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Hydrological Sciences Journal – Journal des Sciences Hydrologiques, 58 (3) 2013 http://dx.doi.org/10.1080/02626667.2013.772298 The effect of ENSO on rainfall characteristics in the tropical peatland areas of Central Kalimantan, Indonesia Gatot E. Susilo1,2, Koichi Yamamoto1, Tsuyoshi Imai1, Yoshiyuki Ishii3, Hiroshi Fukami4 and Masahiko Sekine1 1Graduate School of Science and Engineering, Yamaguchi University, Japan 2Civil Engineering Department, University of Lampung, Indonesia n502wf@yamaguchi-u.ac.jp; gatot89@yahoo.ca 3Institute of Low Temperature Science,

Hokkaido University, Japan 4Geological Survey of Hokkaido, Japan Received 25 May 2011; accepted 24 August 2012; open for discussion until 1 October 2013 Editor Z.W.

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Citation Susilo, G.E., Yamamoto, K., Imai, T., Ishii, Y., Fukami, H., and Sekine, M., 2013. The effect of ENSO on rainfall characteristics in the tropical peatland areas of Central Kalimantan, Indonesia. Hydrological Sciences Journal, 58 (3), 539–548. Abstract The effect of the El Niño Southern Oscillation (ENSO) on rainfall characteristics in the tropical peatland areas of Central Kalimantan, Indonesia, is demonstrated. This research used rainfall data collected between 1978 and 2008. The results suggest a relationship between ENSO events and the trend in rainfall observed in the study area.

Further analyses show that El Niño events have a stronger effect on the rainfall compared to La Niña events. El Niño events were also correlated to the increase in the number of days with less than 1 mm of rainfall in the dry season. The analysis reveals that the impact of El Niño events on rainfall in dry seasons is intensifying annually. Furthermore, ENSO events are not the only factors affecting rainfall trends in the observed area. Other factors, such as deforestation, may also affect the trend.

Key words ENSO; rainfall characteristics; tropical peatland areas L'effet du phénomène ENSO sur les caractéristiques des précipitations dans les zones de tourbières tropicales du Kalimantan central (Indonésie) Résumé L'effet de l'oscillation australe El Niño (ENSO) sur les caractéristiques des précipitations dans les zones de tourbières tropicales du Kalimantan central, en Indonésie, est mis en évidence. Nous avons utilisé pour cette recherche des données pluviométriques recueillies entre 1978 et 2008. Les résultats suggèrent une relation entre les événements El Niño et la tendance des précipitations observées dans la zone d'étude.

D'autres analyses montrent que le phénomène El Niño a un effet plus fort sur les précipitations qu'un évènement La Niña. Les événements El Niño ont également été corrélés avec l'augmentation du nombre de jours de moins de 1 mm de pluie pendant la sai- son sèche. L'analyse révèle que l'impact du phénomène El Niño sur les précipitations en saison sèche s'intensifie chaque année. En outre, les événements El Niño ne sont pas les seuls facteurs qui affectent les tendances plu- viométriques dans la zone observée.

D'autres facteurs, tels la déforestation, peuvent également influencer la tendance. Mots clefs ENSO; caractéristiques des précipitations; zones de tourbières tropicales

INTRODUCTION The archipelago country of Indonesia histori- cally comprised vast areas of wetlands, including 13.30 million ha of lowland swamp (39.8% of total wetland area) and 20.10 million ha of tidal marsh _(60.2%). These wetlands were spread across the country's four major islands of Sumatra (9.37 mil- lion ha), Kalimantan (11.7 million ha), Sulawesi (1.79 million ha) and Papua (10.50 million ha).

Of the original 33.40 million ha of wetlands through- out the country, approximately 3.90 million ha

have been developed for agriculture and plantations (Harsono 2008). Peatland areas, which are important carbon reser- voirs, account for 22.5 million ha of wetlands in Indonesia. Peatland soils absorb and store more car- bon than most other soils and, conversely, massive quantities of carbon are released as peatland areas are burned or converted to other land-cover types.

These areas are rapidly decreasing due to anthropogenic activities, which have major implications for global climate change. Between 1985 and 2005, the area of peatland forest on Kalimantan Island, Indonesia, decreased at a rate of 1.3% per year (CKPP Consortium 2008). In 1995, the Indonesian Government launched a project called the Mega Rice Project (MRP) in Central Kalimantan to support the national food programme. This project was a multibillion US dollar project that called for the conversion of natural peatland areas into paddy fields in both modern and integrated agricultural areas.

Based on the recommendations of several international foundations and other gov- ernment agencies, the programme was discontinued in 1999, because the conversion of these areas into paddy fields required the drainage of peatland ecosys- tems, resulting in the rapid decomposition of peat organic carbon and an increase in annual peat fires. The decomposition of organic carbon into carbon dioxide had, and will continue to have, major nega- tive impacts on air pollution levels in Southeast Asia and on processes related to global climate change.

A huge quantity of organic carbon has been con- verted into carbon dioxide and has polluted the atmo- sphere. Carbon emissions from the degraded peatland areas will continue until all the peat has disappeared. In addition, the land-cover change that occurred under this project ultimately resulted in flooding that destroyed newly created paddy fields, and seawater intrusion that contaminated local freshwater resources (Noor and Sarwani 2003). Following the collapse of the Mega Rice Project, a major peatland restoration project was initiated in Central Kalimantan.

In this programme, a strong understanding of wetland hydrology, including the connections between rainfall, runoff, groundwater and weather conditions, is critical. These hydrological conditions directly affect various processes govern- ing hydro-period conditions in the wetland area and can themselves be influenced by environmental change related to weather patterns, weather anoma- lies, deforestation and land-use change. In par- ticular, knowledge of the effect of environmental _changes on hydrological characteristics is very impor- tant for gaining the understanding required for the effective and efficient restoration of peatland areas.

A major driver of environmental change in this region is the El Niño Southern Oscillation (ENSO). The ENSO can be described as a phenomenon con- sisting of two oceanic phases—the El Niño warm phase and the La Niña cold phase—that are con- nected through a fluctuation in atmospheric pressure over the South Pacific, called the Southern Oscillation (Shrestha and Kostaschuk 2005). During an ENSO event, which occurs on average every 3–7 years (Garcia et al. 2003), the surface temperature of the Pacific Ocean on the west coast of Ecuador and Peru is abnormally high with major world-wide conse- quences.

The result is often flooding in regions such as coastal Peru and Ecuador, as well as drought con- ditions in regions like Indonesia, New Guinea and Australia (Cane 2005). Some research related to the effect of the ENSO in Indonesia (Nicholls 1981, 1984, Ropelewski and Halpert 1987, Konnen et al. 1998, Haylock and McBride 2001) has concluded that the inter-annual variability of monthly rainfall in Indonesia is strongly related to the ENSO (Hamada et al. 2002).

Most of the areas observed for the research were Indonesian islands, especially in Java dan Sumatera Island. The objective of the present study was to inves- tigate how weather anomalies such as El Niño/La Niña influence precipitation characteristics in the Mega Rice Project area of Central Kalimantan. This study analyses more recent and longer time series of hydro-meteorological data obtained locally in Central

Kalimantan and observed further inland.

We anal- ysed monthly precipitation data over peatland areas in Central Kalimantan with ENSO events from 1978 to 2008. The results of this research will be a significant contribution and an important input for the peatland restoration programme in Central Kalimantan in the future. METHODS Data Hydrological data used in this study were recorded at a climatic station located at Tjilik Riwut Airport, Palangkaraya (the capital of Central Kalimantan Province; 2?16r0rrS–113?55r59rrE; Fig. 1).

The data set consists of daily and monthly rainfall data. Daily data are available for 27 years (1978–2004) and

__ Fig. 1 Study area and location of climatic station. The shaded area is the location of the study (Block C of ex-MRP). Hydrological data were recorded at the climatic station at Tjilik Riwut Airport, Palangkaraya, which is about 10 km from the study area. 4000 3500 3000 2500 2000 1500 1975 1980 1985 1990 1995 2000 2005 2010 Time (year) Fig. 2 Annual rainfall amounts at Palangkaraya station, Central Kalimantan, Indonesia.

monthly data for 31 years (1978–2008). The data set was considered to be high quality with less than 1% missing data.

According to this data set, the average annual rainfall in this area was 2865.8 mm with max- imum and minimum annual rainfall of 3614.0 and 1899.0 mm, respectively (Fig. 2). Based on the _values of the skewness coefficient (Cs) and kurtosis coefficient (Ck) of the data, the statistical distribu- tion of the annual maximum daily rainfall at this station fell within a log-Pearson Type III distribu- tion. On a daily scale, rainfall amounts ranged from 0 to 201 mm.

ENSO–rainfall relationship Various methods can be used to determine the years of ENSO events.

In this study, the Southern Oscillation Index method (SOI) was used to identify the strength and phase of ENSO events in the study area. The SOI is an index of the southern oscillation, a phe- nomenon that affects large-scale atmospheric and _Pearson's correlation method, which is one of the most popular methods for measuring dependence between two quantities (Rodgers and Nicewander 1988): 2008 . (xi, j - xj)(yi, j - yj)

oceanographic features of the tropical Pacific Ocean (Adiku and Stone 1995).

The oscillation can be char- acterized by an index based on variations in either sea-surface temperatures or differences in baromet- _ i=1978 xy,j = - x, j y, j _(2)

ric pressures (MSLP) during the ENSO events. The SOI is negative during the warm El Niño phase and positive during the cold La Niña phase (Mabaso et al. 2009). In this study, the SOI was calcu- lated as follows (Australian Bureau of Meteorology 2002): 10(Pdiff - Pdiffav) _where rxy,j is the correlation coefficient between monthly rainfall and SOI for month j; xi,j and yi,j are the monthly rainfall and SOI, respectively, of month j for year i; xj and yj are the average monthly rain- fall and average SOI, respectively, of month j over 31 years (1978–2008); Sx,j and Sy,j are the standard deviation in rainfall and SOI, respectively, for month j over 31 years (1978–2008); and n is the number of data years.
SOI = _SD(P _ diff _(1)) _Finally, the dynamic slope of the segmented regression between the annual average monthly rain-

where Pdiff is the difference between average Tahiti MSLP for the month and average Darwin MSLP for the month; Pdiffav is the long-term average of Pdiff for a given month; and SD(Pdiff) is the long-term standard deviation of Pdiff for the same month. The change in rainfall trends due to the El Niño and La Niña has been discussed by many researchers world-wide. For example, Kane (1999) investigated characteristics and precipitation effects of the El Niño of 1997–1998.

However, some of the previ- ous research suggests that the ENSO is the most significant factor causing global hydroclimatic vari- ability, especially in equatorial Pacific areas (Kahya and Dracup 1993, Allan 2000, Terry et al. 2001), and a major controlling factor of inter-annual cli- matic variability in tropical regions like Indonesia (Aldrian and Susanto 2003, McBride et al. 2003, _fall and SOI is used to determine the strength of the ENSO impact on the rainfall. The segmented regression involves data of the observed year as the centre of the series and the data of the years around the observed year.

The segmented regres- sion is described in equation (3), from which the impact of ENSO toward rainfall trend—described as the dynamic slope—can be calculated. Furthermore, the regression of the dynamic slope can be deter- mined. In order to investigate the possibility of factors other than ENSO affecting the annual rainfall trends, a new data series is created. The new series comprises "intercepts" that are derived also from the segmented regression for the annual average monthly rainfall and monthly SOI, as described in equation (4).

Annas et al. 2007).

In Indonesia, ENSO events pre- dominantly cause a reduction in rainfall that results _k+ m-1 m . i=k- m-1 _SOIiRi - _k+ m-1 . i=k- m-1 _SOIiRi

in a longer dry season with greater water evaporation _ak,m = 2 (3)

and a shorter rainy season with greater surface runoff. _k+ m-1 _? k+ m-1 ?

The ultimate result is reduced ground and surface water storage. The correlation between SOI and monthly rain- fall amounts at the Palangkaraya hydrological station _m . i=k- m-1 _SOI2- _? .

i=k- m-1 _SOIi?
is investigated to determine the effect of ENSO on the hydrological condition in Central Kalimantan using the values of the correlation coefficients between monthly rainfall and monthly SOI for a specific month. The correlation coefficients are obtained by _where Ri and SOIi are the average monthly rainfall and SOI, respectively, for year i for a dry or rainy sea- son; and ak,m is the slope of the regression line for rainfall for year k using m years' data around the year k (m = 3, 5 and 7).

k+ m-1 . i=k- m-1 Rr _ SOI2 _k+ m-1 . i=k- m-1 _ Ri- _k+ m-1 . i=k- m-1 _ SOIiRi _k+ m-1 . i=k- m-1 _ SOIi

k,m = k+ m-1 _(4) ? ? 2

m . i=k- m-1 _SOI2- ? _.

i=k- m-1 _SOIi?

where Rrk,m is the intercept of the regression line for rainfall of year k using m years' data around the year k (m = 3, 5 and 7). RESULTS Thirty-one years of rainfall data at Palangkaraya sta- tion indicated a dynamic linear decrease. The average annual rainfall decreased from 3100 mm to 2600 mm over three decades (1978–2008). The graph in Fig. 3 presents rainfall trend of the dry season (May– October) and rainy season (November–April) for all years. Average rainfall decreased by 6.8 mm/year in the dry season and 4.8 mm/year during the rainy season (Fig. 3). Correlation coefficients between monthly rainfall and SOI were obtained by analysis of the effect of the ENSO on the hydrological conditions in Central Kalimantan.

De-trending of the data, by subtracting the best-fit line (in the least-squares sense) from the data, was performed before conducting the correla- tion analysis, and the values of correlation coefficients are presented in Fig. 4. Figure 4 indicates a positive relationship between ENSO events and rainfall in the month of March and between May and November, as well as a negative relationship from December to _February and in the month of April. Correlation coef- ficients for the dry season had an average of 0.47. The months between July and October are typically sen- sitive to the effects of ENSO; however, these months had only moderate correlation coefficients ($0.3 < r < 0.7$).

The r values for July–October are: 0.53 ($p = 0.002$), 0.68 ($p < 0.001$), 0.50 ($p = 0.007$) and 0.64 ($p < 0.001$), respectively. Other months showed weak correlation to the effects of ENSO, indicated by small correlation coefficients ($-0.3 < r < 0.3$) and p values of between 0.080 and 0.822. Based on the consensus of several institutions, such as the Western Regional Climate Center, USA, the Climate Diagnostics Center of the NOAA and the Climate Prediction Center of the US National Weather Service, El Niño events occurred in 1982, 1987, 1991, 1992, 1994, 1997, 2002 and 2006, with the most extreme El Niño event occurring in 1997. La Niña events occurred in the years 1988, 1998, 2000 and 2007, with strongest La Niña event occur- ring in1988 (Null 2007).

Figure 5 shows the compar- ison between the average rainfall of El Niño years, La Niña years and ordinary years (years with no El Niño or La Niña) for dry and rainy seasons. It can be seen from Fig. 5 that, during El Niño years, the average rainfall in dry seasons was quite

3000 2500 2000 1500 1000 500 0 1975 1980 1985 1990 1995 2000 2005 2010 Time (year) Fig. 3 Trend in annual rainfall during dry and rainy seasons at Palangkaraya station. The y-axis represents the annual sum of rainfall in a given season.

0.800 0.600 0.400 0.200 0.000 –0.200 –0.400 Period (month) Fig.

4 Correlation coefficients between annual average SOI and monthly rainfall at Palangkaraya station for the 1978–2008 period. 500 450 400 350 300 250 200 150 100 50 0 El Nino years La Nina years Ordinary years Fig. 5 Comparison between average dry season and rainy season rainfall in El Niño, La Niña and ordinary (i.e. non El Niño and La Niña) years.

low (75.3 mm) compared to that of ordinary years (170.0 mm). In contrast, during La Niña years, the average rainfall in dry seasons was (221.6 mm), which was higher than that of ordinary years. Both El Niño and La Niña seem to essentially influence the dry season.

Surprisingly, effects of El Niño and La Niña were not clearly shown in the average rain- fall in rainy seasons. The average rainfall in rainy seasons for El Niño years, La Niña years and ordi- nary years was similar, at 319.7, 309.1 and 321.1 mm, respectively. The ENSO events affect the pattern of the num- ber of “rainy days” and “no rain days” or days with precipitation less than 1 mm. Figure 6 shows the number of “no rain days” from the annual data for 1978–2008. The graph in Fig. 6 shows that the num- ber of “no rain days” is generally high during El Niño _events and low during La Niña events. In all years of El Niño events, the number of “no rain days” is more than the average number of “no rain days” for all years.

However, in all years of La Niña events, the number of “no rain days” is less than the average num- ber of “no rain days” for all years. The strongest El Niño happened in 1997, when the number of “no rain days” increased dramatically to 176 days. The year 1988 is recorded as a strong La Niña year. However, the number of “no rain days” for this year is not sig- nificantly different from the number of “no rain days” in other La Niña years. Dynamic slopes formed by segmented regres- sion for m = 5, m = 7 and m = 9 showed positive trends, demonstrating that the impact of ENSO on the rainfall of the area observed increased periodically.

The results of the analysis are displayed for different

300 275 250 225 200 175 150 125 100 75 50 25 0 Time (year) Fig. 6 Number of “no rain days” (i.e. with <1 mm rainfall) between 1978 and 2008. White bars denote the days during El Niño events, black bars—days during La Niña events, and shaded bars—days during ordinary years. Table 1 Dynamic slopes and their regression coefficients for the ak,m series formed by the segmented regression for m = 5, m = 7 and m = 9 for the years, k = 1983, 1993 and 2003.

Season m Slope a1983,m a1993,m a2003,m R2 (mm/year) (mm) (mm) (mm) Dry 5 0.1707 5.15 6.94 10.51 0.290 (May–Oct.) 7 0.1327 5.58 4.36 6.60 0.360 9 0.1344 5.22 3.37 10.06 0.300 Rainy 5 0.0154 0.03 3.99 -2.55 0.001 (Nov.–Apr.) 7 0.0597 -1.25 -2.60 -0.88 0.119 9 0.0870 -1.86 -2.42 -1.11 0.199 12 10 8 6 4 2

0 1975 –2 _ 1980 1985 1990 1995 2000 2005 2010

–4 k (year) Fig. 7 Dynamic slopes formed by the segmented regression for m = 7 (ak,7) using data spanning the years 1978–2008. The upper line is the trend of ak,m for the dry season; the lower one is that for the rainy season.

decades in Table 1. Figure 7 illustrates the trend exam- ples of dynamic slopes for the rainy season and dry season for m = 7.

The values in Table 1 indicate that the absolute value of the dynamic slopes for the dry _season are larger than those of the rainy season for all values of m, suggesting that ENSO effects on rainfall during the dry season were stronger than during the rainy season.

500 450 400 350 300 250 200 150 100 1975 1980 1985 1990 1995 2000 2005 2010 k (year) Fig. 8 Intercepts derived from the segmented regression for m = 5, m = 7 and m = 9. The upper data series are the rainy season data; the lower group is the dry season data.

The new data series calculated from the inter- cepts of the segmented regression analysis of annual average monthly rainfall and monthly SOI was gen- erated to investigate the possibility that factors other than ENSO might affect the annual rainfall. The data were obtained from segmented regression analysis as described in equation (4). In this series, it is assumed that the trend of the data is not affected by the ENSO. However, from the graphs in Fig. 8, a negative trend can be seen for both the dry and rainy seasons, sug- gesting that there may be other factors in addition to ENSO that affect rainfall trends in the study area.

DISCUSSION El Niño Southern Oscillation events are known to influence rainfall in Indonesia, resulting in prolonged droughts and declines in rainfall throughout the coun- try during the dry season. Although the correlation values during these months were less than 0.7 (indi- cating a non-significant correlation), the results sup- port there being a relationship between ENSO events and a decrease in rainfall in Central Kalimantan peatland areas, particularly during dry season months (May–October).

This trend is consistent with previous results showing that El Niño events, characterized by negative SOI values, typically occur between June and October in Indonesia (Hamada et al. 2002). The results also show that El Niño events cor- responded to low average monthly rainfall, suggest- ing that drought conditions in this area are related to ENSO events. Previous studies have shown that El Niño is associated with drought events in many _parts of the world (Ropelewski and Halpert 1987, Kane 1999).

However, La Niña tended to increase the potency of rainfall in the areas of the western equato- rial Pacific, such as Indonesia, Malaysia and northern Australia. Furthermore, the results confirmed that cli- matic responses in this region to ENSO events were stronger during the dry season. Both El Niño and La Niña seem to influence the rainfall in the dry sea- son. El Niño reduced the amount of rainfall in the dry season and, conversely, La Niña increased it. The ENSO events reduce the number of days with measurable rainfall amounts, while increasing the number that had less than 1 mm of rainfall in every data year.

This can be explained by the fact that El Niño events decrease sea-surface temperature due to the movement of warm water vapour in the Pacific Ocean. As a consequence, cloud production in the atmosphere above Indonesia is reduced, further decreasing rainfall production. The effects of El Niño events in Indonesia can also be exacerbated by forest fires that are more likely to occur during the dry sea- son, releasing smog emissions into the atmosphere.

This smog can be extensively distributed throughout the atmosphere and persist for long periods, and may also reduce cloud generation and decrease rainfall quantities (As-syakur 2010). The impacts of ENSO on rainfall appear to be increasing annually as shown by the positive trend in ak,m for both dry and rainy seasons. This suggests that El Niño events drive the decline in rainfall during both seasons. The positive trend in the data indi- cates the dynamic increase of El Niño effects on the rainfall decrease. However, El Niño-related impacts

on rainfall are not as substantial in the rainy season as compared to the dry season.

The results support the conclusions of the Climatology, Meteorology, and Geophysics Agency of Indonesia regarding the poten- tial increase in the intensity of the effects of ENSO events on climate, especially rainfall, in Indonesia (Ikawati 2010). It was also determined that ENSO events are not the only factors affecting rainfall trends in Central Kalimantan during the rainy season. Although the results in this paper do not address this aspect of the question, deforestation in this region could be another factor affecting rainfall trends in Central Kalimantan.

Deforestation and corresponding decreases in rain- fall in tropical forests has been investigated by many researchers (Wright and Calderon 2006, Rollenbeck and Anhuf 2007, Vincent et al. 2009). Deforestation changes surface energy budgets, decreases latent heat fluxes from the surface to the atmospheric boundary layer and increases sensible heat fluxes (Lawton et al. 2001, Nair et al. 2003, Ray et al. 2006a). The result is hotter and drier air over deforested areas, which could reduce dry-season cloud formation and precipitation (Ray et al. 2006b).

In other words, the decrease in forest cover reduces the canopy areas that stabilize surface energy budgets and keep hydrological cycles steady. However, it is quite complicated relationship and it is difficult to quantify climate effects and defor- estation effects in Central Kalimantan peatland areas. The above analysis indicates that both ENSO, as an external factor, and potentially deforestation, as an internal factor, have important influences on the amount of rainfall received in this area.

CONCLUSION AND RECOMMENDATION The effects of ENSO events on rainfall in tropi- cal peatland areas of Central Kalimantan have been discussed in this paper. The research indicates that ENSO events affect the amount of rainfall in this region, especially during the dry season. The research also demonstrates that El Niño events had a stronger impact on hydrological performance than La Niña events in the peatland areas over the observed period.

Specifically, El Niño events increased the number of days with less than 1 mm of rainfall in the dry sea- son. In addition to ENSO events, another unrelated factor may have decreased rainfall in the study area: deforestation that has been occurring for over 30 years in Central Kalimantan and has gradually decreased the forest cover. Previous research has shown a link between the reduction in the amount of rainfall and _the destruction of tropical forests.

However, a quanti- tative analysis of the effect of deforestation on rainfall decrease was not undertaken; to evaluate the effects of deforestation on the decreasing trend of rainfall quantitatively, more data and analysis are needed. Acknowledgements The authors thank Dr Hidenori Takahashi of the Hokkaido Institute of Hydro-Climate for supplying excellent hydrological data for this research and JST/JICA for financing the project. The first author wishes to acknowledge support from the Directorate General of Higher Education of Republic of Indonesia who financed him to carry out this research in Yamaguchi University, Japan.

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