TR10-14 TECHNICAL REPORT:

Early Warning and Response to Fires in Kalimantan, Indonesia

P. Ceccato, I. Nengah Surati Jaya, J.H. Qian,
M.K. Tippett, A.W. Robertson, S. Someshwar

Early Warning and Response to Fires in Kalimantan, Indonesia

P. Ceccato*, I. Nengah Surati Jaya†, J.H. Qian*, M.K. Tippett*, A.W. Robertson*, S. Someshwar*

*International Research Institute for Climate and Society (IRI)
The Earth Institute, Columbia University, Lamont Campus
61 Route 9W, Monell Building
Palisades, NY 10964-8000 USA
Email: pceccato@iri.columbia.edu

† Laboratory of Forest Inventory,
Faculty of Forestry, Bogor Agriculture University,
Bogor, Java, Indonesia

On the web at: http://iri.columbia.edu/publications/id=1037

Abstract

Scientists at the International Research Institute for Climate and Society (IRI) collaborated with Bogor Agriculture University Indonesia to investigate links between climate anomalies and fire hotspots in Kalimantan, Indonesia. During their investigation, a close relationship between satellite rainfall data and fire hotspot activity was found. Rainfall anomalies during the dry season from June-October were particularly critical in determining fire activity. Vegetation greenness and moisture indices derived from MODIS images, however, did not appear to demonstrate a relationship. These findings were used to develop a prototype online tool that enables stakeholders to view satellite rainfall anomalies and forecast fire activity in Kalimantan. Potential fire activity can be inferred from these data and steps can be taken early on to prevent or minimize the effects of regional fire occurrences.

Keywords: Fires, Rainfall Anomalies, Climate Forecast, Early Warning

1 Introduction

Forest and bush fires have become an increasing problem in Southeast Asia in recent years. These fires have many detrimental social, economic and environmental effects. They affect global carbon dynamics and the haze from peat fires in this region has serious negative impacts on the regional economy and human health (deGroot *et al.*, 2006). Kalimantan, Indonesia, in particular, has undergone dramatic ecological and social changes over the past decades. Millions of hectares of forest have been logged and peat swamps have been drained and converted for agricultural use. This drastic change in land use and the local methods used to achieve it have left the area open to large scale, uncontrolled fires and their negative consequences.

In 1997–98, fires associated with an exceptional drought caused by El Niño/Southern Oscillation (ENSO) devastated large areas of Indonesian tropical rain forests (Siegert, *et al.*, 2001). Indeed, several authors have reported strong correlations between large scale fire activity in Indonesia and El Niño, in particular for fire episodes in 1982–83, 1997–1998, 2002 and 2006 (Siegert and Hoffmann, 2000; Siegert *et al.*, 2001; Carmona *et al.*, 2005; Murdiyarso and Adimingsih, 2007; Field and Shen, 2008; Van der Werf *et al.*, 2008).

The aim of the study was to identify the factors that influence fire activity in the four provinces of Kalimantan, to find a method to potentially forecast these factors and to create an early warning system that can predict the fire activity. An early warning system would enable government and other key stakeholders to respond earlier to potential fire events and help prevent some of their damaging consequences.

2 Data

To understand the drivers influencing fire activity in the four provinces of Kalimantan, we studied the relationship between fire activity and several potential explanatory variables. Data on fire activity was derived from National Oceanographic and Atmospheric Administration (NOAA)-Advanced Very High Resolution Radiometer (AVHRR) and TERRA-Moderate Resolution Imaging Spectroradiometer (MODIS) active fire data products covering the period 1998–2006. The explanatory variables that we investigated were associated with human activity, land use, climate and environmental factors.

2.1 Fire database

Few potential approaches are available for the study of fire activity in Kalimantan. Reports of fire activity on the ground are not exhaustive due to the large surface areas to be surveyed. We must, therefore, rely on information that is derived from satellite data. Using satellite data, three approaches are currently available for the identification of fire activity. These methods consist of: *i)* monitoring active fires (hotspot detection), *ii)* monitoring impact of fires (detection of burnt areas) and *iii)* monitoring fire emissions. As an indicator of fire activity, we selected the hotspot detection method because the active fire detection algorithm is a direct measurement of fire activity. The active fire detection algorithm also produces results at higher spatial resolution (1 km) than the emissions approaches. Additionally, hotspot detection is considered to be more accurate than the second two approaches (Langmann and Heil, 2004) for the investigation of fire activity at the temporal and spatial scales required for our study.

Hotspots detected by both MODIS and AVHRR sensors were used in combination to derive the fire database. The data were collected and provided by the South Sumatra Forest Fire Management Project (SSFFMP), the Japanese International Cooperation Agency (JICA) and CARE Indonesia.

For the purpose of this study, the four provinces were studied in Kalimantan: *i)* East Kalimantan, *ii)* Central Kalimantan, *iii)* South Kalimantan and *iv)* West Kalimantan. The hotspot number for each of the four provinces was computed for each month between January 1998 and December 2006. Since the provinces have different surface areas and therefore different relative hotspot numbers, we also computed the density of hotspots detected in each province by dividing the number of hotspots detected by the area of each province. With this transformation of the data we can make comparisons of hotspot activity not only over time for a particular region, but also across the four different geographic provinces.

2.2 Population Density and Land Cover

In order to understand the effect of human activity on the vegetation cover in Kalimantan, we investigated the following sources: *i)* Gridded Population of the World, Version 3 (GPWv3) data set produced by the Center for International Earth Science Information Network (CIESIN, 2005), Columbia University and *ii)* tropical forest cover map in insular Southeast Asia produced by Institute for Environment and Sustainability, Global Vegetation Monitoring Unit, Joint Research Center.

The Gridded Population map displays an estimate of the projected number of people living in each 2.5 arc-minute grid box in the year 2005. CIESIN derived these values from national statistical office estimates of population and adjusted them according to U.N. national population estimates.

The tropical forest cover map (Stibig *et al.*, 2003) was derived by the Joint Research Centre from SPOT4-Vegetation 10-day composites between 1998 and 2000. The map contained a burnt area class that represented the burnt area status in 2000. This map was used to extract those burnt areas in order to establish a baseline status of ground conditions in 2000 for the purpose of our study.

2.3 Precipitation database

Similarly to the scarcity of ground-detected fire information, rainfall stations are also sparse in Kalimantan and cannot provide the spatial distribution required to combine rainfall data with fire information. It was thus necessary to use two satellite rainfall estimate products to retrieve rainfall patterns in the four provinces.

The first product was derived from the NOAA-Climate Prediction Center (CPC) Merged Analysis (CMAP). The CMAP dataset contains global monthly and pentad precipitation constructed on a 2.5° latitude-longitude grid (pixel size) for the period from January 1979 to April 2008 obtained by merging several information sources with different characteristics, including rain gauge observations, estimates inferred from a variety of satellite observations and the NCEP-NCAR reanalysis (Xie, and Arkin, 1997).

The second product was derived from NOAA-CPC, also known as the CPC morphing technique (CMORPH). The Climate Prediction Center morphing method (CMORPH) uses motion vectors derived from half-hourly interval geostationary satellite IR imagery to propagate high quality precipitation estimates derived from passive microwave data. The shape and intensity of the precipitation features are also modified (morphed) by performing a time-weighted linear interpolation between microwave scans. This process yields microwave-derived precipitation analyses, independent of the infrared temperature yield, that are spatially and temporally complete (Joyce *et al.*, 2004). The data are available at very high spatial (8km) and temporal (30 min) resolutions starting from December 2002. For the purposes of this study, however, the dataset contained three-hourly observations at a spatial resolution of 0.25° (pixel size) that were converted to daily values and then accumulated to monthly totals for comparison with the monthly hotspot data.

Both the CMAP and CMORPH products have been validated with rain gauge measurements over complex terrain in Africa (Dinku *et al.*, 2008), Australia and United States (Joyce et al., 2004) and have demonstrated a very strong correlation with the reference rain gauge data in these areas. We used both products in order to double check the consistency of information across the four provinces.

For each of the four provinces, the number of pixels was spatially averaged to provide a monthly value for the province. The monthly values obtained for each province were then averaged and the differences between their actual values and the monthly average value were computed in order to derive a value for monthly anomalies as follows:

$$x_{anomalies} = x_i - \sum_i^n \frac{x_i}{n} \qquad \text{Eq. 1}$$

Where:
x = monthly values
i = specific month

The monthly rainfall and anomaly values were computed in order to obtain both *i*) a temporal series of monthly rainfall values per province and *ii*) a temporal series of monthly rainfall anomalies showing wetter than normal (positive anomaly) or drier than normal (negative anomaly) patterns. Both CMAP and CMORPH monthly rainfall and monthly anomalies for each province were then used as a basis for comparison with hotspot number and density data.

2.4 Vegetation Status

In order to investigate a possible relationship between vegetation status and fire activity, we analyzed a fourth dataset derived from satellite information on vegetation greenness and vegetation moisture content. This dataset was compiled using the MODIS vegetation index (VI) product (MOD13Q1 at 250 m spatial resolution). The MODIS VI algorithm operates on a per-pixel basis and relies on multiple observations over a 16-day period to generate a composite product. This product contains two indices: the Normalized Difference Vegetation Index (NDVI) and an Enhanced Vegetation Index (EVI). It also contains composite surface reflectance bands including the blue (459–479nm), the red (620–670nm), the near-infrared (841–876nm) and the middle infrared (2105–2155nm).

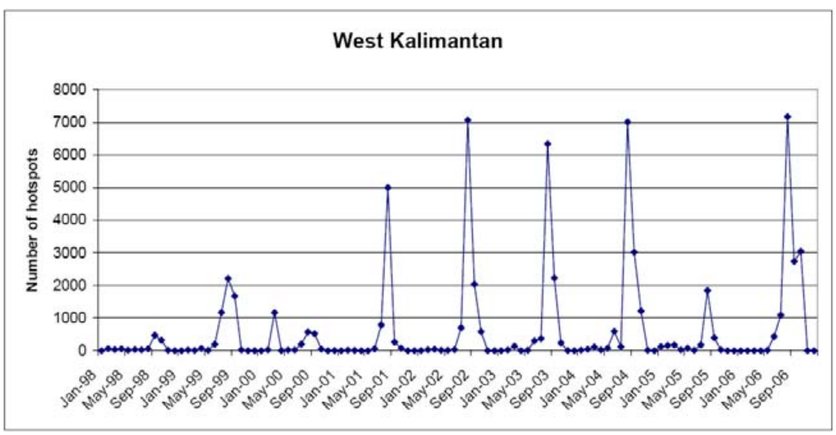
We used the NDVI to monitor vegetation greenness and combined the near-infrared and middle-infrared channel to compute an additional index, the Normalized Difference Moisture Index (NDWI). The new index NDWI provided information on the vegetation water content per unit area (Ceccato *et al.*, 2002). The two indices: NDVI and NDWI were then analyzed to provide information on vegetation status in terms of greenness (NDVI) and moisture content (NDWI) as possible factors influencing fire activity.

3 Results

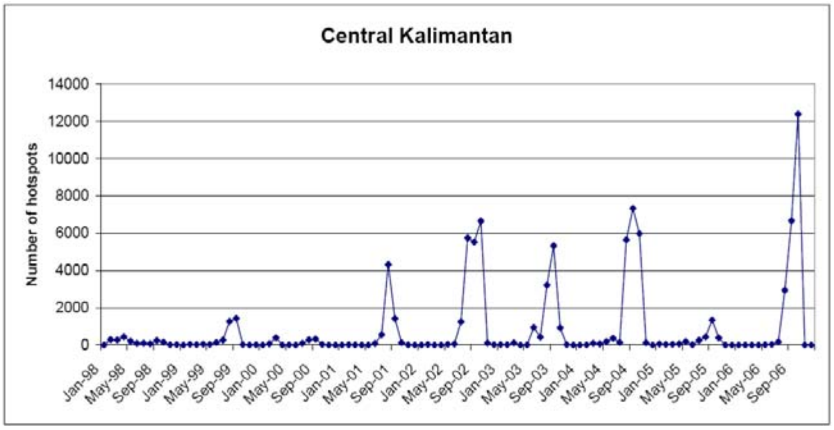
3.1 Analysis of Fire in Conjunction with Human Activity

The temporal analysis of the hotspot number detected in each of the four provinces (Figure 1) shows four interesting features:

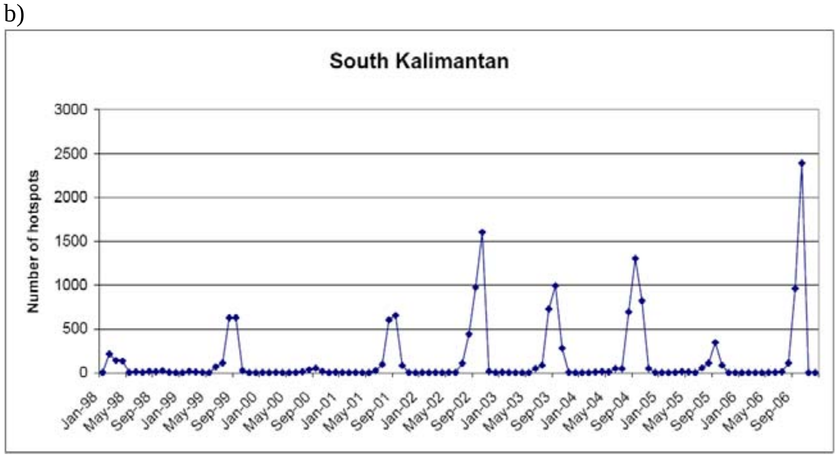
1. The fire season occurred each year with peaks between June and October.
2. The number of fires in East Kalimantan decreased dramatically after the big fire events in 1997– April 1998, as also reported by Siegert and Hoffman (2000).
3. The provinces of West, Central and South Kalimantan still experienced large numbers of fires after 1998.
4. The hotspot time series shows pronounced inter-annual variability in the number of hotspots with some years having a high number of hotspots (like in 2001, 2002, 2003, 2004 and 2006) and other years having less hotspot numbers (like in 1998, 1999, 2000 and 2005).



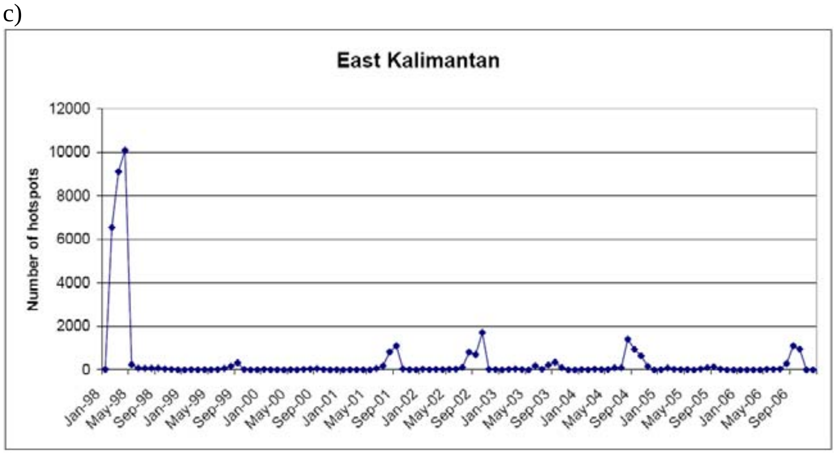
a)


Central Kalimantan
Number of hotspots
14000
12000
10000
8000
6000
4000
2000
0
Jan-98
May-98
Sep-98
Jan-99
May-99
Sep-99
Jan-00
May-00
Sep-00
Jan-01
May-01
Sep-01
Jan-02
May-02
Sep-02
Jan-03
May-03
Sep-03
Jan-04
May-04
Sep-04
Jan-05
May-05
Sep-05
Jan-06
May-06
Sep-06

b)


South Kalimantan
Number of hotspots
3000
2500
2000
1500
1000
500
0
Jan-98
May-98
Sep-98
Jan-99
May-99
Sep-99
Jan-00
May-00
Sep-00
Jan-01
May-01
Sep-01
Jan-02
May-02
Sep-02
Jan-03
May-03
Sep-03
Jan-04
May-04
Sep-04
Jan-05
May-05
Sep-05
Jan-06
May-06
Sep-06

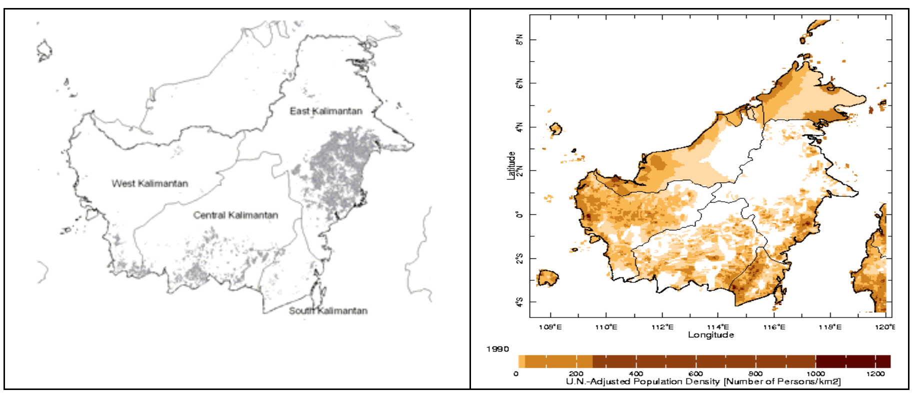
c)


East Kalimantan
Number of hotspots
12000
10000
8000
6000
4000
2000
0
Jan-98
May-98
Sep-98
Jan-99
May-99
Sep-99
Jan-00
May-00
Sep-00
Jan-01
May-01
Sep-01
Jan-02
May-02
Sep-02
Jan-03
May-03
Sep-03
Jan-04
May-04
Sep-04
Jan-05
May-05
Sep-05
Jan-06
May-06
Sep-06

d)

Figure 1: Number of hotspots detected in each of the four provinces between 1998 and 2006; a) West Kalimantan, b) Central Kalimantan, c) South Kalimantan and d) East Kalimantan.

The decrease of fire activity in East Kalimantan after 1998 while the other three regions still experienced large numbers of fires is an interesting pattern that provides evidence of change due to human activity that was explored further. Since April 1998, the use of fire seems to be reduced in East Kalimantan. This is most likely because the majority of land has already been converted into agriculture and palm oil plantations. This can be inferred from the land cover map produced by Stibig *et al.*, (2000) from which we extracted the burned area. Figure 2 shows that the majority of fire activity and burnt area before 2000 occurred in the East Kalimantan province.



a) b)

Figure 2: a) Burnt area (grey areas) detected using the 2000 land cover map produced by Stibig *et al.* (2001), b) Estimate of the projected number of people living in each 2.5 arc-minute grid box on the map in the year 2005 (CIESIN Gridded Population of the World, Version 3 (GPWv3) data set).

The population map, however, indicates that there is no significant difference between the density of population between the four provinces. By comparing the population map and the land cover map, we can infer that the land was intensively transformed in East Kalimantan before 2000. On the contrary, the three other provinces experienced less burning before 2000.

The reduction of fire activity observed in the eastern province compared to the three others provinces is an indicator that land use and fire practices have changed in East Kalimantan since 1998. The reason for the shift in fire practices is not yet clear. Further research should be carried out to understand if there has been any change in the land use (conversion of the forest into palm oil plantations for example) or if external factors such as better fire control strategy, implementation of fire reduction program have had an impact on the fire activity in East Kalimantan and not in the other provinces.

To complete our analysis of fire activity in relation to human activity, we analyzed the temporal evolution in the density of hotspots between the four provinces (Figure 3). Our intention was to investigate whether or not human activity was entirely responsible for patterns in fire activity.

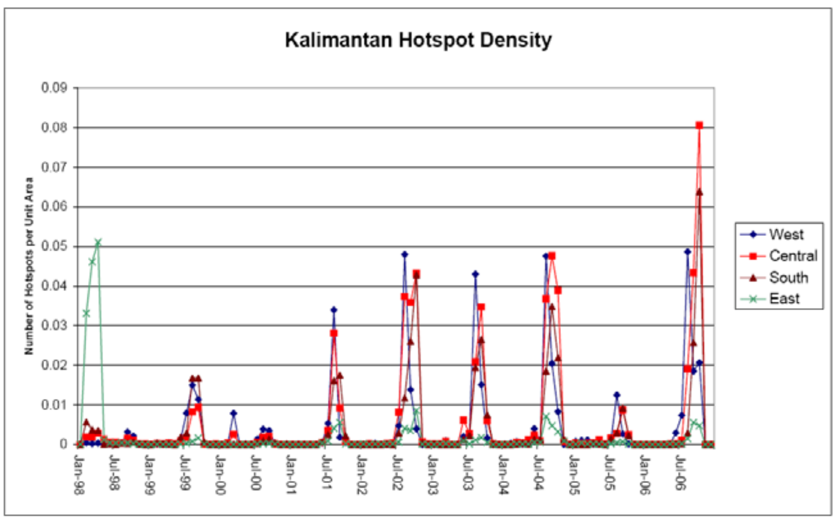


Figure 3: Comparison of fire density in the four provinces between 1998 and 2006.

From this analysis, we observed that the density of fires is quite similar in the three provinces while the density in East Kalimantan is smaller which further supported our findings from the previous analysis. However, we also observed that the inter-annual variability of hotspot density over time is similar in all four provinces. If the human factor was only responsible for the fire activity, we would have expected the same fire density each year. However we observed that there is an increase or decrease from year to year of fire density simultaneously in each of the four provinces. In particular, the years 1999, 2000 and 2005 experienced decreases in fire activity. This leads us to believe that although human activity is a significant driver for the fire activity, there is an inter-annual variability that suggests that external factors may also be influencing the number of fires. We thus turned to our climatic and environmental data sets to explain this type of variation.

3.2 Analysis of Fire Data in Conjunction with Precipitation

Kalimantan experiences significant rainfall throughout the year with maximum rainfall occurring in January and minimum rainfall occurring in August. Figure 4 shows the increase of precipitation from East to West Kalimantan based on the averaged CMORPH precipitation in the dry season (June to November). East and south Kalimantan regions are drier (especially during the months between June to November) than the central and west regions (Qian, 2008), due to a convergence of two factors: *i)* from the large-scale perspective of monsoon migration, in June-July-August-September-October-November, maximum monsoonal rainfall is located northwest of Kalimantan; *ii)* from local-scale perspective, mountain areas are located in west Kalimantan where diurnal cycle of extended sea- and valley-breezes converge and enhance rainfall.

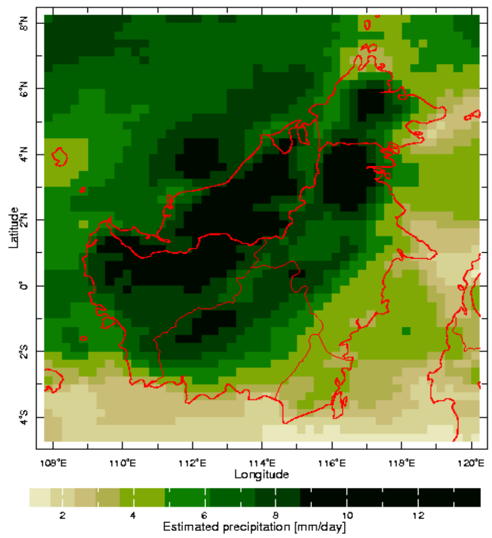
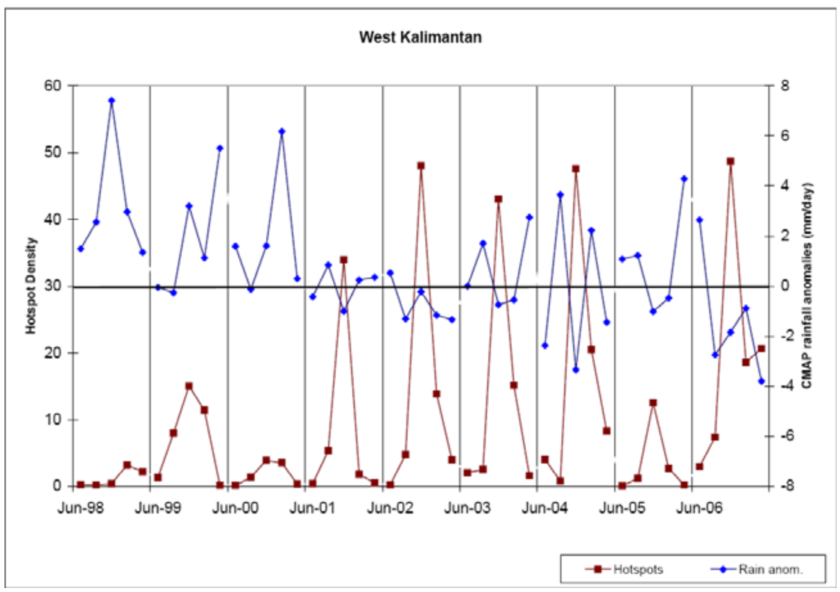


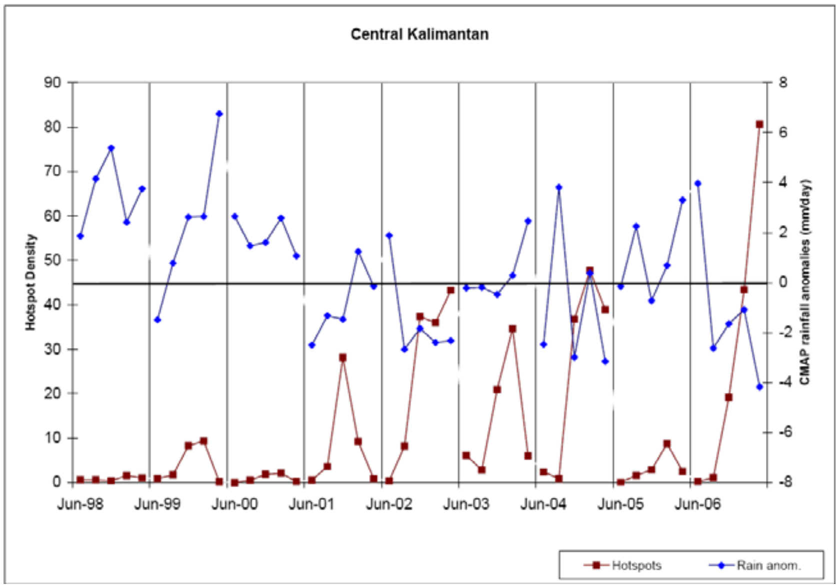
Figure 4: Averaged (2003-2008) CMORPH precipitation (mm/day) in the dry season (June-July-August-September-October-November).

Being drier, we would have expected to see more fires in the east part of Kalimantan and less fire towards the western parts of Kalimantan. However, we observed that East Kalimantan province has less fire density than the three other provinces. From this observation, we determined that rainfall amount is not a driving factor explaining the spatial hotspot density distribution in the four provinces.

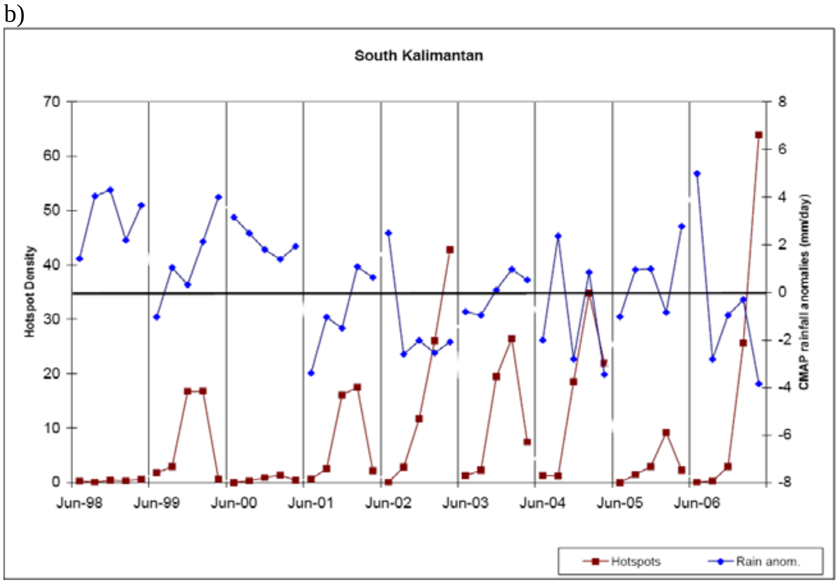
Since the peak of the fire season occurs between June and October of each year, and rainfall still occurs between June to October, we analyzed the rainfall anomalies for the four provinces to understand whether the rainfall conditions (drier or wetter than usual) could influence the fire density observed (Figure 5).



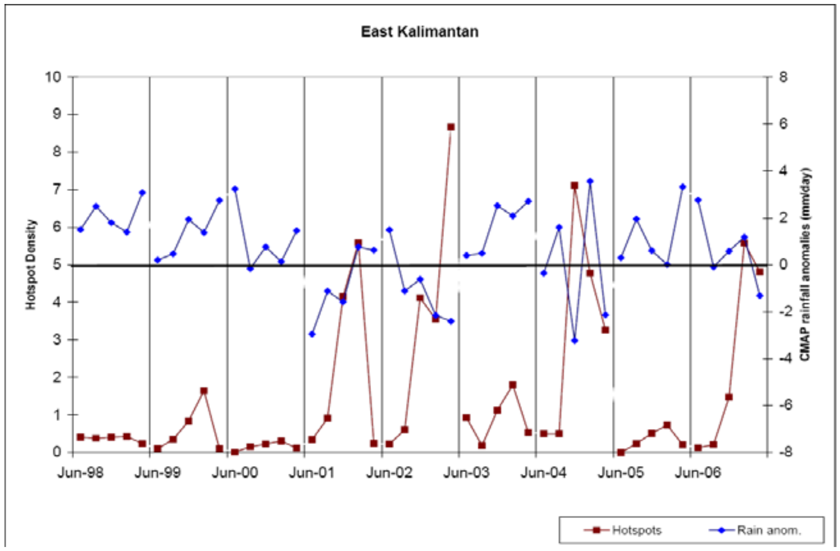
a)


Central Kalimantan
Hotspot Density
CMAP rainfall anomalies (mm/day)
90
80
70
60
50
40
30
20
10
0
8
6
4
2
0
-2
-4
-6
-8
Jun-98
Jun-99
Jun-00
Jun-01
Jun-02
Jun-03
Jun-04
Jun-05
Jun-06
Hotspots
Rain anom.

b)


South Kalimantan
Hotspot Density
CMAP rainfall anomalies (mm/day)
70
60
50
40
30
20
10
0
8
6
4
2
0
-2
-4
-6
-8
Jun-98
Jun-99
Jun-00
Jun-01
Jun-02
Jun-03
Jun-04
Jun-05
Jun-06
Hotspots
Rain anom.

c)



d)

Figure 5: Relationship between hotspot density and rainfall anomalies derived from CMAP rainfall estimates for the four provinces a) West Kalimantan, b) Central Kalimantan, c) South Kalimantan, d) East Kalimantan for June-July-August-September-October of each year between 1998 and 2006.

Figure 5 shows that when the rainfall conditions during June to October are wetter than normal (positive values represented in blue in Figure 5) the hotspot density tends to be low. When the rainfall conditions are below normal (negative values represented in red in Figure 5) hotspot density increases.

Figure 6 shows the relationship between rainfall anomalies and hotspot density for the four provinces. The nonlinear relationship indicates that the hotspot density increases exponentially, as indicated by the Poisson regression curve in each panel, when the rainfall anomalies become negative (conditions are drier than normal).

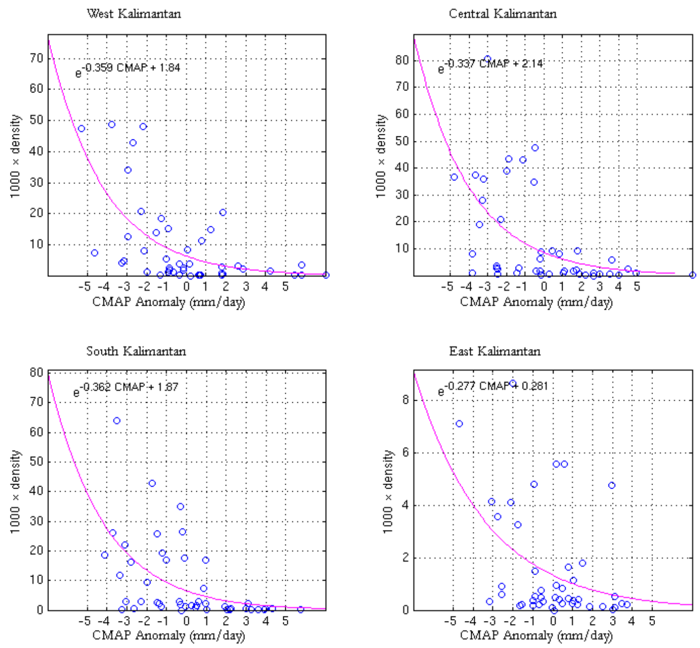


Figure 6: Non-linear relationship between rainfall anomalies and fire density for the four provinces. The solid curve, whose formula is given, was fitted using a Poisson regression.

These results show that fire density in the four provinces is related to the CMAP rainfall anomalies. Although the relationship is noisy especially for low hotspot densities that can occur almost independently of rainfall anomalies, high densities are almost always accompanied by below average rainfall. This explains why the years 2001, 2003 and 2004 experienced a high fire density (drier conditions than normal) and why the years 1998, 1999, 2000 and 2005 experienced low fire density (wetter conditions than normal). These results indicate that by monitoring rainfall anomalies, it is possible to estimate fire activity in the four provinces.

3.3 Analysis of Fire Data in Conjunction with Vegetation Status

Vegetation status is often used as an indicator of fire risk especially in savanna ecosystems (Verbesselt *et al.*, 2007). In order to investigate a possible relationship between vegetation status and fire activity in Kalimantan and use it as a potential predictor, we analyzed: *i*) the vegetation status in terms of greenness (information derived from NDVI) and *ii*) vegetation moisture content (information derived from NDWI). We performed the analysis first at specific sites and then by averaging the 16-day values over the areas of the four provinces. The temporal analysis of the specific sites and over the four provinces showed a seasonality in both NDVI and NDWI with peak values occurring during the period May to July (beginning of the dry season).

To represent the seasonality, we computed a seasonal average for each of the 16-day values over the time period 2001–2008 (Figure 7 and Figure 8). The analysis of the temporal variations of the index values showed a seasonal trend in both greenness and moisture content. The peak of greenness and moisture values are observed between May and July (Figure 7 and Figure 8).

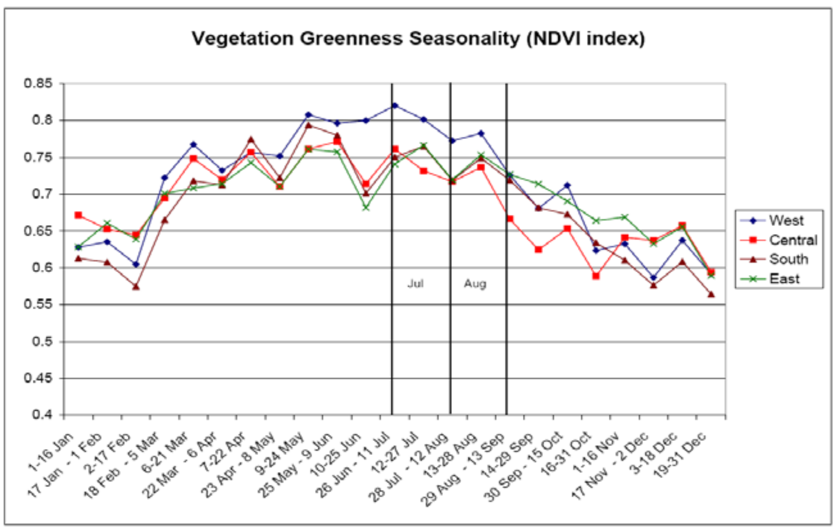


Figure 7: Seasonal variations of 16 day averaged MODIS-NDVI over the time period 2001-2008 for the four provinces.

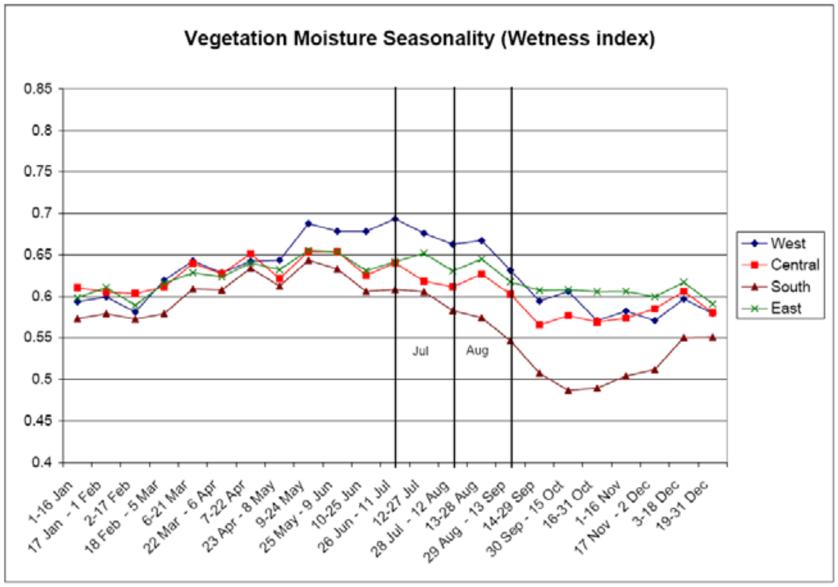


Figure 8: Seasonal variations of 16 day averaged MODIS-NDWI over the time period 2001-2008 for the four provinces.

These findings, however, should be interpreted with caution since the values obtained for NDVI and NDWI are high. In particular for the NDWI, values ranging between 0.6 and 0.7 correspond to a low signal to noise ratio (Ceccato *et al.*, 2002). This indicates that variations in vegetation moisture in the canopy are not correctly reflected by a variation in NDWI. There is a phenomenon of saturation that prevents the detection of vegetation moisture variations when the vegetation water quantity is above a certain threshold (above 2100 $g.m^{-2}$ as identified by Ceccato *et al.*, 2002). The high values of NDVI and NDWI indicate that the vegetation type in Kalimantan has reached that threshold and any variation in canopy moisture can not be detected using measurements in the near and middle infrared.

Our analysis therefore indicates that the use of MODIS images to retrieve vegetation status is limited in Kalimantan and we cannot infer any information on the vegetation status that can be operationally used to detect a risk of fire activity based on the properties of the vegetation. Further investigation on the ground should be carried out to understand the vegetation status when the fire season starts especially in June and July of each year.

3.4 Analysis of Fire Data in Conjunction with ENSO State

Research published to date (Van der Werf *et al.*, 2008) has indicated that the fire activity was related to El Niño events, the warm phase of El Niño-Southern Oscillation (ENSO) or La Niña event, the cold phase of ENSO. This is confirmed in 2002 and 2006 (El Niño years) and 2000 (La Niña year). Although El Niño is generally associated with below average rainfall in the Western Pacific in all seasons, a strong relation between Indonesian rainfall variability and ENSO is present only in the relatively dry season, June through November (Hendon, 2003). El Niño events are also associated with delay in the onset of the rainy season over much of Indonesia including Kalimantan, where onset usually occurs in September (Moron *et al.*, 2009a, 2009b).

Our study has showed so far that fire activity is related to rainfall anomalies. We then explored the relationship between fire activity and ENSO state, with a view to assessing the potential seasonal predictability of fire activity. In particular, we chose an index of ENSO called “NINO4”, which is an average of Sea Surface Temperature (SST) in the equatorial Western Pacific (5S–5N, 160E–150W), because previous research indicated a significant correlation between Western Pacific SST and Indonesian dry season rainfall (Hendon, 2003). Figure 9 shows scatter plots of monthly fire activity (June–October) versus the NINO4 index two months before. There is generally strong a nonlinear relationship between ENSO state and fire activity in each of the four provinces. The regression curves in Figure 9 highlight the exponential nature of the relationship, but it is clear from the large data scatter that the relationship is far from precise, and that a probabilistic relationship is more appropriate.

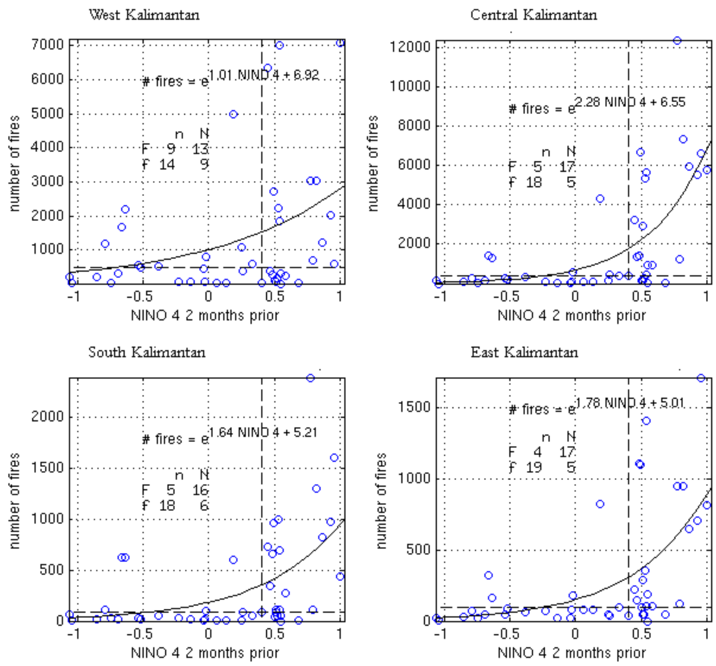


Figure 9: Predicting Fire Activity 2 months in advance. The four graphs show the relationship between the number of fires (June to October) and the NINO4 (May to September) index in the previous month for the four Kalimantan provinces. The dashed lines mark the median values both for NINO4 and the number of fires. The contingency table (numbers related to n, N, f and F in the graphs) represents the number of points in each of the four quadrants delineated by the dashed lines. The contingency table can be used to identify the probability of having above- or below-median fire values respective to the NINO4 index.

The dashed horizontal and vertical lines in Figure 9 indicate the medians of the number of fires and NINO4 respectively. Above-median fire activity tends to occur for below median values of the NINO4 index with a two-month lag, raising the possibility that the risk of fire activity could be predicted for each of the provinces based on the NINO4 index. The strength of this probabilistic relationship is given by the contingency tables that are inset in each panel: for example, for Central Kalimantan there is a 74% chance (17/23) of above-median fire activity two months later, if the value of the NINO4 SST is above its median in the current month. While these results are suggestive of potential predictability of fire activity, a cross-validated analysis is needed to assess the likely skill of such forecasts.

4 Application

Through the results of this study, we provided evidence that fire activity is associated with rainfall anomalies but not with the vegetation status derived from MODIS images. We have also provided evidence of a potentially predictive relationship with the ENSO state (NINO 4 index) with a lead time of 1-2 months.

Based on these relationships, we developed tools to *i*) monitor rainfall anomalies and *ii*) forecast fire occurrence in the four provinces based on antecedent NINO4 Index.

To assist local stakeholders in their efforts to monitor fire occurrence and minimize its impacts, we first developed an online tool which would enable them to view satellite rainfall anomalies and, as a result, take necessary action.
The tool is available via Internet (http://iridl.ldeo.columbia.edu/maproom/.Fire/.Regional/.Indonesia/.Dekadal_Rainfall/ and allows the users to automatically extract time series of anomalies for a specific location and district levels.

We then developed a prototype tool available via Internet (http://iridl.ldeo.columbia.edu/maproom/.Fire/.Regional/.Indonesia/.NINO4.html) that allows the users to visualize the NINO4 Index and assess the probability of fire occurrence based on the graphs presented in Figure 9a) and b).

This tool is still a prototype and further research is under way to improve the forecast of rainfall and therefore fire activity since rainfall anomalies are also influenced by the SST over the Indian Ocean (Saji *et al.*, 1999). We have been preparing in collaboration with the Indonesian meteorological service (BMG) experimental seasonal forecasts of rainfall anomalies over the region with lead times from 1 to 6 months, using a dynamical regional climate model RegCM3, driven by outputs from a global climate model ECHAM4. The coupled ECHAM4-RegCM3 modeling forecast system reflects the impacts of NINO4 over the Pacific as well as other driving factors such as the Indian Ocean Dipole.

The regional model simulates and forecasts rainfall over Kalimantan is still in development and it is expected to provide in the near future higher accuracy of rainfall anomalies forecast than the single use of NINO 4.

5 Conclusion

In our investigation of links between human factors, climate anomalies, biophysical indicators, and fire activity, we have uncovered a clear relationship between satellite rainfall anomalies, fire activity and between antecedent NINO4 Index and fire activity. Although human activity is a significant factor influencing fire, rainfall anomalies during the season from June to October are particularly critical in determining fire density in the four provinces. Vegetation greenness and moisture indices as derived from MODIS images, on the other hand, do not appear to demonstrate a relationship.

Based on these results, we have developed an online tool to enable stakeholders to view satellite rainfall anomalies over Kalimantan, and to make exploratory prediction of fire activity based on ENSO (NINO 4 index) state. A prototype seasonal early warning system has thus been created to enable decision-makers to take earlier action in order to reduce the impact of potential fires.

We are conducting research, in partnership with the Indonesian meteorological service (BMG) to better understand seasonal predictability of rainfall anomalies. Rainfall forecasting products ranging from 3 to 6 months in advance are being developed to forecast rainfall anomalies and subsequently fire activity in Kalimantan.

In order to assess possible types of early action, the current institutional and policy context for fire management in Kalimantan is being assessed by IRI and the Bogor Agriculture University. A seasonal fire early warning system, embedded within a structure of insurance and economic incentives to assist local communities in avoiding fires, is emerging as key to reduce fire incidences.

6. Acknowledgement

This research was part of the Central Kalimantan Peatlands Project (CKPP), a large consortium effort funded by the government of the Netherlands and managed by Wetlands International. Funding of this paper was also provided through a grant/cooperative agreement from the National Oceanic and Atmospheric Administration, NA050AR4311004. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its sub-agencies.

7. References

Carmona-Moreno, C., Belward, A., Malingreau, J-P., Garcia-Alegre, M., Hartley, A., Antonovskiy, M., Buchshtaber, V. and Pivovarov, V. (2005). Characterizing Inter-annual Variations in Global Fire Calendar Using Data from Earth Observing Satellites**.** *Global Change Biology*, **11**(9), 1537-1555, doi: 10.1111/j.1365-2486.2005.001003.x

Center for International Earth Science Information Network (CIESIN), Columbia University; United Nations Food and Agriculture Programme (FAO); and Centro Internacional de Agricultura Tropical (CIAT). 2005. Gridded Population of the World, Version 3 (GPWv3): Population Grids (SEDAC, Columbia University, New York, 2005); available at http://sedac.ciesin.columbia.edu/gpw/.

De Groot, W.J., Field, R.D., Brady, M.A., Roswintiarti, O., Mohamad, M. (2006). Development of the Indonesian and Malaysian fire danger rating systems In D. Murdiyarso and L. Lebel (Ed.), *Mitigation and Adaptation Strategies for Global Change* (Volume 12 No. 1 pp. 165-180). The Netherlands: Springer

Dinku, T., Chidzambwa, S., Ceccato, P., Connor, S.J., Ropelewski, C.F. (2008). Validation of High-Resolution Satellite Rainfall Products over Complex Terrain in Africa. *International Journal of Remote Sensing*, 29(14): 4097-4110

Field, R,D., Shen, S.S. (2008). Predictability of carbon emissions from biomass burning in Indonesia from 1997 to 2006. *Journal of Geophysical Research*, 113, G04024, 1-17, doi:10.1029/2008JG000694.

Hendon, H. H., (2003). Indonesian Rainfall Variability: Impacts of ENSO and Local Air-Sea Interaction. *J. Climate*, 16, 1775-1790.

Joyce, R.J., Janowiak, J.E., Arkin, P. A., and Xie, P. (2004). CMORPH: A Method that Produces Global Precipitation Estimates from Passive Microwave and Infrared Data at High Spatial and Temporal Resolution. *Journal of Hydrometeorology*, 5: 487-503

Langmann, B., and Heil, A. (2004). Release and dispersion of vegetation and peat fire emissions in the atmosphere over Indonesia 1997/1998. *Atmospheric Chemistry and Physics, European Geosciences Union*, 4: 2145-2160

Moron, V., A. W. Robertson and R. Boer, 2009a: Spatial coherence and seasonal predictability of monsoon onset over Indonesia. J. Climate, in press.

Moron, V., A. W. Robertson and J.-H. Qian, 2009b: Local versus large-scale characteristics of monsoon onset and post-onset rainfall over Indonesia. Climate Dynamics, in press.

Murdiyarso, D. and Adiningsih, E.S. (2007). Climate anomalies, Indonesia vegetation fires and terrestrial carbon emissions. In D. Murdiyarso and L. Lebel (Ed.), *Mitigation and Adaptation Strategies for Global Change* (Volume 12 No. 1 pp. 101-112). The Netherlands: Springer

Qian, J-H. (2008). Why precipitation is mostly concentrated over islands in the maritime continent. *Journal of the Atmospheric Sciences*, 65: 1428-1441

Saji, N.H., Goswami, B.N., Vinayachandran, P.N., Yamagata, T. (1999). A dipole mode in the tropical Inidian Ocean. *Nature* 401(6751): 360-363

Siegert F., Hoffmann, A.A. (2000). The 1998 Forest fires in East Kalimantan (Indonesia): A quantitative evaluation using high resolution, multitemporal ERS-2 SAR images and NOAA-AVHRR hotspot data. *Remote Sensing of Environment* 72: 64-77

Siegert, F., Ruecker, G., Hinrichs, A., Hoffmann, A.A. (2001). Increased damage from fires in logged forests during droughts caused by El Niño. *Nature* 414: 437-440

Stibig, H-J., Beuchle, R., Achard, F. (2003). Mapping of the tropical forest cover of insular Southeast Asia from SPOT4-Vegetation images. *International Journal of Remote Sensing* 18: 3651-3662

Van der Werf, G.R., Dempewolf, J., Trigg, S.N., Randerson, J.T., Kasibhatla, P.S., Giglio, L., Murdiyarso, D., Peters, W., Morton, D.C., Collatz, G.J., Dolman, A.J., DeFries, R.S. (2008). Climate regulation of fire emissions and deforestation in equatorial Asia. *Proceedings of the National Academy of Sciences of the United States of America* 105(51): 20350-20355

Verbesselt, J., Somers, B., Lhermitte, S., Jonckheere, I., Van Aardt, J., Coppin, P. (2007). Monitoring herbaceous fuel moisture content with SPOT VEGETATION time-series for fire risk prediction in savanna ecosystems. *Remote Sensing of Environment*, 108(4): 357-368

Xie, P., and Arkin, P. A. (1997). Global precipitation: A 17-year monthly analysis based on gauge observations, satellite estimates, and numerical model outputs. *Bulletin American Meteorological Society*, 78: 2539–2558