# USE OF PASSIVE MICROWAVE SATELLITE OBSERVATIONS TO STUDY SEASONAL INUNDATION PATTERNS IN THE PANTANAL WETLAND OF BRAZIL

Suzanne J. Sippel
John M. Melack
Department of Biological Sciences
University of California
Santa Barbara, CA U.S.A. 93106

Bhaskar J. Choudhury
Hydrological Sciences Branch
NASA/Goddard Space Flight Center
Greenbelt, MD U.S.A. 20771

## ABSTRACT

The 37 GHz polarization difference observed by the Scanning Multichannel Microwave Radiometer (SMMR), which was operated on board the Nimbus-7 satellite, provides a sensitive indicator of surface water. These passive microwave data provide information on seasonal inundation patterns in large tropical wetlands which is presently unavailable. Although the SMMR data are of low resolution, we have been able to estimate seasonal changes in the area inundated within a group of pixels in the Amazon River floodplain by using mixing models which incorporate the major end-members of the observed microwave signatures. We are presently working with SMMR data from the Pantanal wetland with the goal of developing similar mixing models for estimation of seasonal inundation area throughout the region. Examples of the data for the Pantanal are given in this paper.

## RESUMO

A diferença de polarização na freqüência de 37 GHz, observada pelo "Scanning Multichannel Microwave Radiometer" (SMMR) a bordo do satélite Nimbus-7, proporciona um indicador sensível da presença de água superficial. Estes dados de microondas passivas fornecem informações sobre padrões de inundação estacional nas grandes áreas úmidas dos trópicos. Embora os dados de SMMR sejam de baixa resolução, tem sido possível estimar mudanças estacionais na área inundada num grupo de pixels na várzea do rio Amazonas, utilizando modelos que incorporam os principais constituintes do sinal de microondas observado. Presentemente, estamos trabalhando com dados de SMMR para o Pantanal, com o objetivo de desenvolver modelos semelhantes e estimar a área estacionalmente inundável na região. Exemplos dos dados para o Pantanal são apresentados neste trabalho.

## 1. INTRODUCTION

Information on inundation patterns in large tropical wetlands is increasingly required to study the role of these ecosystems in global biogeochemical cycling, and has long been needed for conservation and land management purposes. The remoteness, large extent, and nearly continuous cloud cover during the wet season in many tropical wetlands make it difficult or impossible to use conventional applications of aerial photography or Landsat for observation of inundation patterns (Sippel et al. 1992). Forested wetlands present the additional challenge of detecting standing water beneath closed vegetation canopies.

Passive microwave measurements from satellites can reveal large-scale inundation patterns, even in the presence of cloud cover and dense vegetation (Giddings and Choudhury 1989, Choudhury 1991). However, the spatial resolution of the passive microwave data is about 25 km at the 37 GHz frequency, and this coarse resolution has so far limited the application of these data in studies of the land surface. At this resolution, even large wetlands in South America will generally be imaged as mixed pixels containing substantial fractions of open water, flooded vegetation, and dry land.

The ability to estimate fractional inundation area from passive microwave observations considerably improves the usefulness of these data for regional-scale wetland studies. Sippel et al. (1993) used mixing models of the major end-members of the observed microwave signature to determine the fractional inundation area at a study site in the central Amazon River floodplain. We are presently using a similar approach to study flooding patterns in the Pantanal wetland of Brazil.

## 2. PASSIVE MICROWAVE SENSOR SYSTEMS AND DATA

Satellite-borne passive microwave radiometers measure the natural thermal emission from the Earth's surface (Ulaby et al. 1981); measurements are expressed as brightness temperatures (in Kelvins). The brightness temperature of a surface feature is proportional to the product of its effective temperature and the emissivity of the medium. At satellite altitude, atmospheric water vapor and air temperature also affect the brightness temperature measured by a radiometer. For the study of land surface features, the effects of atmospheric variability can be minimized by calculating the difference between vertically and horizontally polarized brightness temperatures at the 37 GHz frequency. We will hereafter use $\delta T$ to refer to the 37 GHz polarization difference observed by a passive microwave radiometer at satellite altitude. The theoretical basis for interpretation of 37 GHz emission behavior from the land surface has been detailed by Choudhury (1989).

A continuous record of vertically and horizontally polarized, 37 GHz passive microwave observations from satellites is available for late 1978 to the present. From 1978 to August 1987, these data were collected by the Scanning Multichannel Microwave Radiometer (SMMR), operated on board the Nimbus-7 satellite (Gloersen et al. 1984, Fu et al. 1988). Similar observations are available from the Special Sensor Microwave/Imager (SSM/I), which began operation in July 1987 and continues operation now as part of the Defense Meteorological Satellite Program (NASA 1987). SSM/I data are not directly comparable with SMMR data because of differences in scan geometry between the two sensor systems.

The polarization difference at the 37 GHz frequency provides a sensitive indicator of the presence of surface water (Choudhury 1991). The lowest $\delta T$ (ca. 4 K or less for SMMR) is observed for non-flooded land covered with dense vegetation. Perennial tropical savannas lacking surface flooding show SMMR δT around 5-7 K throughout the year (Justice et al. 1989). Higher SMMR δT values are observed for more sparsely vegetated land; the most barren deserts show δT as high as 30 K. The SMMR δT for calm standing water is ca. 60 K. Water-saturated, exposed soils would show a similar δT if the soil surface were very smooth, but lower values are typically observed because of the roughness of soil surfaces. Increasing surface roughness, whether as topographic variation on land or as waves on water surfaces, decreases δT.

The observed seasonal variation in δT for South American floodplains reflects seasonal changes in inundation area rather than vegetation water content. Giddings and Choudhury (1989) and Choudhury (1991) have shown that there is a close correspondence between seasonal variation in river stage height and δT for several South American floodplains. Comparison of δT in flooded areas and adjacent upland areas indicated that atmospheric effects are unlikely to explain the strong seasonal variation in δT in wetland areas, a conclusion which is supported by theoretical calculations of the effect of atmospheric water on microwave transmission (Choudhury 1989). Seasonal changes in the water content of vegetation have a small but detectable effect on δT (Hallikainen et al. 1988, Justice et al. 1989), but this effect is more pronounced where large seasonal changes in biomass occur.

Global SMMR observations are available for approximately 6-day intervals, and are compiled separately for night and day (local equator crossings at noon and midnight)(Gloersen et al. 1984, Fu et al. 1988). The SMMR data presented here are drawn from the global data set of 37 GHz δT observations that was originally studied by Choudhury (1989). This data set uses the daytime SMMR 37 GHz brightness temperatures, which have been calibrated and remapped into 0.25° x 0.25° grid cells on a linear latitude/longitude projection. After calculation of δT for each grid cell, the δT observations were ranked within each month and the second lowest value (usually out of 4) was selected. The purpose of this screening was to eliminate outlying values that might have resulted from particularly dense cloud cover or temporary saturation of soils after heavy rainfall. We analyze data only for the years 1979-85.

## 3. MIXING MODELS

At low water, standing water occurs in the river channels and in permanent floodplain lakes, which are expected to show δT of ca. 60 K. The remainder of the land is non-flooded floodplain and upland; these areas are expected to show δT of ca. 4 K. A mixing model with two end members (60 K and 4 K) should therefore account for the observed δT ($\delta T_{obs}$) at low water:

(1)

$$\delta T_{obs} = (\delta T_{water})f_w + (\delta T_{upland})(1-f_w)$$
$$= (60)f_w + (4)(1-f_w)$$

where $f_w$ is the fractional area of open water visible to the radiometer, and $1-f_w$ is the sum of the upland and dry floodplain area.

As the water levels rise, the vegetated floodplain becomes inundated. Areas with standing water beneath vegetation comprise a third end-member in the mixing model whose δT has not been quantified by previous studies:

(2)

$$\delta T_{obs} = (\delta T_w)f_w + (\delta T_u)f_u + (\delta T_f)f_f$$
$$= (60)f_w + (4)f_u + (\delta T_f)f_f$$

(3)

$$1 = f_w + f_u + f_f$$

where $f_u$ and $f_f$ are the fractional area of upland and floodplain, respectively, and $\delta T_f$ is the $\delta T$ for inundated floodplain. Once $\delta T_f$ is known, the three fractional areas can be solved by simultaneous solution of equations (2) and (3).

Sippel et al. (1993) empirically determined the $\delta T_f$ to be 17 K for flooded rainforest west of Manaus. We are presently determining the $\delta T_f$ for various subregions of the Pantanal, which will make it possible to estimate seasonal inundation area in the Pantanal.

## 4. RESULTS

The Pantanal is a seasonally inundated floodplain of ca. 140,000 km² in the upper Paraguay River basin. Figure 1 shows the δT data for the Pantanal wetland and surrounding upland for June 1979. The southern Pantanal was at its highest water levels for the year when these data were collected. On this date, the δT values range from ca. 3 K to a maximum of ca. 60 K. During the driest period of the year (December), the δT values do not exceed 15 K except where several large lakes occur, causing the values to approach 20 K. Nonfloodable savanna usually ranges from 3-4 K, showing almost no seasonal variation. This observation reveals that seasonal changes in vegetation biomass in the savannas have little effect on δT values.

Seasonal variation in the mean δT for a 4 grid-cell study site north of Corumbá corresponds well with seasonal variation in stage of the Paraguay River (Figure 2). This agreement suggests that inundation of the floodplain by the main stem, rather than the local rainfall which typically peaks several months earlier, drives the seasonal pattern in δT for the Paraguay River floodplain. The lack of a strong effect of local rainfall may be partly explained by the screening procedure, which eliminated extreme δT values within a particular month and thus resulted in monthly δT values that reflect gradual seasonal changes, rather than ephemeral effects such as saturation of soils by rainfall.

In the Pantanal, potential applications of the information available from passive microwave observations include;

1) using the measurement of inundation area over time to extrapolate biogeochemical fluxes such as methane emission to the entire region,

2) detecting long-term changes in flooding patterns due to natural or anthropogenic causes,

3) defining the extent to which nearby rivers or local rainfall control flooding patterns in a particular floodplain area; of interest for hydrological studies and flood prediction,

4) providing a site-specific record of inundation area over time for ecological and limnological studies.

By combining the use of mixing models and some knowledge of the study site, we can increase the information on inundation patterns available from SMMR (1978-1987) and SMM/I (1987- present) despite the low resolution of the data. This kind of information on inundation patterns has many applications and is currently unavailable from other sources.

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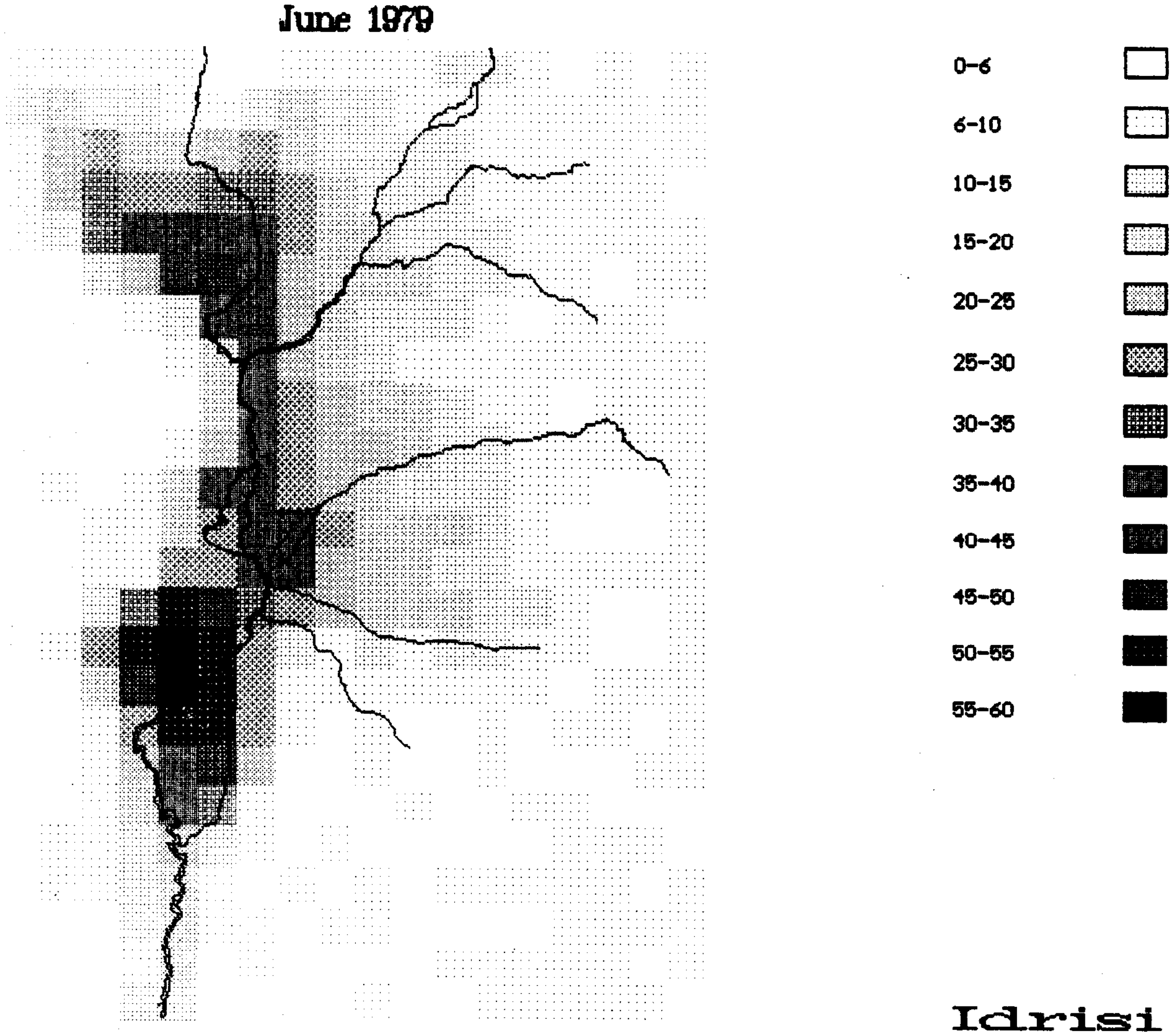

Fig. 1. SMMR 37 GHz brightness temperature difference (δT) observations for the Pantanal wetland and adjacent upland for June 1979 (16°00'S-22°00'S, 54°30'- 59°00'W). The Paraguay River runs from north to south.

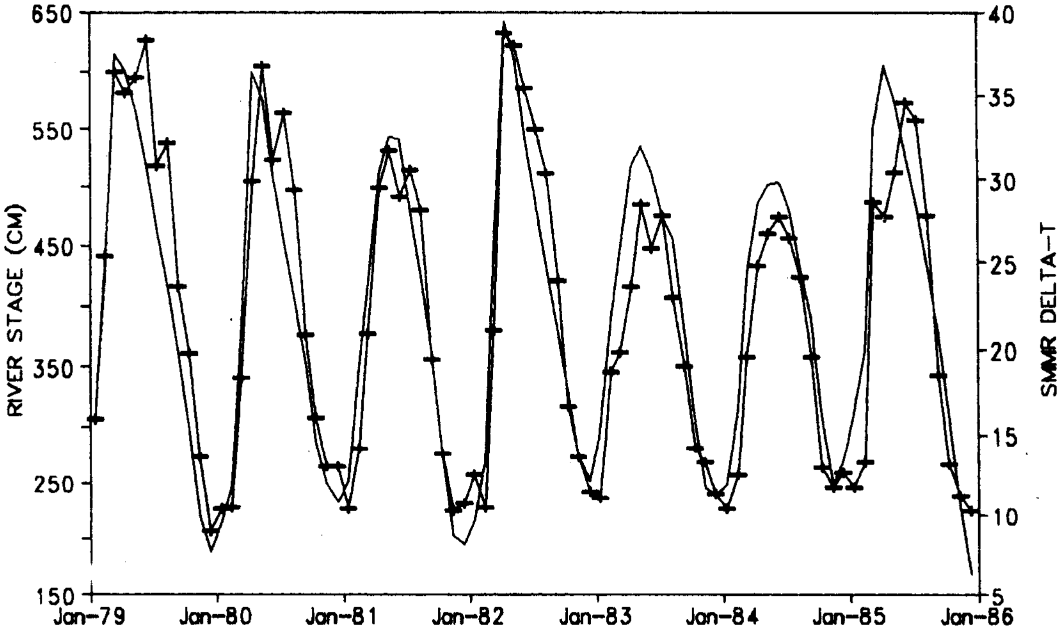

Fig. 2. 7-year time series of the SMMR 37 GHz brightness temperature polarization difference (δT) graphed together with daily stage height for the Paraguay River at Ladario (just south of Corumbá). The δT data are for a 4 grid-cell aggregate just north of Corumba along the Paraguay River. The line without symbols is the stage data.