# Determining the effects of ENSO phenomena on Andean areas by applying radiometric indices on long time series

Yady Tatiana Solano-Correa*,†, Leonairo Pencue-Fierro*,†, Apolinar Figueroa-Casas*
*Grupo de Estudios Ambientales - GEA, Universidad del Cauca, Popayán, Colombia
†Grupo de Óptica y Láser - GOL, Universidad del Cauca, Popayán, Colombia
Red Interinstitucional del Cambio Climático y Seguridad Alimentaria - RICCLISA
tsolano@unicauca.edu.co, leonairo@unicauca.edu.co, apolinar@unicauca.edu.co

***Abstract*—This paper presents the results obtained after applying different radiometric indices over sugarcane crops located in a Colombian Andean area, analyzing their possible correlation with ENSO phenomena. The study was performed over Landsat images acquired during a 28-year period. Given the change of sensor on-board Landsat satellites during the above mentioned period, preliminary radiometric transformations were applied to homogenize the data.Moreover, in order to reduce possible seasonal effects, only images acquired over the same period of the year were considered. Vegetation indices such as NDVI and PRI were applied, and the results were compared with the ONI index, allowing the identification of ENSO events, as well as the identification of patterns corresponding to damage caused by ENSO events. Detailed analysis over the decreased quality of vegetation, and therefore the soil, allowed us to confirm the validity of the proposed methodology.**

***Keywords—Remote sensing; Time-Series analysis; Vegetation monitoring; ENSO; NDVI***

## I. Introduction

As part of the ongoing process of monitoring the climate and its changes over time, it is necessary to identify those variables that somehow could allow us to understand the land cover behavior. Some of them concern on how the different land covers have been affected by rainfall deficit, floods, droughts and other variables such as precipitation, temperature or heat stroke. It is also possible to know the likelihood of such events happening again and through this, create a process of prevention for people living in possible risk areas. The problems of climate variability that have been occurring globally during the last years, have led many researchers to wonder which strategies can be developed in order to understand the changes that are occurring. At Global level, it has been shown that some of these variations are strongly related to El Niño Southern Oscillation (ENSO), in either of its two variants [1]. The presence of ENSO has left a mark in most of the agricultural areas of the countries and therefore we have thought that through the study of the crops, it could be possible to identify occurrences of these phenomena throughout history [1]. At the same time, it can be possible to determine the true involvement of ENSO on the quality of crops and consequently on the soil in which they are planted.

This paper presents the results of a research carried on over an agricultural area located in the south-west area of Colombia, where a quite abundant presence of sugarcane crops is found. This area was selected based on the abundance of a homogenous crop and because there is a large amount of research being conducted in the measurement of the sugarcane quality [2]. The methodology followed in this research can be applied in the same way to any other kind of crops. Moreover, and despite the existence of several studies about the quality of different kind of crops [2], very few of them have been conducted in order to understand the impact of natural phenomena (i.e. ENSO), or the possibility to identify them.

## II. Proposed Methodology

This paper studied the presence of the specific natural phenomena known as ENSO throughout the analysis of sugarcane crops in a long time series, as well as the possible influence of ENSO or other variable on the final crops quality by means of radiometric indices. In order to do this, the availability of satellite images acquired over the specific area of interest over a long period is required. Assuming the availability of the data, it is important to remember that in order to understand the behavior of vegetation, in general, some radiometric indices has been developed based on the physical information contained in the different bands of specific satellites. Being stricter, a radiometric index is defined from the relation that exist between the reflectance values at different wavelengths that are particularly sensible to vegetation coverages. Even though it is not possible to measure, in a direct way, the productivity or availability of certain vegetation, these indices are correlated with those variables, allowing the study of its quality or state [3]. With radiometric indices it is also possible to understand how a specific area of interest has changed over the time.

One of the most well known indices, for the vegetation study, is the NDVI, which allows the identification of green vegetation, the characterization of its spatial distribution and the evolution of its state along the time. This index is quite sensible not only to vegetation variations, but also to seasonal changes. Therefore, it is important that the data used for extracting NDVI have been acquired always around the same season. The NDVI is defined as shown in equation 1, where $\rho NIR$and $\rho RED$ refer to reflectance response in the Near Infra-Red and Red bands respectively. The NDVIwas developed based on the radiometric behavior of vegetation. The vegetation in a good state has a spectral signature characterized

This research is funded by the Project "Programa para el Fortalecimiento de Red Interinstitucional de Cambio Climático y Seguridad Alimentaria" – RICCLISA and Universidad del Cauca.

978-1-4673-7119-3/15/$31.00 ©2015 IEEE

for big changes in the Red (R: 630-690nm) and Near Infra-Red (NIR: 770-900nm) spectrum [3]. The result of NDVI is a quantitative measure related to the state and biomass of the vegetation. Its values can vary from -1 to 1, where values higher than 0.3 will correspond to vegetation presence. The higher the value, the higher the vegetation quality.

$$NDVI = \frac{\rho NIR - \rho RED}{\rho NIR + \rho RED} \tag{1}$$

Yang *et al* [3], showed that NDVI has the potential to indicate the starting, ending, peak and duration of vegetation greenness, as well as the growing rate, the senescence and the photosynthetic activity periodicity. Throughout the analysis of this data in a long period, it is possible to make inferences about the weather conditions and drought seasons. The NDVI is also a variable highly correlated with agronomical parameters associated to development and productivity of the plants [1], [3]. Therefore, it can contribute to the evaluation of crops such as sugarcane. In 1995, Rahman [4] proposed a NDVI scale (Table I), related to the sugarcane quality, and highly used when quality assessment studies on sugarcane are carried on. For the purpose of this research that scale was used as a reference to measure the quality of sugarcane crops in a long time series.

TABLE I. NDVI SCALE PROPOSED BY RAHMAN FOR SUGARCANE

| NDVI Value | Vegetation Quality |
|---|---|
| $NDVI \leq 0.20$ | Very low |
| $0.20 < NDVI \leq 0.25$ | Low |
| $0.25 < NDVI \leq 0.30$ | Moderate |
| $0.30 < NDVI \leq 0.40$ | Good |
| $NDVI > 0.40$ | Very good |

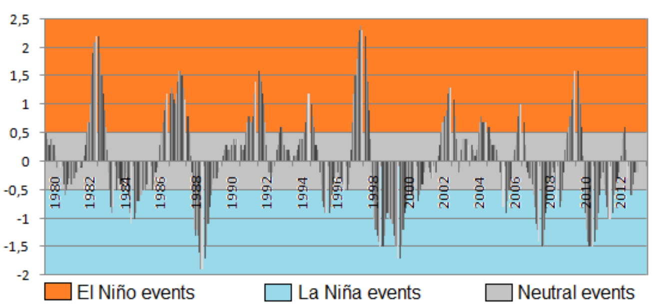


Fig. 1. ONI index for the period 1980 to 2013 over the tropical Pacific [5].

As we aim to identify the effects and presence of ENSO phenomena by studying sugarcane crops, another index must be introduced in order to evaluate and compare the final results. This index, known as Oceanic Niño Index (ONI), has become the standard that the National Oceanic and Atmospheric Administration (NOAA) uses to identify the presence of ENSO phenomena by means of any of its two variation: El Niño (warm) and La Niña (cool) events, happening in the tropical Pacific [5]. Fig. 1 shows the ONI values for the years 1980 to 2013, where values that are higher than 0.5 for more than three consecutive months represent El Niño events, and values lower than -0.5 for more than three consecutive months represent La Niña events [5]. The bigger the difference over 0.5 level, the strongest the event will be. Scales are usually consider as weak for absolute values between 0.5-1.0, moderate between 1.0-1.5 and strong for values higher than 1.5.

As NDVI index is easily affected by external phenomena, such as ENSO, one more radiometric index was considered in order to evaluate the quality of the sugarcane. This index is known as Photochemical Reflectance Index (PRI) and is a physiological index that correlates the state of the xanthophylls in charge of daily reduction of photosynthesis efficiency [6]. It allows to evaluate changes in the vegetation efficiency to use the radiation received, and is defined as in equation 2, where the sub values represent the wavelength values. The use of PRI has been limited by the lack of sensors onboard of satellites with spectral resolutions that include bands centered in 531nm and 570nm. Hernández *et al* [6] presented a variation for PRI, in which the index was adapted to include other spectral ranges, allowing a better analysis and therefore its extrapolation to more satellites. Under this variation, the value 570nm is replaced by 512nm, allowing the application of PRI with Landsat images, as shown in equation (3).

$$PRI = \frac{\rho 570 - \rho 531}{\rho 570 + \rho 531} \tag{2}$$

$$PRI = \frac{\rho BLUE - \rho GREEN}{\rho BLUE + \rho GREEN} \tag{3}$$

## III. Experimental Results and Discussion

### A. Study Area and data

In order to validate the proposed methodology, images acquired by Landsat satellites over an area located in the limits of the Departments of Cauca and Valle del Cauca in the south-west part of Colombia were selected (See study area in Fig. 2.). The coordinates of the study area are 76°12'36.2474"-76°33'4.0007"W and 3°05'48.0323"-3°32'1.3995"N (UTM coordinates), corresponding to the Path/Row 009/058 of Landsat and with altitudes between 950-1050m. Due to the location of the area inside the Andean region, the Equatorial area and to its altitude, the probability to have cloud coverage over the whole year is quite high. This added to theslightly low temporal resolution of Landsat results in a limitation to have frequent images over one single year, leading to a yearly analysis instead of traditional monthly or weekly ones. A total of 14 scenes acquired by Landsat 4, 5 and 7 were selected over a period of 28 years between 1984 and 2012 with a gap between 1991 and 1996, period in which Landsat images acquired over the study area were not stored by the USGS.

In order to guarantee the physical congruence in the results, two criteria were considered in the selection of the images: i) images acquired during similar months, between the period June-August and; ii) images which cloud coverage was lower than 5-10%. The former one in order to reduce as much as possible the seasonal effects and the later one to have coherent data along the time series. Even though we search for images with a low cloud coverage percentage, there were some cases in which this values reached 10-20% range. For those specific cases, the algorithm presented in [7] was used in order to create a mask that allows us to avoid errors due to artifacts coming from clouds and their shadows. Given the use of different sensors and the goal of applying radiometric indices, a preliminary transformation of data from digital numbers to reflectance values was applied. Additionally, in the case of Landsat 7 images, correction for the SLC-off was performed by using an algorithm developed by authors. The final size of images used during this research was of 1261x1609 pixels with a spatial resolution of 30m. For this research purposes, thermal and panchromatic bands were not considered.

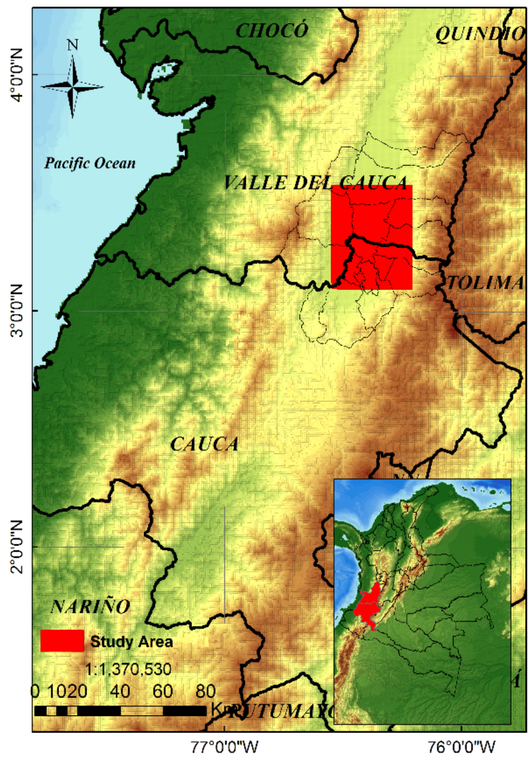


Fig. 2. Study area for the temporal analysis using Landsat satellite images.

## B. *Radiometric Indices analysis*

Before applying the NDVI and PRI indices, a previous classification over the whole dataset was performed in order to separate the sugar cane areas from other land coverages.For this aim we used the algorithm presented in [7], creating two masks: one corresponding to crop areas and another for all the other coverages that were not of our interest. Even though the analysis was performed over a homogeneous area, presence of three different states of sugar cane were found, but only those areas corresponding to mature crops were analyzed.

Fig. 3. shows the mean, maximum and minimum values for NDVI along the period 1984-2012, from which it was possible to stablish a relation between the NDVI response and the El Niño and La Niña events. For warm periods (El Niño), NDVI values decrease due to the loss of water availability, this is in accordance with Aguilar [4]: “for sugarcane, the NDVI decreases dramatically when water availability decreases, either spatially -due to geographical climate variability- or temporarily due to drought”.For cold periods (La Niña), NDVI increase due to the increase of raining periods and therefore water availability. In Fig. 3., red circles represent the periods in which an El Niño event occurred and blue circle represents a period for La Niña event. By comparing results in Fig. 1. and Fig. 3., it is possible to see that presence of ENSO events can be detected by using NDVI index. It is also possible to see that in the particular cases of 1987-1988, 2003-2004 and 2008-2009, were an El Niño period occurred, the NDVI values decreased drastically in comparison with 1998 case, in which a small increase due to a La Niña period occurred. The above is associated with the fact that La Niña phenomena have a high presence of rain that fails to drastically affect NDVI response, while under extreme or constant drought conditions, crops and land cover suffer major changes. These changes go from the decrease in the visibility of green leaves and increased amount of dry leaves or straw, to the loss of nutrients needed for proper plant growth.

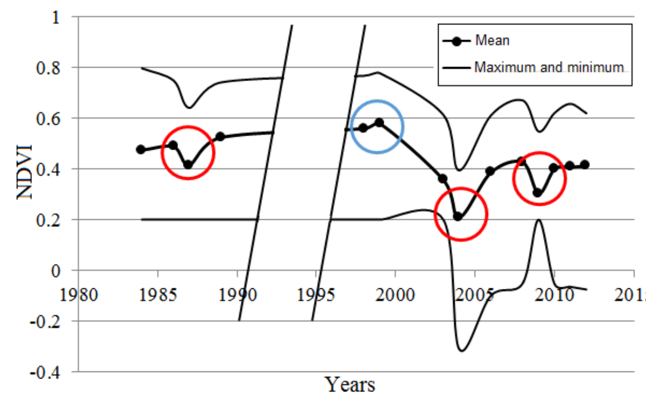


Fig. 3. Mean, maximum and minimum NDVI values obtained from sugarcane mature crops during 1984-2012 period.

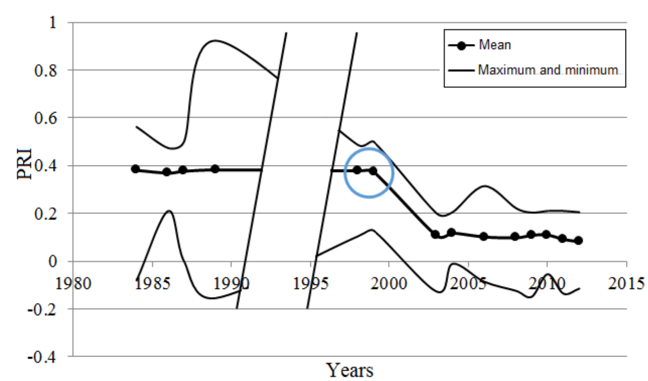


Fig. 4. Mean, maximum and minimum PRI values obtained from sugarcane mature crops during 1984-2012 period.

Fig. 4. shows the PRI results for the study period, in which vegetation quality kept almost constant until 2000 (light-blue circle), when a drastic decrease occurred, resulting in a quality loss of 78.51%. It is also possible to observe that this loss was irreversible. The results are fully associated with preliminary research carried on by other authors, where it is known that after harvesting the sugarcane, and with the high presence of residual material, soils deteriorate compared to the initial quality. If we see this study case, we have a period of 28 years in which undoubtedly many nutrients in the soil have been lost.The big loss around 2000is not only relatedto the loss of nutrients but to the presence of a La Niña event that lasted longer than normal periods.Even though it should represent an

increase in quality due to possible increase of nutrients in the raining period, this ends up being the opposite, because the vegetation reaches a saturation point, ending in an even greater loss of quality. This is supported by the water requirement for the sugarcane cultivation, ranging between 1,600 and 2,500 mm / year. The plant is not in the capacity touse thetotal amount of water supplied to it, therefore, once the plant exceeds the percentage needed, the plant saturates and begins a process of quality loss. This would explain why the peak on Fig. 3., corresponding to a La Niña period, is not as pronounced as those for El Niño period.

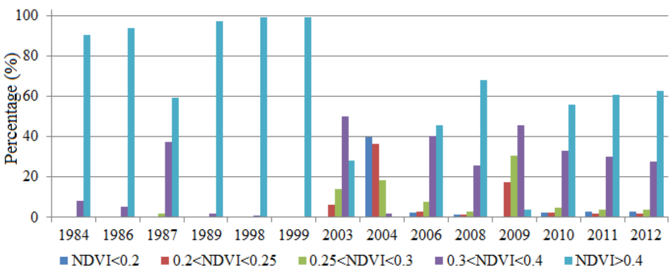


Fig. 5. Percentage of pixels with NDVI in each of the Rahman scale ranges.

A further analysis by making use of Rahman NDVI scale was performed in order to validate the results obtained from PRI index. The minimum and maximum average values for the NDVI in the period 1984 to 2012 ranges from 0.3028 to 0.5790, with a minimum peak in 2004 of 0.2088. According to Rahman scale, these values correspond to a very good and good quality levels, with the exception of the 2004 peak. With these results, it is not possible to understand properly the meaning of quality decrease showed by PRI. Therefore, a deeper analysis of NDVI results was considered by getting the percentage of pixels which NDVI values fall inside the different ranges of Rahman scale along the study period.

Fig. 5. shows the percentage distribution of NDVI along the study period in each of the Rahman scale ranges. From Fig. 5. it is possible to see how the amount of pixels located inside a range higher than 0.40 (light-blue) have decreased from a percentage of 90.14% to 62.56%, at the same time the amount of pixels with a NDVI lower than 0.20, increased from 0% to 2.59%. This increase and decrease of the percentages occurs as we move on the years, but especially in 1999, being in correspondence with the La Niña period and the PRI loss of quality. We can see how the loss of very good vegetation quality is distributed among the other Rahman scale ranges that in the beginning presented lower or non-percentage. With the results shown in Fig. 5. it was possible to understand the real meaning of NDVI and PRI results, were even though the average NDVI shows that vegetation quality has remained relatively constant, its percentages have changed along the years. This decrease allow us to see a concordance with the PRI quality decrease, as well as to understand the roll of ENSO phenomena.

## IV. Conclusions

This paper presents the application of NDVI and PRI indices on a Landsat time-series for the detection of ENSO phenomena and its effects over sugarcane crops. From the analysis done in this research, we show that by applying radiometric indices over specific sugarcane crops, it is possible to detect when natural phenomenon, such as ENSO, have occurred and therefore, it is also possible to measure or detect the damage caused over the vegetation by ENSO events.By analyzing the average NDVI response along the period 1984-2012, it was possible to associate the strong decreases of vegetation with the presence of El Niño period and the increases of vegetation with the presence of La Niña period. On the other hand and with the help of PRI index, it was possible to study how the vegetation quality had behaved along the years, resulting in the association of quality loss with strong La Niña periods. This result was corroborated by using the Rahman scale created for analyzing sugarcane quality based on NDVI. Future works consider the use of other radiometric indices and consider the study of temperature variation over the study area, as well as the possibility to have a higher frequency of images. For the last part, the use of satellites such as MODIS, with a higher temporal resolution, could be considered. But given the lower spatial resolution offered by MODIS, a bigger study area should be selected in order to allow a similar analysis.


## Acknowledgment

This research is being developed under the project “Programa para el Fortalecimiento de Red Interinstitucional de Cambio Climático y Seguridad Alimentaria” – RICCLISA and Universidad del Cauca. Authors would like to thank to the above-mentioned organizations for the support and guidance throughout the research activity.


## References


[1] S. Sarkar and M. Kafatos, “Interannual variability of vegetation over the Indian sub-continent and its relation to the different meteorological parameters,” *Remote Sens. of Environ.*, vol. 90, no 2, pp. 268-280, Mar. 2004.

[2] M. Abdel-Rahman and F. B. Ahmed, “The application of remote sensing techniques to sugarcane (Saccharum spp. hybrid) production: a review of the literature,” *Int. J. of Remote Sens.*, vol. 29, no. 13, pp. 3753-3767, Jun. 2008.

[3] L. Yang, B. K. Wylie, L. L. Thieszen and B. C. Reed, “An analysis of relationships among climate forcing and time-integrated NDVI of grasslands over the U.S. northern and central great plains,” *Remote Sens. of Environ.*, vol. 65, no 1, pp. 25-37, Jul. 1998.

[4] N. Aguilar-Rivera, “Competitividad de la agroindustria de la caña de azúcar en “La Huasteca” México,” PhD thesis, Universidad Autónoma de San Luis Potosí, comunidadpmpca.uaslp.mx/documento.aspx?idT=3, July 2011.

[5] http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml. NOAA. (5 August 2013).

[6] R. Hernández-Clemente, R. M. Navarro-Cerrillo, L. Suárez, F. Morales and P. J. Zarco-Tejada, “Assessing structural effects on PRI for stress detection in conifer forests,” *Remote Sens. of Environ.*, vol. 115, no. 9, pp. 2360-2375, Sep. 2011.

[7] Y. T. Solano, L. Pencue Fierro and A. Figueroa, “Land cover differentiation using digital image processing of Landsat-7 ETM+ samples,” *Computational Modeling of Objects Represented in Images III: Fundamentals, Methods and Applications,* CRC Press, pp. 165-170, Aug. 2012.