FIRE AND EL NIÑO IN BORNEO, SE ASIA

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ABSTRACT:

This project investigates the relationship between fire activity and El-Nino-Southern Oscillation (ENSO) events in South East Asia using Borneo, Indonesia as a case-study. Low spatial resolution NOAA AVHRR GAC satellite data were used to investigate the occurrence of active fires during the El-Niño episodes of the last 20 years. Results showed that the adjusted GAC fire count numbers were very well related to the LAC fire counts of the coincident imagery, indicating the efficacy of GAC data for providing quantitative fire information during El Niño periods and specifically the1997-98 event on Borneo.
The distribution of fires in time was analysed and compared to the strength of the El Niño-Southern Oscillation (ENSO) as measured by the sea surface temperature anomaly (SSTA) in the Niño 3 region of the Pacific Ocean. The strongest ENSO-fire association was observed when the total 16-months sum of ENSO index (Niño 3 anomaly), from January of Year 0 to April of Year 1, compared against the total fire activity of the same time period. These first sixteen months of each 24-month fire event included the majority of the entire fire activity detected, representing the 80.61 per cent of the total 10-years fire activity in Borneo. Therefore, if this ENSO-fire relation remain consistent in future El -Niño events, it could be possible to predict in advance the all-Borneo fire activity based on predictions of Niño 3 anomaly.

Introduction

Previous studies have shown a close relationship among fire activity and ENSO in various parts of the world (Simard et al., 1985; Swetnam and Betancourt, 1990; Kitzberger, 2002). In Indonesia burning occurs annually but a number of unusually large fire events have occurred in recent times. Several studies have documented the increased fire activity occurred in Indonesia during El Niño years, particularly the devastating fire activity of the extreme 1982-83 and 1997-98 ENSO periods, (Malingreau *et al.*, 1985; Legg and Laumonier, 1999; Wooster and Strub, 2002). The aim of this project is to investigate the relationship between fire activity and El-Nino-Southern Oscillation (ENSO) events in South East Asia during the 1982-1998 period using Borneo, as a case-study.

Methods and Results

NOAA AVHRR Global Area Coverage (GAC) satellite data were used to investigate the occurrence of active fires during the El-Nino episodes of the last 20 years. Early nighttime GAC images that included the entire case study region of Borneo for the five study periods over ten years were downloaded from the Satellite Active Archive (SAA). Although GAC data are available since July of 1981, LAC data occur only sporadically in this archive

and not for all of the years. This is mainly due to storage limitations on board the NOAA Polar Orbiting Environmental Satellites (POES) (Kidwell, 1998).

The rationale in terms of fire detection was to use the lowest possible fire detection threshold in order to reduce errors of omission and to minimise the along scan averaging effect of the GAC data production. Therefore, fire detection and false detection identification were performed using a multispectral approach, rather than by applying a single threshold value (Kaufman *et al*., 1990). Thresholds were reduced progressively until contamination of resultant fire counts by the broad background environment became visually apparent. Threshold values were defined first by examining the histograms of AVHRR channel 3, 4, 5 and channel 3 minus channel 4 (T_3-T_4) and second by calculating basics statistics of minimum, maximum, mean, variance and standard deviation values for fire affected pixels and main background features such as cloud free vegetated land, clouds, mainland waterbodies and sea.

The developed pixel-by-pixel multi-channel fixed threshold method was applied to the AVHRR data. According to this method a series of criteria must be fulfilled by a pixel in order to be classified as a fire. These criteria have the following form:

Test (1) $T_3 > 305°K$ to detect features with high channel 3 brightness

temperature i.e. likely (potential) fires

Test (2) T_3-$T_4 > 6°K$ to avoid warm surfaces without fires

Test (3) T_4 or $T_5 > 275°K$ to exclude clouds and sensor noise (damaged

pixels)

Test (4) $p_1, p_2 < 5$-6 %   to prevent false detections by highly reflective

surfaces

Where T_3, T_4 and T_5 represent the top of atmosphere (ToA) brightness temperatures (K) for channel 3, 4 and 5 respectively, p_1, p_2 the % ToA reflectance in channel 1 and 2 respectively while a_i is the brightness temperature threshold for test i = 1, 2, 3, 4 and 5.

However, the GAC images are spatial sub-sample produced from the original Local Area Coverage (LAC) images. The spatial resolution of GAC data is effectively 4.4 km x 1.1 km with a 2.2 km gap between each scan line. This spatial degradation of GAC data may result in a bias of the derived fire information for Borneo (Belward and Lambin, 1990). Therefore, the capability of GAC data in active fire detection was examined in relation to that of LAC data. Thirteen pairs of LAC, and the corresponding GAC data from the same orbit, were collected for the 1997-98 El Niño related year. Since the data volume of the original LAC images is 15 times larger than the contemporaneous GAC product, in order to create an analogous GAC fire count comparable to the LAC fire product, the GAC derived fire counts were multiplied by a factor of 15.

Results showed that the adjusted GAC fire count numbers were very well related to the LAC fire counts of the coincident imagery (r^2 = 0.99, n = 13 p < 0.001) (Figure 1a). The mean percentage difference between the two fire count datasets was –1.6% with a standard deviation of 13.9%. Taking into account the substantial degradation of LAC data during the GAC production, these variations are minor, indicating the efficacy of GAC data for providing quantitative fire information in Borneo during El Niño periods when the fire occurrence is high.
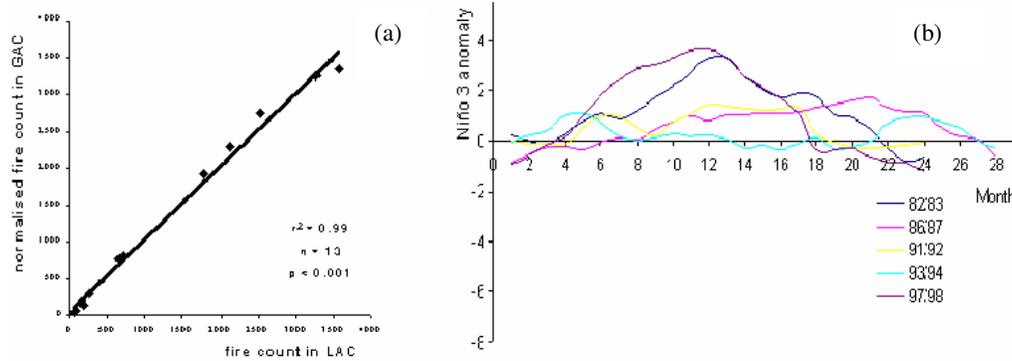
Figure 1 (a) Regression analysis between LAC and adjusted GAC fire counts during El Niño period. (b) Temporal evolution of Niño 3 anomaly during the five El Niño events studied herein. It is clearly indicated the two strongest El Niño events of 1982-83 and 1997-98, these having the highest absolute anomaly values. These data were obtained from the Climate Prediction Centre of the NOAA National weather Service in USA.

The fire counts detected in each GAC image were further adjusted for different cloud cover and observation time of each GAC image (Kaufman *et al.,* 1990; Giglio *et al.*, 2000). The GAC derived fire activity in Borneo for the five El Niño events from 1982 to 1998 is showed in Figure 2. Obviously, there is a distinct interannual constant pattern of fire activity. The major fire activity tends to occur between August-October (1st fire sub-season) of the first year (Year 0), and between February-April (2nd fire sub-season) of the following year (Year 1). The only pronounced exception was the 1993-94 fire event when the major fire activity appeared in the 3rd fire sub-season (August-October of Year 1), most likely associated with prolonged ENSO anomalies (i.e. 1991-92). On the contrary, in November-January (NDJ) and March-July (MJJ) of the El Niño period, the fire activity appeared significantly weakened, revealing the domination of local climate conditions driven by the monsoon circulation. As it is depicted in Figure 1b, during NDJ of Year 0 and MJJ of Year 1, the ENSO index, in most of the studied El Niño events, remained high enough to trigger fire occurrence. However, the Asian monsoon system is active over Borneo during these time periods, particularly during the NDJ of Year 0 when the winter (west) monsoon is substantially stronger than the summer

(east) monsoon, resulting strong convection over that region. This is also supported by the fact that although El Niño is being in its mature phase during NDJ of Year 0 (MJJ of Year 1) and the ENSO index is very high, moving (or just start to decrease) towards to (away from) the peak, negligible fire activity occurred. On the contrary, during the MJJ of Year 0, El Niño was still not fully developed, while in NDJ of Year 1, El Niño was already demised, contributing (resulting) in this way, together with the strong winter monsoon influence, to the almost complete absence of major fire events.

The distribution of fires in time was further analyzed and compared to the strength of the El Nino-Southern Oscillation (ENSO) as measured by the sea surface temperature anomaly (SSTA) in the Niño 3 region of the Pacific Ocean. The Niño 3 anomaly followed a somewhat different evaluation in time over the five El Niño events (1982-83, 1986-87, 1991-92, 94 and 1997-98) (Figure 1b). Conversely, the fire activity presented a strong seasonality occurring constantly in August-October and February-April of the El Niño Year 0 and Year 1 respectively (Figure 2). However, the overall strength of each El Niño event related closely with the corresponding observed fire magnitude, revealing the existence of ENSO-fire link in Borneo.
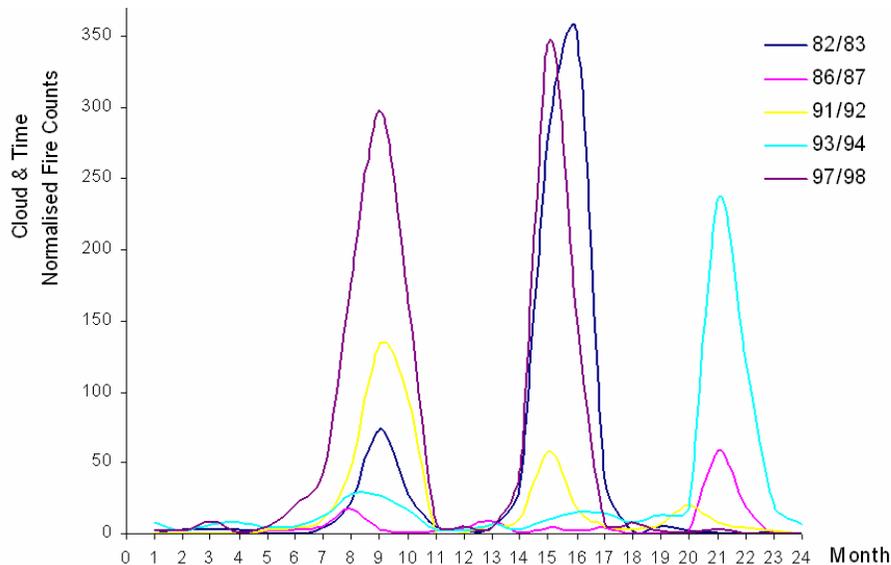
Figure 2 Active Fire Counts from AVHRR GAC data or Borneo for the 24 month period surrounding five individual ENSO episodes. The strong seasonality of fire activity in Borneo is clearly depicted in all five ENSO events, with the majority occurring in August-October of Year 0 or Year 1, and February-March-April of Year 1. The strongest and most prolonged El Niño events (i.e. 1982-83/1997-98 and 1991-94 respectively) were accompanied by the most extreme fire occurrence.

Cross correlation analysis did not indicate clearly any precise lag time of ENSO-fire association which moreover is inconsistent among the five El Niño events (Figure 3). Various lag times were observed between the five different El Niño events when cross correlation was applied to the 24-month ENSO-fire series. However, indeed there is undoubtedly an ENSO-fire association, which according to the cross correlation results, seems to occur somewhere between simultaneously and in seven months lag time.

However, a more clear ENSO-fire relationship was revealed when various time composites of Niño 3 anomaly and fire counts were evaluated. The strongest ENSO-fire association was observed when the total 16-months sum of ENSO index (Niño 3 anomaly), from January of Year 0 to April of Year 1, compared against the total fire activity of the same time period. The stepwise linear regression for the five

ENSO-fire pairs resulted a r-square equal to 0.97 (n = 5, p < 0.001) highly significant (Figure 3f). Consequently, the 97 per cent of the 16-months fire activity in the whole Borneo during the five studied El Niño periods could be explained by the 16-months ENSO strength as measured by the SSTA in the Niño 3 region of the Pacific Ocean. However, Figure 2 reveals that these first sixteen months of each 24-months El - Niño represents the majority (i.e. 80.61%) of the total 10-years fire activity in Borneo. Therefore, if this strong ENSO-fire relation found in the current study remains consistent in the future El -Niño events, it may be possible to predict in advance the all-Borneo fire activity based on predictions of Niño 3 anomaly. Then the accuracy of the derived fire activity would depend primarily on the forecast precision of the Niño 3 anomaly by statistical and/or dynamical-coupled models.
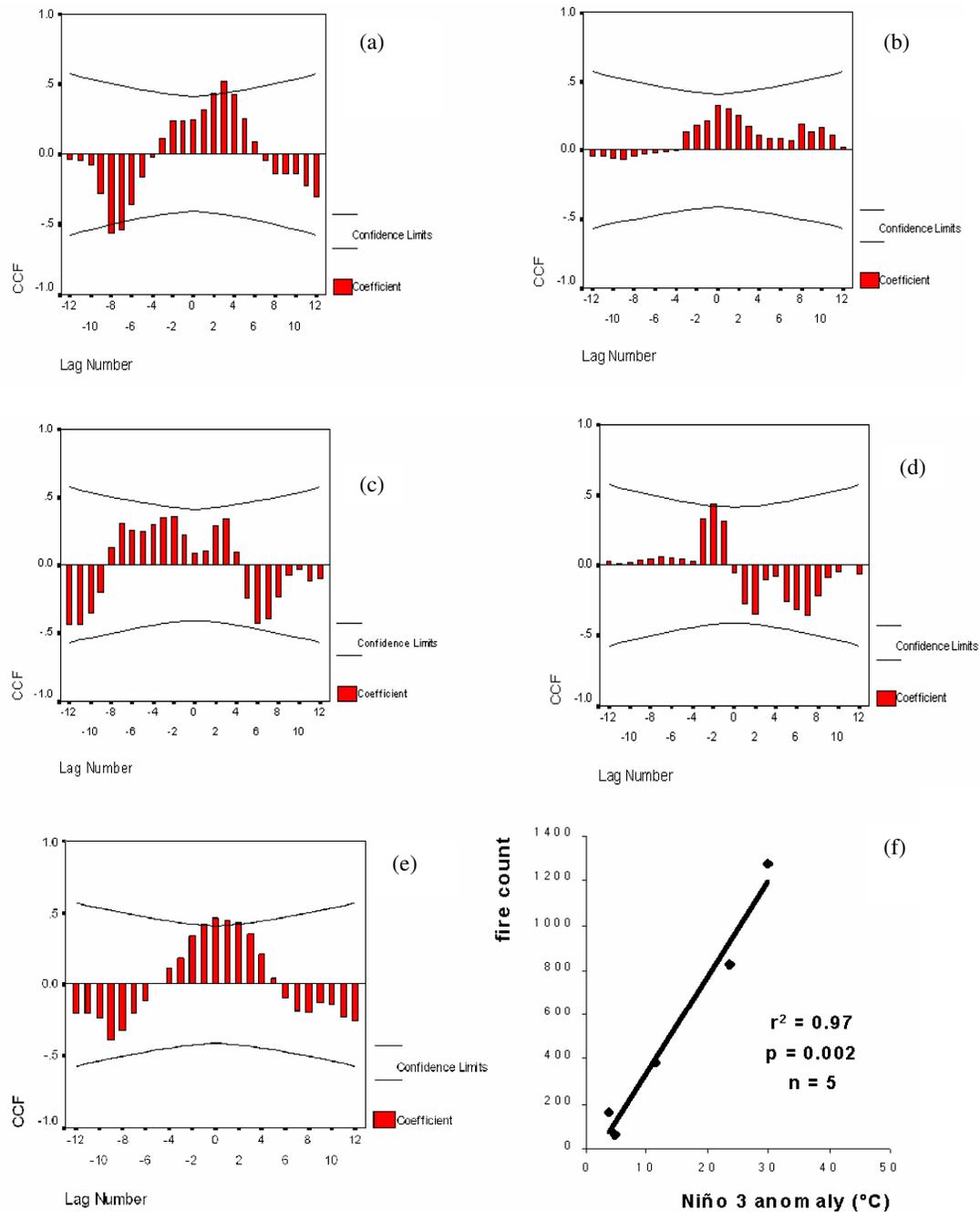
Figure 3 (a-e) The correlation coefficient (CCF) of Niño 3 anomaly-fire count at various lag times (i.e. negative lag number). Positive lag numbers (lead time) were ignored since current and past fire events cannot be explained and attributed to future ENSO variations. The higher the coefficient the stronger the ENSO-fire correlation; horizontal black line depicts the 0.5 confidence limits; (a) 1982-83, (b) 1986-87, (c) 1991-92, (d) 1993-94, and (e) 1997-98. (f) The 16-month sum of Niño 3 anomaly, from January of Year 0 to April of Year 1, versus the 16-month cumulative all-Borneo fire counts over the same time period for the five El Niño events studied.

Conclusion

The spatially low resolution NOAA AVHRR GAC satellite data demonstrated an acceptably high performance to document and quantitatively measure the fire activity in Borneo during El Niño events. Active fire counts on GAC

imagery were derived by applying a developed multispectral fire detection method to the totally 10-years GAC dataset, which corresponds to five El Niño events from 1982 to 1998. The derived fire counts were further adjusted from different cloud coverage and observation time of each GAC image. The majority of fire activity occurred between August-October of the first calendar year (Year 0), and between February-April of the following year (Year 1) in each El Niño event. A strong ENSO-fire relationship was found when the total 16-months sum of ENSO index anomaly in the Niño 3 region of the Pacific Ocean, from January of Year 0 to April of Year 1, plotted against the total fire activity of the same time period. These 16 months counted for 80.61% of the total 10-years El Niño related fire activity in Borneo. Therefore, the fire activity in Borneo over El Niño periods could be potentially forecasted some months in advance based on prediction of Niño 3 anomaly.

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