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# MICROWAVE REMOTE SENSING DATA FROM A SPACEBORNE PLATFORM AS A TOOL TO MONITORE THE HYDROLOGICAL CYCLE OF A FLOODPLAIN AREA ("VARZEA") AT NORTHEAST BRAZIL (TEST SITE: PETROLINA, PERNAMBUCO STATE, BRAZIL)

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RESUMO-NOTAS/ABSTRACT-NOTES


The multiparameter characteristics of the SIR-C/X-SAR experiment (L, C and X bands, HH, HV and VV polarizations for L and C bands, VV for X band, angles of incidence from $15^o$-$55^o$) would provide an unique and excellent opportunity to improve hydrologic and agricultural studies in the microwave domain. Being so, two main objectives are established in this proposal: a) To develop an algorithm to monitor the hydrological cycle over agricultural areas, based on data derived from SAR imagery and meteorological data at a floodplain area; b) To verify the possibility to discriminate among cultures at the date of the experiment and describe and analyse the attenuation properties of the cultures as related to the following radar parameters: frequency, polarizaton and angle of incidence.


OBSERVAÇÕES/REMARKS

Proposal submited and accepted to National Aeronautics and Space Administration / Jet Propulsion Laboratory - Deutsche Forschungs und Versuchsanstalt für Luft-und Raumfahrt E.V. and Piano Spaziale Nationale.

INPE-149

## RESUMO

As características multiparamétricas dos radares de experiência SIR-C/X-SAR (bandas L, C e X, polarizações HH, HV e VV para bandas L e C, VV para banda X, ângulos de incidência entre 15° e 55°), caracterizam uma excelente oportunidade no desenvolvimento de aplicações em Hidrologia e em Agricultura no domínio de Microondas. Em vista desta perspectiva, estabeleceram-se dois grandes objetivos para esta proposta: a) desenvolvimento de um algoritmo para monitorar o ciclo hidrológico em áreas agrícolas, com base em dados extraídos de imagens SAR e dados meteorológicos, e b) verificar a possibilidade de discriminar entre culturas presentes por ocasião do experimento: descrever e analisar as propriedades de atenuação das culturas relacionadas aos seguintes parâmetros dos radares: frequência, polarização e ângulo de incidência.

CONTENTS

## LIST OF FIGURES

## 1. INTRODUCTION

The main objectives of this proposal are:

1) To develop an algorithm to monitor the hydrological cycle over agricultural areas, based on data derived from SAR imagery and meteorological data at a floodplain area ("varzea") in Northeast Brazil (Pernambuco State).

2) To verify the possibility to discriminate among cultures at the date of the SIR C/X-SAR Experiment and to describe and analyse the attenuation properties of the cultures as related to the following radar parameters: frequency, polarization and angle of incidence.

The approach for this study is straightforward, because we think that the SIR-C/X-SAR Experiment will provide an excellent possibility to definitively prove the operational use of spaceborne microwave remote sensing for many applications, including those related to Hydrology. The test site is located at the "Projeto de Irrigação de Bebedouro" (Bebedouro Irrigation Project), an experimental irrigation project, managed by EMBRAPA/CPATSA (Empresa Brasileira de Pesquisa Agropecuária/Centro de Pesquisa Agropecuária do Trópico Semi-Árido). This study will be conducted by INPE in cooperation with EMBRAPA/CPATSA. The latter organization was established in Northeast Brazil (approx. 42km N of Petrolina/Pernambuco State) in order to study and to develop new agricultural techniques, that could be adapted to the specific environmental conditions of NE-Brazil. CPATSA has got already some experience with digital interpretation of LANDSAT images. Furthermore, this organization is very interested in microwave remote sensing techniques, that will hopefully contribute to the solution of hydrologic/agronomic problems under study by this research center at the semi-arid region of Brazil. CPATSA has specialized research teams (M.Sc. and PhD. level) on soil science, irrigation practices, agrometeorology, vegetation science, and statistics among others, and research facilities such as a completely equipped agrometeorological station and a laboratory for physical and chemical soil analysis.

The anticipated results, taking into account the objectives mentioned, are:

1) The establishment of a methodology to estimate soil moisture and evaporation rates at a regional scale, for irrigation projects, climatological studies, and as an input to numerical models for weather forecasting, based on operational SAR systems such as the Earth Observing System (EOS), envisaged for the mid 90's;

2) Set up of a data base relying on a multiparameter SAR system and its' interaction with different tropical agricultural crops;

3) Development and acquisition of software for the classification and enhancement of digital SAR images, which will be very helpful for agricultural and hydrological studies in the future (EOS, Radarsat, ...).

## 2. DESCRIPTION OF THE INVESTIGATION PROPOSED AND TECHNICAL PROBLEMS

### 2.1 - THE PROBLEM

Brazil is a country with continental size,where agriculture plays an important economic and social role. One of the major problems related to the brazilian agriculture is the estimation of planting areas and their productivities. Remote sensing techniques have been very useful tool to perform this work (LANDSAT-MSS, TM and SPOT-HRV). Nevertheless, more than 90% of the agricultural production is from summer crops (December/ April), whose growing season coincides with the rainy season (precipitation above 1200mm at the crop producing region in Southern and Southeastern Brazil). Due to this coincidence, it has been very difficult to obtain useful remote sensing data in the visible and infrared wavelengths on a regular basis. Microwave remote sensing techniques using spaceborne data are considered as a potential alternative to solve these problems.

One of the regions with the highest potential for the expansion of the Brazilian agriculture are the floodplain areas of major Brazilian rivers, specially at semi-arid regions of Northeast Brazil, where large drought periods originate many socio-economical problems.

According to Silva et al. (1981), there are approximately 800,000 ha of floodplains suitable for irrigation, at the Rio São Francisco valley, (a Brazilian south-north flowing river system). From these, around 90,000 ha are actually operational and 75,000 ha are being implanted. One of the major hydrological problems related to these floodplains is the salinization process that frequently occurs in these areas, normally due to inadequate use of irrigation practices.

Within this context, the development of methodologies, that would permit the integration of hydrological data to optimize irrigation techniques, is of a great relevance. Being so, microwave remote sensing techniques are of special interest to estimate superficial soil moisture, one of the fundamental components of the hydrological cycle. The multiparameter characteristics of the SIR-C/X-SAR Experiment, as described at SIR-C Science Plan (JPL, 1986) and X-SAR Science Plan (DFVLR Mitt 85-17) are well suited for the proposal of research described below.

## 2.2 - OBJECTIVES AND RATIONALE

The physical basis of remote sensing depends on the inference of those land surface characteristics that could be measured by the emitted or reflected electromagnetic radiation coming from the earth. The hydrological relevant parameters that have been studied using this approach include: surface temperature, evapotranspiration, soil moisture, precipitation, and components of the radiation balance (Carlson, 1985; Deardorff, 1977; Soares, 1986).

Models that help scientists to understand the hydrologic cycle, require, among others, the knowledge of vegetation, surface features, land use, soil conditions, and meteorological information over extended regions, that have different physical and environmental characteristics. Besides that, these data are required at frequent time intervals, in order to track critical parameters that control the cycle. In the past 5 - 6 years a great progress has been made concerning the use of remote sensing techniques, applied to soil moisture and evapotranspiration studies (Schmugge, 1987).

It is important to keep in mind that these techniques cannot measure quantities as well as those used to obtain in situ data. Nevertheless they could perform measurements over large and often inaccessible areas. A particular example of this problem is the soil moisture determination. Remote sensing techniques can measure only the surface layer, approximately 5cm thick, but repetitive measurements could be made over very large areas. The main task is: how could we make the best use of these measurements, taking into account that they are not very detailed but that they refer to large areas (Schmugge, 1987).

From the physical point of view, microwave remote sensing of soil moisture is based primarily on the strong sensitivity of this frequency to changes in the dielectric constant of the surface, especially to those changes caused by soil moisture or to the boundaries between water and land. The dielectric constant of water is about 80, while that of dry soil is about 3. The dielectric constant of very wet soils may approximate 30. It is well known that the microwave backscattering coefficient is also dependent on surface roughness and vegetation cover. A review of the studies using active microwave sensors for soil moisture monitoring is difficult to resume, due to the great number of studies that have been done. Nevertheless, among several other research groups, the Kansas University team formely headed by Ulaby (Ulaby and Batlivala, 1976-a,b; Ulaby et al. 1979) has been done a very good work. The basic conclusion of these studies is that the longer wavelenghts are best suited for studies related to penetration within vegetation volumes and sampling depth. However, the longer wavelenghts are more sensitive to surface roughness and incidence angle variations. Thus the best "compromise" wavelenght appears to be about 5 to 6cm (C-band). These results are primarily for like polarized radars, i.e., where the transmitted and received radiation have the same polarization. Recent studies have indicated that the cross polarized returns are less sensitive to the surface roughness (Schmugge, 1987).

The applicability of remote sensing techniques to the determination of evapotranspiration rates, results from the ability to estimate surface parameters that affect the moisture flux of the land surface. These parameters include the incoming solar radiation (Diak et alii, 1983), surface albedo, vegetation cover, including both amount and status (Jackson, 1985; Tucker et alii, 1985), surface temperature (Carlson, 1985; Price, 1983) and surface soil moisture.

Most of the approaches using surface temperature observations, rely on the solution of the energy balance equation. In these approaches, the components of the energy flux at the surface are expressed in terms of the surface temperature and on a set of routinely available meteorological variables. The energy balance equation is then solved iteratively, until both the calculated surface temperature and the observed temperature agree. Recently, several reports have been published on the application of these techniques using satellite data. For example the results obtained from AVHRR data (NOAA series) should be mentioned (Carlson, 1985; Taconet et al.,(1986a).

More recently we have performed the combination of the estimates on incoming solar and longwave radiotion, albedo related to surface soil moisture, surface temperature estimates from thermal infrared data and surface soil moisture from an active microwave sensor (C-Band Scatterometer). This approach was used to develop a method to estimate the evaporation from remotely sensed data (Soares, 1986; Soares et al., 1988). Furthermore studies were carried out, in order to relate repetitive measurements of the surface temperature and soil moisture to the hydraulic properties of the soil. The basic assumption here is that soils with different hydraulic characteristics will dry at different rates. These drying rates will be manifested by variations in surface temperature and soil moisture (Bernard et al., 1986).

The next step would be to extend this methodology to satellite data. In this context, a sensor system with a multiparameter capacity such as the SIR-C/X-SAR, would provide an unique and excellent opportunity to improve these studies.

Taking into account these considerations, the following objectives were established for this study:

1) to develop an algorithm to monitor the hydrological cycle over agricultural areas using SAR imagery and meteorological data:

2) to develop algorithms to classifiy and enhance digital SAR images. There is an expectancy that these data would be very hepful for applications with future spaceborne SAR systems; e.g. EOS, ERS-1 and Radarsat;

3) to verify the possibility to discriminate among cultures present in the test site by the time of the experiment and confirmation of the qualitative attenuation properties of the vegetation cover as related to the radar parameters frequency, polarization and angle of incidente;

4) to help the establishment of a data base on a multiparameter SAR system relying on soil/vegetation descriptors.

## 2.3 - APPROACH

### 2.3.1 - DESCRIPTION OF THE TESTE SITE

The experimental study proposed would be conducted at the Bebedouro Irrigation Project, located at the northern Rio São Francisco valley. This test site is located at Northeast Brazil, State of Pernambuco, approximately 42km north of Petrolina (Figures 1, 2 and 4). This irrigation project is being developing by EMBRAPA/CPATSA. The irrigated area is 1750ha large. The size of the individual fields varies between 5 and 12ha.

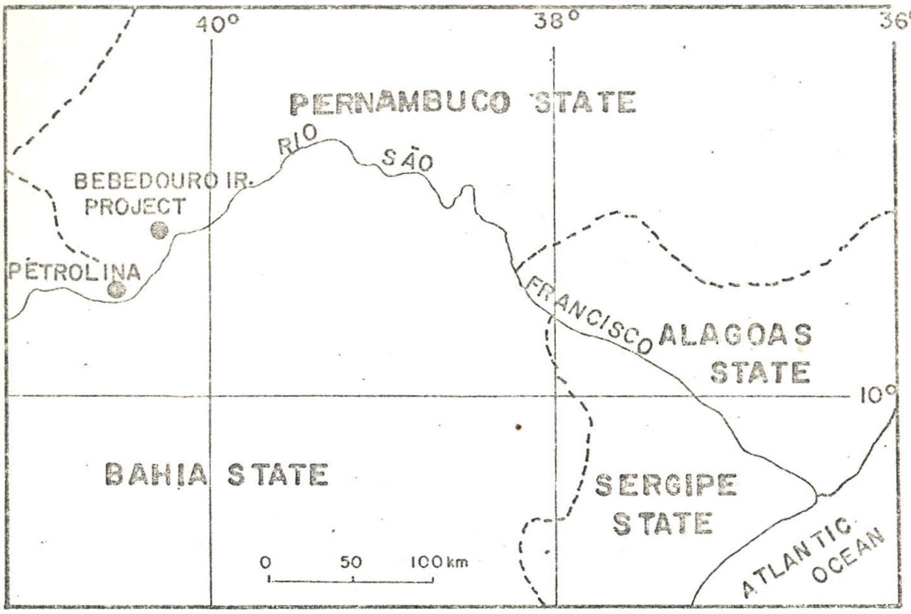


Figure 1 - Localization of the Bebedouro Irrigation Project at NE- Brazil.

The "Centro de Pesquisas Agropecuárias do Trópico Semi--árido" CPATSA (Research Center for Agriculture and Cattle Raising of Semi-Arid regions) was established to improve and to develop new agricultural and cattle raising techniques to be applied specially at the dry sections of Northeast Brazil, totalling an area of approximately 1,8 million km². CPATSA has also made an intensive effort in the evaluation and application of new remote sensing techniques, with the technical advise from INPE. Actually CPATSA has a strong interest on the application of remote sensing techniques to study problems related to soil hydrology: soil moisture and dryness, evapotranspiration and soil and water salinization due to inappropriate irrigation practices, are among the main topics of research.

The climate of this region is classified after Köppen as of Bsh'w type, with minima air temperature of 14$^{o}$C and maxima of 39$^{o}$C, annual precipitation is 391,5mm, relative humidity varies from 56,7 to 67,1% and annual evaporation is 2106mm (Faria et al., 1982).

A specialized team from EMBRAPA described some of the

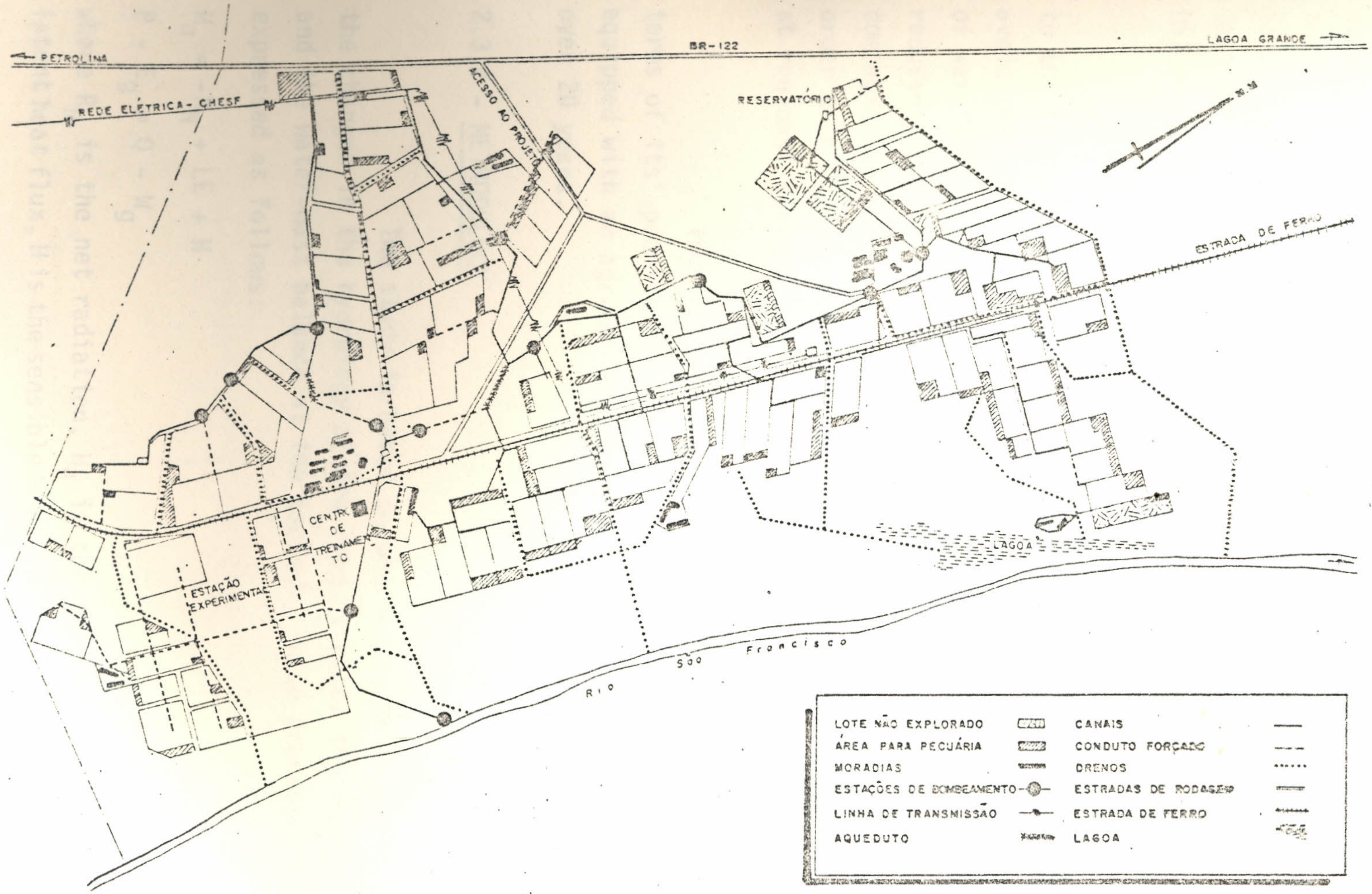


Figure 2 - Location of irrigation plots at Bebedouro Irrigation Project.

hydraulic and operational problems related to the irrigation projects in this region. According to these authors, the following aspects of irrigation must be considered to increase food production: 1) establishment of an irrigation calendar, to properly distribute water to the fields, during the growing cycle of each culture, and 2) there is a demand for highly efficient irrigation methods, easy to implement and to operate (Silva et al., 1981; Faria et al., 1982; Millar, 1988; Valdiviezo-Salazer, 1985a,b).

The determination of the proper water volume according to the demand of each culture, is of great importance, to possibly avoid that the short-term yields are reduced due to excess or deficit of water. On a long term basis (one year) the yields could be strongly reduced due to deficient drainage, soil salinization and by soil compactation due to excess of humidity during the tillage practices. In order to minimize such problems, an estimation of surface soil moisture at regional scale based on satellite data is of great importance.

The test site of Bebedouro is fully described (maps) in terms of its' pedological and geological characteristics. It is also equipped with an agrometeorological station that has been operational over 20 years.

### 2.3.2 - METHODOLOGY

The study is based on monitoring the processes that drive the changes in the hydrology of the land surface: the energy balance and the water-mass balance at the surface. These processes can be expressed as follows:

$$H_a = -R_N + LE + H \qquad (1)$$

$$P - E_g = Q - W_g$$

where $R_N$ is the net radiation, $H_a$ is the soil heat flux, LE is the latent heat flux, H is the sensible heat flux, P is the precipitation, $E_g$ is the evaporative flux, Q is the runoff, and $W_g$ is the change in soil moisture. Figure 3 shows a simplified two layer model that describes the heat and mass fluxes for bare soil.

As stated above, we have worked with such a model (that would be extended to satellite data) using a C-band scatterometer to monitor temporal changes of surface soil moisture (0-10cm) and an infrared radiometer to measure the surface temperature (Soares et al., 1988). In the case of Bebedouro Irrigation Project the runoff has not to be considered (flat surface and almost no rain). Hence, the soil moisture, $W_g$, will be the result of the surface balance (P-E) and the flux at the first layer/second interface ($Z_1$, Figure 3). In a similar way the temporal evolution of the first layer temperature, $T_g$ (assumed to be equal to the surface temperature, Ts) is a result of the atmospheric forcing and heat transfer at level $Z_1$.

The water flow equations are:

$$\frac{\partial Wg}{\partial t} = \frac{P - Eg}{Z_1} + C\,(W_2, Wg)\,(W_2 - Wg) \tag{3a}$$

$$\frac{\partial W_2}{\partial t} = \frac{P - Eg}{Z_2} \tag{3b}$$

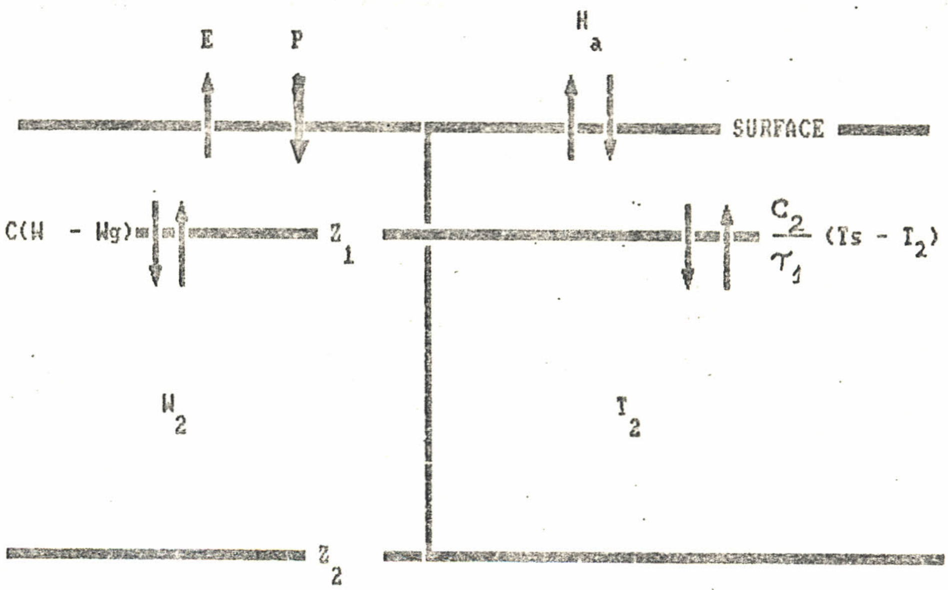


Figure 3 - Description of the simplified model to monitore vertical transfer of wafer and heat.

where $E_g$ is the evaporation flux at the soil surface expressed in depth of water per unit time: $Z_1$ and $Z_2$ (10cm and 120cm) are the thickness of the two layers respectively; C is a "pseudo-diffusivity" (Bernard et al., 1986), that depends on $W_2$ is the representative water content in the second layer. The heat flux are expressed as follows (Deardorff, 1977, 1978).

$$\frac{\partial Tg}{\partial t} = - C_1 H_a - C_2 (T_g - T_2) \qquad (4a)$$

$$\frac{\partial T_2}{\partial t} = - \frac{Ha}{Cg(365\ DG\ \tau_1)^{1/2}} \qquad (4b)$$

$T_2$ is the representative temperature of the second layer assumed as in Taconet et al. (1986a) equal to the air temperature during the last 24h period, Cg* is the heat capacity of the soil, Dg* is the thermal diffusivity of the soil and $\tau_1$ is the period considered (24h). $C_1$ and $C_2$ are given by:

$$C_1 = \frac{2\pi^{\cdot 1/2}}{Cg(Dg\ \tau_1)^{1/2}} \text{ and } C_2 = \frac{2\pi}{\tau_1}$$

These equations (3a to 4b) are linked to equations (1) and (2). LE and H from equation 1 can be obtained by classical formulas (the transfer coefficients can be estimated according to Soares (1986), Taconet et al., (1968a), taking into account the meteorological data).

The following ground truth data would be obtained during the SIR-C/X-SAR Experiment (or shortly before or after, depending on the type of the data):

1 - "In situ" data acquisition:

a) meteorological routine data to be obtained from - EMBRAPA/ CPATSA Agrometeorological Station:

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*$C_g$ and $D_g$ depends on $W_g$ (Taconet et al., 1986-a).

air temperature and humidity,
wind (velocity),
global radiation,
Pan evaporation,
Precipitation rate and frequency (probably there will be no rain at all) during the Shuttle overflights).

b) depth of water at the irrigation plots.

c) micro-meteorological tower (1 at least; 2 or 3 if possible) automatic estimation of surface fluxes based on a simplified aerodynamic method following Itier (1981) and Perrier et al. (1975, 1976). These data will be employed for comparison purposes at local scale.

d) acquisition of soil samples for the granulometric analysis. The samples will be representative of the entire area.

e) acquisition of soil samples for moisture measurements in order to calibrate SIR-C data for surface soil moisture estimations following Wang et al. (1986). The gravimetric method will be used; the soil samples will be taken from the 0-5cm layer over three selected sites with three different average soil moisture (induced by different irrigation dephts). The area surface of each site would be about 10ha and about 100 samples would be taken in each one.

f) acquisition of other relevant agronomic parameters, such as density of seeding, soil type (pedological maps), roughness, and estimation or measurement of the Leaf Area Index of the cultures.

g) acquisition of characteristic curves of the soils available at CPATSA and of a soil water profile (by neutron probe sampler) and of the suction potential soil profile (by tensiometers) to confirm the actual characteristics curve and estimate the representative water content of the soil ($W_2$).

2 - Data from airborne and spaceborne sensors (other than SIR-C/ X-SAR):

a) surface temperature (1km x 1km pixel) from AVHRR/NOAA as ancillary data set to fit the temperature estimated by the two layer bare soil models (four images/day can be registered at INPE facilities);

b) surface temperature from an airbone infrared radiometer (PRT-5). These ancillary data will be also used to fit the simulated surface temperature (from the two layer method);

c) backscattering coefficient to be obtained from a dual frequency/dual polarization airborne scatterometer (C - and x X-bands), from INPE, if it is operational at the time of the Experiment;

d) multispectral images from SPOT or LANDSAT scanners series by the time of the Shuttle overflights in order to improve the regional monitoring;

e) color infrared aerial photograhs from the area of interest;

f) other ancillary data available.

The airbone sensors would be operated with the airplane Bandeirante EMB-110-B1 from INPE.

## 3. SIR-C/X-SAR DATA REQUIREMENTS

The data requirements concern to the two periods envisaged for the two Shuttle flights (January/July), in order to verify the seasonal variations of vegetation cover, soil use, atmospheric forcing (if any) and to test the methodology after fitting those data obtained from the first SIR-C/X-SAR overflight. For the soil moisture investigations, the following SIR-C data are required:

- L-band and C-band quad polarization (HH, VV, VH, HV) data at 20° incidence angle. The cross-polarization will be used to verify the lower sensitivity to soil roughness (Schmugge, 1987).

For vegetation observations:

- X-band data (VV polarization) at the same angle of incidence, although greater angles of incidence would be better to perform this task.

The products required in a standard form (level 2 products) are:

(1) 4 - look data
(2) detected image data

The special products (level 3) needed are radiometrically calibrated products in backscatter coefficient. If available, the same products from X-SAR are required.

According to both the SIR-C Science Plan (JPL Publication 86-29) and to the X-SAR Science Plan (DFVLR Mitt, 85-71), and to the objectives of this proposal, the data required must be in 8-bit quantization level, dual frequency (SIR-C) quad-pol (SIR-C) and in a low-resolution mode (10 MHz bandwidth). This corresponds to a 15km swath width and we would like to have 65km a long track. The geographical coordinates of the Bebedouro Irrigation Project are presented in figure 4.

## 4. ANTICIPATED RESULTS

The anticipated results, taking into account the objectives of this study, are:

1) the establishment of a methodology to estimate soil moisture and evaporation rates at a regional scale. This methodology is of interest for the Irrigation Project of Bebedouro, for climatological studies and as an input to numerical models for weather forecasting, based on SAR systems that would become operational in the mid 90's, such as the Earth Observing System (EOS), RADARSAT and other systems;

2) the set up of a data base relying on a multiparameter SAR system and it's interaction with different tropical agricultural crops;

3) development and acquisition of algorithms for the classification and enhancement of digital SAR images, that are expected to be very helpful for agricultural and hydrological applications in the future (EOS, RADARSAT, ...).

## 5. MANAGEMENT PLAN

### MANAGEMENT

The Principal Investigator (P.I.) for the study proposed, will be Dr. João Vianei Soares, Agricultural Engineer, employee at INPE, Docteur Ingénieur at Université de Paris VII, 1986, areas of interest: radar systems, soil and vegetation moisture, agrometeorology, modeling of soils and vegetation. His functions are to coordinate the proposed study in close cooperation with Dr. Hermann Johann Heinrich Kux, the main Co-Investigator,Geographer, Doctor rer. nat. at Universität Freiburg/F.R. Germany, 1976; areas of interest: soil hydrology, SAR data evaluation.

### OTHER CO-INVESTIGATORS FROM INPE

- Mr. Ulf Walter Palme, Agronomist, M.Sc. in Remote Sensing at INPE 1986. Areas of interest: modelling of soil moisture and vegetation.
- Mrs. Sherry C. Chen, Agronomist, M.Sc. at Cornell University/USA, 1971. Areas of interest: experiment design and data evaluation.
- Dr. Gerald Francis Banon, Electronic Engineer, Docteur d'État at Université Paul Sebatier, Toulouse, France, 1977, areas of interest: stochastic processes and SAR image processing techniques.

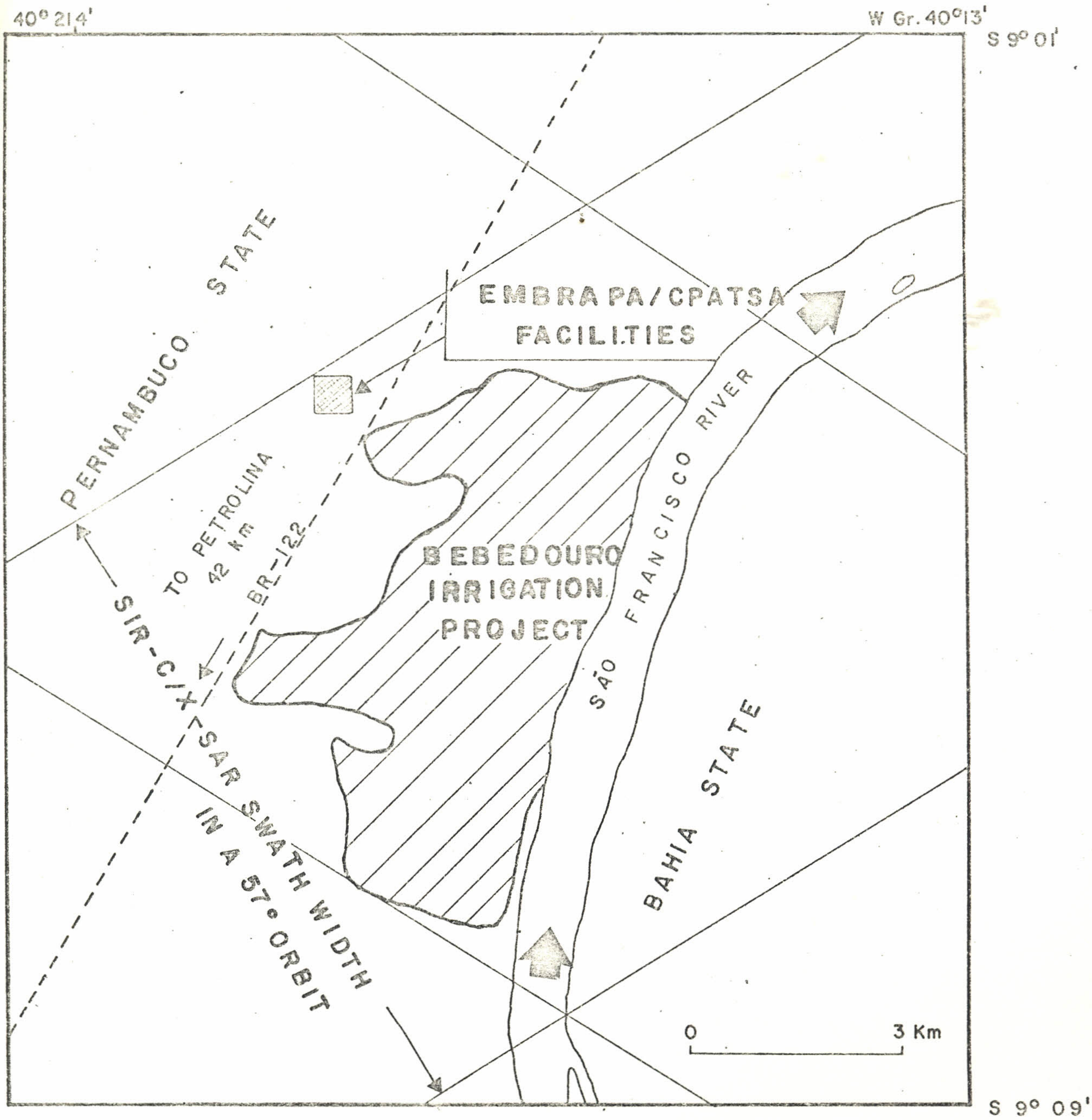


Figure 4 - Localization of the area under study and of SIR-C/X-SAR possible swath width in a 57º orbit (ascending and descending).

CO-INVESTIGATORS FROM EMBRAPA/CPATSA

- Mr. Antonio Carlos Shiffino, M.Sc. in Geography, 1984, Coordinator of the Natural Resources Evaluation Programme.
- Mr. Iedo Bezerra de Sá, Agronomist, M.Sc. in Remote Sensing at INPE (in conclusion), Specialist in vegetation Science.
- Mrs. Eliane Nogueira Choudhury, Agronomist, M.Sc. in Soil Physics, 1976, Specialist in Irrigation.
- Mr. Gilberto Cordeiro, Agronomist, M.Sc. in Irrigation and Drainage, 1980.

EMBRAPA/CPATSA will participate essentially at the following activities:

- to obtain all ancillary data of relevance to this study, such as, information on soils (physical, chemical, infiltration data), vegetation, microclimate, etc.
- to perfrom, together with INPE's team, detailed ground truth collection specially during the Shuttle overflights.
- to evaluate SAR data to be obtained during the SIR-C/X-SAR Experiment, together with the INPE team involved in this study. INPE will perform all other activities mentioned in the text, partially in close cooperation with EMBRAPA/CPATSA.

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