the evapotranspiration is still high because during few weeks the chlorophyllian activity is important. Thus, the evaporation is principally due to the transpiration of vegetation and compensates the decrease of soil evaporation.

If we monitor the soil water content value for the layer 0 - 50 cm, we note a decrease of this value which is less than the cumulted evaporation. To explain this deficit, it is necessary to use the second layer of soil to feed the vegetation. This has been taken into account in the modeling when the ratio S/Sm is less than 0.7.

But this modeling tends to under-estimate the soil water content until to reach a value of 30% less than the one measured at the end of the period.

After the end of the rainy season, there is not an initialization of the soil water content by the precipitations. Thus, the under-estimations of soil water content are cumulated which conduct to an important error at the end of the period.

It will be then necessary to correct this under-estimation of the soil water content taking into account the vertical availability of water in function with implanting. This can be done through the soil moisture tension in function of volume ao available water retained.

VI. CONCLUSION

The hydrological model enables to calculate the soil water content. It successfully linked the surface radiometric temperature to the savanna evaporation rate. The model simulation agrees with the field measurements data.

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