MONITORING SOIL CONDITION IN LA PLATA BASIN ECOSYSTEMS USING AMSR-E DATA

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Abstract

The La Plata Basin (LPB) is located in South America and covers about 3.6 million km^2. It is the fifth largest basin in the world with extensive and important native forest, very productive agricultural areas, wetlands, important human settlements and infrastructure developments. The principal sub-basins are those of the Paraná, Paraguay and Uruguay Rivers

A multitemporal analysis of AMSR-E signatures, covering a time interval between May 2006 and the end of 2007 was carried out. In particular, maps based on the normalized polarization index (PI) at C band and the normalized frequency index (FI) at C and Ka band were produced. The study was carried out over the whole basin, where three ecosystems were analyzed in more detail: Chaco Forest, the Submeridional Lowlands, and the Paraná river floodplain. Information about fundamental variables, such as forest biomass, water level of main rivers and precipitation distribution maps were available to us. Along the Paraná river, multitemporal PI images show wide regions characterized by higher PI values, related to flooding. The spatial and temporal extent of these effects is related to rain intensity and duration, velocity of flooding, channel and floodplain morphology. Within the Chaco forest, a strong rainstorm produced an appreciable increase of PI and FI also in developed forest areas. This result can be important, since the problem of forest opacity receives much attention at present time. Within the Submeridional Lowlands, the PI response was carefully analyzed together with precipitation information showing the sensitivity of this index to soil condition.

1. Introduction

The La Plata Basin (LPB) covers about 3.6 million km2. In terms of geographical extent, it is the fifth largest basin in the world. The principal sub-basins are those of the Paraná, Paraguay and Uruguay Rivers. The annual mean total precipitation in the De La Plata Basin is about 1,100mm, of which only about 20% reaches the sea as surface water. The other 80% is evaporated and infiltrated into the ground. Consequently, any small change in the evaporation and infiltration rate may lead to greater changes in the runoff.

The International Program on the La Plata Basin (LPB) was endorsed by the GEWEX and CLIVAR Panels of the World Climate Research Programme; it has three major topics of interest to countries in the basin:

• What climatological and hydrological factors determine the frequency of occurrence and spatial extent of floods and droughts?

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• How predictable is the regional weather and climate variability and its impact on hydrological, agricultural and social systems of the basin?
• What are the impacts of global climate change and land use change on regional weather, climate, hydrology and agriculture? Can their impacts be predicted, at least in part?

The LPB watershed contains several key ecosystems. (1) The great Pantanal wetland, shared by Brazil, Bolivia, and Paraguay behaves as a regulator of the entire LPB hydrological system by slowing the flow of the Paraguay River's waters to the Paraná River, thus avoiding a conjunction of the maximum volume and flow rates from both rivers; (2) The highlands of both Paraguay and Paraná basins are important ecological corridors linking the Cerrados to the Pantanal; (3) The Cerrado biome covers about 2,000,000 km2 of Central Brazil, 25% of the country's territory; (4) The Chaco region, another key ecosystem, is dominated by dry woodlands and savannas, and an alluvial area formed by the sediments of the Bermejo and Pilcomayo Rivers. This region constitutes a key ecological corridor among mountains, cloud forests (Yungas rainforests), high elevation deserts (Puna), and the shallow plains of the Chaco; (5) The Pampas is the ecosystem with the most fertile soils of the LPB, largely converted to agricultural production; (6) Another important biome is the Atlantic Rainforest in the northeast of the LPB, characterized by intense deforestation and agricultural use.

Current and future technology of microwave wide-swath sensors can provide daily or near daily measurements. In this line of work, a recently approved SMOS AO project "SMOS observations of La Plata Basin: analysis of products and their contribution to surface hydrology in Argentina" addresses soil moisture for climatology applications, soil condition under Chaco Forest, wetlands of the Paraná sub-basin, and soil condition in agricultural lands.

As a first step for understanding the interactions between passive microwaves and these ecosystems, we analyzed a set of AMSR-E data covering the period 2006-2007. This paper presents observed features and their interpretation. Work in progress includes electromagnetic modeling in the Chaco forest and more detail studies related to hydrological applications in the Paraguay sub-basin. Figure 1 shows the extent of the La Plata Basin, each one of the countries sharing this region and main rivers.

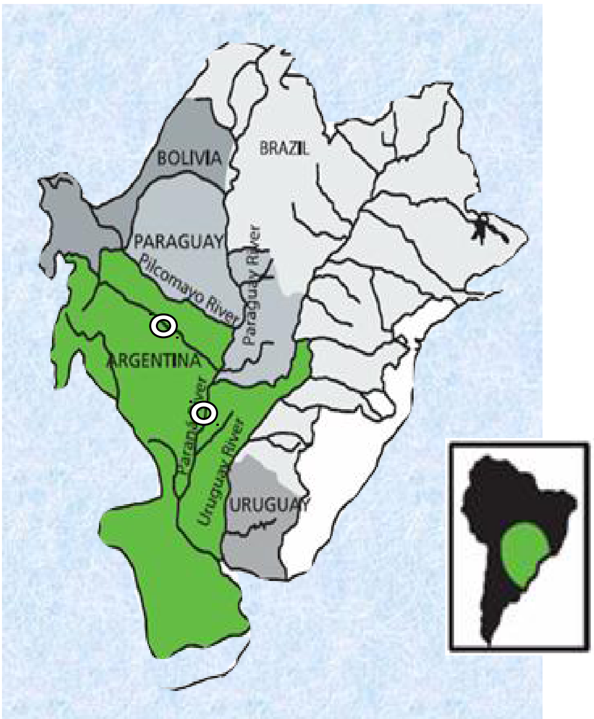

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Figure 1: La Plata basin location, extent, countries and main rivers. Argentine is shown in green. Circles in white indicate the location of the regions addressed in this presentation.

The following sections present a brief description of the AMSR-E instrument, the methodology used for data interpretation, first results obtained and conclusions.

2. The instrument and the data set

AMSR-E is a microwave radiometer operating at six frequency bands: 6.925 GHz (C),10.65 GHz (X), 18.7 GHz (Ku), 23.8 GHz, 36.5 GHz (Ka), and 89.0 GHz [1],[2]. Lower frequencies are more suitable for terrestrial applications, while higher frequencies, i.e 23.8 GHz, 36.5 GHz and 89.0 GHz, are influenced by atmospheric water vapor and clouds. A conical scanning is used, to observe the terrestrial surface with an angle of 55°. The IFOV is equal to 43 X 75 km at 6.925 GHz, is reduced to 29 X 51 km at 10.65 GHz, and is narrower at the higher frequencies. The data are stored in Hierarchical Data Format (HDF), which is compatible with NASA HDF-EOS standard. In this study, we have used L1b data, which contain values of brightness temperature, at vertical (V) and horizontal (H) polarization, corrected and calibrated. Each file, is 80 Mb, contains brightness temperature values along a 1450 km strip. The data have been downloaded from NASA site http://nsidc.org/ims-bin/pub/nph-ims.cgi/u885372. Low resolution data have been used at all frequencies.

3. The use of radiometric indexes

The exploitation of signatures made available by spaceborne radiometers was prepared by a large amount of experimental and theoretical studies. It is well known that the brightness temperature decreases with increasing soil moisture, and the better sensitivity to this effect is obtained at the lower frequencies, i.e. C band and, possibly, L band [3]. When the frequency increases, the sensitivity to soil moisture is reduced by effects of soil roughness and vegetation cover [3], [4]. Some studies were aimed at investigating also the potential of radiometry to estimate the biomass of agricultural fields [5] and forests [6]. C and X band proved to be effective in the monitoring of crops, while lower frequencies, i.e. from L to C band, are suitable to monitor forest biomass. A main operational problem in the exploitation of radiometric signatures is related to the dependence of the measured brightness temperature on two fundamental variables, i.e. the surface emissivity and the surface temperature. Since the application parameters to be monitored, such as soil moisture and vegetation biomass, are related only to the emissivity, it is necessary to have an a priori estimate of surface temperature. This estimate can be difficult, or affected by appreciable errors, especially in wide and sparsely populated areas. A possible way to overcome this problem is the use of normalized indexes, which are based on a combination of brightness temperatures, measured at different frequencies or different polarizations. The indexes do not depend on surface temperature, and keep the dependence on surface variables, such as soil moisture or vegetation biomass. The Polarization Index PI was defined as [5]:

$$PI = 2\frac{T_{bv} - T_{bh}}{T_{bv} + T_{bh}} \quad (1)$$

T_{bv} and T_{bh} are the brightness temperatures at vertical and horizontal polarization, respectively, and at a given frequency. Experimental studies, confirmed by a simple zero order radiative transfer model, demonstrated that this index is sensitive to vegetation biomass [5]. In fact, at high angles the difference between T_{bv} and T_{bh} is high over bare soils, and is reduced with increasing vegetation. A further parametric study, carried out by means of a discrete physical model, confirmed the main finding of experimental studies and pointed out that the same PI index is also sensitive to soil moisture, at least at frequencies lower than 10 GHz [7]. This dependence on soil moisture was confirmed by an experimental analysis of C band signatures collected at global scale by the SMMR radiometer [8].

As an alternative to the use of PI, combinations of brightness temperatures collected at different frequencies can be used. The basic rationale of this technique is explained below. At all frequencies, the brightness temperature is proportional to the surface temperature. However, at lower frequencies (e.g. C band) it is influenced also by soil moisture and vegetation biomass, while at the higher frequencies (e.g. Ka band) the influence of temperature is dominant [9]. Therefore, we can use the ratio between C band and Ka band brightness temperatures, as proposed in [9], or, in alternative, a Frequency Index (FI) defined as:

$$FI = 2\frac{T_{bh1} - T_{bh2}}{T_{bh1} + T_{bh2}} \quad (2)$$

T_{bh1} and T_{bh2} are the brightness temperatures at horizontal polarization and at Ka band and C band, respectively.

4. Analysis of AMSR-E observations

Chaco forest

Effects of biomass and average rainfall

A first investigation was aimed at evaluating the effects of forest biomass and soil properties on the Polarization Index at C band. Forest biomass was measured in some samples and the average yearly rainfall in the area was available. Figure 1 shows a map, with colours associated to PI at C band, with a 0-0.35 scale, collected on September 18, 2006. The lines with given rainfall values are indicated. Also the points where forest variables were measured are shown. The biomass was in a range between 60 and 150 t/ha.

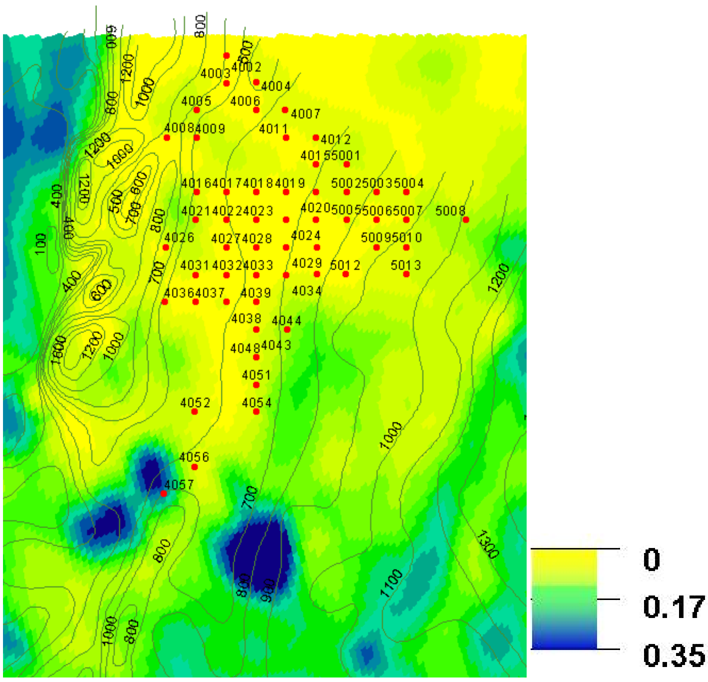

Figure 2. Map of PI measured in the Chaco forest on September 18, 2006. Red points indicate sample sites, and lines average yearly rainfall.

The multitemporal trends of PI during the winter season are plotted in Figure 2. The dates are given in Julian numbers, starting on January, 1, 2006. No severe rainstorms occurred in that period. The different colors correspond to different values of moisture, expressed as average yearly rainfall. For each moisture value, two samples, with higher and lower biomass, are taken. It is evident from the figure that the PI is affected by both the moisture and the forest biomass. The higher PI's are observed for the areas with higher average rainfall,

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as expected. For each area, the higher PI's are observed for the lower biomass values. Also this result is in agreement with theory and previous experiments.

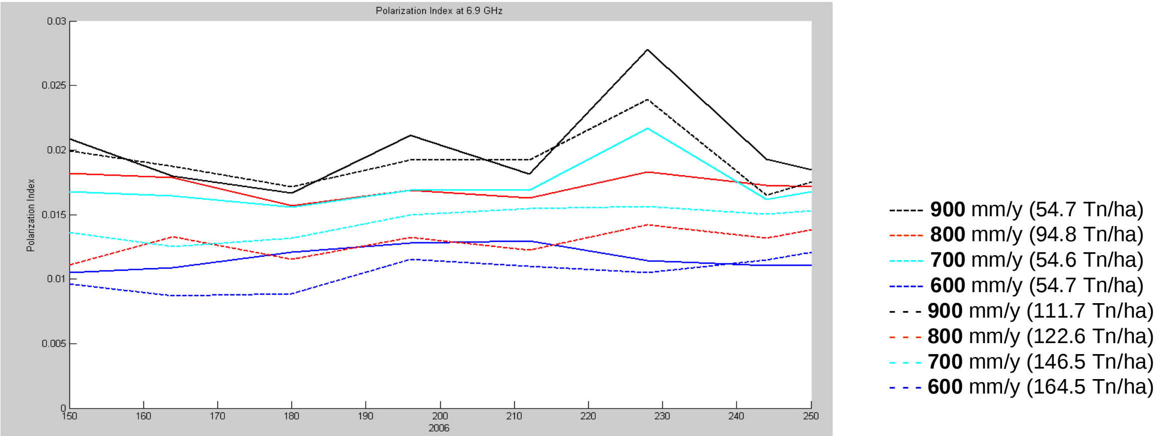

Figure 3. Multitemporal trends of PI at C band in winter time. The dates are given in julian numbers. Continuous lines: lower biomass (60-100 t/ha). Dashed lines: higher biomass (110-150 Tn/ha).

Effects of a heavy rainstorm

A heavy rainstorm occurred in the lower part of Chaco forest on September 3, 2006. The event occurred after a long dry period, so that produced a strong variation of soil moisture. Maps of PI at C band collected in the area, before and after the rain event, show and increase of PI in the lower part of the area, and also in zones in which the forest is more dense and homogeneous.

More specifically, two forest pixels have been considered, characterized by homogeneous forest cover and a biomass slightly higher than 100 t/ha. Sample 1 is closer to the area mostly affected by rain, while sample 2 is located closer to the centre of the forest. The temporal trends of FI, PI at C band and PI at X band are shown in Figure 4. A time interval of 35 days, including the rainstorm, is considered. The brightness temperature at Ka band is strongly influenced by clouds, making the interpretation of FI trends difficult. The PI shows a clear increase associated to the rainstorm (day 276) and decreases when the soil becomes again dry. As expected, the effect is more evident at C band than at X band, and is more evident for the sample located closer to the area mostly affected by the rainstorm. The increase is moderate, but appreciable, although the forest cover was uniform.

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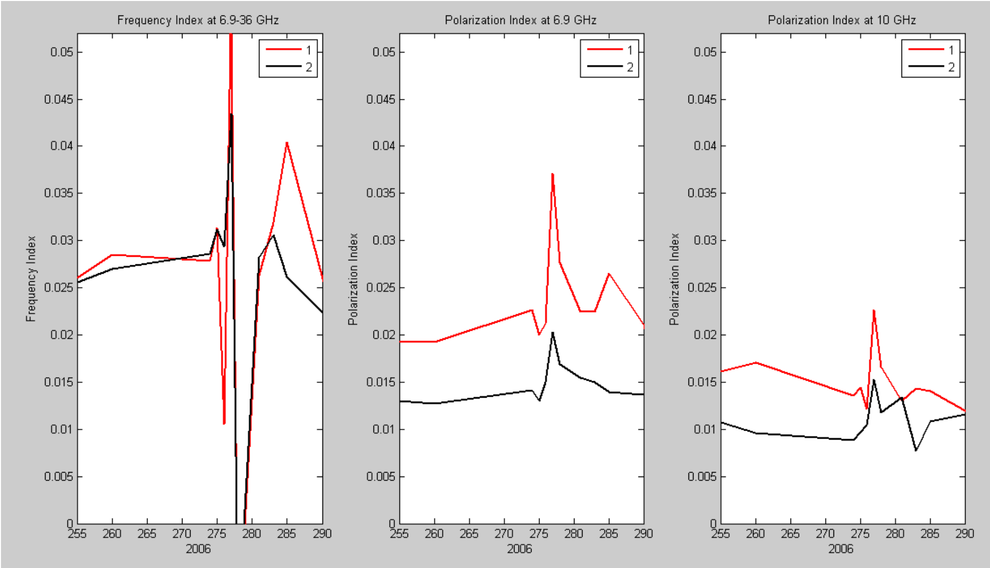

Figure 4: Temporal trends of FI, PI at C band and PI at X band, in the period including the rainstorm.

Paraná sub-basin observations

During the period of observations, important flood events took place in the Paraná sub-basin. The potential of previously defined PI and FI indexes to monitor flooding events was also investigated. It is expected that flooding produces an increase of both PI and FI, related to a strong increase of soil moisture and, in the extreme cases, to a reduction of emerged vegetation. Images of PI at C band confirm this expectation. A comparison between PI values in normal conditions and after a flooding event is shown in Figure 5. An increase of PI in the lower part of the image is observed.

In order to evaluate more specifically the variations of the indexes as a function of time, three specific points have been selected along the Parana river. The data acquired by hydrometric stations located geographically next to these points were analyzed (Figure 6).

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The trend of FI is shown in Figure 7. A polynomial interpolation was applied to all trends. The time is shown in Julian numbers, starting from January, 1 2006.

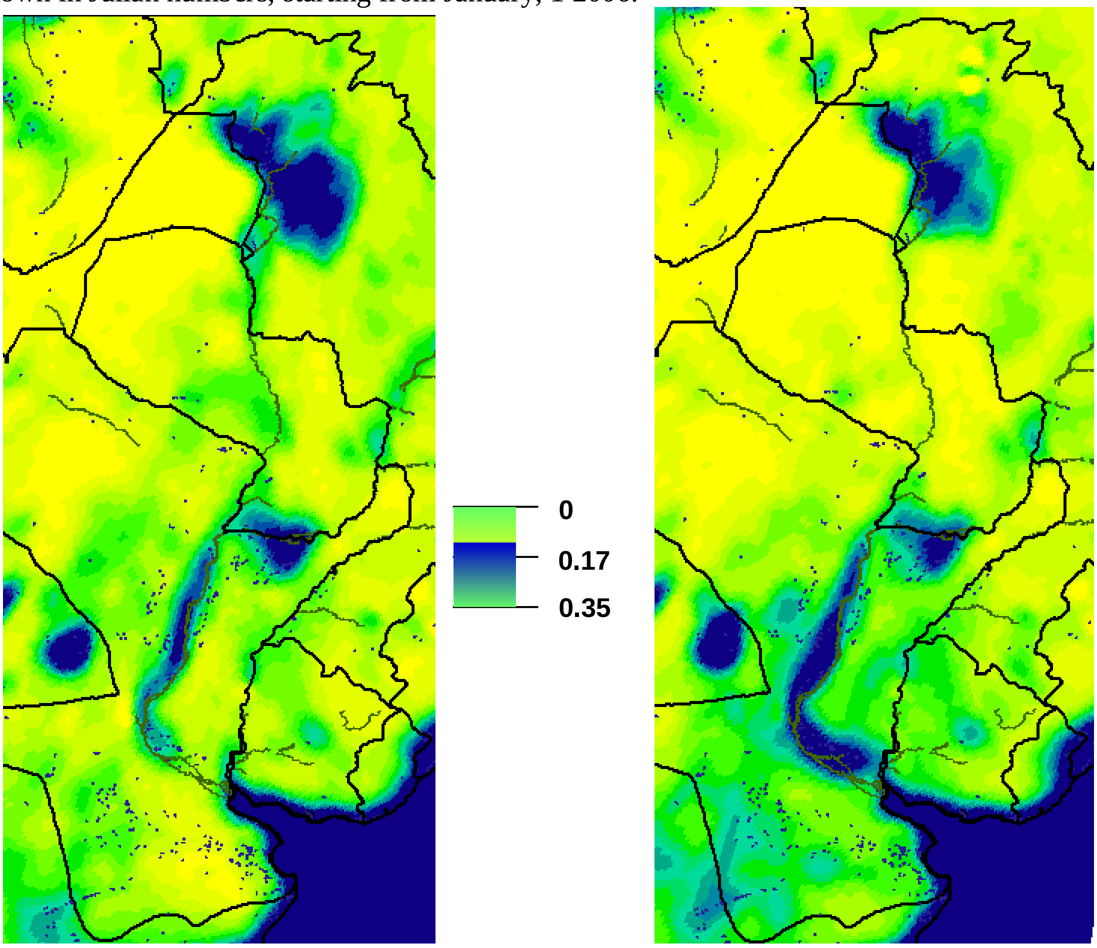

Figure 5: Maps of PI at C band in the lower part of Parana river. Left: February 8, 2007 (before flooding): Right: March 28 2007 (after flooding).

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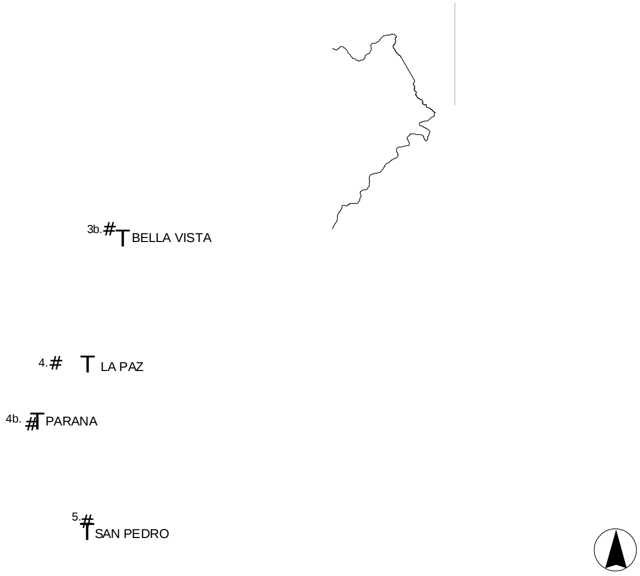

Figure 6: Location of hydrometric stations

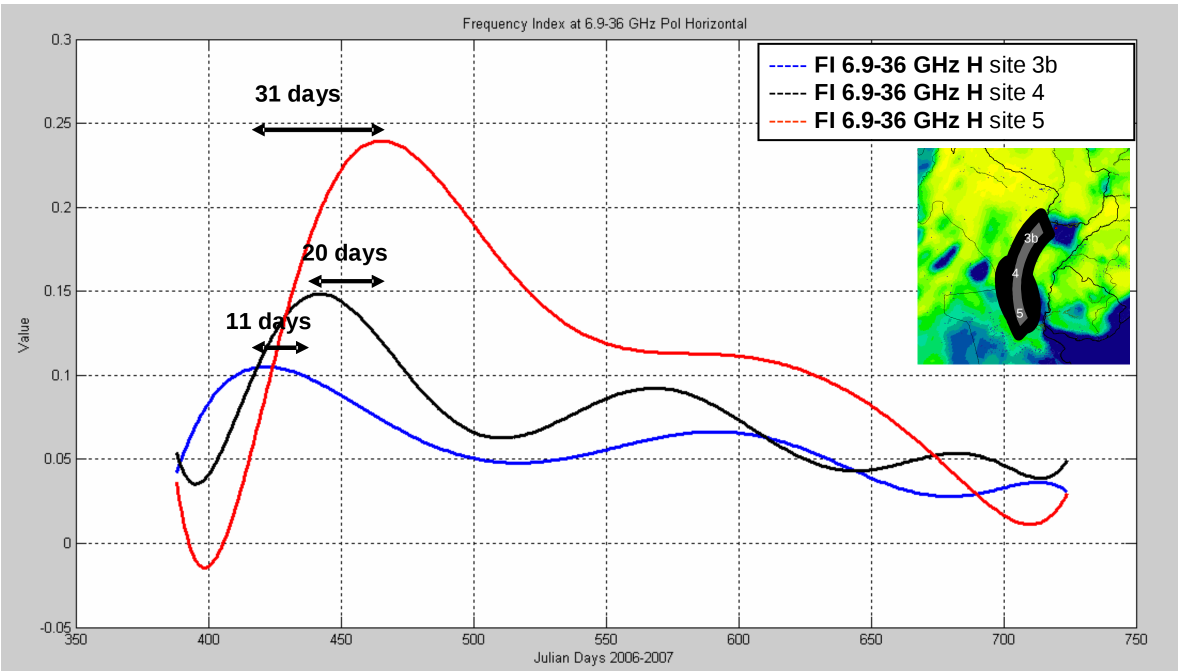

Figure 7: Flood wave temporal behavior

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In an interval located between about day 400 and day 480 (i.e. February to April, 2007) there are appreciable increases of the indexes in all points. The lag time of the flood wave is also indicated. When comparing these lag times with local stations data, sound values area obtained. Figure 8 shows these results. Site 5 shows an unusual increase due to the additional contribution of local rains. This could explain the difference in lag time between AMSR-E and hydrometric data.

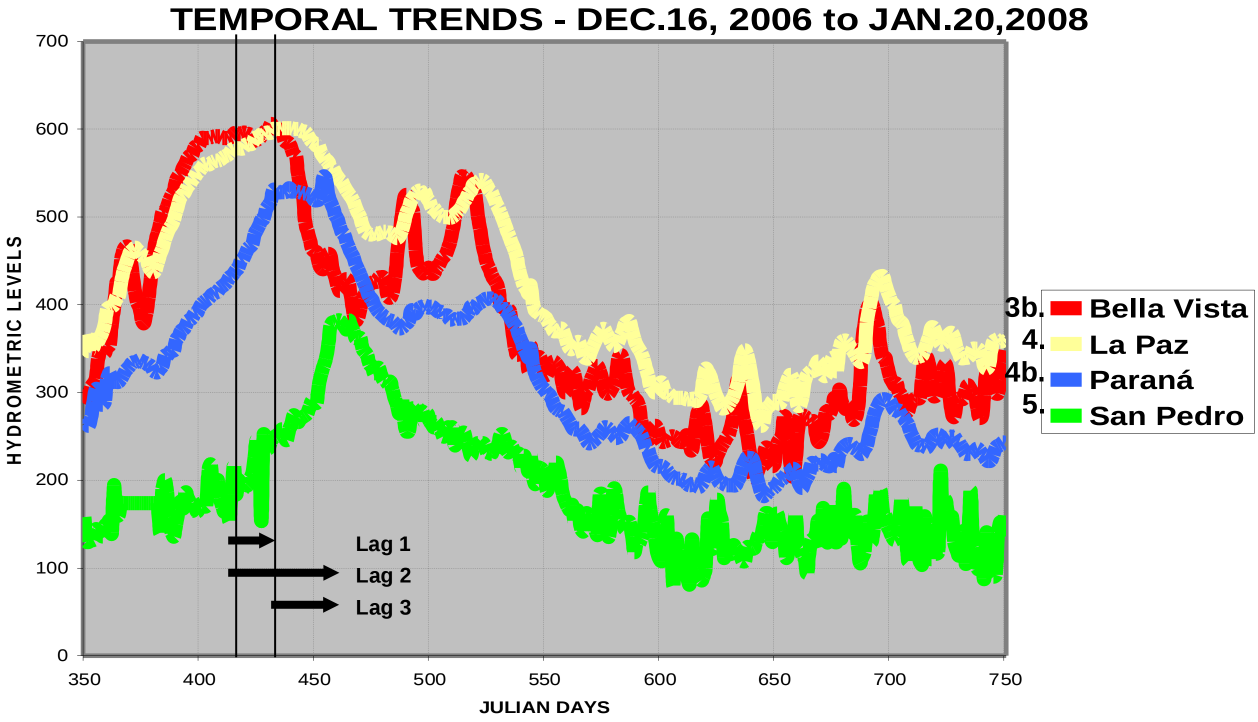

Figure 8. Water levels as function of time for four different stations located along Paraná river. Lag 1 = 8, Lag 2 = 25, Lag 3 = 22.

Conclusions

The results of Parque Chaqueño indicate that AMSR-E data at C band shows some sensitivity to rain events and average yearly precipitation, even under homogeneous forests. This could be important, since there are different opinions regarding this subject in the scientific community.

In Paraná sub-basin the trends of PI and FI as a function of time, for points located along the river at its end, show a maximum. Although the absolute values of PI and FI depend on land cover, for which we have not detailed information, it is reasonable to think that the maxima are related to an increase of water flow and, hence, water level along the river. Moreover, the temporal location of these maxima is shifted in time, going towards the end of the river. The analysis of water level data at close stations, show similar lag times.

These results are promising in view of future exploitation of SMOS and Aquarius data in La Plata basin.

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