WATER BALANCE MONITORING IN SAHELIAN REGIONS WITH THERMAL IR AND VEGETATION INDEX DATA FROM METEOROLOGICAL SATELLITES

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ABSTRACT

Within the EEC program for characterizing the dynamics of desertification south of Sahara by the use of remotely sensed data, a research program has been initiated by three french organizations INRA-IRAT-LERTS on the monitoring of crop water conditions during the rainy season by use of satellite data.

Primarily focused on the Senegal area, the study was carried out in collaboration with two local organisations, namely : ISRA and Météorologie Nationale. Since it proved to be almost impossible to get access to NOAA-AVHRR data (GAC or LAC) with satisfying delays, the study was mainly performed with use of Meteosat daytime (13:30 pm UT) thermal IR data, and aimed at establishing a relation between the satellite derived surface temperatures and the actual evapotranspiration (ET) through the classical surface energy budget method.

After a preliminary study based on two scenes acquired in 79 and three in 83, the stess was put on the summers of 84 and 85. Sixteen dates were selected for cloud-free conditions for each rainy season (between 1 and 2 dates per week), ordered to ESOC in Damstadt and processed in LERTS Toulouse. Resulting surface temperatures were compared to measured rainfall and computed ET from the IRAT water balance model for 10 agrometeorological stations on a north-south transect despicting a large water balance gradient.

The following results were obtained

a. Cumulated T_s along the rainy season are linearly correlated to the amount of cumulative rainfall, thus allowing to draw rainfall maps where spatial interpolation is more precise than with the classical ground data.

b. The use of a simplified relationship approach allowed to compute the spatial variability of ET, in spite of the large error in the estimates of T_s from Meteosat data.

c. By the analysis of crop production statistics in relation to ET/ETM ratios, millet production maps may be proposed at the end of the rainy season.

Perspectives and limits of these applications are discussed in conclusion.

INTRODUCTION

Within the frame of the global action "Caractérisation par les techniques de télédétection de la désertification à la périphérie du Sahara" undertaken by the European Economic Community, Directorate of Development (DG8/A2), a research program has been developed by three french laboratories for assessing the possible use of meteorological satellites for the monitoring of crop water conditions along the rainy season in Sahelian regions. The project was mainly focused on Senegal, both because of the high rainfall gradient (from 150 mm in the Senegal valley to about 400 mm at the latitude of Dakar during the study period, within a distance of nearly 300 kms) and the existence of a dense agrometeorological network.

I. THE OBJECTIVES

Using recent work performed in the "Station de Bioclimatologie INRA d'Avignon" about the use of meteorological satellite thermal IR data to estimate evapotranspiration (see SEGUIN et al., 1985, for a global review), the objectives were :

a. To globally check the possible use of these data during the rainy season to assess the spatial extent of rain episodes.

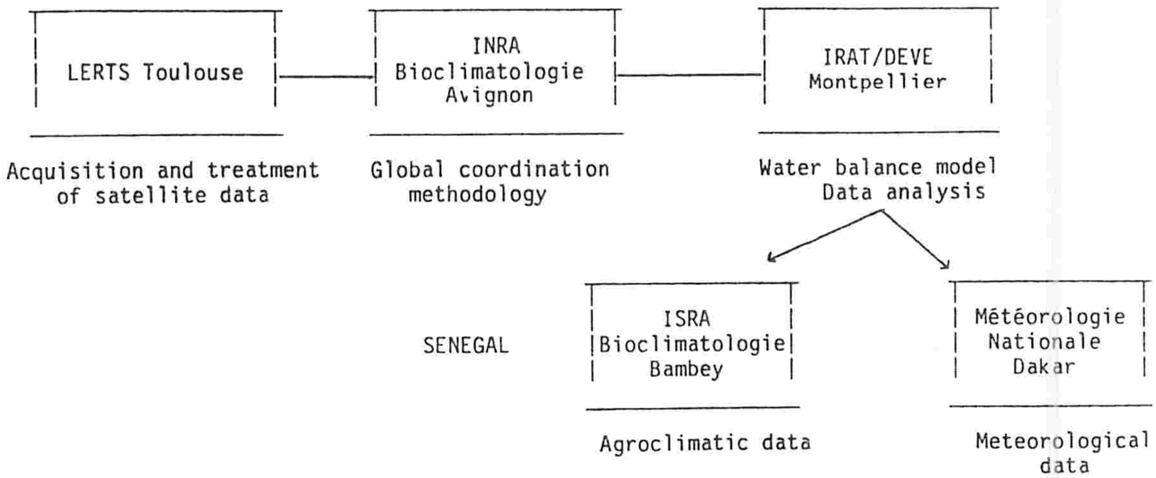
b. To evaluate the ability of mapping the actual evapotranspiration ET by using a simplified relationship developed after the suggestion of JACKSON et al. (1977) and thereafter checked both by experimental approach and theoretical analysis (SEGUIN et al., 1982 ; SEGUIN et ITIER, 1983 and SEGUIN et al., 1985).

$$ET_d = Rn_d + A - B\ (T_s - T_a)$$

where daily ET (ET_d) is computed, for each pixel, from the daily net radiation Rn_d, the surface temperature T_s derived by satellite and the air temperature T_a measured in the ground network.

c. Finally, to test the suitability of that ET mapping for establishing maps of final yields for main crops, by a combination with agroclimatological models relying upon the regression of these yields with the ratio ET/ETM of the actual ET over the maximum ET, thus expressing the degree of satisfaction of water needs.

For fulfilling these objectives, the project needed a high complementarity and a full cooperation between the various components. That was achieved by the following organization.



The project allowed the analysis of two rainy seasons (1984 and 1985), after some preliminary analysis of some dates in 1979 and 1983.

II. THE BASIC DATA

The study first needed climatic and satellite data along the rainy season

2.1. Climatic data

They were derived from the ground meteorological network of the Météorologie Nationale and the agrometeorological stations of ISRA (figure 1).

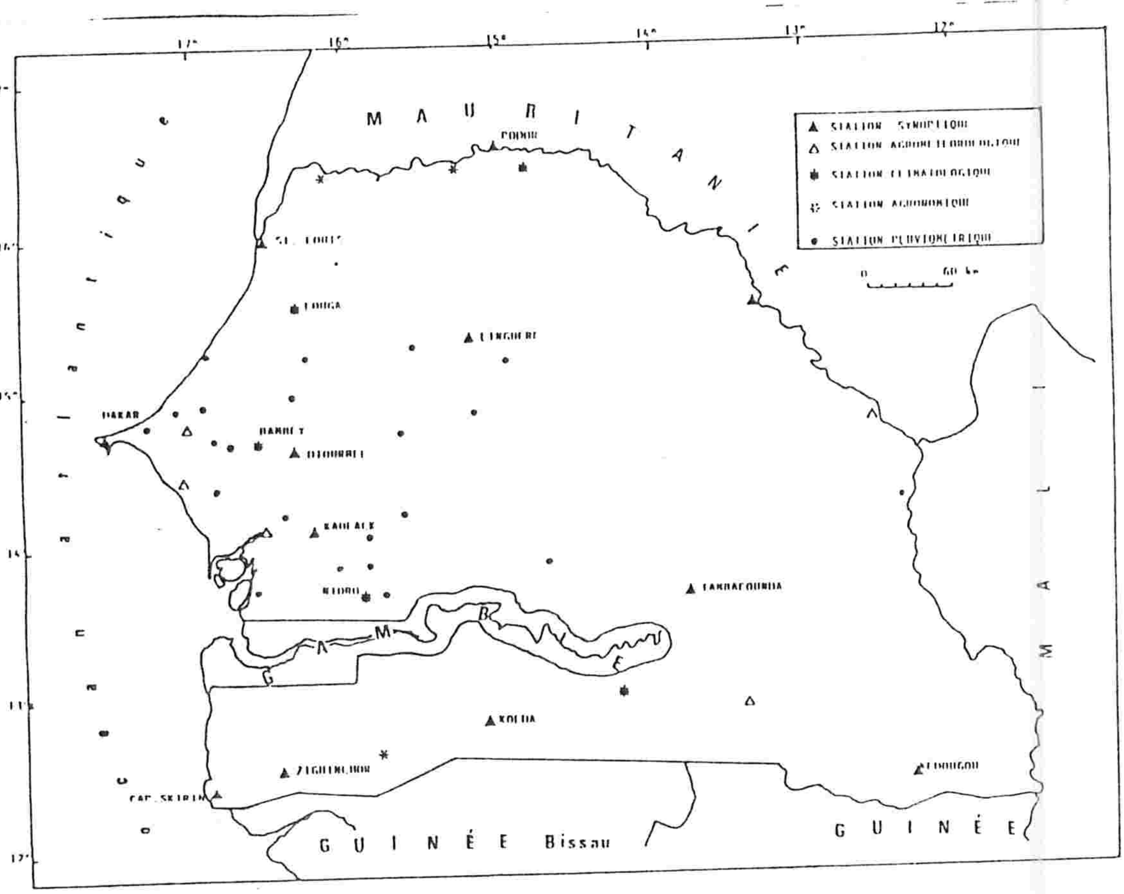


FIGURE 1

The available network of meteorological and agrometeorological stations

From that network, the following parameters were obtained : air-temperature (maximum), insolation, relative humidity, rainfall, evaporation of Class A pan, global radiation (for 4 stations only).

2.2. Satellite data

We originally planned to use both Meteosat and NOAA for that study. But, due to a lack of receiving stations in Africa at that time (Mas Palomas is now operating from july 86), the ordering to NOAA in USA first reduced the number of available scenes and secondly introduced a large delay (one year and more). So that the available dates only allowed a first insight into the characteristics of NOAA data and a direct comparison with Meteosat on one common day (23|06|86).

Meteosat was then the only available satellite for an objective of monitoring (which supposes at least one or two scenes per week). After a selection of clear days (using ISCCP-B2 Format images or ground meteorological data concerning the nebulosity), CCT were ordered to ESOC in Darmstadt and processed by LERTS in Toulouse.

III. THEIR PROCESSING

The setting-up of the proposed methodology supposed to combine climatic and satellite data at the location of ground stations in order to use remote sensing for spatial extrapolation in a second phase.

For that purpose, the following operations were performed by LERTS with original Meteosat CCT : degradation of visible data in order to be superposable to thermal IR pixels (5 km x 5 km), extraction of Senegal zone, localisation of ground stations, extraction of physical parameters (albedo and surface temperature). The main problem was encountered with that last basic parameter, due to the poor calibration of the thermal IR chanel of Meteosat. The ESOC procedure was applied, but it only allows to account for the long terme evolution of the radiometers and does not involve the atmospheric transmission. Obtained T_s were then too low by some 10 to 20°, so that it was necessary to use atmospheric correction procedures. We used both LOWTRAN procedure and the PRICE model (PRICE, 1985), with rawisonde data for the only available station of Dakar. The method of PRICE gave the best results, both in stability and order of magnitude. They will be discussed later in the paper.

For which concerns climatic ground data, rainfall and temperature were used directly. But their main interest lied in the computation of daily ET thanks to the water balance model developed at IRAT by FRANQUIN and FOREST (1977). For a given crop, that model uses both climatic data (rainfall and Class A evaporation), soil information (the useful reserve R_u) and phenological informations on crop stages to compute the ratio ET|ETM and then ET on a pentad-basis.

That model has been previously tested in the Sahelian zone (see ASSAD, 1984 ; FOREST and KALMS, 1984 ; FRETEAUD et al., 1985) and appears to give satisfactory results.

The main problem here encountered was to compute a "regional" ET for pixels of 25 km^2. The only possible solution was to use the ET outputs for the main cultivated crops (namely millet, peanut and cowpea) as well as for the mature grass, concerning noticeable surfaces. A global ET was then derived by weighing each crop contribution by its relative importance in the surface deduced from land use official statistics.

A specific set of informations was also derived from a micrometeorological campaign achieved at the CNRA of Bambey (100 km east of Dakar) during the months of July-August 1985 (see detailed results in LAGOUARDE et al., 1985), with 3 main objectives.

- obtain ground-based estimates of ET by micrometeorological measurements, which, even if they could not be used for validating satellite derived ET because of the large difference in spatial scales (some hundred of m^2 compared to 25 km^2), gave reference values of one given crop (here peanut) and allowed to check the ET values computed by the water balance model

In spite of usual difficulties to find adequate time scales to compare atmospheric and soil-based ET estimates, the following results were obtained.

Period (dates in 1985)	24|7-11|8	12|8-18|8	19|8-23|8	24|8-29|8
ET (aerodynamic method) in mm	56.7	25.6	21.4	27.3
ET (soil moisture budget) in mm	64.9	22.6	32.7	32.1

In the same manner, the use of surface temperature measurements is restricted because of its very reduced spatial validity (some 1 m^2). However, it confirmed both the answer of T_s to soil moisture conditions (figure 2) and the general underestimation by Meteosat data with the improvement by using the Price model (figure 3).

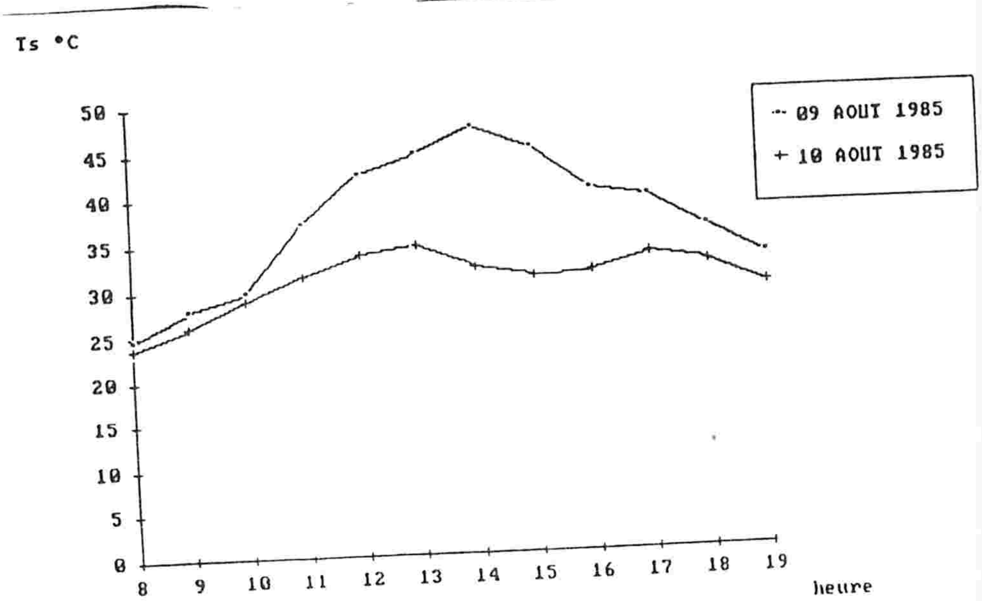


FIGURE 2

Daily evolution of Ts for the dates of 9 and 10 august 1986
(24 mm rainfall during the night between them)

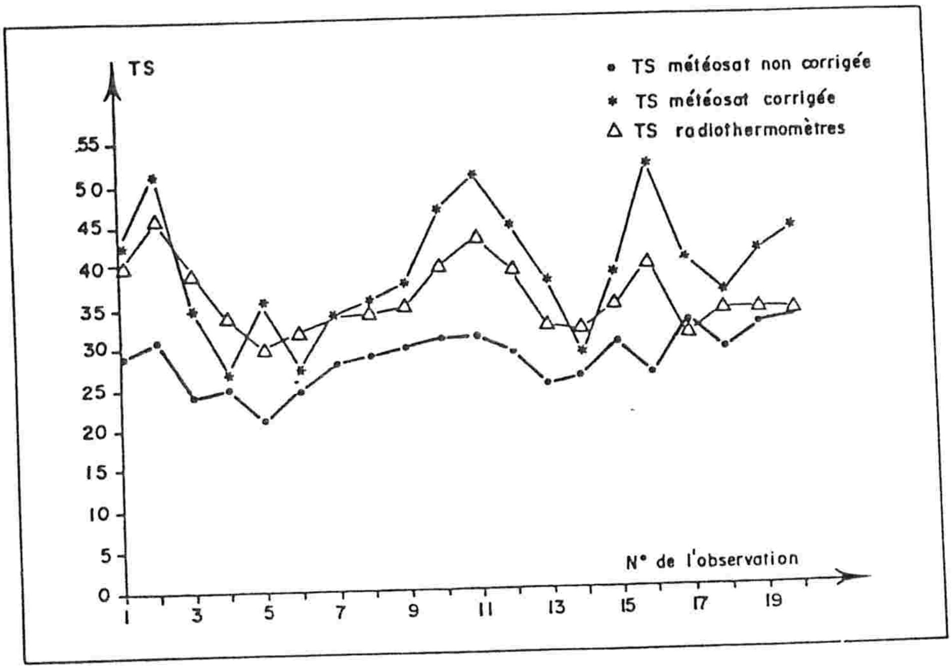


FIGURE 3

Comparison of ground T_s in Bambey to Meteosat estimates without and with atmospheric correction

IV. OBTAINED RESULTS

They may be presented according to the main objectives defined in the introduction.

4.1. Rainfall monitoring by surface temperature

The preliminary analysis of 79 and 83 images confirmed the expected trend of spatial variations for T_s, grossly increasing from the wet south to the dry north. The appearance of a somewhat linear relationship, for one given date at the beginning of the rainy season in july 1979, between T_s and the amount of fallen rainfall since the beginning of that rainy season (figure 4)

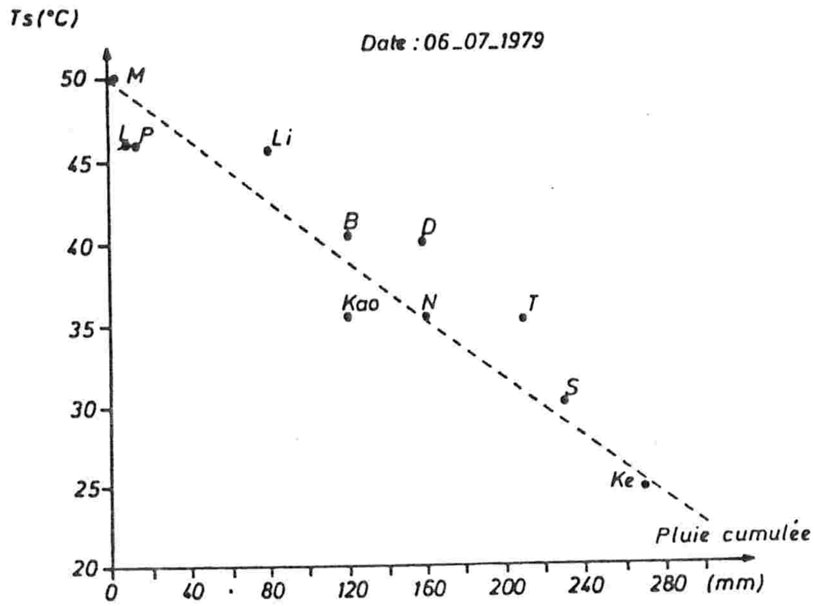


FIGURE 4

Relationship between T_s and cumulative rainfall for the date of 06/07/79

led us to look at the temporal evolution of the summation fo T_s (ΣT_s) compared of the cumulative rainfall (ΣP) along the rainy season. The 24 dates of 84 and the 34 of 85 despicted a slowly increasing correlation coefficient of that linear regression, allowing a significant relationship at the end (figure 5.)

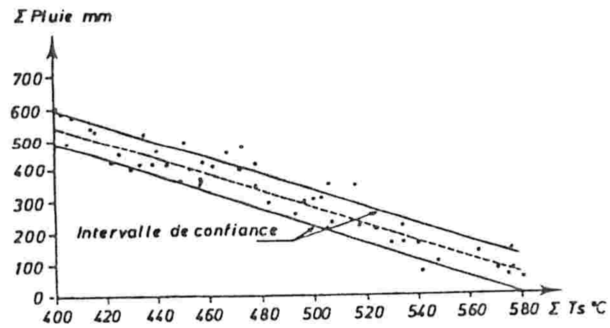


FIGURE 5

Relationship between ΣT_s and ΣP at the end of the rainy seasons (years 84 and 85)

That result, if obtained empirically, may be justified by the linear relationship between T_s and ET (as expressed by the simplified approach) and the approximative linear dependence of ET against rainfall P along the season. It may be used as a possible operational procedure for mapping rainfall and estimating the spatial extension of rainy episods, as shown by figure 6

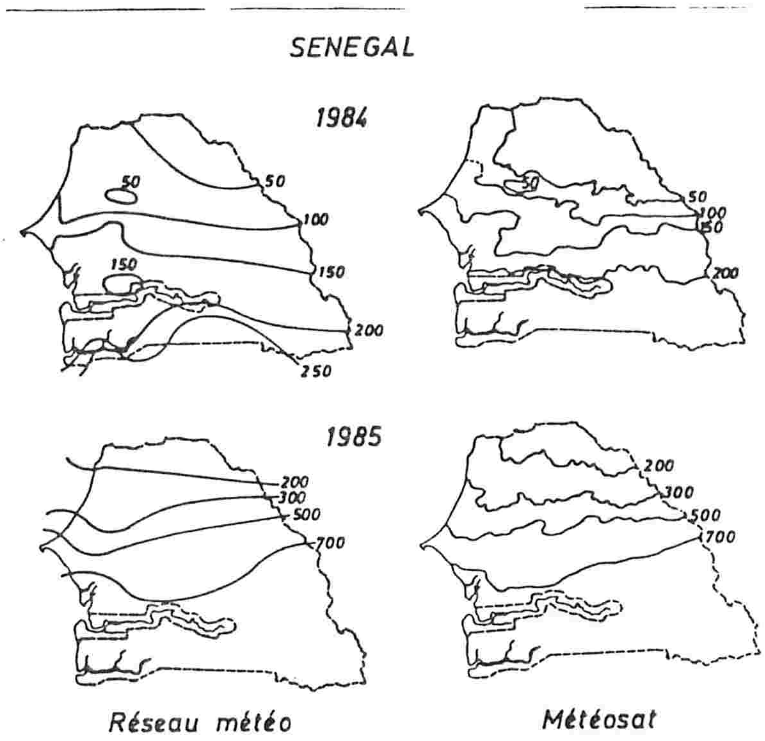


FIGURE 6

Comparison of isohyets derived from Meteosat
to those established by climatological ground services

4.2. Computation of regional ET

The estimate of ET by the simplified approach appeared as a difficult challenge because of the uncertinities both in the exact values of T_s and the reference ET values computed by the water balance at the pixel scale. That explains the large dispersion observed, especially in 1985 (figure 7)

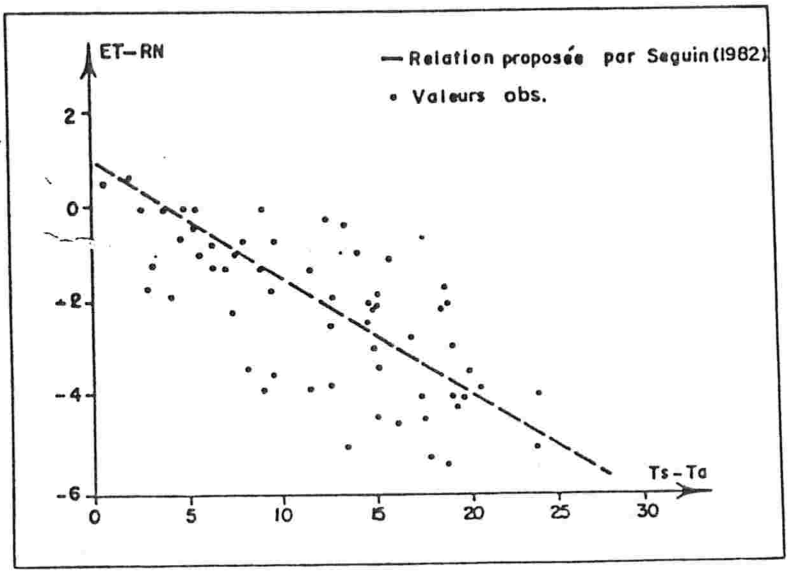


FIGURE 7

Established simplified relationship for 1985

However, these first results may appear encouraging, due to the limitations of that study. A further test with NOAA-AVHRR (allowing to significantly reduce the uncertainity in T_s, by using the two IR channels and the split-window method) appears as necessary to clearly establish the potentialities of the simplified approach. Moreover, the access to the LAC resolution (1 km^2) by the Mas Palomas receiving station could allow to validate ET so derived estimates by ground measurements.

4.3. The application to yield mapping

The high dependence of Sahelian main productions to water conditions allows to hope to be able to propose a mapping of rough estimates of expected yields at the end of rainy seasons using remote sensing data. For that purpose, we need agrometeorological models of final yields related to water parameters. The main problem lies on the only approximative value of production statistics allowing to establish these models.

In our case, we used statistics from the Ministry of Agriculture giving main yields by administrative districts for the period 1975-1984. If the dispersion with global rainfall data is not surprising, the relationship with the global ET|ETM ration along the whole rainy season is not so bad (figure 8)

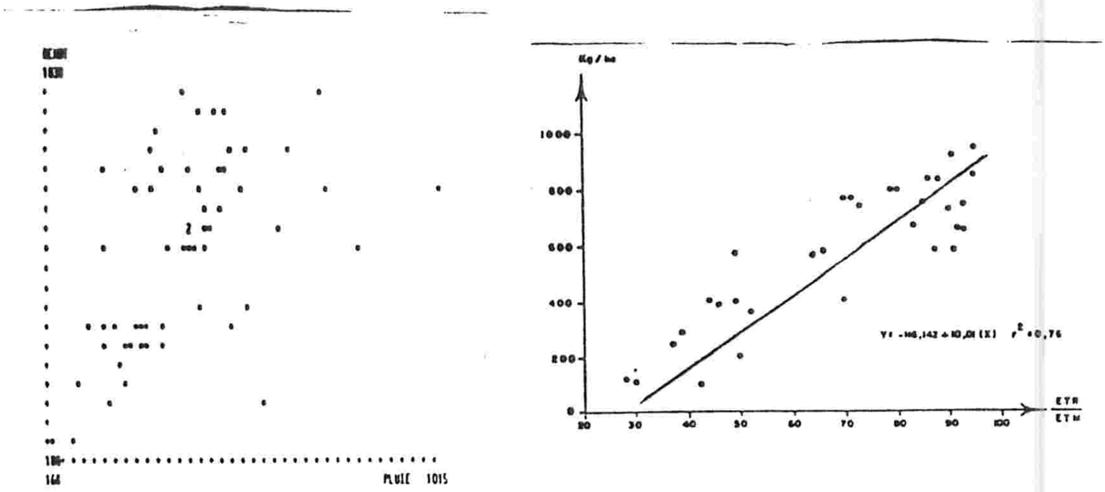


FIGURE 8

Relationship of millet annual yield with rainfall (a) and ET|ETM (b)

which authorizes us to propose a mapping of millet production in Senegal by linking that relationship to the estimates of ET|ETM spatially derived from the ET computation. These colour maps have been displayed in the poster session during the conference, and are not reproducible here. However, we can state that they allow to exhibit the possible impact of the methodology here defined, with some interesting features (shifting of isoyields from south to north from 84 to 85, large differences inside administrative units...) even if the absolute values have to be considered with caution due to the large dispersion.

VI. CONCLUSION

From that preliminary study, mainly based on a methodological approach, we may conclude :

1. That the use of clear day thermal IR data may give valuable estimates of fallen rainfall for a long term (as least one month), thus being complementary of studies attempting to compute rainfall from cloud indexations on a short term basis.
2. That the project of computing ET from the same thermal IR data may appear feasible, in spite of the problems arising both form the precision in the estimation of T_s and the computation of ground ET acting as references.
3. The possible way to drawing maps of expected rough yields has been demonstrated. The problem here lies in the uncertainities about the true production in the sahelian context.
4. That surface temperature appears to be very complementary in these regions of vegetation index, and that the simultaneous analysis of these two parameters will be of great interest, especially in the case of NOAA-AVHRR since it is the only meteorological satellite to combine the two informations.

Aknowledgements

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