ENSO effects on hydric conditions of Pampa Region: a preliminary evaluation using LST and EVI

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Abstract. El Niño Southern Oscillation is associated to climatic variability in south-eastern South America and can affect several human activities and ecosystem conditions. The combination of Land Surface Temperature (LST) and Enhanced Vegetation Index (EVI) can provide information on soil moisture conditions over large areas. In this work, a multitemporal Moderate Resolution Imaging Spectroradiometer (MODIS) data products of LST and EVI was employed to obtain information about soil moisture for the Pampa Region of Argentina and Uruguay over a La Niña and El Niño period of 2007-2008 and 2009-2010, respectively. According to the scatter plot of the LST and EVI of each selected Area of Interest (AOI), the "wet edge" and the "dry edge" equations and its parameters for each spring and summer months were calculated. The Temperature-Vegetation Index (TVDI) using the driest "dry edge" and the wettest "wet edge" relationship to reveal changes of the land surface soil moisture conditions over the two analyzed events was obtained. The results showed that there no was the trend that could be expected about wetter conditions in El Niño than La Niña in AOI's of La Pampa and Buenos Aires provinces, Argentina. In contrast, the AOI of Uruguay showed this trend slightly from October to February. TVDI could be a suitable tool to understand and monitor the ENSO effects at regional scales and spatial variations inside the regions.
Key words: remote sensing, Land Surface Temperature, Enhanced Vegetation Index, El Niño, La Niña, sensoriamento remoto, Temperatura da Superfície da Terra, Índice de vegetação realçado.

1. Introduction

El Niño Southern Oscillation (ENSO) is an important cause of interannual climatic variability in South America. The occurrence of anomalously wet or dry climate conditions can affect several human activities, such as hydroelectric power production and agriculture. Scian (2000) analyzed the relation between the Southern Oscillation Index (SOI), the Sea Surface Index (SST) of the Pacific Ocean, and the variability of rainfall over the central-western Pampa Region and found a strong correlation between them at the end of spring and early summer. However, Compagnucci and Agosta (2008) found that there is no relation between the SST of the equatorial Pacific Ocean and the rainfall of central-western Argentina.

Some authors have used satellite images to study the influence of ENSO on vegetation. The advantage of remote sensing is that it allows us to obtain data easily and to understand great areas. Asner and Townsend (2000), Kogan and Wei (2000), Poveda et al. (2001), Gandini and Castellar (2009) analyzed the relation between ENSO and the conditions of vegetation in southern South America. Kogan and Wei compared this relation with NOAA images during an El Niño and a La Niña period in Argentina. They found deterioration in vegetation during La Niña and improvement during El Niño with the greatest differences from August to February. Using the Normalized Difference Vegetation Index (NDVI), Gandini and Castellar (2009) found different conditions in vegetation during ENSO events in Buenos Aires province, Argentina.

When combined, the vegetation index and surface temperature parameters can provide information on vegetation and soil moisture conditions on the surface. While Vegetation Indexes reflect the conditions of vegetation and land cover information, Land Surface Temperature (LST) reveals the status of soil moisture (Sandholt, 2002).

In this work, EVI (Enhanced Vegetation Index) and LST MODIS data products were used to evaluate the ENSO effects on hydric conditions in the Pampa Region over an El Niño and

La Niña period. EVI was combined with LST, a method similar to TVDI (Temperature-Vegetation Dryness Index), which combines NDVI with LST.

2. Methodology

The two types of MODIS data products included the eight-day composite Land Surface Temperature (MOD11A2) and the 16-day composite ground Vegetation Index (MOD13A2). The images were processed with ENVI software and projected on projection Geographic, Datum WGS-84. The two-temporal phases eight-day composite LST data were processed to match up with a single temporal-phase 16-day composite EVI image. The resolution of images is around 68 ha.

Fourteen periods of MODIS EVI and LST data products were selected, one period per month from August 2007 to February 2008 (La Niña period) and from August 2009 to February 2010 (El Niño period) and a pair of images was assembled for each month. These periods were selected based on Niño 3.4 index (Figure 1). This index shows the mean anomalies of Sea Surface Temperature in the region 5ºN-5ºS and 120ºW-170ºW and one period is considered a La Niña (El Niño) when SST is lower (greater) than -0.8 (+0.8) (www.bom.gov.au).

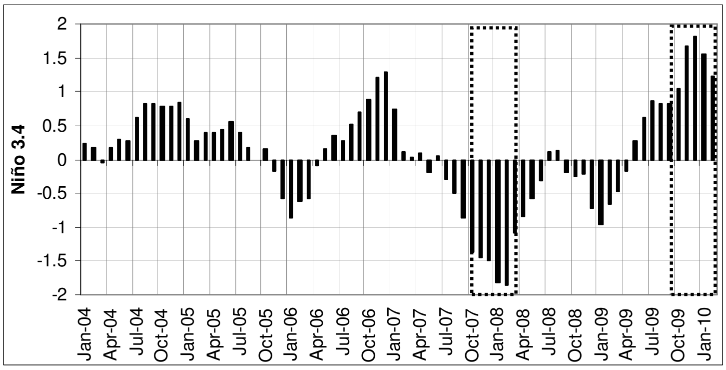

Figure 1. The Niño 3.4 index and study periods.

For this analysis an area of 1505 km by 892 km (31º46’13.8’’S 68º13’41.79’’W upper left coordinate and 39º55’48.95’’S 51º30’54.01’’W lower right coordinate) was used. In this area, 3 uncultivated or natural areas of interest (AOI), which could show variability in hydric status possibly associated to ENSO, were selected in Buenos Aires province (Argentina) (BA), La Pampa province (Argentina) (LP) and Uruguay (Ur). The AOI’s of BA and Ur are areas of grassland of wet weather and the AOI of LP is an area of *Prosopis caldenia*, a deciduous wood of semiarid weather (Figure 2).

Having previously filtered the pixels with clouds and water, the basic statistics of LST and EVI (mean, median and standard deviation) for each AOI were calculated.

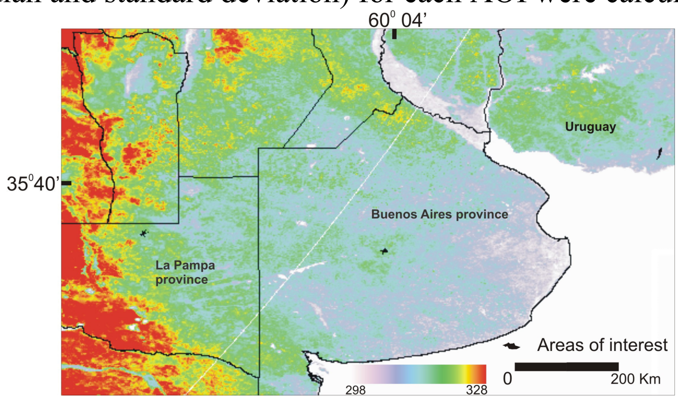

Figure 2. Map of the Pampa Region and location of AOI’s (image of LST December 2007).

- **Temperature Vegetation Dryness Index**

Remote sensing can provide information about the energy and water status. A simple method, not dependent on ancillary data, is based on the surface temperature-vegetation index space (LST-NDVI). This method, called “the triangle method”, has been applied by several authors for estimation of soil moisture (Carlson et al. (1995); Sandholt et al. (2002); Han et al. (2010)). While NDVI provides information about the growing states and conditions of vegetation on the ground, land surface temperature reflects status of soil moisture. NDVI is a rather conservative indicator of water stress, because vegetation maintains itself in good conditions after initial water stress. The surface temperature can rise rapidly with water stress (e.g., Goetz (1997)). The combination of both can establish a relationship to know land surface moisture.

The LST/NDVI relationship generally shows a strong negative correlation (Gillies et al. (1997)). Frequently, scatter plot of surface temperature and vegetation index results in a triangular shape (Price (1990), Carlson et al. (1994)) if a full range of fractional vegetation cover and soil moisture contents are represented in the data.

Isolines can be drawn in the triangle defining the LST/NDVI space. To obtain information on the surface soil moisture content, a dryness index (TVDI) having the values of 1 at the “dry edge” (limited water availability) and 0 at the “wet edge” (maximum evaporation and transpiration thereby unlimited water access) can be defined (Sandholt et al. (2002)):

$$TVDI = \frac{LST - LST\min}{LST\max - LST\min} \tag{1}$$

and where $LST\max = a \times EVI + b$, LSTmin is the minimum surface temperature in the triangle, defining the wet edge; LST is the observed surface temperature at a given pixel; LSTmax is the maximum surface temperature observation for a given EVI and, a and b parameters, define the dry edge as a linear fit to the data (Figure 3).

In this work, EVI was used in Equation 1 instead of NDVI. EVI was chosen because it presents more advantages compared with NDVI since EVI incorporates coefficients which consider the effect of soil on the signal received by satellite (Figure 3).

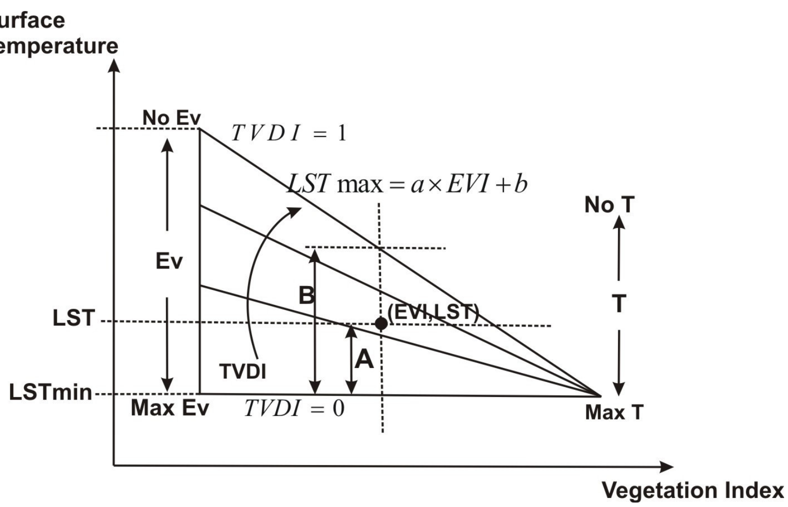

Figure 3. Definition of the TVDI. TVDI for a given pixel (EVI, LST) is estimated as the proportion between A and B (adapted from Sandholt et al. (2002))

In order to determine the parameters describing the dry edge, the maximum temperature observed for small intervals of EVI was extracted in the LST/EVI space, and the parameters were found using linear regression on the sloping side of the upper edge. LSTmin in Equation 1 was estimated as the mean minimum temperature for the EVI intervals.

3. Results and Discussions

A. Relationship between LST and EVI

In Equation 1, a and b parameters were estimated for each analyzed month on the basis of pixel values. Table 1 shows the obtained dry edges and Table 2 shows the wet edges parameters for each month.

Table 1. Dry edge parameters obtained and determination coefficient.

Date	$LST\max(K)$ 2007-2008	$LST\max(K)$ 2009-2010
August	$LST\max = -16.433EVI + 298.7$ $R^2 = 0.91$	$LST\max = -24.53EVI + 304.4$ $R^2 = 0.93$
September	$LST\max = -30.759EVI + 309.7$ $R^2 = 0.92$	$LST\max = -23.63EVI + 309.3$ $R^2 = 0.98$
October	$LST\max = -14.806EVI + 307.5$ $R^2 = 0.88$	$LST\max = -34.34EVI + 319.8$ $R^2 = 0.97$
November	$LST\max = -21.904EVI + 317.5$ $R^2 = 0.92$	$LST\max = -38.8EVI + 330.4$ $R^2 = 0.97$
December	$LST\max = -22.545EVI + 321.7$ $R^2 = 0.92$	$LST\max = -26.8EVI + 326.4$ $R^2 = 0.96$
January	$LST\max = -34.59EVI + 333.4$ $R^2 = 0.98$	$LST\max = -29.47EVI + 327.8$ $R^2 = 0.99$
February	$LST\max = -33.491EVI + 329.6$ $R^2 = 0.99$	$LST\max = -28.7EVI + 324.1$ $R^2 = 0.99$

The 2007-2008 period could be characterized by an increase in LST from August to January, with a decrease in February and October. During 2009-2010 LST increased from August to November with lower values in December, January and February. There was a negative relationship between LST and EVI, with determination coefficients which fluctuated between 0.88 and 0.99.

Table 2. LSTmin obtained in the study area.

Date	$LST\min(K)$ 2007-2008	$LST\min(K)$ 2009-2010
August	287.3	289.2
September	289.2	291.6
October	292.2	294.2
November	296.6	297.9
December	300.0	305.8
January	301.2	301.7
February	299.9	298.7

In 2007-2008 period, the LSTmin increased from August to January, with a decrease in February. During 2009-2010 LST increased from August to December, with a decrease in January and February.

The LSTmax of January 2007 ($LST\max = -34.59 EVI + 333.4$) and the LSTmin of August 2007 (287.3 K) were selected as extreme edges to show the temporal behaviour of the three analyzed AOI's.

Figure 4 shows LST and EVI values for BA, LP and Ur AOI's for analyzed months using the obtained triangle space.

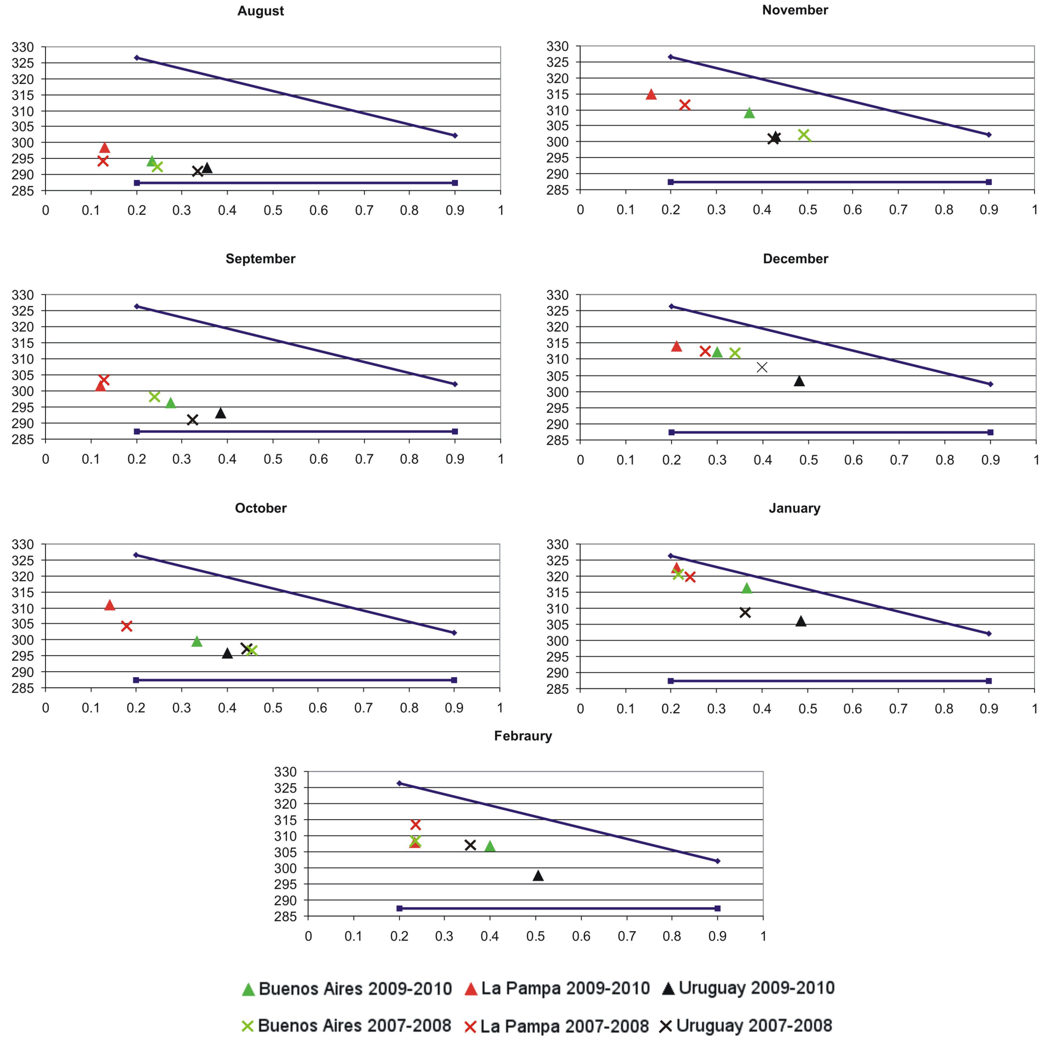

Figure 4. EVI and LST values at the AOI's in 2007-2008 (La Niña) and 2009-2010 (El Niño) periods.

The position of points in the triangle for each period could show the hydric status of surface and vegetation in these periods (Figure 4). For the AOI of LP, in August EVI was similar for both periods with lower LST in 2007; in September EVI was similar with lower LST in 2009; in October 2007 LST was lower and EVI greater than 2009; in November, December and January 2007-2008 LST was lower and EVI greater than the same months of 2009-2010; in February EVI was similar with an increase in LST in 2008.

The AOI of BA showed lower LST and greater EVI in 2007-2008 than in August, October and November, 2009-2010 with the opposite behaviour in September, January and February; in December LST were similar in both periods with lower EVI in 2009 than 2007.

The AOI of Ur showed similar EVI and LST values in August and November for both periods. In September EVI and LST were greater in 2009 than 2007. In October EVI and LST were greater in 2007 than 2009. In December, January and February EVI was greater and LST lower during 2009-2010 than 2007-2008.

The overall trend in EVI was the highest values in Ur, the lowest in LP, with intermediate values in BA and the overall trend in LST was the highest values in LP, the lowest in Ur, with intermediate values in BA and some similarities in October, November, January and February.

B. Temporal evolution of TVDI

Equation 1 was used to calculate monthly TVDI with mean EVI for each AOI's. So that data could be comparable, the LSTmax and the LSTmin were selected as dry and wet edges of extreme aforementioned triangle, respectively. Figure 5 shows temporal evolution of TVDI values for each considered AOI.

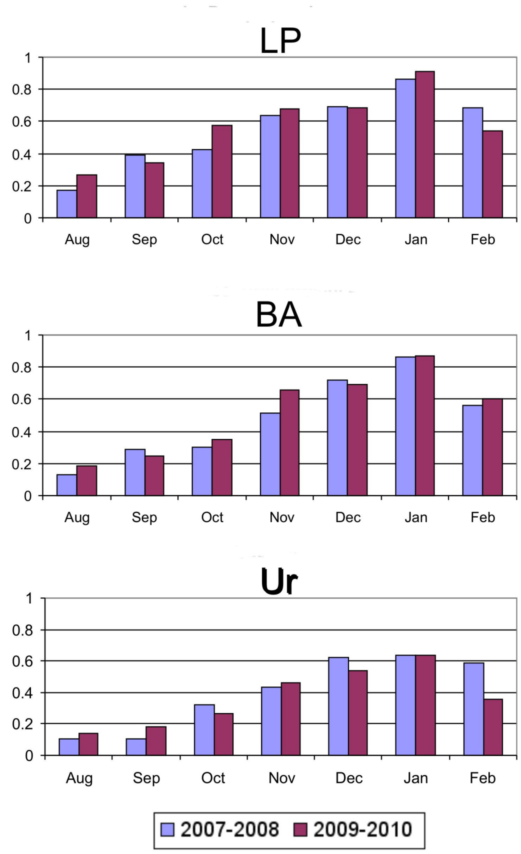

Figure 5. TVDI from August to February for the three analyzed AOI's.

In LP, there were TVDI values in August, October, November and January 2009-2010 greater than 2007-2008, with similar values in December. The global trend in this AOI was values in 2009-2010 greater than 2007-2008.

In BA, there were TVDI values in August, October, November and February 2009-2010 greater than 2007-2008, with similar values in January. The overall trend in TVDI was values in 2009-2010 greater than 2007-2008 for the analyzed months.

The AOI of Ur showed TVDI values in October, December and February 2009-2010 lower than 2007-2008, with the same values in January. The overall trend in TVDI was values from October 2007 to February 2008 greater than the same months of 2009-2010 period.

Comparing Figure 4 with Figure 5, it can be seen that the former could be useful to observe values of LST and vegetation condition in a particular AOI. However, the soil evaporation extracts water from the top soil while roots do this at a larger soil depth, so in most cases soil dries first and then the vegetation when it cannot obtain enough water supply.

Consequently, TVDI is more efficient reflecting the hydric status than visual perception of the triangle because it combines the changes of land temperature and vegetation status.

4. Conclusion

In this work, the combination of EVI and LST MODIS data products in TVDI index was used for studying the variability in soil moisture during two springs and summers of a La Niña and El Niño event. This combination allowed to know the changes in soil moisture conditions for three large Areas of Interest in the Pampa Region of Argentina and Uruguay.

The results of TVDI have demonstrated that in the studied period there was no trend that could be expected about wetter conditions in El Niño than La Niña in AOI's of La Pampa and Buenos Aires province, Argentina, even the opposite happened in several months. In contrast, the AOI of Uruguay showed this trend slightly from October to February. One hypothesis could be that the analyzed La Niña and El Niño periods were preceded by weak El Niño and La Niña events, respectively; therefore, this could affect the precedent soil moisture. It will be necessary to include more ENSO events in future studies to test this hypothesis.

The relationship between LST and NDVI given in TVDI index can reflect the state of the regional soil moisture. This interesting index calculated from remote sensing data could be a suitable tool to understand and monitor the ENSO effects at regional scales and spatial variations inside the regions.

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