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Climate change: is Southeast Asia up to the challenge?: the roles of climate variability and climate change on smoke haze occurrences in Southeast Asia region

Report

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The roles of **climate variability** and climate change on smoke haze occurrences in Southeast Asia region

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Abstract

This paper discusses the smoke-haze episodes in the Southeast Asia region and how their occurrence can be related to climate variability and future climate change in the region. The haze episode over this region has been an almost yearly occurrence but becomes severe during the prolonged dry period associated with the El Niño phenomenon. The longest and most severe case was the episode of September to November 1997 that occurred in conjunction with the extreme 1997/98 El Niño. This event resulted in more than US$4 billion in economic losses to the region and a colossal 93% of the cost was incurred in Indonesia.

There have been other serious episodes including those in 1982-83, 1987, 1991, 2002, 2004, 2005, 2006 and the episode that occurred this year (2009). Prior to the 1980s, fire outbreaks were mainly in Sumatra; it was only after the 1980s that large fires were recorded in Kalimantan. These patterns of large fire occurrences in Sumatra and Kalimantan were attributed to changes in land-use and an increase in population. Despite the increased role of humans in biomass burning, El Niño has been identified as a major contributing factor that induces a drier than normal condition over the Southeast Asia region especially during the period from June to November. Interestingly, despite expected changes in the mean climate, both the droughts occurred under warmer environments and the El Niño characteristics of the 21st century remain similar to that of the 20th century in this region. These findings, although yet to be assessed by the Intergovernmental Panel on Climate Change (IPCC), seem to suggest that the risks associated with the El Niño induced drought would not be significantly affected by anthropogenic climate change. Nevertheless, the risk may increase if unsustainable practices in land use in the region were to continue without effective mitigation measures.

1. Introduction

Haze episodes have become a major environmental problem for countries in the Southeast Asian region especially Malaysia, Indonesia, Singapore and Brunei since the late 1980s. Previous episodes occurred in 1982-83, 1987, 1991, 1994, 1997-98, 2002, 2004, 2005, 2006 and the most recent one was this year, 2009. Most of these haze episodes occurred in conjunction with a period of prolonged drought associated with the El Niño phenomenon. Prior to the 1980s, fire outbreaks occurred mainly in Sumatra (Field et al. 2009). The most extreme episode was the 1997-98 event that occurred during the extreme El Niño that year. This episode was considered the most costly and exerted huge impacts on countries in the region. A conservative estimate of the damage by the Economy and Environment Program for Southeast Asia (EEPSEA) and the Worldwide Fund for Nature (WWF) was US$4.5 billion (e.g. Schweithelm and Glover 2006). Despite the apparent roles of large-scale climate phenomenon such as El Niño that induces an anomalously dry condition; unprecedented levels of human activity have been a major factor in the fire outbreaks that cause the haze (e.g. Field et al. 2009). The activities related to shifting agriculture, timber extraction and palm oil plantations contribute to fire outbreaks during the extremely dry period associated with El Niño and subsequently induce haze episodes (e.g. Cotton, 1999). As haze episodes become a regular recurrence, the question remains as to whether their frequency and severity would increase in the future. Coupled with increases in land use patterns, an intensification of El Niño under a warmer environment due to anthropogenic climate change would exacerbate both the intensity and frequency of haze over this region. This paper investigates this issue, particularly the roles of climate variability and future climate change on future occurrences of smoke-haze episodes.

2. Haze episodes in the Southeast Asia region

There have been several haze episodes since the early 1980s including 1982/83, 1987, 1991, 1994, 1997, 2002, 2004, 2005, 2006 and this year's 2009 episode (e.g. Nicol 1997; Heil and Goldammer 2001). Field et al. (2009) described the occurrence of haze episodes for a period from 1960 to 2006. During the period 1997 – 2006, there were two major fires (1997/98, 2006) and two minor episodes (2002, 2004) based on the Global Fire Emissions Database (GFED). According to Field et al. (2009), prior to 1997 there were no high-quality or continuous records of fires. Thus in their study, the so-called monthly mean extinction coefficients were derived from visibility records from the World Meteorological Organization's meteorological stations in Sumatra and Kalimantan for the period 1960 - 2006. The extinction coefficients provide an index of visibility where high values indicate poor visibility (and hence a smoke-haze episode). Interestingly, the re-constructed index managed to capture the events prior to the 1980s. Based on this index, a clear distinction can be made between the Sumatra and Kalimantan haze episodes and the differences can be related to land use changes and population density (Field et al. 2009). Historically, large fires have occurred since at least the 1960s. There were three notable events based on the extinction coefficient index i.e., 1961, 1963, and 1972 (Figure 1). All these events occurred during the El Niño period. In contrast, in Kalimantan, the history of biomass burning was different as severe haze episodes were only recorded from 1982 onwards despite the drought episodes prior to the 1980s (Figure 2). These records showed that there was a significant change in Kalimantan during the period between the 1972 and 1982 droughts; leading to Kalimantan's fire environment changing from highly resistant to highly fire-prone. Field et al. (2009) attributed this to the human amplification of drought-induced biomass burning through the land use pattern in these regions. From 1950 to 1985, the rate of deforestation in Kalimantan was only 0.7% i.e. half that of Sumatra (1.4%). It was only between 1985 and 1997 that the deforestation rate in Kalimantan (i.e. 2.2%) began to equal that of Sumatra (2.6%). Kalimantan's accelerated deforestation is attributed to broader development patterns as reflected by the increase in agriculture and population (Field et al. 2009).

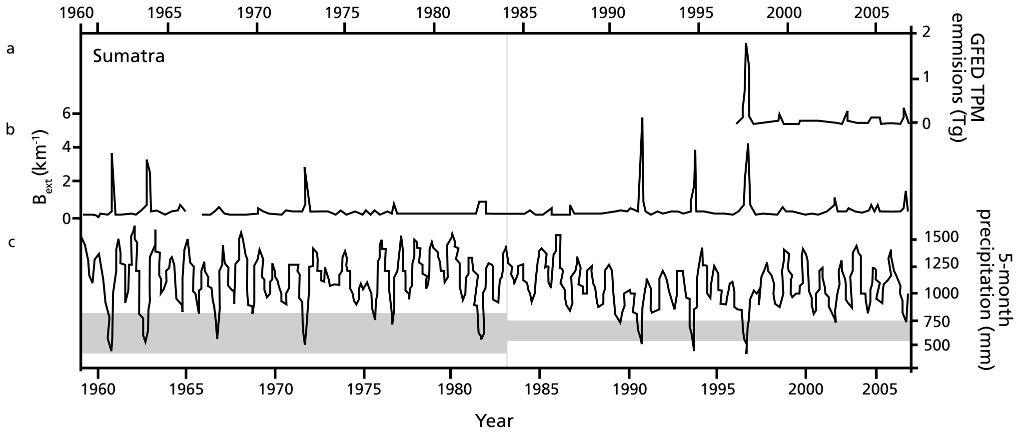


Figure 1: Monthly time series for Sumatra: (a) GFED TPM emission estimates,, (b) mean extinction coefficients (Bext) and (c) the precipitation time series (After Field et al. 2009)

The transmigration program, part of the Indonesian government's policy to ease the population pressure on Java, targeted Sumatra throughout the 1960s and 1970s, whereas Kalimantan only began to have a similar program in the 1980s. In Kalimantan, the situation was exacerbated by a change in land use pattern from small-scale subsistence agriculture to large-scale industrial agriculture and agro-forestry. One good example was the draining of the peatlands under the Mega Rice Project in the 1990s; resulting in the largest contribution to emissions across all of Indonesia during the 1997 fire event (Field et al. 2009).

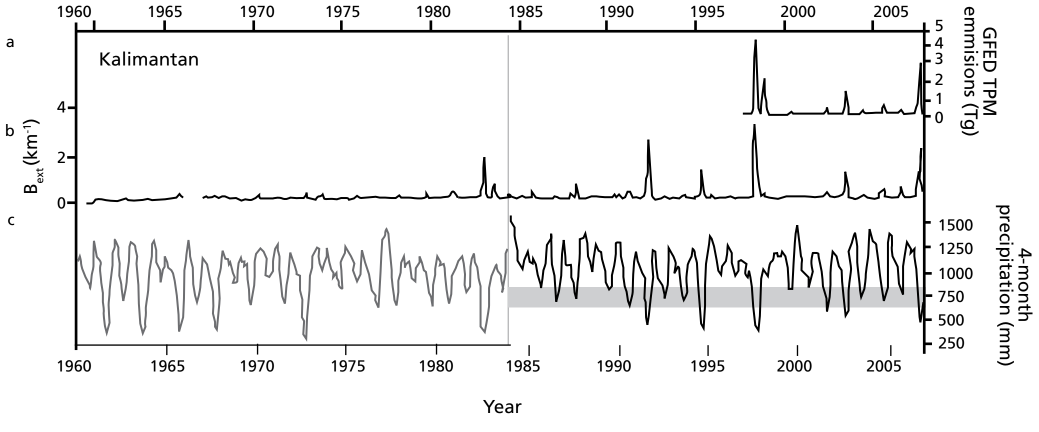


Figure 2: As for Figure 1 but for Kalimantan (After Field et al. 2009)

3. Chemistry and constituents of haze

The generally established constituents of haze due to biomass burning comprise a large variety of chemical pollutants such as particulate matter (<10 mm), which was the most consistently elevated pollutant in haze episodes, as well as inorganic gases such as SO^2 and NO^2, hydrocarbons, aldehydes and polycyclic aromatic hydrocarbons (PAH), with benzopyrene being the most carcinogenic (Stephen and Low, 2002). Gas compounds released include carbon dioxide (CO^2), carbon monoxide (CO), oxide of nitrogen (NO^x), ammonia (NH^3), and hydrogen (H^2) (Heil and Goldammer, 2001). Generally, more than 95% of the carbon emitted by biomass fires is in the form of CO and CO^2. Smoke particles emitted during biomass combustion are generally <10 μm in diameter. Studies of biomass fires reveal that the particles cover a broad size spectrum. Particles from 0.01 to 43 μm in diameter have been measured with a pronounced number concentration peak at 0.15 μm. Between 40 and 95% of the mass of particles consist of particles <2.5 μm in diameter, while particles >2.5 μm but smaller than 10 μm account for less than 10% of the particle mass (Radojevic, 2003). Other than gases, aerosols are a main component of haze. Aerosols usually contain small particles and water vapour. In the case of anions and cations, the composition of aerosols based on the composition of dust fall are dominated by ammonium and sulphate (Latif and Rozali, 2000). The high composition of sulphate in aerosols collected due to biomass burning in Indonesia has been correlated to the amount of sulphur in peat swamp areas due to accumulated volcanic sulphur through wet and dry deposition. Indonesia's arc of volcanoes have been permanently degassing for thousands of years, thereby contributing significantly to the total emission of sulphur species in that region. Abas et al. (2004a) identified a high concentration of tracers for smoke (e.g., levoglucosan) and almost all were found in samples collected during a haze episode. The concentration of n-alkanols and n-alkanals are higher in samples collected during the day, whilst n-alkanoic acids and PAHs are almost absent in the daytime samples, which may be attributed to enhanced photooxidation processes. Levoglucosan (1,6-anhidro-β-D-glucopyranose) is an organic molecule that can be used as an indicator of biomass burning (Abas et al., 1995; Abas et al., 2004b; Bergauff et al., 2008; Elias et al., 2001; Engling et al., 2006; Puxbaum et al., 2007; Wang et al., 2007). It is formed through the thermal breakdown alteration of the cellulose present in vegetation (Dos Santos et al., 2002). Levoglucosan was reported to have been present in the fine particle phase and remained stable in the atmosphere, showing no decay over an eight hour exposure to ambient conditions and sunlight (Larsen III et al., 2006; Puxbaum et al., 2007). The organic material within smoke aerosols is composed of a highly complex mixture of compounds covering a wide range of molecular structures, physical properties, and reactivity. Graham et al. (2002) showed that water soluble organic compounds (WSOC) of aerosols collected in the Amazon Basin during the 1999 burning season. This indicates that the product of biomass burning is a complex mixture of oxygenated compounds derived primarily from biomass burning. The pronounced increase in organic composition is due to the production of a secondary organic compound as a result of photochemical reactions.

4. Impacts of Haze

4.1 Impact on the climate system and environment

The air pollutants from biomass burning can affect the climate system in several ways. The greenhouse gases (GHGs) emitted during the fires (e.g. CO^2, CH^4, N^2O) contribute to global warming (Radojevic 2003). Under drought conditions, large-scale biomass burning, especially in Sumatra and Kalimantan, is a disproportionate contributor to the emission of GHGs. The smoke particles also alter the earth's radiation balance by scattering and absorbing radiation. The smoke particles also act as could condensation nuclei (CCN) and affect the precipitation processes and patterns.

4.2 Impacts on Human Health

Deteriorating air quality during haze episodes brings significant health risks to populations in the region. Almost 100 million people in the Southeast Asia region were exposed to acute health risks during the 1997 smoke–haze episode. An estimated 20 million people in Indonesia suffered from respiratory problems during the episode (Heil and Goldammer 2001). In Malaysia an estimated of 18 million people (or 83.2% of the population) were exposed to health risks during the episode. The major pollutant that causes adverse health is the particulate matter, particularly the fine particle fraction. The fine particle (PM2.5), has been correlated with the increase in daily mortality (Schwartz et al. 1996). The Malaysian Ministry of Health has identified a number of illnesses which are common and most likely to increase during a haze episode due to a direct relationship between the disease and the haze constituents. The most significant immediate health impacts of haze are respiratory and eye-related illnesses such as asthma, bronchitis, upper respiratory infections (URI) and conjunctivitis (Stephen and Low, 2002). The most significant immediate health impacts of the 1997 haze in Indonesia were URI, bronchial asthma, diarrhoea, eye irritation and skin diseases. The number of URI cases decreased significantly in parallel with the decreased incidence of forest fires (Aditama, 2000).

Other studies indicate the effect of air pollution in Malaysia on human health especially air pollution related to suspended particulate matter and haze conditions (Afroz et al., 2003; Mott et al., 2005; Omar et al., 2006; Sastry, 2002). Whether the effect of dust from biomass burning is more toxic than the dust from vehicles and industries is still being debated (Vedal and Dutton, 2006), but there are clear indications of an increasing trend of people with acute and respiratory infection and asthma requiring treatment at the hospital during the haze episode (Brauer and Hisham-Hashim, 1998; Heil and Goldammer, 2001a; Latif and Othman, 2001). A study by Mott et al. (2005) in Sarawak between 1995 and 1997 found significant increases in respiratory hospitalisation during the 1997 haze episode, particularly for asthma-sufferers within the age categories of 19-39 and 40-64 years. In addition to immediate health risks, exposure to smoke-haze also has long-term health implications. Some of the organic micro-pollutants observed in haze are known or suspected carcinogens, mutagens and teratogens (e.g. benzene, toluene, xylene, PAHs) (Radojevic 2003).

4.3 Economic Impact

4.3.1 Malaysia

Every serious haze episode exerts significant socio-economic impacts on Malaysia. However, the 1997 episode was the only well-documented episode with respect to economic impact. Shahwahid and Othman (1999) provided a comprehensive estimate of economic losses associated with the episode. Based on this study, the estimated value of haze damage to Malaysia for the period of three months from August to October 1997 was RM802 million (US$321 million based on the exchange rate at the time). These losses were collated from various sectors including health, production, tourism, transportation and fisheries. The poor air quality exposed people to various illnesses such as asthma, bronchitis, upper respiratory infections and conjunctivitis. The incremental cost incurred by the population for treatment of haze-related illnesses (both at private and government hospitals and clinics) and for self-treatment was about RM5.02 million (US$2 million). The number of hospitalisations due to haze-related illnesses also went up with an incremental cost of about RM1.2 million (US$580,000). However, Malaysia also suffered losses in productivity due to health-related illnesses. Hence the adjusted incremental cost of illnesses for the 1997 haze episode from August to October 1997 was RM21.02 million (US$8.408 million) (Shahwahid and Othman 1999). During the 19-28 September 2007, a state of emergency was declared in Sarawak when the Air Pollution Index (API) exceeded 500. Shahwahid and Othman (1999) estimated the loss in profit due to this state of emergency at RM393.5 million (US$157.2 million). This amount contributed to almost half of the total economic loss. The second largest contribution with around 40% of the total loss came from the sharp decline in tourist arrivals during the haze period. Shahwahid and Othman (1999) estimated the figure at around RM318.55 million (US$127.42 million). Two other sectors that contributed substantially to losses were fisheries, in terms of a decline in fish landings, and the cost of fire-fighting, with RM 40.58 million (US$16.23) and RM25 million (US$10 million), respectively. These figures represent 5 and 3.12% of the total losses, respectively. Other contributions came from cloud seeding operations at RM2.08 million (US$.83 million, 0.26%), expenditure on masks at RM0.71 million (US$0.28 million, 0.09%) and the cancellation of flights at RM0.45 million (US$.18 million, 0.06%).

4.3.2 Singapore

Hon (1999) provided an assessment of the economic impact of the 1997 haze episode. The losses to Singapore were between S$97.5 million to S$110.5 million (US$69.3 million to US$78.8 million). This estimate represents about one-fifth to one-fourth of Malaysian's economic losses during the same episode. Between 75 to 85 % of the total amount came from the tourism sector while about 10 % was contributed by losses from the airline industry and the health sector contributed the rest. However, these estimates were conservative as other costs were not taken into account.

4.3.3 Indonesia

Indonesia suffered much higher economic losses compared to Malaysia and Singapore. Ruitenbeek (1999) estimated that the economic losses to Indonesia exceeded US$3.7 billion. The health costs that included medical costs, productivity and indirect impacts amounted to US$924 million or 22.62% of the total loss. The losses related to the tourism sector, including tourism impacts, airline impacts and airport closures amounted to US$87.89 million or 2.15% of the total damage. Both impacts to the health and tourism sectors are related to the haze which amounted to US$1,011.89 million (or 24.77%). A large chunk of the total economic damage was attributed to fire impacts. With regards to the direct impact on Indonesia, fire impacts included timber losses, agricultural/ plantation losses, direct forest ecosystem production losses, indirect forest ecosystem function losses, domestic biodiversity losses and fire-fighting costs, amounting to US$2,787.79 or 68.5% of the total damage. The sub-total of the global impact due to fires, including carbon release, global biodiversity losses and fire-fighting costs amounted to US$285.56 million or 7.01% of the overall total. Overall the direct economic losses to Indonesia amounted to US$3,798.69 million i.e. more than 11 times those incurred by Malaysia or 50 times larger than the economic losses incurred in Singapore.

5. Climate variability and its role in the haze episode

The Southeast Asia region is subjected to the influence of a climate phenomenon known as El Niño. This is a naturally occurring climate phenomenon associated with atmosphere-ocean interaction over the Pacific Ocean. This interaction generates an oscillation known as the El Niño –Southern Phenomenon (ENSO) that exerts its influence around the globe. The El Niño event is the dry phase (or warm phase) of ENSO while the La Niña event is the wet phase (or cold phase) of ENSO. The Southeast Asia region receives the direct influence of this phenomenon as it is located over the rising branch of the east-west zonal atmospheric circulation known as the Walker Circulation. This "rising branch" coincides with a low pressure centre whilst the "descending" branch located over the eastern Pacific Ocean coincides with a high pressure centre. The east-west atmospheric pressure gradient actually drives the Walker Circulation. In normal years, moisture converges to the region to feed the deep convection that normally occurs over this region. However, during an El Niño event, changes in the tropical Pacific sea surface temperature distribution triggers an eastward migration of the low pressure centre from the Southeast Asia region to the central Pacific Ocean, leaving this region with diminished ascending motions and an increasing atmospheric stability. The establishment of a high pressure centre and a strong divergence over this region suppresses precipitation for the months of an El Niño event. This causes reduced rainfall that basically prolongs the atmospheric residence time for fire products as they are less influenced by precipitation (Heil and Goldammer 2001).

Several studies have been conducted to understand the relationship between anomalous rainfall over the Southeast Asia region and the evolution of ENSO (e.g. Tangang and Juneng 2004; Juneng and Tangang 2005; Aldrian and Susanto 2003; Chang et al. 2003)). Juneng and Tangang (2005) showed that the most dominant mode of inter-annual variability of anomalous precipitation over the Southeast Asia region (Figure 3) was that associated with the ENSO phenomenon. This mode or pattern explains about one-

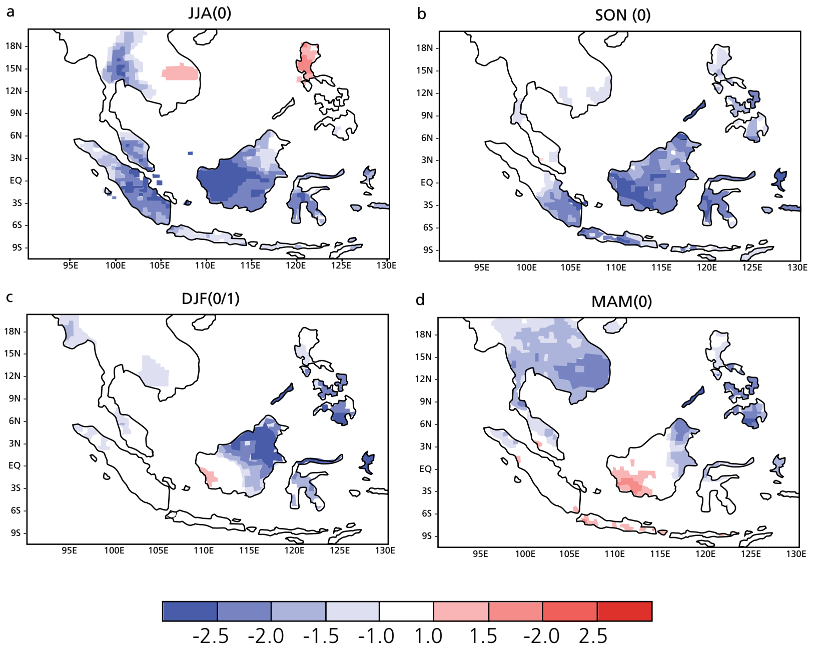


Figure 3: The spatial pattern of the most dominant mode of the anomalous Southeast Asia precipitation using the extended empirical orthogonal function (EEOF) analysis. The shaded values represent the eigenvector of the EEOF (After Juneng and Tangang 2005)

fifth of the total variance. The shaded values in the figure represent the so-called the eigen vector of the first mode of the extended empirical orthogonal function (EEOF) analysis. During an El Niño event, negative values (blue) represent deficit rainfall while positive values (red) indicate surplus rainfall. The period from JJA(0) to MAM(1) represents the one year evolution period of a typical El Niño from the July-June-August (JJA) season of the El Niño year (i.e. year 0) to the March-April-May (MAM) season of the following year (i.e. year 1). As an example for the 1997/98 El Niño, the JJA(0) represents the JJA of 1997 whilst the MAM(1) indicates the MAM of 1998. Figure 4 represents the time evolution of the patterns plotted with the time evolution of the most dominant mode of anomalous sea surface temperatures of the tropical Pacific and Indian Oceans shown in Figure 5. Clearly the seasonal evolution of the pattern of anomalous Southeast Asia precipitation in Figure 4 is not random but tightly coupled with the evolution of the anomalous sea surface temperature associated with the ENSO phenomenon. The sequence depicts a northeastward movement of the drought affected area from the beginning of an El Niño event to the period when it weakens. This evolution is related to the strengthening of the ocean-atmosphere interactions in the Southeastern Indian Ocean (SIO) during the SON(0) and in the western north Pacific (WNP) region during the DJF(0/1) period (Wang et al. 2003; Juneng and Tangang 2005). During the developmental stage of an El Niño (JJA(0)), almost the entire Maritime Continent experiences deficient rainfall.

This condition, coupled with lower seasonal rainfall and warm temperature associated with El Niño, (e.g. Tangang et al. 2007) creates an extremely favourable and conducive environment for large-scale fire outbreaks in Sumatra and Kalimantan. However, the role of El Niño would be secondary in nature to human related activities in agriculture, forestry and plantation sectors would be the main factor in initiating this sequence (e.g. Field et al. 2009). Anomalous wind during this period is southerly

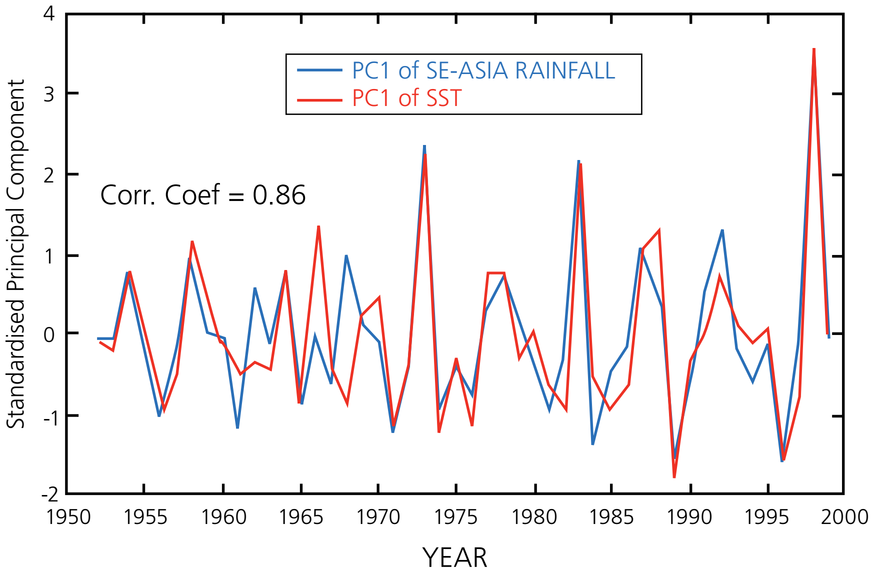
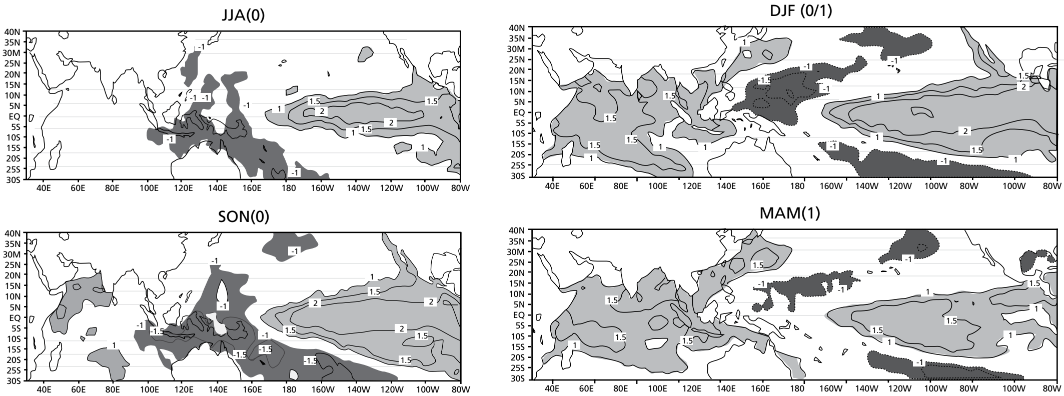


Figure 4: The time series represent the temporal evolution of the dominant pattern of the Southeast Asia anomalous rainfall shown in Figure 3 and that of the anomalous SST shown in Figure 5 (after Juneng and Tangang et al. 2005).

i.e. the winds blow to the north from Kalimantan and Sumatra. This enhances the seasonal wind during the period (i.e. the southeasterly winds) which facilitates the advection of smoke-haze from Sumatra and Kalimantan northward to Singapore, Peninsular Malaysia, Sarawak, Brunei and Sabah. During the SON(0) period, the southern parts of Sumatra and Kalimantan continue to experience deficit rainfall whilst the condition over Peninsular Malaysia returns to normal. However, the area of deficit rainfall extends northward to cover the whole of Borneo. At this stage the condition over Southern Sumatra and Kalimantan remains extremely favourable for large-scale fire outbreaks. Anomalous southeasterly wind over the region during this period facilitates the advection of smoke-haze to other regions from Kalimantan and Sumatra. However, during this period, the northern parts of Borneo begin to experience drought and this condition continues until the mature period of El Niño (DJF(0/1)) creating favourable conditions for fire outbreak in this region. The occurrence of haze in Sarawak, Brunei and Sabah in 1998 was related to local fires associated with dry conditions in this region (Radojevic 2003). By the MAM(1) period, only the northern tip of Borneo experienced drought. During both the DJF(0/1) and MAM(1) periods, the conditions in Peninsular Malaysia, Sumatra and Kalimantan returned to normal or slightly below normal, minimizing the risk of fire outbreak in this region.


JJA(0)

DJF (0/1)

SON(0)

MAM(1)

Figure 5: As in Figure 3 except for the anomalous sea surface temperature (after Juneng and Tangang 2005).

The evolution of a rainfall deficit area over the Malaysian and Indonesian regions from the JJA(0) to the MAM(1) periods unveils the susceptibility of the region to drought and hence the risk of forest fires during the occurrence of El Niño. This typical seasonal evolution of deficit rainfall and anomalous atmospheric circulation over the region during an El Niño event provides useful meteorological information. Coupled with the fact that El Niño itself is a predictable event by at least 6 months in advance (e.g. Tangang et al. 1998)), this information is relevant in mitigating the risk of forest fires and the recurrence of smoke-haze. In fact, Juneng and Tangang (2008) showed that precipitation anomalies in the region can be forecasted at least 5 months in advance using sea surface temperatures in the tropical Pacific as predictors. However, there could be other phenomena that could influence smoke-haze episodes. Field et al. (2009) identified that the Indian Ocean Dipole (IOD) could also be a contributing factor. The IOD is an ENSO-like phenomenon associated with atmosphere-ocean interaction over the Indian Ocean (Saji et al. 1999). It can occurred in conjunction with the El Nino or independently. A recent study by Juneng et al. (2009) also showed the possible modulation of PM10 distribution by intra-seasonal fluctuations (10-20 days and 30-60 days associated with the Madden-Julian Oscillation (MJO)).

6. Climate change and future climate projection over the Southeast Asia region

Section 5 describes the roles of El Niño induced drought in increasing the risk of fire outbreak and smoke-haze. However, questions remains as to how future characteristics of drought over this region might change in relation to anthropogenic climate change. The behavior of droughts over this region would determine to some extent the trend and characteristics of future smoke-haze episodes. This section discusses the projection of mean climate, drought and El Niño in the 21st century.

6.1 Change in mean climate and extreme events such as drought

The Fourth Assessment of the Inter-Governmental Panel on Climate Change states that the warming of the climate system is unequivocal based on evidence from observed increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level (IPCC AR4 2007). Recent and potential increases in global temperatures will likely impact the hydrological cycle, including changes in precipitation and increases in extreme events such as droughts and heat waves. Increases in the occurrence of drought over this region would eventually raise the risk of large-scale forest fires and widespread haze. To date there has been no prior investigation of future drought trends focusing on this region. However, useful information can be gathered from those of global scale studies mainly based on low resolution general circulation models (GCMs). Although the usefulness of such studies is limited for a particular locality, on a regional scale the information is relevant and useful. The IPCC AR4 showed that for the last 100 years or so, the temperature over Southeast Asia has been increasing at the rate of 0.15-0.25°C per decade. However, the warming rate has been accelerating over the last 2-3 decades. Tangang et al. (2007) showed that for several locations in Malaysia, the rates of warming for the last 40 years were as high as 0.4°C per decade. In contrast to global air temperature, the long-trend of global precipitation is difficult to establish. However, Zhang et al. (2007) was able to attribute the zonal mean precipitation around the globe to anthropogenic climate change. For the tropical region (including the Southeast Asia region), precipitation from 1925 to 1999 appears to be decreasing. This appears to be consistent with the time series of the Palmer Drought Severe Index (PDSI) produced by Dai et al. (2004) and highlighted in the IPCC Technical Paper VI on Climate Change and Water (Bates et al. 2008, Fig. 3.1). For the last two decades the Southeast Asia region experienced drier than average conditions.

Depending on the emission scenario, the projected global mean temperature at the end of the 21st century is between 1.8°C (for B1 Scenario) to 4.0°C (for A1F1 scenario) with a likely range of 1.1°C to 6.4°C (IPCC AR4 2007). The warming of the atmosphere is likely to cause changes in hydrological cycles including precipitation, soil moisture, runoff, evaporation and evapotranspiration (Bates et al. 2008). The frequency and intensity of extreme events such as droughts, floods and heat waves would also change. Sheffield and Wood (2008, yet to be assessed by the IPCC) described projected changes in drought occurrence under future global warming based on multi-model, multi-scenario IPCC AR4 simulations. This study indicated that for future projections, the models show decreases in soil moisture globally for all scenarios with a corresponding doubling of the spatial extents of severe soil moisture deficits and twice the frequency of short-term (4-6 month duration) droughts from mid-20th century to the end of the 21st century. Long-term droughts (more than 12-month duration) become three times more common. However, these increases in trends of drought occurrences vary regionally. The Southeast Asia region appears to be less affected compared to regions such as Central America, Central North America, the Mediterranean and southern Africa. This result may suggest that the characteristics of drought for the Southeast Asia region in the 21st century do not differ from those of the middle of the 20th century. The results of this study may also be interpreted to indicate that there will be no significant change in the risk of forest fire and smoke-haze in the 21st century.

6.2 Projected changes in El Niño characteristics in the 21st century

Section 5 highlights how the seasonal evolution of El Niño-induced drought over the region could prolong atmospheric residence time for forest fires to grow out of control and cause smoke-haze episodes. However, the interaction between anthropogenic climate change and ENSO may change future drought characteristics. A recent study by Coelho and Goddard (2009, yet to be assessed by the IPCC) highlighted the separability of climate change and ENSO-climate climate variability in the tropics. Thus the changes in mean precipitation within the tropics are largely independent of a model's ENSO characteristics. Coelho and Goddard (2009) also found that there is no significant change in relative El Niño strength or robust change in frequency based on various model simulations for the 20th and 21st centuries. However, as mean climate is projected to change in the 21st century, the risk of a predefined event such as drought will change. Based on models with good fidelity in reproducing ENSO, an increased risk has been found in some regions especially western Africa. However, there appears to be no significant change of risk for the Southeast Asia region and thus the results of this study are broadly consistent with that of Sheffield and Wood (2008). However, these findings have yet to be assessed by the IPCC. The preparation of the IPCC Fifth Assessment Report (AR5) is in progress and expected to be completed by 2013. The IPCC AR5 would provide greater regional emphasis and issues related to drought risks over this region are expected to be discussed in this report.

7. Conclusion and recommendations

The investigation by Field et al. (2009) reiterated Man's role in amplifying drought-induced biomass burning in Indonesia. Although the characteristics of both El Niño and droughts may not be affected by the changing of mean climate associated with anthropogenic forcing, the present ENSO oscillation guarantees the region an El Niño occurrence once in every 2-7 years and there is always a possibility of an extreme El Niño like the 1997/98 event recurring. Hence mitigation and policy response in reducing the risk of future large fire outbreaks and smoke-haze episodes are relevant. As indicated by Schweithelm et al. (1999), steps to improve fire management and steps taken to address the causes of fires need to be implemented. Various measures have been recommended to manage and prevent fires and reduce the risk of recurrence of large-scale smoke-haze such as the 1997 episode. Unfortunately, these measures were advocated about a decade ago, yet we have experienced at least another five smoke-haze episodes since 2000, including this year. Thus the issue of how to minimize and prevent smoke-haze episodes is far from over. Countries concerned may need to evaluate present mitigation measures and examine why they were ineffective in preventing the recurrence of smoke-haze. The smoke-haze episode of 1997 was a major disaster with colossal economic impacts and the region certainly cannot afford it to recur in future.

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References

Abas, M. R., Simoneit, B. R. T., Elias, V. O., Cabral, J. A., and Cardoso, J. N. (1995). Composition of higher molecular weight organic matter in smoke aerosol from biomass combustion in Amazonia. Chemosphere 30, 995-1015.

Abas, M. R. B., Rahman, N. A., Omar, N. Y. M. J., Maah, M. J., Samah, A. A., Oros, D. R., Otto, A., and Simoneit, B. R. T. (2004a). Organic composition of aerosol particulate matter during a haze episode in Kuala Lumpur, Malaysia. Atmospheric Environment 38, 4223-4241.

Abas, M. R. B., Oros, D. R., and Simoneit, B. R. T. (2004b). Biomass burning as the main source of organic aerosol particulate matter in Malaysia during haze episodes. Chemosphere 55, 1089-1095.

Aditama, T. Y. 2000. Impact of haze from forest fire to respiratory health: Indonesian experience. Respirology 5: 169-174.

Afroz, R., Hassan, M. N., and Ibrahim, N. A. (2003). Review of air pollution and health impacts in Malaysia. Environmental Research 92, 71-77.

Aldrian E, Susanto RD (2003) Identification of three dominant rainfall regions within Indonesia and their relationship to sea surface temperature. Int J Climatol 23:1435–1452

Balasubramanian, R., Victor, T., and Begum, R. (1999). Impact of biomass burning on rainwater acidity and composition in Singapore. Journal of Geophysical Research D: Atmospheres 104, 26881-26890.

Bates, BC., Kundzewicz ZW, WU S and Oalutikof JP, Eds, 2008: Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp.

Bergauff, M., Ward, T., Noonan, C., and Palmer, C. P. (2008). Determination and evaluation of selected organic chemical tracers for wood smoke in airborne particulate matter International Journal of Environmental Analytical Chemistry 88 473-486

Brauer, M., and Hisham-Hashim, J. (1998). Fires in Indonesia: Crisis and reaction. Environmental Science and Technology 32, 404A-407A.

Chang CP, Wang Z, Ju J, Li T (2003) On the relationship between western Maritime Continent rainfall and ENSO during northern winter. J Clim 17:665–672

Coelho CAS and Goddard L (2009), El Niño-induced tropical droughts in climate change projections, J Clim, DOI: 10.1175/2009JCLI3185.1

Cotton, J (1999), The "Haze" over the Southeast Asia: Challenging the ASEAN Mode of Regional Engagement, Pacific Affairs, 72, 331-351.

Dai, A, Lamb PJ, Trenberth KE and Qian T (2004), A global data set of Palmer Drought Severity Index for 1870-2002; relationship with soil moisture and effects of surface warming, J. Hydrometeorol., 5, 1117-1130.,

Dos Santos, C. Y. M., Azevedo, D. D. A., and De Aquino Neto, F. R. (2002). Selected organic compounds from biomass burning found in the atmospheric particulate matter over sugarcane plantation areas Atmospheric Environment 36 3009-3019

Elias, V. O., Simoneit, B. R. T., Cordeiro, R. C., and Turcq, B. (2001). Evaluating levoglucosan as an indicator of biomass burning in Carajás, amazônia: a comparison to the charcoal record. Geochimica et Cosmochimica Acta Volume 65, 267-272

Engling, G., Carrico, C. M., Kreidenweis, S. M., Collett Jr., J. L., Day, D. E., Malm, W. C., Lincoln, E., Hao, W. M., iinuma, Y., and Herrmann, H. (2006). Determination of levoglucosan in biomass combustion aerosol by high-performance anion-exchange chromatography with pulsed amperometric detection Atmospheric Environment 40 40 (SUPPL. 2), 299-311

Field RD, van der Werf GR, and Shen SP (2009), Human amplification of drought-induced biomass burning in Indonesia since 1960s, Nature Geoscience, 2, 185-188.

Graham, B., Mayol-Bracero, O. L., Guyon, P., Roberts, G. C., Decesari, S., Facchini, M. C., Artaxo, P., Maenhaut, W., Koll, P., and Andreae, M. O. (2002). Water-soluble organic compounds in biomass burning aerosols over Amazonia - 1. Characterization by NMR and GC-MS. Journal of Geophysical Research-Atmospheres 107, art. no.-8047.

Heil, A., and Goldammer, J. G. (2001). Smoke-haze pollution: A review of the 1997 episode in Southeast Asia. Reg. Environ. Change 2, 24-37.

Hon PML (1999). “Singapore” in Indonesia’s Fire and Haze, the cost of catastrophe, Glover D and Jessup T (eds), the Institute of Southeast Asias Studies (ISEAS), 22-50

IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Juneng, L and F.T. Tangang (2005). Evolution of ENSO-related rainfall anomalies in Southeast Asia region and its relationship with atmosphere-ocean variations in Indo-Pacific sector. Climate Dynamics, 25:337-350

Juneng L, and Tangang FT (2008). Level and source of predictability of seasonal rainfall anomalies in Malaysia using canonical correlation analysis. International Journal of Climatology, 28: 1255–1267

Juneng , L, Latif M T, Tangang FT and Masnor H (2009), Spatio-temporal characteristics of PM10 concentration across Malaysia, Atmospheric Environment 43, 4584-4594.

Larsen III, R., Schantz, M., and Wise, S. (2006). Determination of levoglucosan in particulate matter reference materials Aerosol Science and Technology 40 781-787

Latif, M. T., and Rozali, M. O. (2000). Inorganic component of dust fall during 1997 haze episode. Malays. J. Environ. Manage 1, 55-72.

Latif, M. T., and Othman, M. R. (2001). Concentration of several air pollutants and its effect to human health. In “National Seminar on Environmental Menagement Issues and Challenges in Malaysia”, pp. 524-531. Pusat Pengajian Siswazah, Universiti Kebangsaan Malaysia.

Mott, J. A., Mannino, D. M., Alverson, C. J., Kiyu, A., Hashim, J., Lee, T., Falter, K., and Redd, S. C. (2005). Cardiorespiratory hospitalisations associated with smoke exposure during the 1997 Southeast Asia forest fires. International Journal of Hygiene and Environmental Health 208, 75-85.

Nicol J (1997), Bioclimatic impacts of the 1994 smoke-haze event in Southeast Asia, Atmospheric Environment, 31, 1209-1219

Omar, N. Y. M. J., Mon, T. C., Rahman, N. A., and Abas, M. R. B. (2006). Distributions and health risks of polycyclic aromatic hydrocarbons (PAHs) in atmospheric aerosols of Kuala Lumpur, Malaysia. Science of the Total Environment 369, 76-81.

Puxbaum, H., Caseiro, A., Sa?nchez-Ochoa, A., Kasper-Giebl, A., Claeys, M., Gelencse?r, A., Legrand, M., Preunkert, S., and Pio, C. A. (2007). Levoglucosan levels at background sites in Europe for assessing the impact of biomass combustion on the European aerosol background. Journal of Geophysical Research D: Atmospheres 112.

Radojevic, M. (2003). Chemistry of forest fires and regional haze with emphasis on Southeast Asia. Pure and Applied Geophysics 160, 157-187.

Ruitenbeek , J (1999), "Indonesia" in Indonesia's Fire and Haze, the cost of catastrophe, Glover D and Jessup T (eds), the Institute of Southeast Asias Studies (ISEAS), 86-129.

Sastry, N. (2002). Forest fires, air pollution, and mortality in Southeast Asia. Demography 39, 1-23.

Schweithelm J and Glover D (1999), Causes and Impacts of the Fires, in Indonesia's Fire and Haze, the cost of catastrophe, Glover D and Jessup T (eds), the Institute of Southeast Asias Studies (ISEAS), 1-21.

Schweithelm J, Jessup T and Glover D (1999), "Conclusion and Recommedations" in Indonesia's Fire and Haze, the cost of catastrophe, Glover D and Jessup T (eds), the Institute of Southeast Asias Studies (ISEAS), 130-143

Shahwahid M H O and Othman J (1999), "Malaysia" in Indonesia's Fire and Haze, the cost of catastrophe, Glover D and Jessup T (eds), the Institute of Southeast Asias Studies (ISEAS), 22-50

Sheffield, J and Wood EF (2008), Projected changes in drought occurrence under future global warming from multi-model, multi-scenario, IPCC AR4 simulation, Clim Dyn, 31:79-105

Stephen, A., and Low, L. G. (2002). Impact of haze on health, mortality and mitigation programme. In "World Conference on Land and Forest Fire Hazards 2002", pp. 319 - 323, Kuala Lumpur.

Tangang, F.T and L. Juneng (2004). Mechanisms of Malaysia rainfall anomalies. J Clim, 17(18), 3615-3621.

Tangang, F.T., L. Juneng and S. Ahmad (2007). Trend and interannual variability of temperature in Malaysia: 1961-2002. Theoretical and Applied Climatology. 89, 127-141.

Tangang FT, Tang B, Monahan AH, Hsieh WW (1998) Forecasting ENSO events: a neural network-extended EOF approach. J Clim 11(1):24–41

Vedal, S., and Dutton, S. J. (2006). Wildfire air pollution and daily mortality in a large urban area. Environmental Research 102, 29-35.

Wang, Q., Shao, M., Liu, Y., William, K., Paul, G., Li, X., Liu, Y., and Lu, S. (2007). Impact of biomass burning on urban air quality estimated by organic tracers: Guangzhou and Beijing as cases. Atmospheric Environment 41, 8380-8390.

Wang B, Wu R, Li T (2003) Atmosphere–warm ocean interaction and its impacts on Asian–Australian monsoon variation. J Clim 16:1195–1211

Zhang et al. (2007), Detection of human influence on twentieth-century precipitation trends, Nature 448, 461-465.