Assessment of El-Nino’s influence on vegetation conditions in Indonesia

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El-Nino southern Oscillation (ENSO) is a widely acknowledged global climatic phenomenon caused by a rapid increase of sea surface temperature in the tropical Pacific. The ENSO phenomenon has effects throughout the world and one of these effects is redistribution of rainfall from Indonesia, New Guinea and Australia into the Pacific and to the pacific coast of South America. This redistribution leads to drought conditions in wide areas of South-East Asia. The goal of this study was to investigate and to quantify the relationship between variability of ENSO and drought events over Indonesian archipelago. We investigated the teleconnection effect between vegetation activity and ENSO by calculation of correlations between Normalized Difference Vegetation Index data derived from the Advanced Very High Resolution Radiometer (AVHRR) and two ENSO indices, Sea Surface Temperature Anomalies (SSTA) and Southern Oscillation Index (SOI) for the period 1982-2003. Correlation analysis revealed a strong relationship between the analysed variables in terms of variability and amplitude. The results indicate considerable influence of SST and SOI in the tropical Pacific on the vegetation conditions over Indonesia. The major ENSO impact over the Indonesian archipelago was a prolonged dry period with anomalously low amounts precipitation. The net effect of these changes was a significant decrease in the NDVI value throughout the affected areas. Pixels with statistically significant correlation coefficients were considered to represent territories affected by ENSO. These territories were mapped and measured. The study established the relationship between the intensity of ENSO-events and the dimension of area affected. The results of this study serves to a better understanding the origin and driving forces of droughts in South-East Asia as well as efforts to estimate their impact on the vegetation cover.

Анализ влияния Эль-Ниньо на состояние растительности в Индонезии

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Эль-Ниньо – феномен резкого увеличения температуры воды Мирового океана в экваториальном поясе, вызывающий неожиданные изменения глобального распределения осадков на суше, следствием чего предполагаются засухи во многих регионах Земного шара. Целью данного исследования было выявление зависимости между интенсивностью и частотой Эль-Ниньо и метеорологических засух на островах Индонезийского Архипелага. В исследовании проведен анализ корреляции временных рядов аномалии температуры поверхности воды и атмосферного давления для экваториальной области Тихого океана с нормализованным дифференциальным индексом NDVI для территории Индонезии, охватывающих период с 1981 по 2005 годы. Корреляционный анализ установил тесную связь между индексами Эль-Ниньо и NDVI, как для периодичности, так и для амплитуды указанных переменных. Доказано влияние температуры водной поверхности и атмосферного давления в области экватора Тихого океана на состяние растительности островов Индонезии. Значительное снижение NDVI, наблюдаемое в периоды Эль-Ниньо, обусловлено метеорологическими засухами, являющимися результатом перераспределения осадков в Южной части Тихого океана. Выявлены и картированы площади, охваченные засухой для каждого периода Эль-Ниньо. Установлена закономерность между интенсивностью Эль-Ниньо и величиной площадей, подверженных его влиянию Данное исследование служит улучшению понимания механизма возникновения засух и Юго-Восточной Азии и оценки их влияния на растительный покров.

Introduction

From current published studies it is known that the vegetation on the surface of the Earth is rapidly changing. Change is occurring to the phenology, to distribution of vegetation on the Earth surface and to the annual dynamics of photosynthetic activity by vegetation. These changes are both natural and anthropogenic nature. Driving forces whose influence on vegetation cover is very strong are periodical short-time climate fluctuations such as El Nino-Southern Oscillation (ENSO) events. A typical characteristic of this cycle is the emergence of huge mass of warm and cool water in the central and eastern tropical Pacific. The ENSO phenomenon is a coupled atmospheric and oceanic mechanism responsible for changes in the Walker cell circulation system that has effects throughout a vast area of the world [1, 2, 3]. One of these effects is to shift rainfall distribution from Indonesia, New Guinea and Australia into the Pacific and to the pacific coast of South America. The total societal impacts of the ENSO are estimated in billions of dollars. For example, the resultant impact of the largest ENSO event of the twentieth century (June 1997 to May 1998) killed about 2100 people and caused at least 33 billion US dollars in property damage [3].

There is a great demand for a better understanding the nature of impacts of ENSO events on the ecosystem as a whole system and on the vegetation cover as an important component of this system at all scales from global to regional and local. This understanding requires detailed investigations on the vegetation response to ENSO events. On the one hand, knowledge of this response holds the potential for discrimination of threatened areas and forecasting of damage grade by ENSO events. On the other hand, this knowledge subsequent improves planning of protection arrangements. Another benefit is associated with forecasting of regional agricultural yields for ENSO years what improves planning for food supply for times of food scarcity.

Satellite remote sensing has been widely used for monitoring impacts of ENSO on vegetation cover. Commonly, these studies used data time series from the Advanced Very High Resolution Radiometer (AVHRR) in combination with any conventional ENSO index. The AVHRR product usually used for these investigations is the Normalized Difference Vegetation Index (NDVI) which proved to be a good general surrogate for vegetation activity [4, 5]. The majority of the remote sensing research that has examined ENSO-vegetation variation relationship has focused on Africa and North America [6, 7, 8, 9]. Only a few studies have concentrated on Southeast Asia and particularly on the Indonesian archipelago [10, 11].

The goal of this study was to analyse and describe the vegetation response to anomalous climate conditions in Indonesia throughout the period of 1982-2003. We investigated the teleconnection effect between vegetation activity and El Nino-Southern Oscillation calculating cross-correlation between Normalized Difference Vegetation Index data and ENSO indices for the period 1982-2003. We determined, mapped and measured areas affected by each ENSO event from the study period. Threshold values of vegetation sensitivity to climate fluctuations were computed for each vegetation type.

Data used in the study

GIMMS NDVI dataset

To monitor temporal variations in vegetation activity we used the Global Inventory Monitoring and Modelling System (GIMMS) NDVI dataset compiled by the GIMMS research group from the data delivered by the Advanced Very High Resolution Radiometer (AVHRR) launched by the National Oceanic and Atmospheric Administration (NOAA) in 1978. The data, at 8-km spatial resolution, are originally processed as 15-day composites using the maximum value procedure to minimize effects of cloud contamination [12]. For this research, we created monthly composites from two 15-day composites in any given month to further minimize the effects of clouds on the vegetation signal. These monthly NDVI data for consecutive three and twelve months were averaged to generate seasonal and annual NDVIs for each year. The dataset covers the period from 1982 to 2003. Additionally, we have calibrated the GIMMS NDVI data against three time invariant desert targets using a method described by [13].

ENSO indices

There are different ways to describe the phase and intensity of a particular ENSO event. most widely used methods implement proxies – so called indices which are built e.g. on basis of anomalies of climatic factors measured in the Pacific ocean: Surface Temperature (SST), the Southern Oscillation Index (SOI) and Outgoing Long-wave Radiation (OLR). In present study we the SST and SOI were used as ENSO proxies. The SOI refers to standardized difference in sea level pressure between the eastern and western Pacific and is computed as:

$$SOI = 10 * [\delta p(Papeete) - \delta p(Darwin)] / \sigma \qquad (1)$$

The associated measurements points are located in Papee (Tahiti) and Darwin (Australia). High negative values of SOI (< - 10) and positive anomalies of SST (1.5 – 2°) indicate a warm event i.e. El Nino. The correspondent high positive values of SOI and negative anomalies of SST indicate a cold event – La Nina. The fluctuations in the chosen indices have been shown to be significantly correlated with global scales precipitation anomalies throughout the tropical belt and thus reflect the interaction of ocean-atmosphere system with teleconnection effects over the land in the form of precipitation redistribution [3].

The data comprised monthly values of both indices and covered the period of 1981-2005. The dataset of ENSO indices is freely available in Internet on the web-side of NCEP. The SST data are associated with the NINO 3.4 ENSO monitoring region located in the eastern equatorial Pacific between 5° S to 5° N latitude and 120° W to 170° W longitude and is considered to be the most sensitive to the fluctuations, duration, and magnitude of ENSO events. The SST of NINO 3.4 has already been recently used in studies of relationships between ENSO and vegetation variability from different regions in Africa, North America and South America [6, 7, 8].

Methods

The main aim of present work is to study teleconnection effects between variability in vegetation cover properties represented by NDVI and variability in ENSO represented by SOI and by SST of NINO 3.4 and to define areas which exhibit high vulnerability to ENSO. To reach the goal we used the well known approaches such as time series analysis and correlation analysis. The data were analysed at three spatial scales (average of Indonesia, average of individual land cover classes, per-pixel) and at two time-scales (monthly scale within individual ENSO event, inter-annual scale comprising mean annual values).

The data analysis at monthly time-scale is performed using the mowing window correlation techniques (MVS). This technique disaggregates global statistics and calculates a local cross-correlation separately at every point of the time series. It conducts correlation analysis on a window which is much shorter than the entire time series data. We computed correlations between spatially averaged monthly time series of NDVI anomalies and the ENSO indices with a lag range of -2 to +2 months and a window size between 24 and 40 months. Application of this local correlation technique enabled to identify a correlation coefficient at every time-point (month) of the study period. The MWC should highlight temporal non-stationarity in the relationship between variables to be analysed. We supposed that vegetation response to SST and SOI should be stronger during ENSO episodes and weaker during non-El-Nino months.

To investigate a relationship between inter-annual variabilities of NDVI and ENSO, the correlation analysis was performed using generated time series of mean annual NDVI and corresponding means for each of the ENSO proxies. For calculation of within-event correlation, we utilized monthly values of the years of a certain ENSO episodes. These procedures were carried out for data both spatially averaged over the whole Indonesian archipelago and at per-pixel scale. Significance at the 5% confidence level was used as a criterion for the analysis. Areas with significant correlations were mapped and measured.

Results

Dynamics of NDVI, SST and SOI during the period 1982-2003

Figure 1 shows 22-year courses of monthly standardized NDVI anomalies versus SST anomalies and SOI. One can observe a clear relationship between temporal patterns of both ENSO proxies and NDVI anomalies. During the time between 1982 and 2003, Indonesia has experienced at five El-Nino events and El-Nino-like years. The most significant of them are associated with the years 1982-83, 1987-88 and 1997-98. The lowest SOI and the highest SST were observed in 1982-83. However, the longest warm episode occurred in 1997-1998 and it is considered as the worst known in the history since the beginning of instrumental weather observations. A number of years within the study period exhibited El-Nino-like conditions or weak warm events. These are 1991-1995 and 2001-2002. Due to a number of years with El-Nino-like conditions in 1991-1995 it is possible to consider the 1997-1998 ENSO as part of a longer cycle that has been developing through much of this decade: since 1991, the SOI had been overwhelmingly negative.

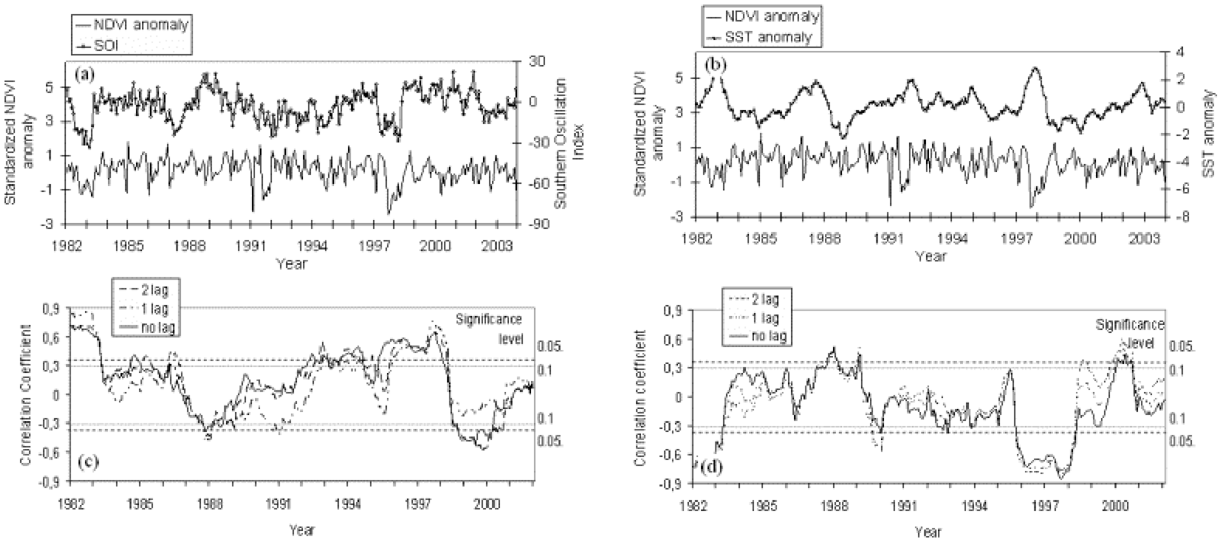

Figure 1. Monthly time series of area-averaged standardized NDVI anomalies versus SOI (a) and versus anomalies of SST in NINO 3.4 (b) for the period 1982-2003. (c) Correlation of the SOI and spatially averaged NDVI anomalies from 1982 to 2003, calculated for 30-month mowing window at lags ranging from 0 to 2. (d) The same as in (c) but for SST anomalies and NDVI

Negative NDVI anomalies with values under -1 standard deviation are strongly associated with warm ENSO events and thus with negative SOI. Negative NDVI anomalies of high magnitude are associated with the values of the SOI under -15-20 and with high positive values of SST e.g. during warm events of

1982-83, 1986-87 and 2001-2002. The absolute minimum of NDVI for the study period (< -2) was observed during 1997-98 El Nino associated with monthly SOI values under -20 and SST anomalies over 2°C.

Relationships between monthly anomalies of NDVI and the ENSO proxies

The analysis of the monthly time series of the NDVI anomalies and the both ENSO proxies revealed presence of relationships between them. These relationships seem to vary in time. It was apparent that during a certain ENSO episode the relationships were stronger than in during the inter-phase time. In order to investigate the strength and variations of this relationship, we applied a moving window regression for calculation of correlation coefficient between the time series of spatially averaged NDVI anomalies and the two ENSO indices. Having tried different size of the moving window (from 12 to 48 months) and different lag range (from -3 to 3 months), we found the best correlation coefficients for every month during the period 1982-2003. The results of computations are presented in Figure 1 (c, d). The results allowed monitoring of not only the relationships for separate ENSO events, but also for the “normal” states of system. The vegetation response to El-Nino effects during cold events was also apparent. The value of the correlation coefficients varies from one month to another but its time series exhibit clear pattern throughout the entire study period. This pattern is associated with ENSO parameters. Obviously, the highest positive values for NDVI-SOI correlation and the lowest negative values for NDVI-SST correlation are bound to the strongest ENSO events of 1982-83 and 1997-98. The values of correlation coefficient during the weaker warm ENSO events were neither statistically significant nor consistent, whereas some cold ENSO events have shown statistically significant correlation.

From Figure 1 is apparent that the NDVI anomalies were predicted by variability in the SOI during more than 5 years of the last decade of the 20 century. High correlation coefficients are associated with the period between 1992 and 1998 with a short interruption at the end of 1994 - start of 1995 and the maximum values at the end of 1997 -start of 1998. This devises the cumulative impact of the last largest El-Nino event. The time series of correlation coefficient devise the 1997-98 El-Nino event as a part of a longer cycle that has been developing through much of the decade. Since 1992, the signal of the ENSO in the variability of NDVI is evident. But the most significant impact is associated with 1996-1998 when the correlation coefficient achieved maximal values for this period. For the relationship between NDVI and the SST anomalies, the duration of the period with significant correlation was shorter. It continued from the end of 1996 to the begin of 1998, other years from the ENSO cycle of 1991-98 did not exhibit significant correlation. The results clearly demonstrated that the 1982-83 event was more intense than the 1997-98 event. It was apparent from higher correlation coefficients between NDVI anomalies and the SOI associated with the first. However, the second event considered to have a far greater impact on the environment due to the cumulative effect described.

The 1982-83 and 1997-98 ENSO episodes

Generally, most El-Nino events persist for about a year and typically occur 3-5 years apart. Even though no two El-Nino events are ever the same, - they significantly vary in their duration, intensity, pronounce and environmental impact, - we have seen in the previous sub-section, certain patterns in variability of ENSO indices are discernible. These patterns seem to be associated with patterns in NDVI variability over the study period. One such significant pattern is that EL-Nino episodes are generally phase-locked to an annual cycle. Most events begin and end during the period between March and June. In order to “scale down” from the entire 22-years period to the period of divided events, we extracted the 1982-83 and 1997-98 El-Nino events and analysed them more closely. According to SOI, the 1982-83 El-Nino episode began between May and June (Figure 2, a). The SOI rapidly declined from -3.8 in April to -8.2 in May and -20.1 in June. During the summer months, the SOI continued to decline and reached its first deep minimum in August (-23.6). The second minimum was reached in November (-31.1), and finally, the absolute minimum for this ENSO event was observed in February (-33.3). Thereafter, the SOI rose sharply to 6 in May but declined again to negative values in June-July and changed to positive in August-September. The SST of equatorial Pacific began to rise in May-June and reached the maximum in January exhibiting an anomaly value of + 2.85 (Figure 2, a). After that, the SST had gradually declined during the following months until it reached its normal value in July.

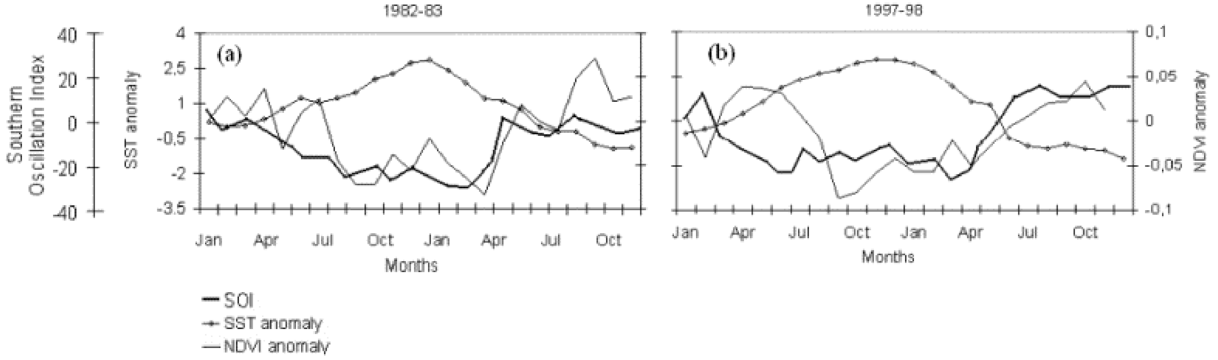

Figure 2. Monthly time series of standardized NDVI anomalies versus SST anomalies and SOI during the ENSO events of 1982-83 (a) and 1997-98 (b)

Temporal patterns in NDVI anomalies during the 1982-83 are strongly associated with that of the ENSO indices. In order to prove this association statistically, we carried out simple correlation analysis. Correlation coefficients were computed for NDVI anomalies and SOI as well for NDVI anomalies and SST. The results confirmed that the relationship between these variables is statistically significant and strong (Table 1). From the graphs of time-series, one may propose a time-lag between the ENSO event and the response of vegetation to its impact. Really, the highest value of correlation coefficient between the NDVI anomalies and the ENSO indices has been achieved with a time-lag of 1 month imposed to the NDVI data. About 45% of all variance in the NDVI anomalies are explained by the SOI, whereas about 55 % are determined by variations in SST. According to SOI values, the 1982-83 El-Nino episode was shorter but more intense than the 1997-98 (Figure 2, b). By contrast, the 1997-98 El-Nino began earlier in the year, continued longer and was characterized by two distinct periods of intensity: May-June 1997 and January-April 1998 (Figure 2, b). Due to its prolonged effect, the 1997-98 El-Nino episode had the far greater impact on the environment. The NDVI anomalies fell under the value of -0.08, whereas that computed for the 1982-83 episode had not fell under -0.06. The relationships between NDVI and the ENSO indices are strong and statistically significant at 0.05 confidence level. The SOI has explained about 25 % of variance in NDVI during the years of the 1997-98 ENSO event (Table 1). More than 44 % of variance in NDVI is explained by the Sea Surface Temperature. Other ENSO events from the study period, the 1986-87, the 1991-92, and the 2001-02, have not exhibited such clear temporal patterns as the two strongest episodes from 1982-83 and 1997-98. Their impact on the pattern of spatially averaged NDVI anomalies is either weak or statistically not significant.

Table 1. The values of R^2 between time series of spatially averaged NDVI anomalies and the ENSO proxies for warm ENSO events within the period 1982-2003.

ENSO event	***1982-83***	***1986-87***	***1991-92***	***1997-98***	***2001-02***
SOI	0.44	0.17	0.28	0.34	0.11
SST	0.54	0.14	0.31	0.42	0.12

Detection of areas showing high vulnerability to ENSO

A warm El-Nino event produces a decrease in precipitation over a wide area. However, the effect is never total but always scattered, with some localities far less affected than others and some localities quite not affected. The results clearly indicate that there were significant variations in the percentage of affected pixels between affected areas associated with different ENSO events (Figure 3). The highest percentage of affected pixels is associated with the 1997-98 ENSO episode (Figure 3, d). Over the entire study region, 54.14 % of all pixels showed significant correlation with the combination of the ENSO indices. The lowest percentage is associated with the 1991-92 ENSO event (Figure 3, c). This El-Nino warm episode affected about one-third (32.11 %) of the entire territory of Indonesia. The ENSO episodes of 1982-83 and 1987-88 exhibited 38.03 % and 38.20 %, respectively (Figure 3, a, b).

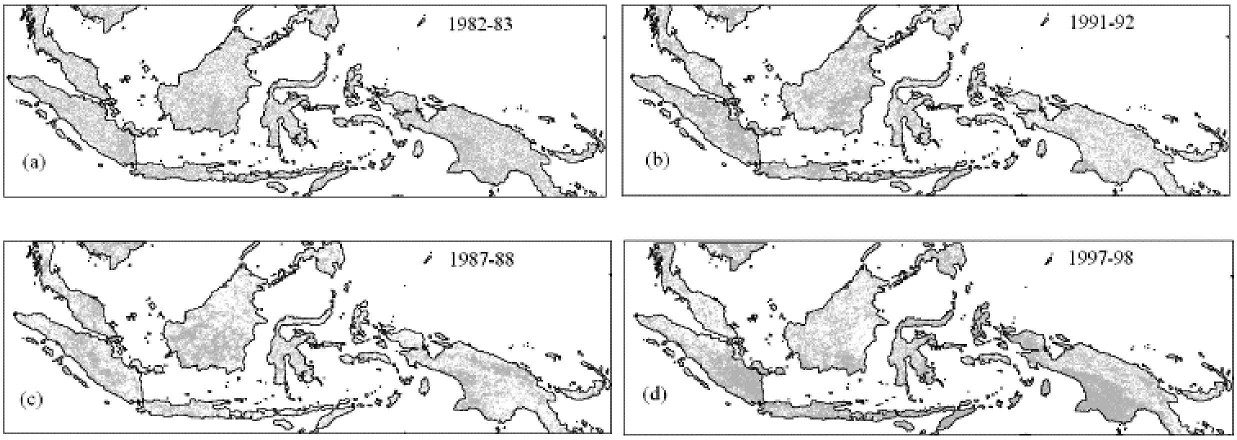

Figure 3. Spatial distribution of areas showing high response to (a) the 1982-83, (b) the 1987-88, (c) the 1991-92, and (d) the 1997-98 ENSO events

With respect to spatial distribution of areas affected during any ENSO event it was an important question whether this distribution varies randomly or there is some pattern in these areas recognizable for every El-Nino episode. In order to prove this, we compare maps of the high response areas for different ENSO events and detected frequency of occurring at the per-pixel scale. The results are demonstrated in Figure 3. Even though the spatial distribution of the high response areas for every El-Nino event seems to be like but the intersection of the maps displays that only a small part of the entire Indonesian archipelago revealed high response during all five ENSO events. According to our measurements, only 4.57 % of the entire area of Indonesia experienced significant impacts of all five El-Nino warm events during the period 1982-2003. About 10 % of all vegetated pixels showed high response during three ENSO events, and 27.62 % of all pixels were affected during at least two ENSO episodes.

The results demonstrate that, even though all El-Nino impacts occurred in Indonesia not everywhere and not with the same devastating effects, there are areas which were affected during more than one El-Nino event. This indicates a presence of strong patterns in distribution of areas of ENSO impacts. It is appropriate therefore to consider these impact areas as core regions of vulnerability to ENSO dynamic. Most of these pixels are concentrated in the southern part of Borneo, in north-east and north of Sumatra and Java and in south of New Guinea. These regions can be considered to be high exposed to ENSO. Most devastating effects on ecosystems are to expect here.

The distribution of other areas localized out of the core regions seems to be random. It means influence of other than ENSO factors on vegetation cover in these areas. These other factors amplify or inhibit the response of vegetation cover to a particular El-Nino event. The influence of these factors can be suggested to present a sequence of human activity in different parts of the country or effect of fires. The literature reported about severe fires in forested areas of Indonesia associated with El-Nino years. The largest fires in recent history occurred during the 1982-83 El-Nino when an estimated area of 3.5 million hectares burnt. The 1997-98 ENSO is also characterized by severe fires. An assessment of area burnt comes to 9.5 million hectares. There were less intensive fires in 1987 and 1991 [14].

Conclusions

This study has demonstrated that there is potential in using NDVI for monitoring the effects of ENSO-induced drought stress on tropical regions. The NDVI data derived from the Advanced High Resolution Radiometer (AVHRR) were successfully combined with the southern oscillation index and sea surface temperature anomalies to model the teleconnection effect and to detect vegetation areas of high response to unfavourable climatic conditions caused by ENSO events during the period of 1982-2003. The results of this study may be helpful for forecasting of the devastating El-Nino impact on vegetation cover in Indonesia and can be used for planning of protection arrangements.

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