Tropical Forests and Climate Change Adaptation (TroFCCA)

Climate change projections for Indonesia

Background document for the Southeast Asia kick-off meeting of the project
Tropical Forests and Climate Change Adaptation (“TroFCCA”)
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Based on General Circulation Models (GCMs), the future Indonesian climate will become warmer than the current situation. The annual average precipitation is expected to increase for the whole region, except the southern part including Java. Extreme weathers in relation to inter-annual climate variability are more difficult to predict. However, climate records show that the intensity and frequency of those events tend to increase.

Introduction: predicting future climate

Climate is a complex system that forms a dynamic interaction of energy balance between its components which include the atmosphere, the oceans, the land surface, the cryosphere and the biosphere (GARP, 1975; Cotton and Pielke, 1995; Houghton *et al.*, 1995). The earth’s climate is supposed to remain constant if the contribution of each component to the global energy balance remains the same. Any change in the contribution of any component can cause an imbalance in the energy budget (a deficit or surplus of radiative forcing[1]) that may lead to warming or cooling of the average global temperature. In response, climate will change in order to re-establish the radiative balance. The adjustment can include an increase in temperature, changes in cloud cover and wind patterns, and other changes in the variables that constitute the climate.

An increasing trend in the annual global mean-temperature has been identified (Figure 1). As shown by measurement records, the global average temperature has been warming by 0.3°-0.6°C since 1860 (Jones *et al.*, 1999) and there is a strong belief among the scientific community that the observed global warming of the last 50 years is associated with an increasing concentration of the greenhouse gases (GHGs) in the atmosphere (National Research Council, 2001; IPCC, 2001) (Figure 2).

Future climate patterns are difficult to predict. In particular, the future radiative forcing from the GHGs is difficult to quantify because emissions of these gases depend upon many uncertain factors like demographic changes, the use of carbon fuel as an energy source, technological development, economic development, policy and attitudes towards environment. For this reason, scenarios (estimates of plausible future patterns or conditions) of net GHGs in the long term (100 years or more) are required in order to support the sensitivity analyses on vulnerability and potential impacts of these gas emissions on the climate system.

There are a variety of ways to construct climate scenarios (IPCC-TGCIA, 1999). The most sophisticated one is by using a general circulation model (GCM) output. GCMs are complex numerical climate models that try to represent physical processes that make up the climate system. They are considered as the only credible tool currently available for simulating the response of the global climate system to increasing concentration of greenhouse gases (GHGs) (e.g. Schneider and Dickinson, 1975; Manabe, 1975; Cotton and Pielke, 1995; Goodess, 2000). Results from the experiments from different centres can differ because of assumptions being used and geographic considerations in the development of models.

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[1] A radiative forcing is defined as the change in average net radiation at the top of the atmosphere because of a change in either the solar or infrared radiation. A **positive** radiative forcing tends to warm the earth's surface, while a **negative** radiative forcing tends to cool it.

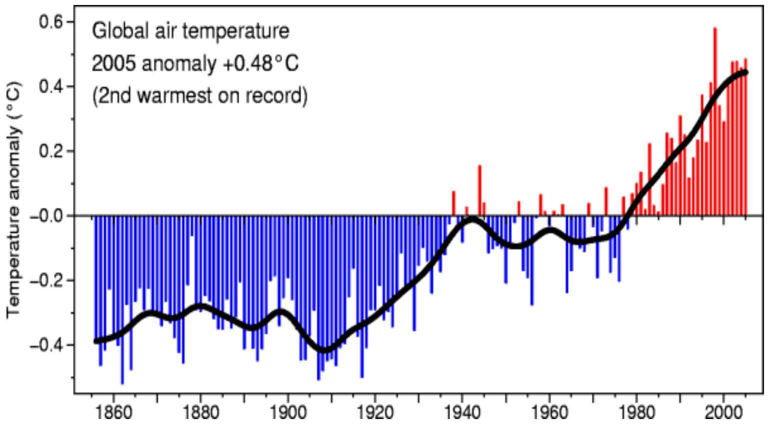


Figure 1: Average global air temperature relative to the 1961-1990 mean. The warmest year in the entire series was 1998. [Source: Jones and Palutikof (2006). The key reference for this series is: Jones et al. (1999). The record is continually updated and improved, and available on-line <u>http://www.cru.uea.ac.uk/cru/info/warming</u>.]

The current GCMs normally give a coarse resolution in the order of 2.5º latitude and 3.75º longitude. However, a higher resolution (less than 50 km) is required for climate change impact studies at the regional level. This implies the need to downscale the coarse grid size climate variables of GCM results to the grid size as required for the impact studies. Nowadays, there are a number of methods to downscale the output of GCMs to finer resolutions and produce regional climate models (Lins *et al*., 1997). Techniques include high resolution experimentation, nesting techniques and statistical downscaling (UNFCCC, 2004).

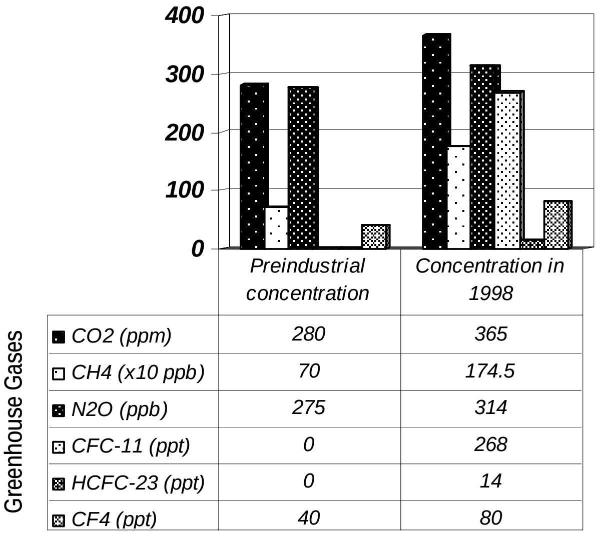
Climate change scenarios over Asia

Global warming causes changes in the climate that may vary in magnitude from place to place (IPCC-TGCIA, 1999; Kattenberg *et al*., 1996). The most comprehensive report on future climate changes for Asia is perhaps the article in the Third Assessment Report (TAR) of the IPCC Working Group II (Lal *et al*., 2001). Hulme and Viner (1998) presented one of the few reports on the climate change specifically in tropical areas.

Lal *et al.* (2001) reported scenarios of future climate change in Asia based on the radiative forcing inferred from likely future increases in GHGs and sulphate aerosols as prescribed under IS92a emission scenarios (Leggett *et al*., 1992; Houghton *et al*., 1995). The report uses four models for the analysis of climate change in the Asian region, namely HadCM2 (Hadley Climate Centre, U.K.), ECHAM4 (German Climate Research Centre), CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and CCSR (Center for Climate System Research, Japan).

A summary of climate changes in the Asian region and tropical sub-regions of South Asia and Southeast Asia is illustrated in Figure 3. The mean air temperature for the area is shown at the upper diagram and precipitation at the lower diagram. The scenarios of changes in air temperature and precipitation were developed with a 1961-1990 baseline, with three future time periods of projection centred around the 2020s (2010-2029), the 2050s (2040-2069), and the 2080s (2070-2099).

With an increase in atmospheric concentration of GHGs under the IS92a emission scenarios, the annual mean warming over the whole land region of Asia is projected to increase by 1.6°C in the 2020s, 3.1°C in the 2050s, and 4.6°C in the 2080s. A combined influence of GHGs and sulphate aerosols will limit the increase of surface warming to 1.4°C in the 2020s, 2.5°C in the 2050s, and 3.8°C in the 2080s. For the Southeast Asian sub-region, under an increased concentration of GHGs only, the annual mean

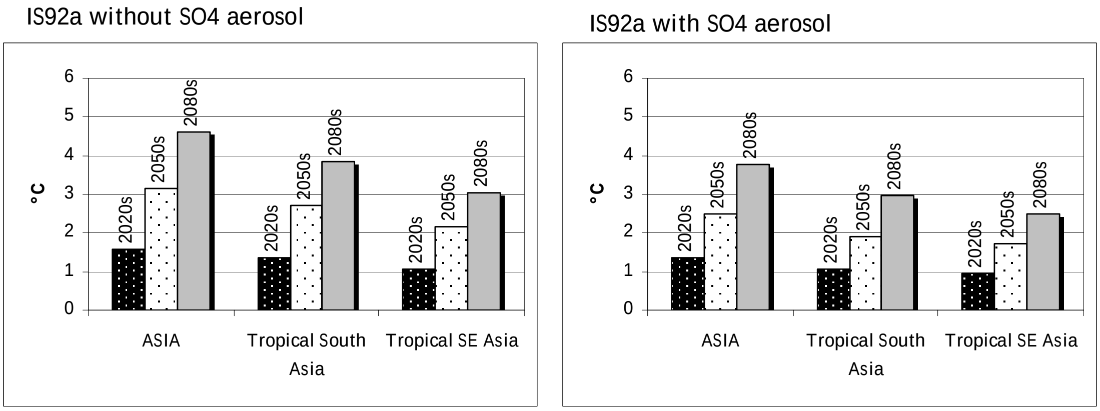


Greenhouse Gases	Preindustrial concentration	Concentration in 1998
■ CO2 (ppm)	280	365
□ CH4 (x10 ppb)	70	174.5
▩ N2O (ppb)	275	314
⊡ CFC-11 (ppt)	0	268
▧ HCFC-23 (ppt)	0	14
▨ CF4 (ppt)	40	80

Notes:
ppm = part per million by volume
ppb = part per billion by volume
ppt = part per trillion (million million) by volume

Figure 2: Examples of greenhouse gases that are affected by human activities. (Source of data: Houghton et al., 2001)

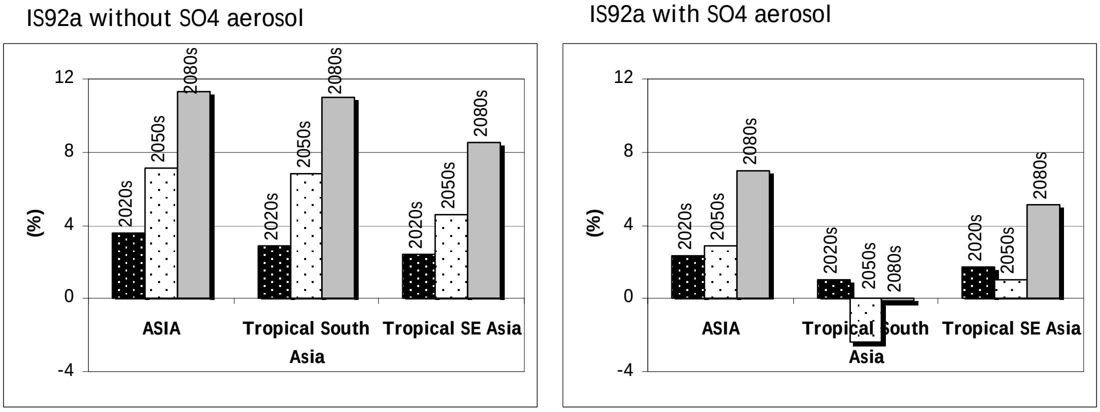
Change in air surface temperature



IS92a without SO4 aerosol

IS92a with SO4 aerosol

Change in precipitation



IS92a without SO4 aerosol

IS92a with SO4 aerosol

Figure 3: Plausible changes in area-averaged annual surface air temperature over Asia, tropical South Asia and Southeast Asia (upper diagram), and annual precipitation (lower diagram), as a result of future increases in greenhouse gases (under IS92a emission scenarios) as inferred from an ensemble of data generated in experiments with CCSR/NIES, CSIRO, ECHAM4, and HadCM2 AOGCMs. Left diagrams were simulated without sulphate aerosols, and right diagrams with sulphate aerosols. (Source of data: Lal et al., 2001.)

warming is projected to increase by 1.05°C in the 2020s, 2.15°C in the 2050s, and 3.03°C in the 2080s. With a combination of GHGs and sulphate aerosols, the annual mean warming is restricted to 0.96°C in the 2020s, 1.72°C in the 2050s, and 2.49°C in the 2080s.

The analysis also shows that the seasonal variations over the land regions of Asia also change, with warming in winter being higher than warming in summer. These different magnitudes of seasonal warming are also expected to occur in the Southeast Asia, but with relatively lower magnitudes.

Precipitation is also expected to increase in most parts of Asia, resulting from an increase of atmospheric concentration of GHGs (under the IS92a emission scenarios). The annual area-mean precipitation over the land regions of Asia is projected to increase by 3.6% in the 2020s, 7.1% in the 2050s, and 11.31% in the 2080s. When sulphate aerosols are combined with the GHGs, the increase is limited to 2.3% in the 2020s, 2.9% in 2050s and 7.0% in the 2080s. A similar case is encountered in Southeast Asia, where, under the IS92a emission scenario, the precipitation is projected to increase by 2.4% in 2020s, 4.6% in the 2050s, and 8.5% in the 2080s. With the inclusion of sulphate aerosols, the increase is 1.7% in the 2020s, 1.0% in the 2050s, and 5.1% in the 2080s.

In summary, climate scenarios resulting from GCM experiments suggest that the climate of the Southeast Asian region will be warmer and wetter in all seasons relative to current conditions. The changes in Southeast Asia will happen at a lower rate than in the rest of the world.

Climate change scenarios over Indonesia

Hulme and Sheard (1999) presented some details of climate change scenarios for the Indonesian region. In general, the changes in Indonesia's climate show a similar trend to the changes in the Southeast Asian region. Hulme and Sheard (1999) generated climate change scenarios for Indonesia based on four IPCC's SRES (Special Report on Emission Scenarios) scenarios (B1, B2, A1 and A2) (IPCC, 2000). These four SRES scenarios represent GHG emissions ordered from low levels of emission to high levels.[2] Three different sensitivity values were chosen: 1.5ºC (low), 2.5ºC (medium), and 4.5ºC (high). Future global warming was calculated by using a simple climate model created from a combination of the SRES scenarios and climate sensitivity (i.e. B1-low, B2-mid, A1-mid and A2-high). The simulations of the climate response to the increased GHG concentrations for Indonesia were performed by seven climate laboratories located in six different countries. The results described here are the median responses of the seven climate model simulations.

The air temperature in Indonesia will increase rather slowly in the future compared to the global average, with a rate in a range between about 0.1ºC/decade for the B1-low scenario and 0.3ºC/decade for the A2-high scenario compared to the global average, which is in a range between 0.1ºC/decade for the B1-low and 0.4ºC/decade for the A2-high. This rate of warming is quite uniform throughout the year for the whole region, including Java, and is quite comparable to the rate of increasing trend of temperature data from 12 selected climate stations in Indonesia which is between 0.2 and 0.4ºC/decade since 1970 (De Rozari, 1993).

The future annual average precipitation over the Indonesian region is expected to increase across the majority of Indonesia, except in the southern part of the region including Java. During the high rainfall season (December-February), parts of Sumatra and Kalimantan become 10-30% wetter in the 2080s. However, the southern part of Indonesia (including Java and Bali) may become drier by about 5-15% (under B1-low and A2-high scenarios respectively). During June-August (low rainfall season), the changes in precipitation are generally smaller. Negative changes (drier) may occur in the southern part of Indonesia, particularly in south Sumatra and south Kalimantan with a range of changes from 0% to about 10% (B1-low and A2-high), and Java with a range of changes from 0% to about 15% (B1-low and A2-high) in west and central Java and from 0% to about 25% (B1-low and A2-high) in east Java.

Uncertainties in climate change

Different models sometimes result in different regional climate responses to the same greenhouse gas emission and, therefore, provide some degrees of uncertainty in the climate scenarios. For both Sumatra and Kalimantan, the majority of models used by Hulme and Sheard (1999) suggest that climate will become wetter although there is a wider scatter of results for Sumatra than for Kalimantan. This wide range of possibility needs to be taken into account in order to demonstrate the wide range of impacts. However, in order to increase the confidence, it is wiser to conduct model validations before conducting impact assessments if measured data are available. For some impact studies, seasonal changes, such as drier less-rainfall season that may cause more severe drought and more precipitation in the rainy season that can cause floods, are more important than annual changes and therefore selection of models will affect the outcomes of the assessments (Figure 4). In general, the order of increasing uncertainty is from changes in global temperature, changes in mean regional climate variables (temperature, precipitation, etc.), changes in seasonal regional climate variables, and changes in climate variability such as ENSO (El Niño-Sothern Oscillation) and daily precipitation.

Climate variability and extreme events

In general, the climate variability of tropical Southeast Asia is controlled by the Hadley circulation and Walker circulation. The Hadley circulation is driven by a temperature difference between the northern and southern hemispheres due to the solar position relative to the earth's surface. This circulation controls monsoonal rainfall patterns with a contrast amount of precipitation between the rainy season and the

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[2] The change in carbon emissions from energy/industrial sources in comparison to the year 2000 emissions (estimated) for the four scenarios ranges from a decrease of 4% (scenario B1 - the lowest) to an increase by 320% (scenario A2 - the highest). Atmospheric CO_2 concentrations increase for all scenarios from about 370 ppm (part per million by volume) to 550 ppm by 2100 (the lowest) and to over 830 ppm (the highest).

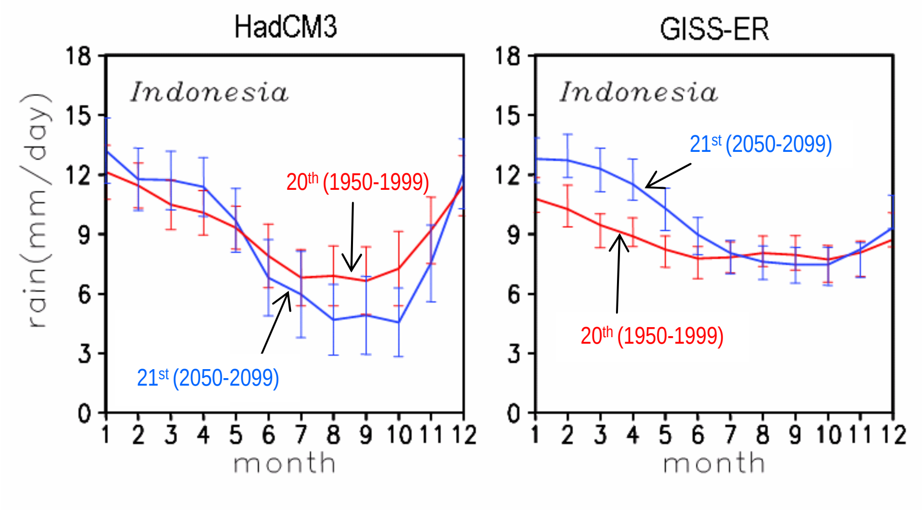

Figure 4: Different results on seasonal changes over Indonesia revealed by two different models, HadCM3 (Hadley Climate Centre, UK) and GISS-ER (Goddard Institute for Space Studies, NASA - USA) (Wenhong Li, 2006 in: Canadell et al., 2006).

dry season. The Walker circulation is driven by the change in energy absorption between the water in Pacific Ocean and the Asia-Australia continents. This circulation controls the inter-annual climate variation such as El Niño and its opposite, La Niña, which affect the rainfall amount over the Indonesian region. The Indian Ocean Dipole Mode (IODM) is another phenomenon that affects the inter-annual climate variability in Indonesia, which drives the wind direction and affects the rainfall distribution, in particular in the western Indonesia. When a positive dipole and El Niño occur at the same time, severe drought may result such as the droughts in 1982/1983 and 1997/1998.

IPCC has recognised that extreme events in the Asian region have increased in intensity and frequency (Lal *et al*., 2001). This is supported by Irawan (2002) who reported that, based on the Southern Oscillation Index (SOI) values during the 1876-2000 period, the frequency of El Niño tended to increase from once in every 8 years during the 1876-1976 period to once in every 4 years during 1977-2000. The El Niño events with the highest intensity were recorded in 1982 and 1997 with the annual average SOI values were -21.4 and -18.1 respectively.

Being able to model the changes in the variations of these extreme events is important for anticipating in advance their occurrence. The mechanism of the El Niño phenomenon is commonly associated with the Southern Oscillation. The El Nino Southern Oscillation (ENSO) phenomenon variation has been identified and predictable (Obasi, 1997). However, the repeatability of this phenomenon is still unpredictable because what triggers the mechanism of this event is still not well understood (Cuny, 2001).

No clear consensus exists linking the frequency and intensity of extreme weather events, including hurricanes and windstorms, to global warming (Saunders, 1999; Tompkins, 2002). However, it is quite reasonable to say that the link exists (Francis, 1998) and that additional warming will change the distribution of heat and thus the flow of energy through the climate system and in turn will alter the circulation patterns of the atmosphere and the hydrological cycle (Flohn *et al*., 1990). As a result, some areas would be exposed to more storms and heavier rainfalls while some will have prolonged dryness. Different types of weather events due to widespread increase in the amount of water that is circulated through the hydrologic cycle can be also generated and the warmer air will also increase the air's capacity to hold moisture that causes more moisture in the atmosphere will fall as heavy rain and snow. In addition, global warming will cause larger convection area and therefore the global precipitation distribution will alter.

In the future, GCMs will be expected to be able to simulate and predict inter-annual climate variability as well as seasonal forecasts since these becoming very important for early warning of climate hazards (Murphy *et al*., 2001).

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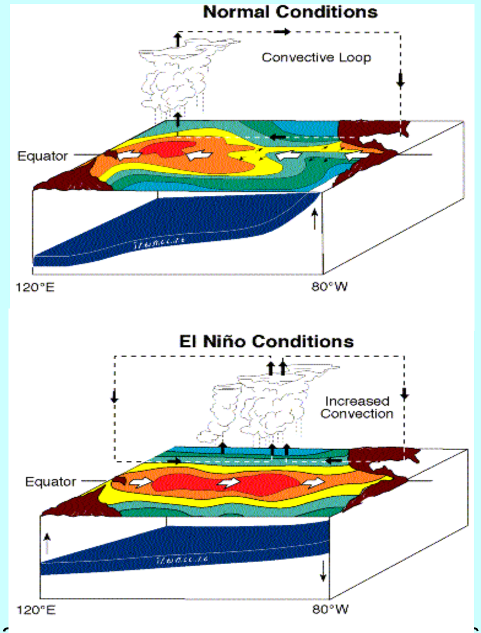
El Niño-Southern Oscillation and Indian Ocean Dipole Mode

Climate phenomena such as El Niño (and La Niña) and Indian Ocean Dipole Mode (IODM) have significant impacts in Indonesia. The El Niño causes severe drought while La Niña causes unusually heavy rainfall. When El Niño occurs at the same time with a positive IODM, a severe drought may result.



Source: NOAA

El Niño is a large scale oceanic warming that affects most of tropical Pacific (e.g. Nicholls, 1993; Henson and Trenberth, 1998). Its meteorological effects can extend throughout the Pacific Rim and to eastern Africa. In normal condition (see Figure), the trade wind blows towards the west across the tropical Pacific. This causes an increase of sea surface in the western Pacific by about 0.5m higher than in the eastern Pacific and a warmer temperature by 8ºC in the west than in the east due to upwelling cold water from the deep ocean. Rainfall is therefore higher in the western Pacific than in the east. During El Niño, the trade winds relax in the central and western Pacific that causes a decline of thermocline in eastern Pacific and an elevation in the west, which in turn reduces the upwelling of cold water in the eastern Pacific. This leads to a rise in sea surface temperature in the central Pacific that causes changes in the convective Walker circulation, which can be proven by weakening of easterly trade wind. Rainfall shifts to the east following the shift of warm water eastward that causes flooding in Pacific coasts of Peru and Ecuador and drought in Indonesia and Australia.

of which the thermocline is elevated in the eastern Pacific and decline in the west. This caused a strong cold water upwelling in the east that pushes the warm water further westward. In turn, this causes unusually heavy rainfall in Indonesia and dryness in the west coast of Southern America.

IODM in positive phase is characterized by an anomaly of warmer sea-surface temperature in the western Indian Ocean and cooler sea-surface temperature in the eastern Indian Ocean (Saji *et al*., 1999; Vinayachandran *et al*., 2002). This dipole mode event is accompanied by easterly wind anomalies along the equatorial Indian Ocean and upwelling of cold water off the western Sumatra that results in less rainfall in western Indonesia. On the other hand, the negative phase IODM results in an increase of rainfall in western Indonesia and drought in western Indian Ocean.

Saji *et al*. (1999) showed that the IODM is independent of ENSO (El Niño-Southern Oscillation), but this statement was argued by Allan *et al*. (2001) which showed the varying lag correlation between IODM and ENSO. Nevertheless, Amien *et al*. (2005) indicated that severe drought in Indonesia in 1997/1998 was caused by the positive IODM and El Niño that occurred at the same time. However, a weak El Niño in 2002 caused drought in Nusa Tenggara but at the same time floods in Sumatra and Kalimantan occurred due to negative IODM. In 2003, an opposite phenomena occurred of which the non El Niño year together with a positive IODM caused more intense dryness in west Kalimantan, south Sumatra, east Java and south Sulawesi than in the El Niño year of 2002.

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