ENSO IMPACT ON THE VEGETATION IN MURRAY-DARLING BASIN: A SATELLITE MONITORING FROM 1998 - 2007 BASED ON SPOT/VEGETATION NDVI TIME SERIES DATA

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ABSTRACT:

The El Niño Southern Oscillation (ENSO) phenomenon produces an important inter-annual variability of oceanic and atmospheric conditions with irregular periods and amplitudes in many regions of the world. Some research showed that the strongest connections between Southern Oscillation and Australian rainfall occur in northern and eastern Australia, especially in Murray-Darling basin. In the present study, we evaluate the ability of Normalized Difference Vegetation Index (NDVI) to monitor the Murray-Darling Basin vegetation behaviour to ENSO induced precipitation anomalies. 10 year time series of Spot/VEGETATION 1km NDVI imagery product (1998-2007) were collected. We calculate the correlation between NDVI and ENSO quantitative indices like the Southern Oscillation Index (SOI). Although the SOI is only a temporal index, we use it as a general indicator for the water stress probability. In this research, we focus on Murray-Darling Basin, at same time, we choose Murray Irrigation Area as our detail analysis region since where we carry out field experiments every year. According to our results, NDVI presents a good correlation with SOI anomalies at seasonal time scale. On the Murray-Darling Basin scale, we clearly show the geographic patterns of the highest sensitivity to El Niño or La Niña. We also illustrate the inter-annual variability of these events in term of magnitude and geographic distribution. This variability is clearly explained by precipitation anomalies in relationship with ENSO events.

1. INTRODUCTION

The modelling of water and energy exchanges between Soil-Vegetation and the ATmosphere (SVAT) often assimilates remotely sensed time series of Vegetation Indices (VIs). At first order, spectral combinations like the Normalized Difference Vegetation Index (NDVI) are known for its ability to witness the geographic and seasonal distribution of greenness on continental surfaces by tracing the phonological trend. As plant growth in the MDB region is assumed to be mainly limited by water availability, an equal connection should be found between ENSO events and remotely sensed vegetation indices, e.g. NDVI. The El Niño Southern Oscillation (ENSO) phenomenon produces an important interannual variability of oceanic and atmospheric conditions with irregular periods and amplitudes (Cobb et al., 2003) in many regions of the world. On the Australian continent, El Niño events are generally associated to droughts (Potgieter et al., 2005; Ropelewski et al., 1987), while La Niña events produce above normal rainfall (Suppiah, 2004). Several authors showed that the strongest connections between Southern Oscillation and Australian rainfall occur in northern and eastern Australia (McBride et al., 1983), whereas being more important in Southern Hemisphere spring (Drosdowsky *et al*., 1991, Maisongrande *et al*., 2007). As plant growth in this region is assumed to be mainly limited by water availability, an equal connection should be found between ENSO events and remotely sensed vegetation indices, e.g. NDVI. The typical reflectance spectrum of vegetation), in which red light is absorbed for photosynthesis purposes and near-infrared radiation is mostly reflected, shows that these three spectral bands can be used to determine the amount of photosynthetically active vegetation in a specific region. The most common is the Normalized Difference Vegetation Index (NDVI), defined as difference between surface reflectance (ρ) in the near-infrared (NIR) and red channels normalized (divided) by their summation.

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}} \quad (1)$$

This index has widely been used as an indicator of vegetations' leaf area index (LAI) and thus plants' potential to intercept and use photosynthetically active radiation.

2. STUDY AREA DISCRIPTIONS

The Murray-Darling Basin is the catchments for the Murray and Darling Rivers and their many tributaries. It is one of Australia's largest drainage divisions and covers one-seventh of the continent, ranked fifteenth in the world in terms of length and twenty first in terms of area. The Murray-Darling Basin is very important for its biodiversity and it is also very important for rural communities and Australia's economy. It extends across one-seventh of the continent and has a population of nearly two million people. Another million people outside the region depend heavily upon its resources. The Murray-Darling Basin generates about 40 percent of the national income derived from agriculture and grazing. It supports one quarter of the nation's cattle herd, half of the sheep flock, half of the cropland and about 85 per cent of all irrigation in Australia takes place in the Murray-Darling Basin, which supports an agricultural industry worth more than $9 billion per annum. The long-term productivity and sustainability of the Murray-Darling Basin is, however, under threat from over-allocated water resources, salinity and climate change. Agriculture is the dominant economic activity in the Murray-Darling Basin. The Basin has been termed Australia's agricultural heartland, its 'food basket', but it is much more than that, as its agricultural output makes a major contribution to the national economy. However, the drought conditions which have occurred over the last decade (since about 1995) have affected, to varying degrees, almost all parts of the MDB and has resulted in reduced output and incomes of many agricultural enterprises (ABS 2001).

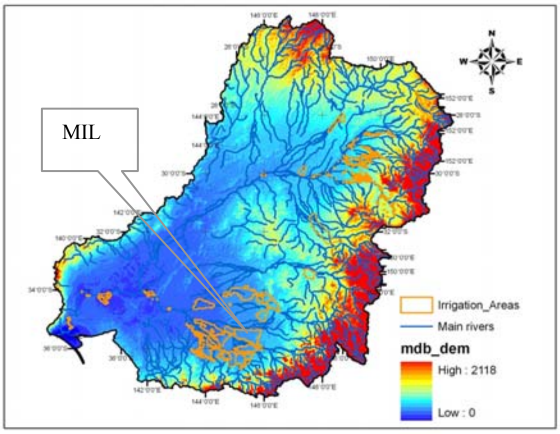

Figure.1 Digital elevation map with main rivers in Murray-darling Basin

3. DATA SET AND METHODOLOGY

3.1 The Time Series SPOT/VEGETATION NDVI Dataset

The present study is based on data acquired by the SPOT4/VEG1 and SPOT-5/VEG2 missions (VGT1 & VGT2) which performs a daily global monitoring of continental surfaces at the kilometric resolution. On the principle of maximum NDVI selecting, 10-day composite images are built after correction for atmospheric effects. This entire processing chain is made at CTIV (Centre de Traitement des Images VEGETATION) and resulting 10-day synthesis (S10 products) are available free of charge at http://free.vgt.vito.be.

3.2 Pre-processing of NDVI Data

Although the Normalized Difference Vegetation Index (NDVI) time-series data, derived from SPOT/VEGETATION, has been successfully used in research regarding global environmental change, residual noise in the NDVI time series data, even after applying strict pre-processing, impedes further analysis and risks generating erroneous results (Maisongrande, 2004). Based on the assumptions that NDVI time-series follow annual cycles of growth and decline of vegetation, and that cloud or poor atmospheric conditions usually depress NDVI values, we applied the method introduced by (Jin Chen, et al., 2004) based on the Savitzky–Golay filter to smooth out noise in NDVI time-series, specifically that caused primarily by cloud contamination and atmospheric variability. Savitzky and Golay (1964) proposed a simplified least squares-fit convolution for smoothing and computing derivatives of a set of consecutive values (a spectrum). The general equation of the simplified least-squares convolution for NDVI time-series smoothing can be given as follows:

$$F^{*} = \frac{\sum_{i=-m}^{i=m} C_i F_{j+1}}{N} \qquad (2)$$

Where F is the original NDVI value, F* is the resultant NDVI value, Ci is the coefficient for the ith NDVI value of the filter (smoothing window), and N is the number of convoluting integers and is equal to the smoothing window size (2m+ 1). The index j is the running index of the original ordinate data table. The smoothing array (filter size) consists of 2m+ 1 points, where m is the half-width of the smoothing window. In our study, all the filtering work was implemented in ENVI 4.3+IDL 6.3 software package.

3.3 Classification and Interpretation

Multispectral classification is the process of sorting pixels into a finite number individual classes, or categories of data, based on imagery data values. The per-pixel binary approach is the most widely used method, international Geosphere-Biosphere Programme (IGBP) DISCover dataset (Loveland *et al*., 2000) and the GLC2000 dataset all applied this methodology. In this study, we applied the per-pixel binary approach using coarse-resolution SPOT/VEGETATION 1km data and fine-resolution land cover products derived from Landsat images as auxiliary data (Zhan *et al*., 2000; Friedl *et al*., 2002). An unsupervised classification procedure (ISODATA) was used for image classification (ENVI version 4.4. According to field campaign and prior knowledge spectral characterises delivered from Landsat TM or ETM+ imagery data, NDVI data stack in year 2002-2003 (April 2002 to April 2003) was analysed. 35 spectral clusters were generated with the following parameters: convergence threshold (95%), maximum number of merge pairs (2), minimum class standard deviation (1), minimum number of pixels in a class (35), and maximum number of iterations (10). According to Australia land use/cover classification scheme, and study region situation (irrigation area), we felt that it was necessary to develop a more object-oriented land cover classification scheme. Our land cover classification scheme contains three classes of woody vegetation, two classes of protected land use, three classes of pastures, two classes of cropland, three classes of water bodies, and three classes horticultures, there is one class of residential, wetland and one class of other minimal use in our study.

The land use/cover dataset in 2000 from Murray irrigation Limited Corporation (MIL), which was derived from Landsat Enhanced Thematic Mapper (ETM+) images acquired in 2000, and Landsat imagery data in year 2002 and 2003 (path-92, 93; row-84, 85), also national vegetation information system dataset (Department of Environment and Heritage, 2003) provided information on the spatial extent of the major grassland categories in Darling-Murray Basin were used as an aid for interpretation and labelling of the spectral clusters. Decision tree classification method was applied by combining classification result from ISO-DATA and vegetation information system dataset and other land use dataset (Muchoney, 1999). Still there is some several classes need to be revised by manual operation of the classified result by applying interactive class tool in ENVI 4.4.

3.4 El Niño and Precipitation

To identify the different ENSO periods, values for the Southern Oscillation Index (SOI) often referred to as Troup index (Troup, 1965) are taken. This index describes a standardised anomaly of the Mean Sea Level Pressure difference between Tahiti and

Darwin. Sustained and strong negative and positive values of this index are respectively considered as an indicator of El Niño and La Niña events. The evolution of SOI data from 1998 to 2007 are obtained from the website of Australian Bureau of Meteorology (http://www.bom.gov.au/climate/current/soihtm1.s html). In our study, there are 36 SPOT-NDVI time series data in one year, however only 12 SOI data in the corresponding period, so linear interpolation was applied for the SOI data to match NDVI data sets. Precipitation and temperature data were downloaded from SILO website (http://www.bom.gov.au/silo), but only some typical area were analyzed in this study.

3.5 Analysis the impact of SOI on MDB vegetation

In our study, correlation analysis between SOI and SPOT-NDVI were done by pixel scale with IDL 6.3 software package. After interpolation, 36 corresponding SOI data sets were produced, and time series of NDVI data was extracted. Correlation coefficient between NDVI and SOI were calculated pixel by pixel over the study region. Still some typical regions were selected, and further analysis between NDVI and precipitation, temperature were done within our study period to support our study result.

4. RESULTS AND DISCUSSIONS

4.1 MDB landscape characteristics

Figure.2 shows the general landscape structure in the MDB region. Land in agricultural production occupies 83.7% of the total area of the Basin. While the rest parts are mainly natural conservation and protective land, water bodies and forest. Whilst crop production is of critical importance to the MDB's agriculture, it occupies only a relatively small proportion of the area of land in farms. Most of the agricultural land in the MDB is devoted to grazing. There is great variation in the types of grazing lands, from the improved pastures of the high-rainfall areas to the semi-arid and arid native vegetation used for very extensive grazing in rangeland areas. Sown pastures areas are mainly in irrigated regions, which are used for grazing and hay production. The main livestock in the Basin is beef cattle and sheep, and there also a big portion of dairy cattle in some irrigated areas. the total area devoted to agricultural crops in the MDB is 11 million hectares. This is 53% of the Australian crop area of 20.6 million hectares and which is about 12% of the total farm area in the MDB. Major agricultural crops considered here are cereals, coarse grains, rice, cotton, hay, lucernes, oilseeds, peanuts, and the horticultural corps of grapes, fruit, and vegetables.

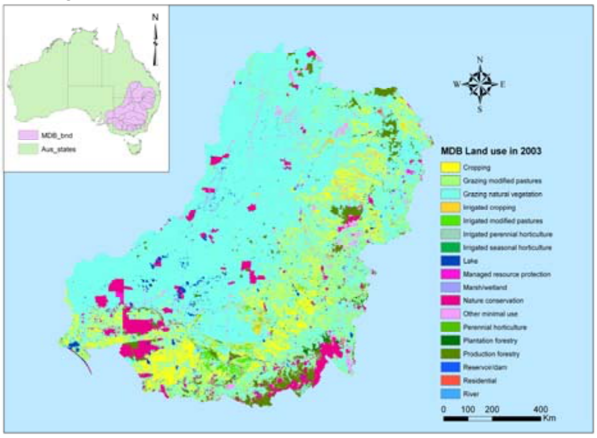

Figure.2 Land use distribution in Murray-darling Basin in 2003

4.2 NDVI and SOI times series trend analysis

During our study period, Australia experienced server successive drought years, these climate events cause an obvious impact on vegetation at both regional and national scale. A first look is taken on a 130km*200km geographic window around Murray irrigation area that has been investigated for several field campaigns (see Figure 1 for geo-location), located in New South Wales. The land cover of this region is mixture of scrublands, swamp, irrigated cropland, grazing pasture and forest. The temporal evolution of NDVI spatial mean values can be seen in Figure 3 (which were done by land use masking method). In most of cases, the seasonal variability in this region presents peak values during the winters which can be understood as a season with no severe water limitation for the plants with a combination of low evaportranspiration. NDVI curves are strongly correlated precipitation in the region. There are two obvious NDVI decreased curve value in year 2002-2003 and 2006-2007, which is direct result from severe drought conditions of the year. For all the other years, though there are some variations of different land cover, the general NDVI curve trend is similar.

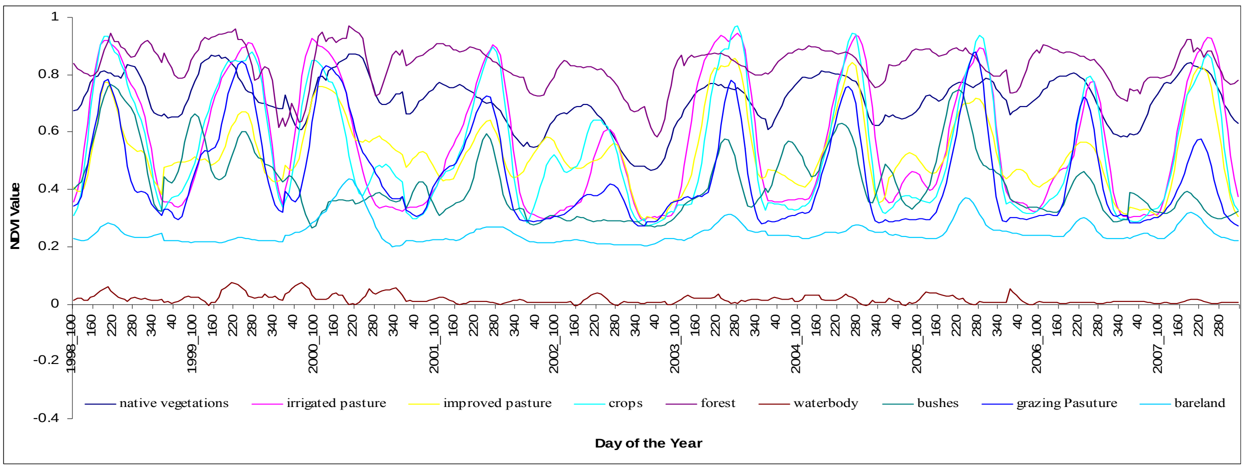

Figure.3 Typical land use NDVI change pattern in Murray Irrigation Area from 1998 to 2007

Figure 4 is the interannual variability of SOI. It was La Niña period during 1998-2001, with high SOI values, while for year 2002-2003, 2004-2005, and 2006 are the El Niño periods. This general result corresponds very well with what has been shown for the precipitation in the MIL irrigation area (Fig.5). However, besides the general positive correlation between curves on a large time scale, we notice weaker correlation between SOI and NDVI when considering the seasonal time scale.

In the Murray Irrigation Area, the average annual precipitation is about 570mm, and the average annual evapotranspiration is about 1620mm (this value is derived from 12 weather stations data from 1900 to 2007 locate in the Murray Irrigation Area). It can be seen from figure.3 and figure.5, NDVI time series trend is more likely to correlate with precipitation trend which may caused by ENSO change pattern.

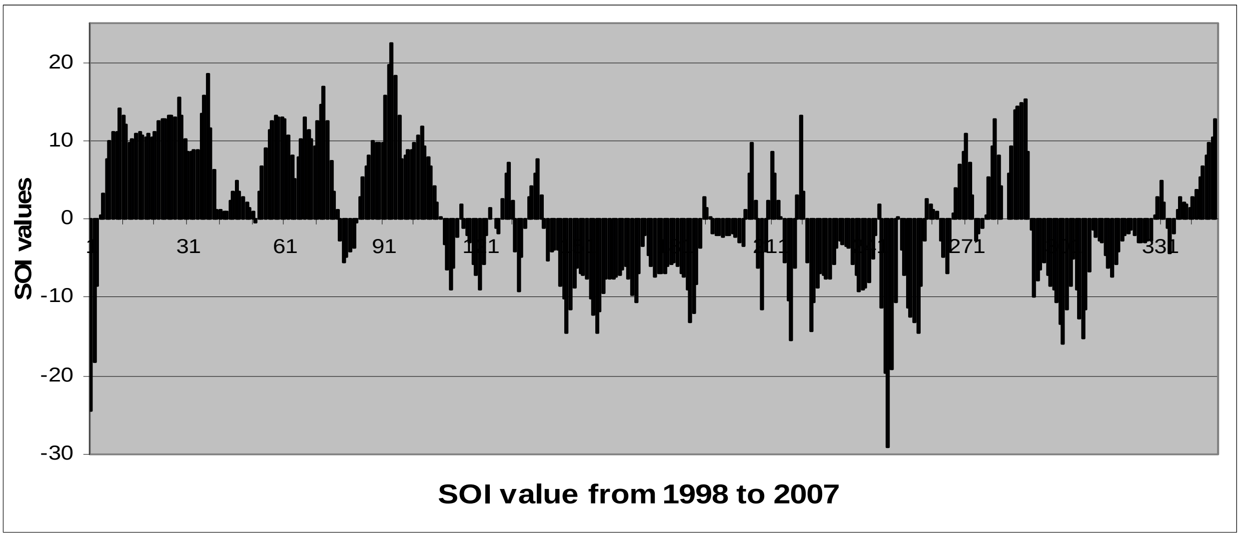

Figure.4 SOI change patter in Australia from 1998 to 2007

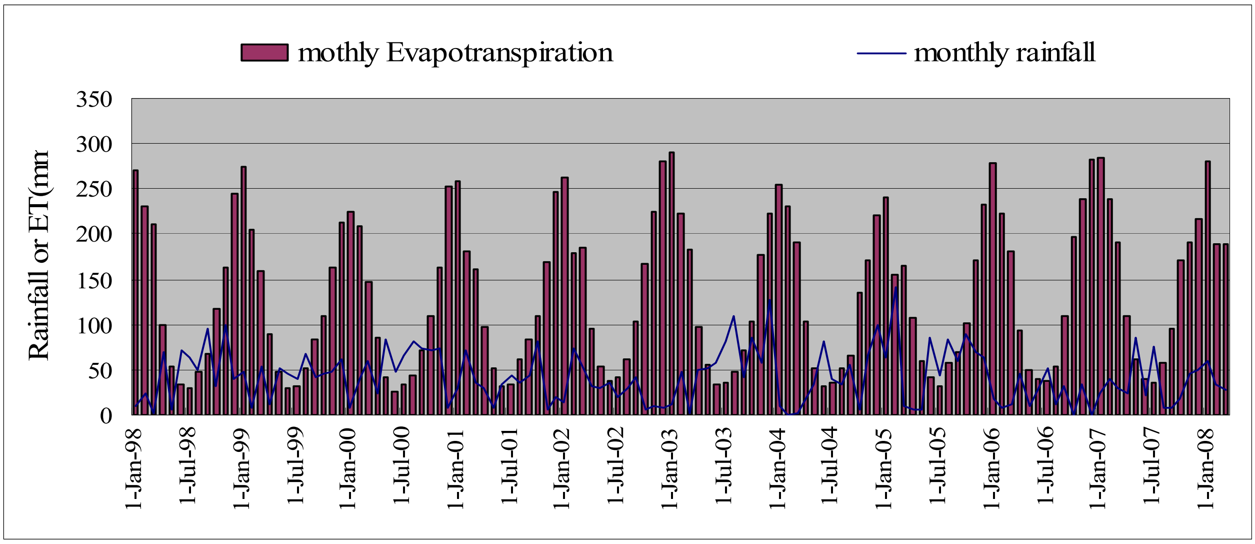

Figure.5 Precipitation and Evapo-transpiration in Murray Irrigation Area from 1998 to 2007

4.3 Mapping the Geographic Correlation Pattern between NDVI and SOI

In an attempt to verify the geographical patterns of ENSO influence on Australia shown by different authors who generally find, high (low) ENSO influence on northern and eastern (southern and western) regions (Potgieter et al., 2005; Drosdowsky et al., 1991). In this study, we calculated the correlation between SOI and NDVI for each pixel to derive the correlation coefficient map of the MDB. The results are given in Figure5. We first notice that the positive correlation previously found in the Murray-darling conjunction area and Great Division Range fringe area. Negative correlation can be found in the south west part and the north west part of MDB region. However, in other parts of the continent a different behaviour is observed and no strong correlation. Compared with figure.2, it seems there no direct relation with landscape patterns in our study region. There is an obvious correlation trend in year 1999, in the north part of the MDB region, the correlation shows an positive pattern, while it shows negative pattern in most of the southern part of the MDB region. Meanwhile in the north centre parts of MDB, very small negative correlations can be observed. As for 2000, there is also an almost obvious inverse correlation trend pattern compared with that in 1999. Still it should be noticed that the correlation coefficient value is not high for the positive value area.

Correlation trend pattern in 2001 is similar to that of 1999. In year 2002, most of forest and grazing forest in the MDB region show positive correlation, however in most parts of the dryland cropping area show negative correlation values. It was La niña events periods during 1998 to 2000, however there is no obvious pattern in 2001. While, it was El niño events during the year2002-2003, 2004-2005 and 2006 according to SOI value (see figure.4). Generally speaking, La niña event bring more rainfall in the MDB region, while it often experiences drought period when El niño events take place.

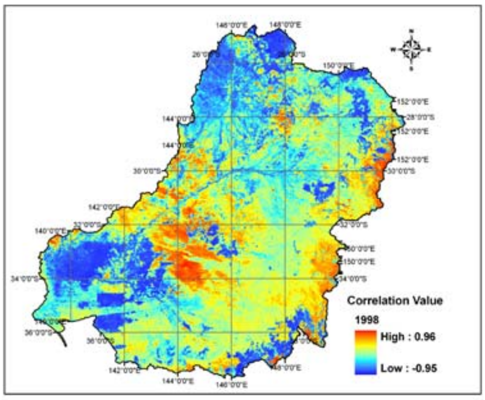

Figure.5a NDVI and SOI correlation distribution in Murray-darling Basin in 1998

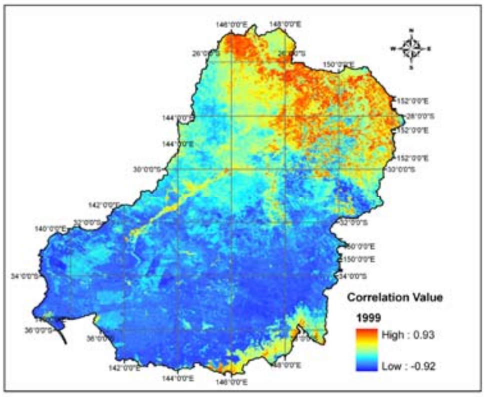

Figure.5b NDVI and SOI correlation distribution in Murray-darling Basin in 1999

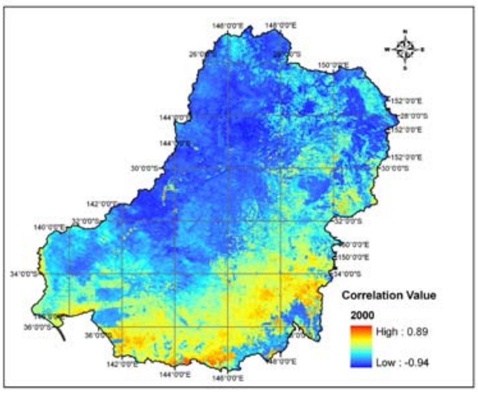

Figure.5c NDVI and SOI correlation distribution in Murray-darling Basin in 2000

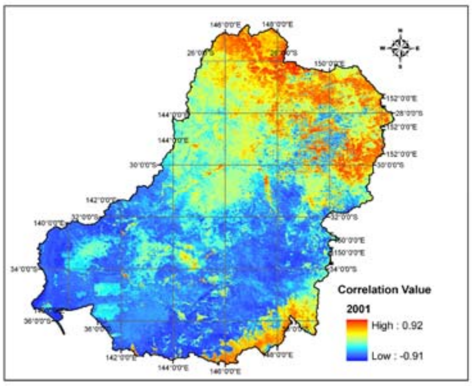

Figure.5d NDVI and SOI correlation distribution in Murray-darling Basin in 2001

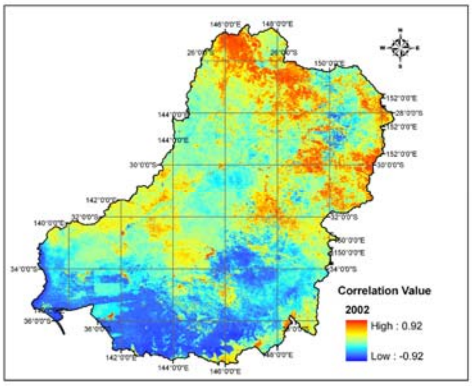

Figure.5e NDVI and SOI correlation distribution in Murray-darling Basin in 2003

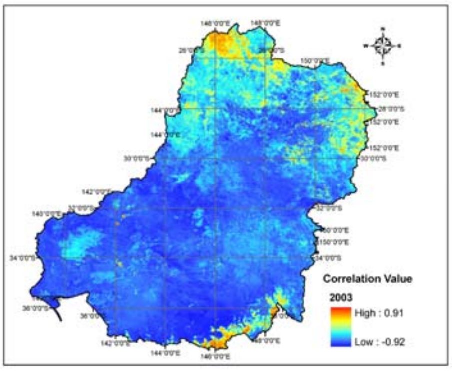

Figure.5f NDVI and SOI correlation distribution in Murray-darling Basin in 2003

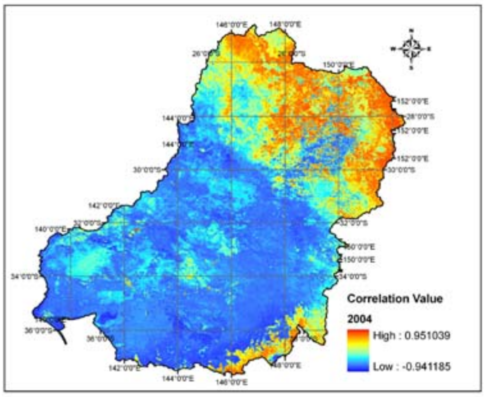

Figure.5g NDVI and SOI correlation distribution in Murray-darling Basin in 2004

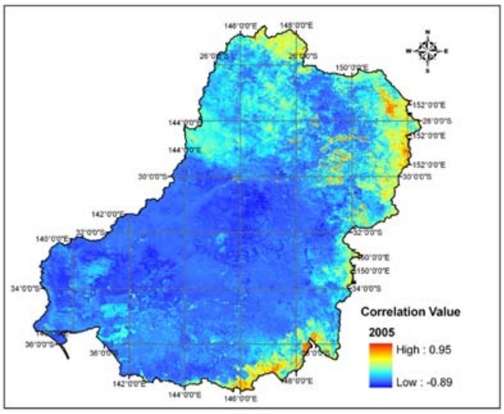

Figure.5h NDVI and SOI correlation distribution in Murray-darling Basin in 2005

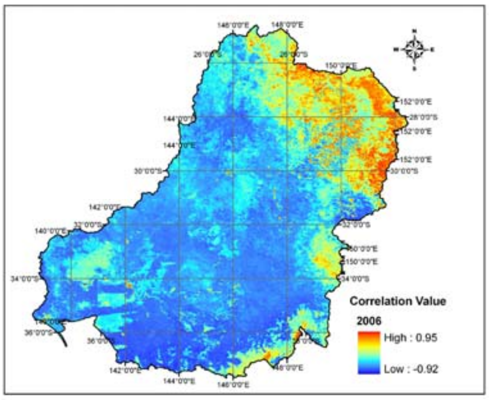

Figure.5i NDVI and SOI correlation distribution in Murray-darling Basin in 2006

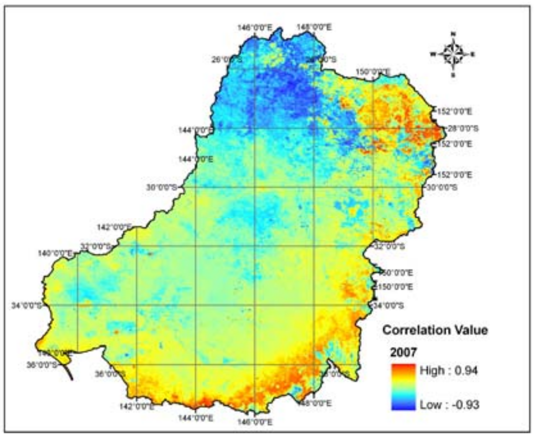

Figure.5j NDVI and SOI correlation distribution in Murray-darling Basin in 2007

It was experiencing El niño event in 2002, however, most of the MDB region, especially native grazing forest and production forest show positive correlation trend. This maybe explained by the difference of soil moisture retention ability between forest and grass and cropping area. Forest or grazing forest and bush can still growing relatively well even in some drought period for soil moisture left from last year, however in dry land crop or other improved pasture, it is very hard to retain the soil moisture because of the quick evaportranspiration. Australia experienced a very severe drought year during 2002-2003 (El niño event), it cause obvious NDVI reduction in the MDB region (see figure.3). Correlation between NDVI and SOI once again verify this drought event by showing negative values nearly all over the MDB region. Though there is no obvious El niño or La niña events during 2003-2004, the previous year drought still cause some impact on NDVI value in the MDB region, and most southern part of the MDB regions shows the negative correlation values. It was El niño period during 2005-2006, and in most part of the MBD region, the correlation shows negative value in year 2005, and 2006 as well except northeast corner of the MDB region. It was La niña period again during 2007-2008, so the correlation coefficient shows positive value in most the MDB region; however there is no strong correlation except these forest landscape along the east boundary of the MDB region. It can be found by comparison figure.5 and figure.2 that production forest or grazing forest tend to show positive correlation values in most of the time, however dryland crop and native grassland pasture is more sensitive the El niño or La niña events that directly or indirectly cause drought or more rainfall in the region. Actually, rainfall and temperature pattern are different caused by El niño or La niña events that may more directly result in the final pattern of NDVI and SOI correlaiton.

5. CONCLUSION AND FUTURE STUDY DIRECTIONS

This study has taken advantage of the available time series of SPOT/VEGETATION data. Owing to the geometric and radiometric quality of VEGETA TION products delivered free of charge at website on http://free.vgt.vito.be, we collected 10 years time series (1998-2007) NDVI for the MDB region. This archive made possible our investigation on the way ENSO events impact the behaviour of the vegetation ongoing and senescence of greenness variation and its geographic distribution. Moreover, we did also investigate the relevance of NDVI and SOI to investigate the plant water stress status. Our result indicates that the geographic patterns of the highest sensitivity to El Niño or La Niña in the MDB region. We also illustrate the inter-annual variability of these events in term of its relationship with SOI and of its geographic distribution. This variability is clearly explained by precipitation anomalies in relationship with ENSO events. Through comparison between NDVI and SOI correlation pattern and landscape structure in the MDB region, it was found that production forest and grazing forest more resilient to ENSO events, while dryland crop and natural grass grazing pasture is more sensitive to ENSO events. This can be explained by soil water retention ability, so forest have more resilient ability to drought climate in some condition, but for long term severe drought, it will also cause prominent impact on NDVI amplitude and seasonal trend of greenness ongoing and senescence. It should also pointed out that the rainfall and temperature pattern change caused by ENSO events that have direction impacts on NDVI change pattern, eventually change the correlation pattern in the MDB region.

There have several aspects need to be investigated in the future. First of all, rainfall and temperature pattern in the study region need to be produced by interpolation, and then analysis the relationship between these two parameters and NDVI. Though SOI have an impact on NDVI, but more directly it change the precipitation and temperature pattern in the MDB region. Future work on how the ENSO impact on precipitation and temperature, and finally impact on the vegetation growing status in the MDB region need to be addressed. Also in our work, only relationship between SOI and NDVI were analysed based on yearly data. Actually, the ENSO trend maybe have its own trend, so it would be more reasonable to analyse these data according to ENSO pattern rather than basing on yearly NDVI data set, and it would be will be more acceptable to explain its impact on NDVI or vegetation growing status according to ENSO pattern.

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