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Types of biomass burning in South East Asia and its impact on health

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Abstract
The frequency and severity of forest fires in Southeast Asia (SEA) have increased significantly since the 1960s, and particularly since the 1980s. Due to climate change and land - use changes, biomass burning have become more ubiquitous. Biomass burning (BB) is a significant issue of the Earth system that profoundly affects and being affected by global climate patterns, vegetation cover, and anthropogenic activities, and this is a major contributor of air pollution at numerous scales, from the local to the global. SEA fires are results from a variety of factors of both natural, the El Niño southern oscillation weather pattern and anthropogenic factors. It has been observed that the frequency and severity of BB episodes, such as excessive pollution, and haze, increase rapidly in ENSO (El Niño Southern Oscillation) and IOD (Indian Ocean Dipole) years, 1997/1998, 2006, 2009 and 2015 are some the examples in which such changes were witnessed. Rice straw open burning contributed the most to total crop residue open burning emissions, accounting for 19-97% which varies from species to species, which is responsible for episodic regional haze events in various parts of SEA. Peat swamp forest has been intensively logged and drained for monoculture cultivation, production of tree crops such as oil palm and Acacia species, and for farming and agribusinesses on both commercial and small scales. As a consequence, a drastic fall has been witnessed in the Southeast Asian peatland forest cover between 1990 to 2015 it has declined from 76% in 1990 to 29% in 2015. Despite the region's high incidence of fires, there has been lack of scientific research on biomass burning and its impacts in SEA than other parts of the world. This review focuses on biomass burning related issues in Southeast Asia, focusing on the types of fires that occur and the natural and human factors that cause them.

Keywords
Biomass burning, Peatland, Trans- boundary Haze, El Niño Southern Oscillation, Indian Ocean Dipole.

Introduction

Southeast Asia, the geographical Southeastern sub-region of Asia, lies in 31.29°N, -12.37°S, 152.93°E, and 88.59°W, with a total area of 4,545,792km2 ranging from the territories South-east of the Indian subcontinent, South China, and the north-west part of Australia.

SEA is composed of two main regions:

- A mainland Southeast Asia or continental extension- it comprises of Cambodia, Laos, Myanmar (Burma), Thailand, Vietnam, and the small city-state of Singapore comprise Mainland Southeast Asia (Frederick et al., 2020).
- In addition, to the south and east of the mainland, there are a number of archipelagoes (insular Southeast Asia) - Indonesia and the Philippines are two archipelagic countries that make up insular Southeast Asia.

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Figure 1. *Map of the study region showing the location of the countries of south East Asia.*

There are many natural and cultural connections between the Malay Peninsula and the nearby islands, and it serves as a link between the two zones. The Malay Peninsula extends approximately (1,100 km) southward from the main island into insular Southeast Asia; although technically part of the mainland, it shares many natural and cultural connections with the nearby islands, and it serves as a connection between the two regions. Malaysia is a country that is both continental and insular, having a western component on the Malay Peninsula and an eastern half on the island of Borneo (Frederick et al., 2020). Every country in the region, with the exception of Brunei and Singapore, relies on agriculture as their primary source of income. Almost all of Southeast Asia is located within the tropical and subtropical climate regions, and most of the area gets a substantial amount of annual rainfall. Continental Southeast Asian region has mixed deciduous woods, such as the rich Teak forests, may be found throughout most of the, while the insular sub-region maintains extensive areas of very productive evergreen Dipterocarpus forests. The Southeast Asian region is home to more than 655 million people, accounting for approximately 8.5 percent of the world's population. This is the 3rd largest geographic location in Asia, after south Asia.

Population pressure and food production are key factors driving forest contraction in Southeast Asia, which has resulted in land use and land cover change in patterns as a result of their recent preference for cash crops. The land is being cleared, peat lands are being drained, and forests are being degraded on a massive scale. This has led to a landscape that is very different from what it used to be and where there are many human-caused fires. When there is a lot of drought, areas of normally wet peat land and forest can quickly dry, start fires, and burn for weeks or months.

However, as new land is cleared for permanent agriculture, cash crop expansion may result in increasing forest fires. Furthermore, agricultural residue burning may rise. Varied land-use patterns have different predicted emission levels, but the actual amount and spatial and temporal pattern of these emission rates on an intraregional scale remains an empirical challenge (Streets et al., 2003) Tropical deforestation is thought to be responsible for 15% of all human-caused global emissions (Van der Werf et al., 2009; Stibig et al., 2014), with Southeast Asia having the highest deforestation rate.
Biomass burning has been identified as a significant factor that affect or are affected by global climatic factors, vegetation cover, and anthropogenic impacts. Fire has always been connected with certain types of plant and land uses in Southeast Asia, but in the last five decades or so, particularly in peat

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swamp forests, fire has become more widespread in Indonesian forests, notably in the last two to three decades. (Taylor, 2009). Fires have been a common occurrence in Southeast Asia over the previous 3-5 decades. Fires in this region frequently occur during the local dry season due to high rainfall and a generally moist surface (Giglio et al., 2006; Hansen et al., 2008; Cohen, 2014). The large-scale use of fire for agricultural, such as rice, sugar, palm, rubber, and pulp, combined with land removal to accommodate a growing urban population, clearly renders these fires anthropogenic in origin (Field et al., 2009; Cohen, 2014). Additional factors involved are the role of unusual climate events associated with fluctuation in the Pacific and Indian oceans, such as El Niño, Indian Ocean dipole. Biomass burning may become more common as a result of climate change and land use changes, posing a harm to biodiversity and human health while also causing positive climate change feedbacks (Taylor, 2009). Forest fires have been more common in Southeast Asia since the 1960s, especially since the 1980s, with substantial regional and possibly global consequences (Taylor, 1999; Taylor 2009). Biomass burning has become a frequent event in Southeast Asian rainforests, where people have contributed in the moulding and extension of very fire-prone environments. Humans have reduced huge portions which were previously closed canopy, robust, and diversification of rainforest to burn-scarred secondary vegetation and scattered sections of deliberately logged timber stands. Oil palm trees thrive inside the tropical climates and soils of Southeast Asian countries like Malaysia and Indonesia. Deforestation, on either hand, happens due to the lack of suitable plantation areas, especially in peat swamp areas.

Total, carbon losses from biomass and peat are projected to be roughly 427.2 ± 90.7 t C ha^{-1} and 17.1 ± 3.6 t C ha^{-1} $year^{-1}$ due to the conversion of tropical virgin peat swamp forest into oil palm plantations, correspondingly (Uning et al., 2020). This is indeed crucial to note that the most recently selectively logged regions are especially fire-prone due to the large volume of dead and injured vegetation left behind by loggers, as well as the fact that colonized plant dries quickly and readily in these conditions (Siegert et al., 2001). Over the last two to three decades, peat lands of low-lying forests in Indonesia have been a major focus of biomass burning in Southeast Asia. Whenever peat land forests and the deeper strata of peat beneath it are both emptied and preferentially logged, both become extremely vulnerable to wildfires. Ground-level forest fires are especially damaging, not just to plants but also to the foundation for future recovery. Throughout Southeast Asia, fires, notably peat land burning, are becoming a major source of concern for both the ordinary people and government officials in the region. This is due to the fact that aerosols generated from these kinds of fires can cause prolonged haze occurrences in downwind places during favorable weather circumstances, impairing visibility and creating human health problems as a result. In the transition from shifting cultivation to sedentary cash crop farming, land relations play a major role.

When it comes to boosting cash crop development, governments must address this issue because land has traditionally been considered as a free resource in the absence of land ownership. Land rights policies are becoming more common in countries like Thailand and Vietnam. As a result, upland farmers can transition from traditional shifting agriculture to an economically viable business model. Another method governments try to stop the practice of shifting cultivation is through forest-use policies. Because forest preservation laws have not been strictly enforced in many places, land access has remained largely unrestricted. Nevertheless, conditions have beginning to transform (Rerkasem & Rerkasem 1995). It is hoped that shifting agriculture will be prevented in forest regions in Laos by removing people from upland areas through the Land–Forest Allocation Program. Unfortunately, the policies' effectiveness has been constrained by a lack of implementation. Biomass burning is inextricably linked to land use in subsistence agriculture, cash crop production, and logging. Some agricultural practices, particularly shifting cultivation, have been intensively investigated due to their great potential for generating fire. Ironically, while the linkages between cash crops, logging, and fire are becoming increasingly significant in Southeast Asia, they remain a woefully underdeveloped body of knowledge (Munroe et al., 2008).

When compared to other parts of the world, less scientific research has been done on biomass burning and its effects in Southeast Asia, despite the fact that the region has experienced a large number of fires. This

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study focuses on Biomass Burning-related concerns in Southeast Asia, with a particular emphasis on the kinds of fires that occur and the natural and human factors that generate them. Deforestation, intentional forest fires, drainage, as well as peat mineralization and fire, all contribute to the acceleration of carbon dioxide emissions. Also addressed the consequences of a major increase in fire frequency on air quality, human health, ecological resilience, and the global carbon cycle. The review adds further to identify future fire risks as a part of its recommendations, as well as actions to deal with the biomass burning problem.

Materials and methods

Data selection

The following keywords: Biomass Burning, Southeast Asia, forest fires, Crop residue open burning, Peatlands, Haze, Trans-boundary haze, ENSO, IOD were searched in Science direct, PubMed, Google Scholar, Atmospheric Chemistry and Physics (ACP), and Nature, for the purpose of completing this review. This review focused mostly on Southeast Asian studies, however other works from Asia and internationally were included as a point of reference as necessary. In all, 110 papers were selected for full-text examination, with 91 of them addressing Biomass Burning and related topics directly. Figure 2, depicts the selection procedure for the articles included in this review.

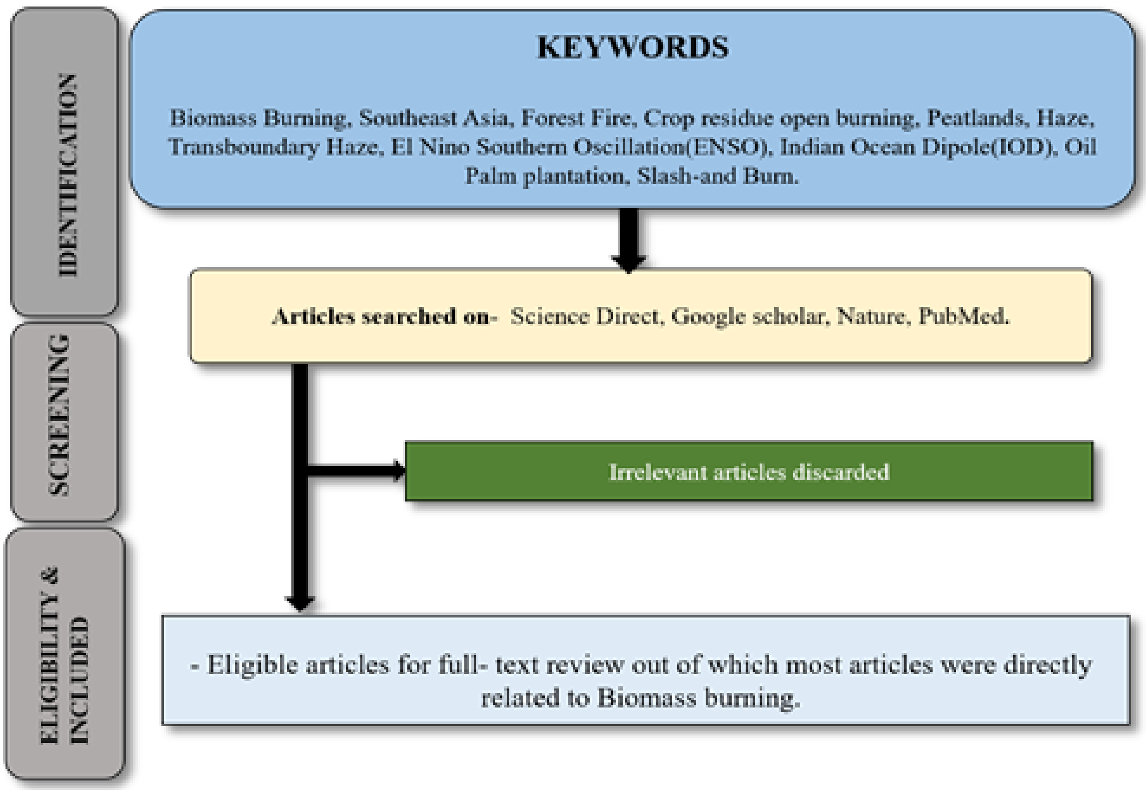

Figure 2. *Flowchart of paper selection.*

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Table 1. *An overview of research pertaining to the BB in SEA*

References	Study Period and Region	Model/ Source	Major finding
Taylor (1999)	- Southeast Asia (Sunda-shelf)	Forest fires- AVHRR coupled ocean-atmosphere Global Circulation Model (GCM)- estimate for global warming	Intense fires are likely to persist in the future as well, Hence fundamental reforms should be made to stop the destruction of rainforest and important steps should be taken for its revival.
Siegert et al., (2001)	1997-1998 Indonesia	Fire occurrence- AVHRR, 1,100-m ground resolution, Active Microwave Instrument (AMI), 25-m ground resolution synthetic aperture radar (SAR) Burned Area -European Remote Sensing Satellite (ERS)-2	A total of 5.2±0.3 million hectares including 2.6 million hectares of forest was burned with varying degrees of damage. Forest fires primarily affected recently logged forests; primary forests or those logged long ago were less affected.
Fuller et al., (2003)	July 1996-December 2001 Southeast Asia (Sunda-shelf)	Forest/ Non forest Map- MODIS	3 million Hectares of forest had been lost in Kalimantan, after the big El Nino event of 1997-98, almost
Munroe et al., (2008)	Mainland SEA	Fire products- AVHRR Fire and thermal anomalies product derived- MODIS. Aerosol data- MISR level 2 aerosol data, AERONET, MODIS Level 2 Aerosol Product.	Land-cover and fire-management practices reflect two temporal trends. First, policy changes such as new land rights in Vietnam and Laos have shifted land-use systems. Second, there are significant seasonal variations in the vegetation burned.
Field et al., (2009)	1960- 2006 Indonesia	Fire episode- GFED(Global Fire Emission Data) Precipitation- PRECL (Precipitation over land)	Fires are associated with severely poor air quality and occur when precipitation falls below a certain threshold.
Inoue et al.,(2010)	2001–2006. Laos	Slash & Burn land-use satellite images - Landsat-MSS, TM and ETM+ satellite images IKONOS and Quick Bird satellites.	The temporal average of carbon stock in 1C + 10F cycles, for example, was greater by 33 MgC ha1 than in 1C + 2F land-use patterns. The regional ecosystems lost 42 MgC ha−1 of carbon between 1990 and 2004. Where cropping (C) and fallow (F)
Miettinen et al.,(2011)	2008-2009 Peninsular Malaysia & islands of Sumatra, Borneo and Java	Active fire detection- thermal infrared (TIR) radiation (MODIS) active fire data. 2 Land cover maps- **1**.500-m spatial resolution regional land cover map- for mineral soil areas. **2**. 250 MODIS Surface Reflectance Product images, Shuttle Radar Topography Mission (SRTM) 90 m.	Insular Southeast Asia's fire regime characteristics are strongly linked to the presence of peat soil and land management status. This results in a wide range of fire activity within this region, both annually (depending on weather patterns) and over a longer time period.
Schwalm et al., (2011)	(1997-2009) 13 years Equatorial region	Net Ecosystem Exchange (NEE) - FLUXNET data using land cover maps and weather reanalysis.	El Nino events have, when globally integrated, both enhanced and weakened terrestrial sink strength, with no consistent response across events

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Carlson et al., (2012)	1990-2010 Indonesia (Kalimantan)	Land cover classification and validation: 1990 and 2000-era Landsat 5 Thematic Mapper and Landsat 7Enhanced Thematic Mapper Plus images Oil palm identification- Quick bird, IKONOS or ALOS PALSAR imagery.	A lot of oil palm plantations were on mineral soils by 2010, and these plantations made up 61% to 73% of net oil palm emissions between 1990 and 2010, which were 0.20 to 0.24 GtC yr-1. Plantation growth in Kalimantan alone is expected to account for 18–22 percent (0.12–0.15 GtC yr1) of Indonesia's CO2-equivalent emissions in 2020.
Permadi & Kim Oanh, (2012)	2007 Indonesia	Forest fire- MODIS [MCD45A1] Crop residue field burning- MODIS [MCD45A1] 500m resolution.	Crop residue open burning accounted for more than 80% of total biomass open burning emissions, followed by forest fire (2-12%) and municipal solid waste MSW-related open burning (1-8 percent)
Wooster et al., (2012)	1980–2000 Borneo	Active fires sites- MODIS Post 2000 studies – AVHRR Advanced very high resolution radiometer	Due to its influence on precipitation, El Nino has a major influence on the magnitude of fire activity caused by land cover changes.
Stibig et al., (2013)	1990-2010 SEA	Images were obtained- Landsat TM+ETM and from archives of US Geological survey (USGS, 2013)	The most prominent drivers of forest change in SEA are the shift of forest cover to cash crop plantation (e.g. palm oil), selective logging, and tree plantation installation.
Cohen, (2014)	2000-2012 SEA	12yr [2000-2012] AOD data- MISR on terra satellite analysis of MISR AOD data Quantitative approximation of BC emission – AERONET	According to Black carbon BC estimates, heavier burning years result in a considerable increase in global BC emissions.
Fujii et al., (2015)	September 2011 and June 2012 Malaysia	PM2.5 samples- Tisch high-volume air sampler (model TE-3070V-2.5-BL)	During the southwestern monsoon season, the chemical characteristics of PM2.5 in Malaysia appeared to be significantly influenced by Indonesian peat land fire (IPF).
Spessa et al., (2015)	1997–2010 Indonesia	Fire data- GFED4 + Remote sensing resolution RSS Forest cover data- AVHRR at 1km MODIS at 500m(2000-20100 Rainfall data- GPCP one degree daily 1DD	Instead of depending just on indices, more physical-based strategy should be employed to predict fires.
Zhang et al., (2015)	(1951–2013) Tropical Indo-pacific region	Carbon monoxide (CO) mid tropospheric estimation- MOPITT & AIRS Upper atmospheric CO data- Aura Microwave limb. Aerosol characterization- MODIS AOD (over land and ocean) Fire activity data – Terra and Aqua MODIS active fire detection.	Recent decadal shift in El Nino regime altered the link between El Nino and IOD significantly. In the context of seasonal forecasting, this has significant ramifications.
Huijen et al., (2016)	2015 Maritime SEA	Biomass Burning emission- Global fire Assimilation system Temporal CO- MOPITT	Carbon emissions from 2015 fires will be the highest seen in the maritime SEA since the 1997 El Niño year.

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Phairuang et al.,(2016)	2014 Thailand	Forest fires emissions (PM and other gases)- Global Atmospheric Pollution Forum Air Pollutant Emission Inventory Manual (GAPF) version 5.0 Hotspot data- (MODIS) active fire product (MOD14)	Open burning of rice residues has the largest contributor to pollution, followed by sugarcane and cassava wastes. In the northern region of the country, where over 70% of the forest is at danger of fire, forest fire emissions are a major source.
Lee et al., (2016)	2002 -2014 SEA	Atmospheric evolution of chemical species- WRF(weather research forecasting)-Chem Daily 36km resolution PM 2.5 emission- Fire inventory from NCAR version 1.5 (FINNv1.5) Global Fire Emission Database- GFEDv4.1s	To improve overall air quality, mitigation techniques targeting both biomass and fossil fuel burning sources must be applied across SEA.
Yin et al., (2016)	1997–2015 Equatorial Asia	MODIS daily active fire products- MOD14A1 from terra and MYD14A1 from Aqua at local time 10:30 & 13:30 Satellite total column retrieval of CO- MOPITT	Because of a less severe water deficit, 2015 emissions were 0.51+- 0.17 Pg. carbon, less than half of the preceding 1997, strong El Niño.
Fanin & Werf et al., (2017)	1997–2015 Indonesia [Sumatra and Kalimantan]	_	In Indonesia, non-linearity between rainfall and fire is caused by longer durations without rain during exceptionally dry years.
Kim Oanh et al., (2018)	2010–2015 SEA	Mapping & spatial distribution of SEA CROB(crop residue open burning) annual emission- GIS	Thailand, Indonesia, Myanmar, and Vietnam dominated total biomass open burning emissions. In total CROB emission from 8 crops, rice straw open burning dominated (19-97%).
Islam et al., (2018)	2015 SEA	Multivariate ENSO index MEI- data collected from NOAA & ESRL [ICOADS] International comprehensive Ocean Atmospheric data set- for determination of MEI	Due to the influence of ENSO, IOD, and MJO during the 2015 BB episode, regular monsoon rainfall was delayed in MC, resulting in increased fire and severe haze.
Pan et al., (2018)	1967-2016 Indonesia	SST- ERSSTv4 GPCPv2.3- Precipitation rate. MERRA-2 : Wind, cloud fraction GFWED(Global Fire Weather Database)- drought code	Drought and fires in Indonesia are more severe and last longer in the eastern pacific type, whereas carbon emissions are nearly double those in the central pacific type.
Pimonsree & Vongruang, (2018)	2011-2017 SEA Mainland cities	Fire hotspots (FHS)- MODIS Anthropogenic emission- NASA SEA composition, cloud, climate coupling regional study (SEA C4RS)	Biomass burning outside the city had a significant impact on PM concentration within the city, contributing around 85% for PM 10 and 85% for PM 2.5.
Samsuddin et al.,(2018)	2015 Malaysia	Illustration of the wind vectors- e Grid Analysis and Display System (GrADS) Fire Radiative Power (FRP) GFAS emission data- Monitoring Atmospheric Composition & Climate (MACC) (http://join.iek.fz-juelich.de/macc) Wildfire CO data- MACC site	In both Muar, Site A and Cheras, Site B, the average concentrations of PM10 and carbon monoxide were two times higher during haze episodes than during non-haze episodes. In comparison to sulphur dioxide and ozone, haze had a greater impact on nitrogen dioxide.

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Adam et al.,(2019)	May 2017 to March 2018 Singapore	Temporal variations of BC- Atmospheric Research Station (ARS) National University of Singapore (NUS) Aethalometer- real-time measurements of BC MicroAeth (Model AE51) - measure BC concentrations in real-time during the mobile study. Portable air sampler (MiniVol) - collect PM2.5 samples.	It was found that BC concentrations were higher in the south-west monsoon SWM, than in the north-east monsoon NEM (SWM, 2.60 ± 1.56 mg/m3,NEM, 1.68 ± 0.96 mg/m3)
Edwards et al., (2019)	2015 Indonesia	Thermal hotspot detections- (MODIS) Active Fire Products (MCD14ML) Nino 3.4 SSTA, recorded in the central Pacific Ocean- to measure El Nino-Southern Oscillation (ENSO) effects on fire	The flames released more CO2 than the whole US economy on numerous days. El Niño occurrences account for most annual fire variability. The construction of new districts exacerbates the effects of El Niño on fire and rural economic development has accompanied the usage of fire.
Vadreru et al., (2019)	2003–2017 SEA & south Asia	Active Fire products- Collection 6 MODIS active fire products [MCD14ML]	Recurrent fires happened throughout 30% of Southeast Asia, with the highest numbers in Laos, Cambodia, Thailand, and Myanmar.
Vetrita & Cochrane, (2019)	Indonesia	Burned area collection- Terra and MODIS combined [MCD64A1] Peat land LULC map- Centre for remote imaging , sensing and processing	It has been discovered that LULC modification has a substantial impact on changing fire regimes. Sumatra and Kalimantan's peat swamp forests will perish if Indonesian peat land is not reduced to a manageable level of burning.
Dhandapani & Evers (2020)	2018 Malaysia	Carbon dioxide and methane emission- Los Gatos(ultraportable greenhouse gas analyzer)	Slash-and-burn activities in oil palm agriculture had the greatest impact on surface peat layers up to 20cm depth.
Khan et al. (2020)	2015 Malaysian Peninsula & Borneo region of East Malaysia	Non-dispersive infrared absorption (NDIR)- CO monitoring - SO2- A florescence -based sensor (NOx) and O 3- Chemiluminescence Transport of air mass on a monthly basis: (HYSPLIT 4.9) Hybrid Single Particle Lagrangian Integrated Trajectory	Wildfires from Borneo impacted the Southern Malaysian Borneo more seriously than that from Sumatra region.
Shiogama et al., (2020)	2015 Equatorial Asia (EA)	Fire CO2 & fire PM2.5 emissions- GFED4s SST changes- by taking the ensemble mean differences between the all-forcing historical runs and the natural-forcing historical runs of the CMIP5 AOGCMs. MIROC5 HAPPI (Half a degree Additional warming, Prognosis and Projected Impacts)-to study the changes in extremely hot days	Historical anthropogenic warming will significantly increase the chances of severe meteorological drought exceeding the 2015 observations in the EA area during the 2015 major El Niño event, (from 2 % (1 %–4 %) in Nat to 9 % (6 %– 14 %) in Hist). HAPPI (1.5 and 2.0 ◦C warming) and HAPPI extension (3.0 ◦C warming) runs, showed that the probabilities of drought exceeding the 2015 observations will largely increase: 82 % (76 %–87 %), 67 % (60 %–74 %), and 93 % (89 %–96 %), respectively

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Sricharoenvech et al., (2020)	May 2017 - April 2018 Yangon, Myanmar	Chemical Mass Balance (CMB) model- Identification the major sources of particulate matter. Dust estimation- Crustal elements.	The composition of PM10 fluctuates periodically due to both weather (precipitation and temperature) and human activity (firewood and yard trash burning). Dust, secondary inorganic aerosols (SIA), and secondary organic aerosols (SOA) were the main sources of PM in Yangon, with contributions from biomass burning increasing in the winter.
Nguyen et al., (2021)	23 March - 12 April 2015 Pha Din [PDI] region of northwest Vietnam	CO, CO2, CH4- Cavity-ring down spectrometer - O3- UV absorption Biomass burning locations— MODIS from aqua & terra platform [MCD14DL]	BB activities in northern Southeast Asia have a significant impact on regional organic aerosol loading, carbonaceous PM2.5 components, and trace gases in northwestern Vietnam.
Punsompong et al., (2021)	Central, North and Northeast Thailand	Ground based PM2.5 observation- Beta gauge style or TEOM Active fire product- VIIRS	Forest fires dominated the north (73%) and northeast (48%) regions, while agriculture fires dominated the central (52%). The PM 2.5 AQI level in Thailand was mostly governed by trans boundary BB effect (67%) and local contribution (33%).

Types of biomass burning

Forest Fire. Forests are the most important component of the ecosystem, and they play a critical role in preserving the ecosystem's harmony. Southeast Asia has nearly15% of the Global tropical forest (DeFries et al., 2005) and includes four of the world's biodiversity hotspots (Sod hi et al., 2010). Deforestation in the tropics is rapidly increasing. As per a recent global survey, over 1% of the globe's existing natural tropical-forest area, or approximately 14.2 million hectares, was destroyed each year between 1990 and 2000, majority of the loss is due to the conversion of tropical forests to intensive agriculture (FOI, 2001). Given these figures, and the fact that in the early 2000s, over 90% of Southeast Asia's forests remained unprotected (Sodhi et al., 2010), Over 40% of the country's biodiversity is predicted to be eliminated by 2100, as per estimates. In recent past Human induced fire has become a primary reason in the attenuation and savannization of tropical forests (Goldammer. J, 1999).

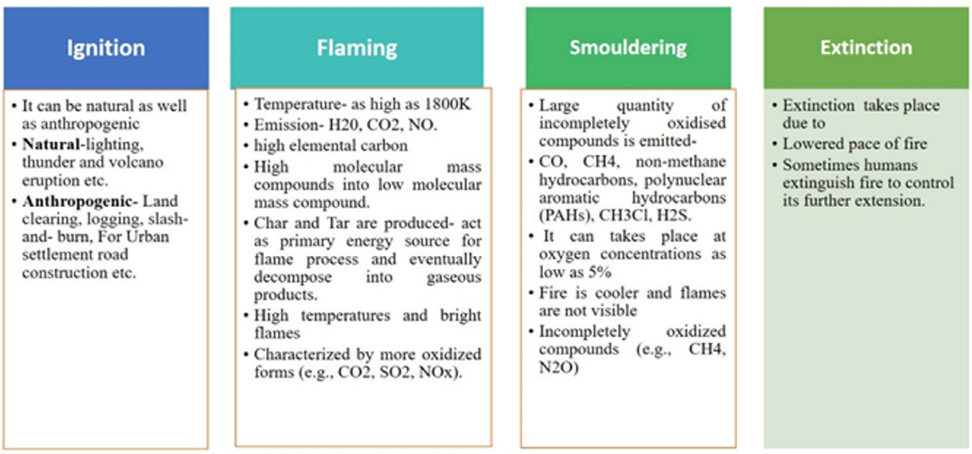

Figure 3. *Four main Stages of forest fire progression: a) Ignition, b) Flaming, c) Smouldering and d) Extinction.*

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Across many developing countries in Southeast Asia, Africa, and South America, the slash and burn approach has long been practiced as a low-cost method of clearing forests for agriculture. This technique involves cutting of forest or vegetation as it increases the soil fertility (Verma A, 2003; Lohman et al., 2007). Based on evidence from satellite images and ground investigations, Oil palm farms, notably those based in Singapore and Malaysia, have been blamed for a large part of the problem. Investigations are increasingly focusing on the role of mid-level private landowners and subsistence farmers, who utilise similar techniques to remove land for a low price (Kim Oanh et al., 2018).

Seasonal dryness and the El Nino occurrence, which induces drought like situation in the area, intensifies natural bush fires and manmade fires caused mainly due to land clearance.

The Great Fire of Borneo burned through a region rich in biological diversity, destroying a major portion of one of Southeast Asia's last large tracts of lowland tropical rain forest. Forests that were cut or altered in some way before to the wildfire were by far the most severely harmed. The incident highlighted that human impacts might increase the likelihood of burning in tropical rain forests, especially in periods of intense drought. The events that unfolded demonstrated that this these lessons have been largely overlooked (Aiken, 2019)

Figure 4 , shows the total SEA Crop residue open burning emissions of all species, with Indonesia accounting for 33-42% of the total, followed by Vietnam (15-25%), Myanmar (11-23%), Thailand (7-21%), the Philippines (8-12%), and Cambodia (1-2 %). Overall, the remaining four countries, Laos (0.5-5%), Malaysia (0.3-9%), East Timor (0.06-0.2%), and Brunei (0.06-0.2%), all had relatively low emission shares, constituting 0-6 %.

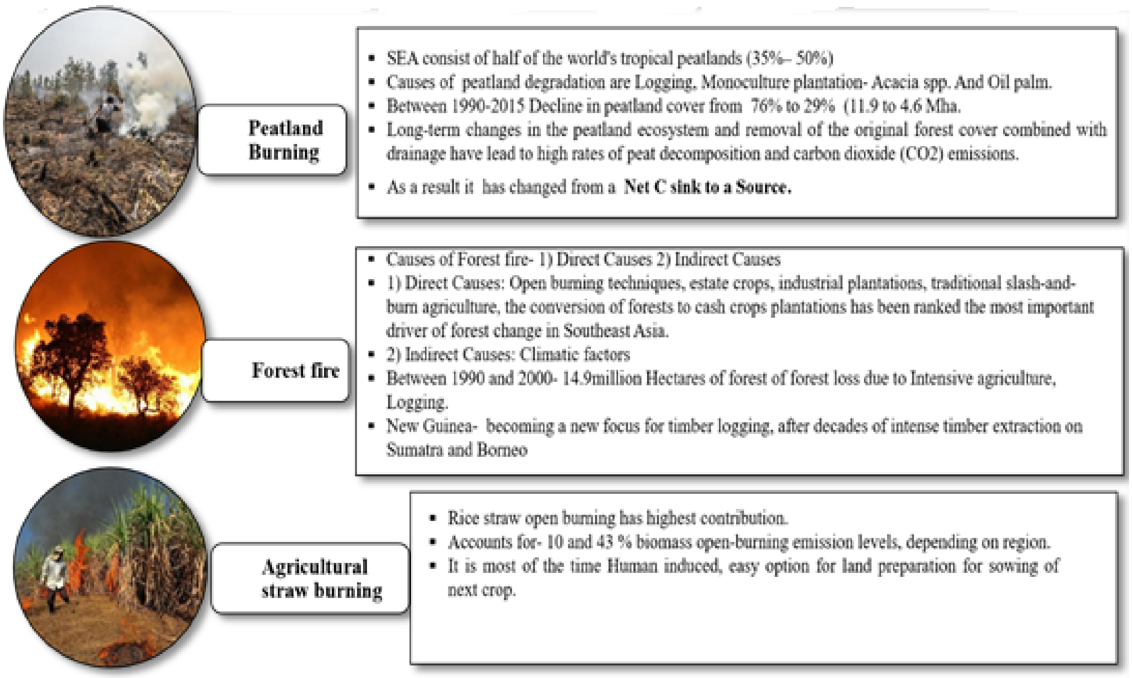

Figure 4. *Representation of key points related to types of Biomass Burning a) Peatland b) Forest fire c) Agriculture straw burning*

Agriculture straw and waste burning

Southeast Asia (SEA) is a rapidly expanding region in terms of both economic and people. The majority of SEA's countries are agronomic, with the agricultural sector accounting for the majority of their economic development. A seasonal pattern of biomass burning exists in the Southeast Asian region: Mainland SEA in March–April and Maritime SEA in September–October, when smoke trails from forest fires blanket most of the region. While agricultural biomass burning is prevalent on the SEA's landmass at the end of the dry season (primarily in March and April), maritime fires (agricultural biomass burning and peat fires) are prevalent in Indonesia's Sumatra and Kalimantan

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provinces south of the equator during the dry season and from August to October, respectively (Field et al., 2016; Duc et al., 2019). Agricultural output has been improved to make certain food availability for the region having 600 million people or more and to accommodate trade flows, which has resulted in the annual release of a massive amount of crop waste. It produces a significant amount of agricultural crop waste, which is regularly burned on the field to make space for the following crop sowing (Kim Oanh et al., 2018). Local growers see Crop residue open burning (CROB) as the inexpensive and most convenient means to empty land for the following crop, and has thus been widely used for many years (Kanabkaew & Kim Oanh, 2011). Different biomass products, such as grass, agriculture waste, forest vegetation, and municipal solid waste, are burned openly (OB) is referred to as "biomass open burning" (Permadi et al., 2012). Shifting agriculture or slash and burn cultivation is still performed in some Southeast Asian countries, notably Indonesia, Malaysia and Laos etc. and some other Southeast Asian region (Li et al., 2014). Although shifting cultivation is supposed to increase soil quality, the heat from fire can damage the soil's composition and destroy organic particles which rich in humic substances on the top. (Sanchez et al., 2005), while also wasting large amounts of agro-residue biomass. In many SEA countries, the Crop residue open burning implications are typically underestimated, and society is usually less concerned about them than the apocalyptic SEA Trans boundary haze created by burning of forest. The persistent Trans boundary haze problem in Southeast Asia (SEA) seems to be caused mainly by open burning smoke (Koe et al., 2001). Open burning of crop residue in general is the vegetation smoldering at low temperatures, which results in the release of massive amounts of partial combustion products, like particulate matter (PM), carbon monoxide (CO), volatile organic compounds, black carbon (BC) and organic carbon (OC), all of which are toxic air pollutants (VOCs) (Tipayarom & Kim Oanh, 2020). Potent greenhouse gases such as methane (CH4), carbon dioxide (CO2), and nitrous oxide (N_2O) are also present, as are some nitrogen oxides (NOx) and sulphur oxides (SOx) in small levels, though the emitted Carbon dioxide is thought to be picked up by crop growth the in the coming time (Kim Oanh et al., 2018).

Crop residue open burning emissions are concentrated in populated regions and occur primarily during months with low precipitation, when level of air pollution in Southeast Asian region are often high. As a result, they may have substantial local health and environmental consequences. Significant levels of dioxins, PAHs, as well as enormous amount of hazardous small particles, released annually from agricultural waste field burning, should be a cause of worry and a focus point for increasing awareness about the need to end Crop residue open burning activity (Kim Oanh et al., 2018).

According to (Kim Oanh et al., 2018), who studied the SEA Crop residue open burning emission from 2010-2015- Crop residue open burning (CROB) accounted for between 10 and 43 % biomass open-burning emission levels, depending on the country: Vietnam and the Philippines are the most prominent, while Indonesia, Myanmar, and Thailand were much less prominent. Rice straw has high silica and cellulose content and therefore, it requires long periods of natural decomposition. Owing to the long decomposition process, rice straw is typically stacked in the farm area and managed through open burning (Logeswaran et al., 2020). Rice straw open burning contributed the most to total crop residue open burning emissions, accounting for 19-97% (differing by species) of total CROB emissions, followed by maize (2-78 %) and sugarcane (0.4 – 26 %), with the remaining five crop types accounting for only minor contributions (0-4.4%). Sugarcane residue open burning was prevalent in Thailand, owing to the large number of plantations that provided raw material for the sugar industry in the country, which is known as the world's second largest sugar exporter after the United States.

Peatland fire

Peatlands are a key component of carbon soil atmospheric exchange processes and serve as a substantial carbon reservoir (Page et al., 2011). The peat land area in SEA covers about 26 million hectares (Wösten et al., 2008). In Southeast Asia, Indonesia has the world's third largest peatland area and the world's largest tropical peatland area. As per the Global Fire Emission Database, fires in Southeast Asian peatlands are a significant source of greenhouse gas emissions into the atmosphere, with average annual emissions of approximately 100 Tg/C year. Peat lands, are wet and high in carbon by nature, and are constantly used, specifically for drainage purposes as a result of agricultural intensification (Natali et al., 2021; Othman & Latif, 2012; Miettnen & Liew,

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2010). The exploitation of peat land has occurred over the previous several decades, with large-scale deforestation and draining and these disturbances have been the primary reason behind the major haze episode in SEA. In Southeast Asia, the major culprit of peatland burning was illegal land clearance with fire, which often spun out of hand and extended over extended areas (Harrison et al., 2009). Peatland is prone to fire because it contains a lot of organic stuff, either as degraded trash or as material that is still decomposing. Peatland exploitation affects the water table in certain locations, increasing the frequency and size of peat fires (Latif et al., 2018; Evers et al., 2017; Turetsky et al., 2015). Peats are combustible in dry weather and generates a heavy flame when burned. (Latif et al., 2018; Budisulistiorini et al., 2017; Zaccone et al., 2014).

At low temperatures, excess moisture level, and less oxygen concentrations, smoky combustion can extend somewhere from a week to a month (Turetsky et al., 2015). Othman & Latif (2013), witnessed that one hour of peat burning emits 13.850–20.610 g m3 Carbon monoxide, while burning peat soil produce an array

of pollutants into the air and have a substantial impact on atmospheric chemical reactions. It is well recognised that degraded peat lands are prone to fire (Natali et al., 2021; Wösten et al., 2008). Peatlands are lowland marshy ecosystems where organic matter production outweighs breakdown, leading to a net accumulation of organic matter. Peat conservation and formation are influenced by a favourable moisture equilibrium of climate (precipitation-evaporation), elevated humidity, topographic and geological factors that favour storage of water, and nutrient availability & low substrate pH are all elements that influence peat production and conservation (Page. S et al. 2006). Most of the Globe's peat lands are found in the temperate & boreal zones, wherein they grew up in climate having high precipitation and low temperature. More GHG emissions occur during extreme fire years, such as 2015, when estimates range from 227 Tg C (Huijnen et al., 2016) to 510 Tg C (Yin et al., 2016) in Southeast Asian peatlands.

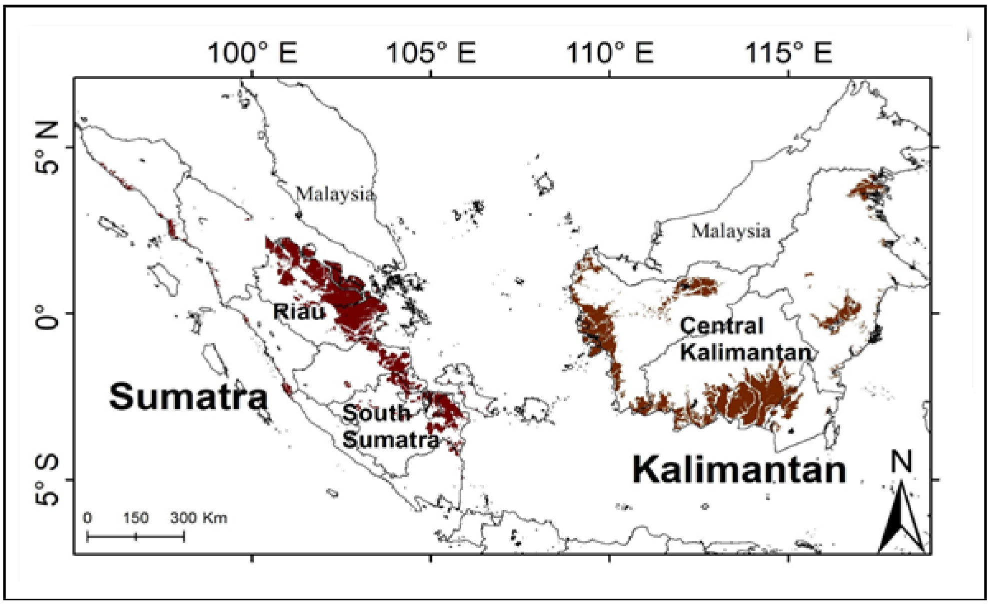

Figure 5. *Southeast Asia's peatland distribution pattern. Most peatlands are located on Sumatra and Borneo (Kalimantan, Sarawak and Brunei) as well as Peninsular Malaysia. There is a lack of information on the true size and depth of these deposits (Vetrita & Cochrane, 2019).*

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Pollutants from Biomass Burning

The pollution of the atmosphere induced by biomass burning (BB) is a significant cause of worry in many regions of the world, especially SEA and it is a key source of primary carbon - containing aerosol pollutants. Biomass burning contributes significantly to trace gas budgets on a global scale (Andreae & Merlet, 2001). Airborne particulate matter (PM; aerosols) and chemically reactive gases, such as sulphur dioxide (SO2), nitrogen oxides (NOx), ammonia (NH_3), and volatile organic compounds (VOCs) as well as unreactive gases, such as carbon dioxide (CO2) and methyl chloride (CH3Cl), contribute to BB-induced smoke haze (Crutzen & Andreae, 1990; Adam et al., 2020).

Biomass Burning has been reported to cause significant increase in $PM_{2.5}$, PM_{10}, Black Carbon, Smoke Aerosols (He et al., 2016; Qi and Wang, 2019; Shikwambana, 2019; Targino et al., 2019). Since only a few hours of daytime ageing are necessary to double the bulk of submicrometer particles (Vakkari et al., 2018), secondary aerosol generation is significantly increased as a result of biomass combustion (Lim et al., 2019; Rastogi et al., 2014; Singh et al., 2021; Sun et al., 2016). Trace gases such as O_3, CO, NO_2 and SO_2 have been shown to dramatically rise during and post the biomass burning phase (He et al., 2016; Kumari & Lakhani, et al., 2021; Sinha et al., 2014). This behaviour has such a detrimental effect that it violates NAAQs and WHO standards (He et al., 2016; Sinha et al., 2014). Biomass burning has a significant influence in reducing visibility (Lee et al., 2017). The formation of secondary aerosols as a result of biomass burning results in the presence of severe haze pollution (Sun et al., 2016) and Smog episodes (Vongruang and Pimonsree, 2020).

Various types of biomass burning, including wildfires, agricultural open-burning, household biofuel combustion, forest fires, grass burning, and peatland fires, have the potential to create and release significant quantities of pollutants into the atmosphere (Andreae & Merlet, 2001; Van der Werf et al., 2010). Brief description of the biomass burning process is as follows: When biomass fuels are burned, the compositions begin to hydrolyze, oxidise, dehydrate, and pyrolyze as the temperature rises, producing flammable volatile compounds, sticky substances, and extremely active carbon - containing char (Cullis & Norris, 1972).

The main component of particulates that come from burning biomass is PM2.5, which is a type of particle with an aerodynamic diameter of less than 2.5 m. This type of particle has been linked to serious health problems. As BB-impacted air masses are transmitted over great distances, the mass, composition, and characteristics of aerosols and reactive gases change as a result of a combination of physical and chemical reactions, as well as the formation of new aerosols and reactive gases. As a result of these complex processes, secondary air pollutants such as ozone (O3), secondary inorganic and organic aerosols, and other pollutants are formed in the ambient air. As a result of the diverse range of air pollutants found in BB-impacted air masses, the quality of the air, visibility, and climate are all affected, and human health is jeopardized as well. Furthermore, heavy smoke can delay the onset of precipitation, affecting the water cycle (Andreae et al., 2004). Despite the fact that dry plant matter can be approximated by the empirical formula CH2O, it also contains the following elemental constituents: N (0.3–3.8% w/w), K (0.5–3.4% w/w), and S (0.1–0.9% w/w), and P (0.01–0.3 % w/w), among others (Radojvic, 2003). Under ideal conditions, biomass combustion should produce only CO2 and H2O:

$$CH_2O + O_2 \quad > \quad CO_2 + H_2O \qquad [1]$$

Incomplete combustion, on the other hand, releases CO as well as a large number of unburned hydrocarbons. During the combustion process, the sulphur and nitrogen present in the biomass are converted to oxides:

$$S + O_2 \quad > \quad SO_2 \qquad [2]$$

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$$2N + O_2 \quad > \quad 2NO \qquad [3]$$

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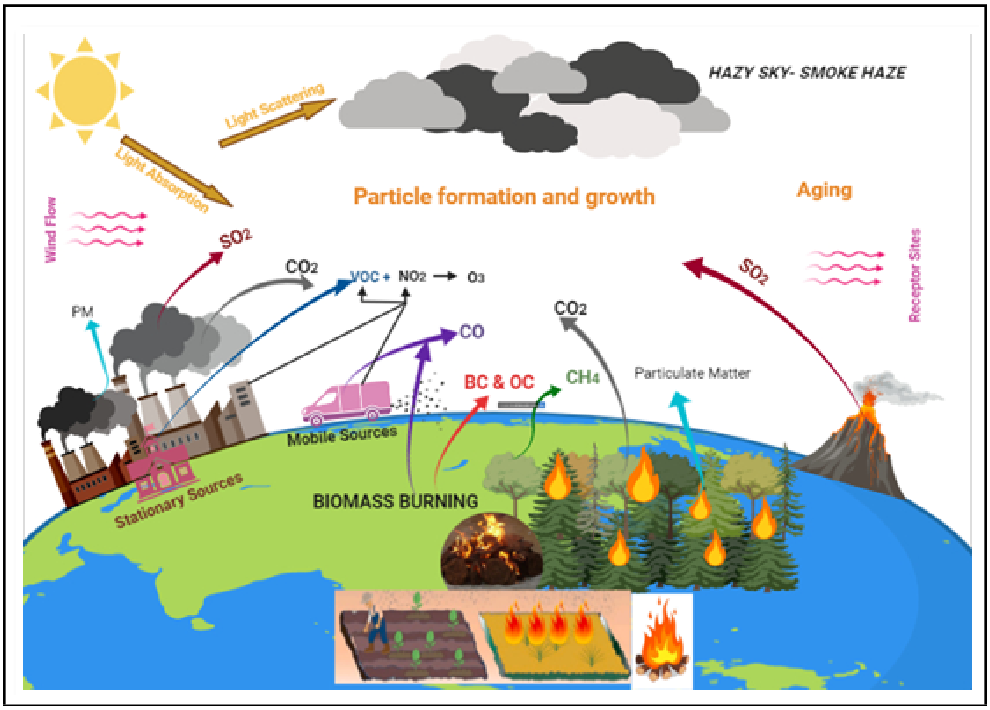

Figure 6. *Diagram illustrating numerous sources of pollutants emitted during various combustion processes.*

SEA is a major source of LACA (Light absorbing carbonaceous aerosols) due to the large human population and linked human impacts in the region, along with BB emissions for instance uncontrolled forest and peat fires, crop residue combustion, and indoor cooking with biofuels (Budisulistiorini et al., 2017; Adam et al., 2019). (LACA) are a significant component of airborne particulate matter (PM) due to their ability to absorb significant amounts of solar radiation and, as a result, have an impact on the climate of the Earth. LACA is made up of black carbon (BC) and light-absorbing organic compounds called brown carbon (BrC) (Menon et al., 2002; Andreae & Gelencser, 2006; Laskin et al., 2015; Ramanathan & Carmichael, 2008; Adam et al., 2019). Despite the fact that light-absorbing carbonaceous aerosols (LACA) containing black carbon (BC) and brown carbon (BrC) have gotten a lot of attention lately because of their climate and health implications, the sources, characteristics, and fates of LACA in Southeast Asia remain a mystery Southeast Asia. SEA's high population density necessitates long-term advantages from efficient LACA mitigation on both local and regional scales, as BC and BrC emissions from Fossil Fuels and BB combustion have climate and associated complications (Adam et al., 2019). Because of its short lifetime, BC is classified as a short-lived climate forcer (SLCF) (a few weeks). Due to the incomplete combustion of fossil fuels (FFs) and biomass burning, both BC and primary BrC are released into the atmosphere (BB) (Andreae & Gelencser, 2006; Adam et al., 2019).

Major drivers of fire over South-East Asia

Climate induced droughts and its relation with rainfall and fire. In addition to human-made fires, drought-induced fires triggered by the El Nino-Southern Oscillation (ENSO) are frequent in Southeast Asia (SEA). Biomass is one of the most environmentally friendly, cost-effective, and long-term energy sources available. According to the National Oceanic and Atmospheric Administration (NOAA), an El Niño condition is a non-regular occurrence in the tropical Pacific region that occurs when surface water in the equatorial Pacific becomes warmer than average and east winds blow weaker than normal. An El Niño event is defined as a Nino Z index anomaly of less than 0.5 degrees Celsius in five consecutive months, and a strong El Niño event is defined as a Nino Z index anomaly of more than 1 degree Celsius in five consecutive months (Zhai et al., 2016).

During El Nino droughts, unusually huge flames break out, posing a threat to human health, the environment,

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and the economy (Field et al., 2009; Marliar et al., 2015). The 1997 El Nino-induced Indonesian fire event, which was projected to release 0.8–2.6 Pg C into the atmosphere, is an iconic example (Page et al., 2002). Fires raged across Indonesia in 2015, with the worst damage occurring in Sumatra and Kalimantan. The fire season started in July in Sumatra and a month later in Kalimantan. By September, a dense haze had settled over much of Sumatra and Kalimantan, stretching as far south as Singapore, Malaysia, and Thailand. For more than two months, a large number of people were subjected to hazardously low air quality. Over the past four decades, three devastating forest fires have occurred in Sumatra and Borneo in 1982/1983, 1997/1998, and 2015. These ENSO-driven forest fires released massive GHGs into the atmosphere, and the most severe fire, which occurred in 1997/1998, was estimated to emit 0.95 Gt of carbon.

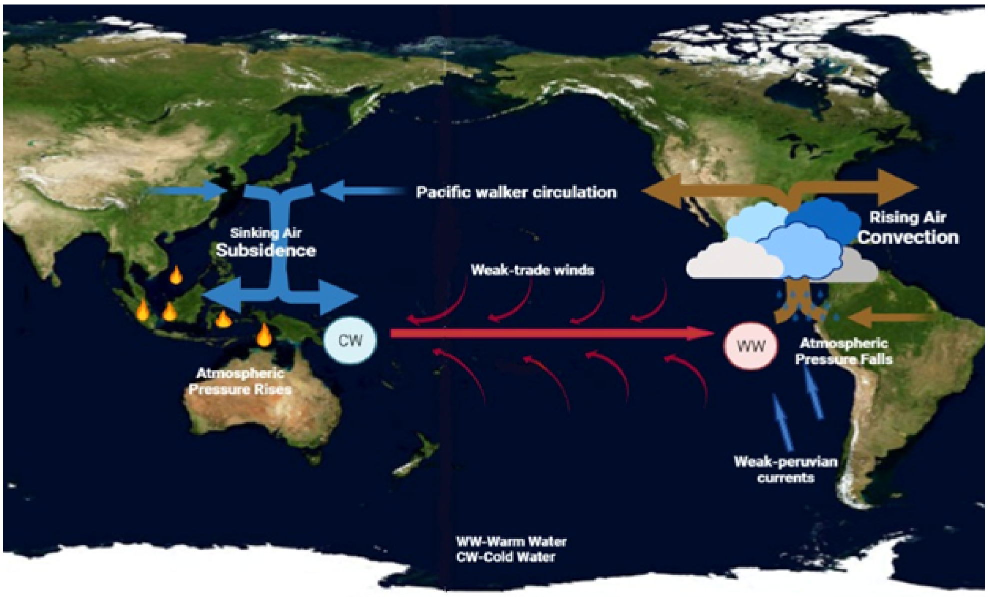

Figure 7. *Schematic representation of El Nino Phenomenon.*

Interactions between El Niño and IOD. The El Nino–Southern Oscillation (ENSO) is the primary moderate climate event in the tropical Pacific, emerging from linked ocean-atmosphere interactions. Even though ENSO begins in the tropical Pacific, its changes can be detected in far-flung seas thanks to the atmospheric link phenomenon (Klein et al., 1999). It is known that the tropical Indian Ocean (IO) experiences a rise in sea surface temperature (SST) throughout the mature (winter) and diminishing (spring) stages of El Nino. This rise is due by the ENSO-produced subsurface heat flow abnormalities that occur during these periods (Saji et al., 1999; Webster et al., 1999). The cooling of sea surface temperatures near the Java-Sumatra shoreline and the rise of sea surface temperatures in the western tropical Indian Ocean are the characteristic features of a positive IOD episode in the eastern tropics. The fact that ENSO and IOD have a positive correlation during boreal fall shows that IOD episodes have intimate linked with ENSO (Positive and negative IOD episodes typically occur concurrently with the occurrences of El Niño and La Niña, alternately.) (Baquero-Bernal et al., 2002; Xie et al., 2002; Annamalai et al., 2003). Other research (Such as, Saji et al., 1999; Webster et al., 1999; Saji & Yamagata, 2003; Meyers et al., 2007; Zhang et al., 2015) contested this assumption, arguing that the Indian Ocean Dipole represents is a distinct form of connected ocean-atmosphere climatic variability in the tropical IO. Even though ENSO/IOD connection has always been up for discussion, observational and modelling results generally imply that the IOD is a weak natural mode that can be triggered by external forcing like ENSO variability (Li et al., 2003; Schott et al., 2009). The regional SST anomaly pattern of ENSO is quite complicated. Traditional El Niño episodes (Eastern Pacific, or EP El Niño) are defined by maximum SST anomalies over the eastern

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equatorial Pacific, while the Central Pacific, or CP El Niño, has happened more consistently in recent years (Ashok et al., 2007; Kao and Yu., 2009; Kug et al., 2009; Zhang et al., 2015).

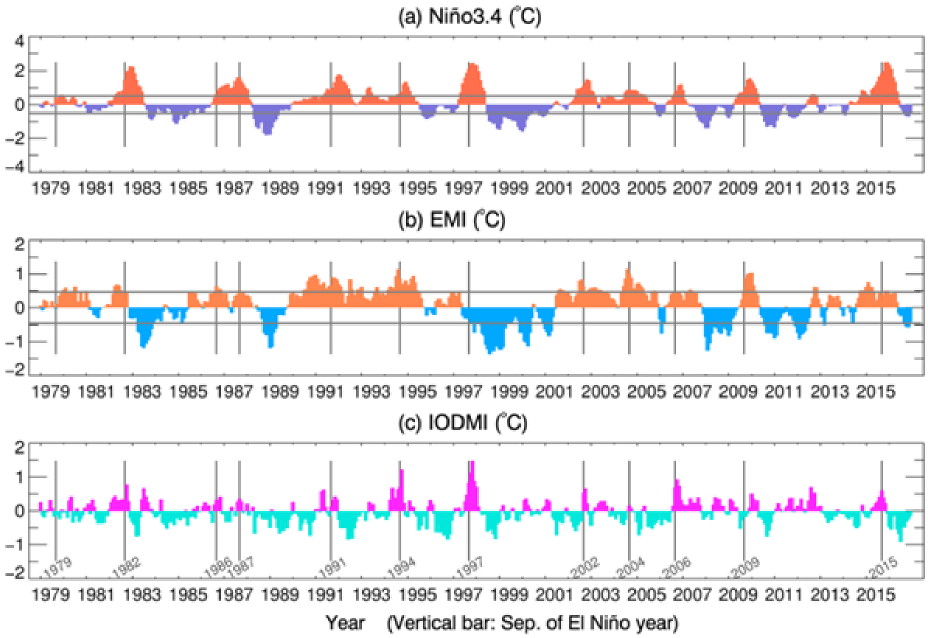

Figure 8. *Time series of sea surface temperature anomaly-related indices for the period of 1979–2016: (a) Niño3.4, (b) EMI, and (c) IODMI (reddish for positive and bluish for negative values). Vertical gray lines in (a)–(c) indicate the month of September in El Niño years. Gray horizontal lines in a represent the threshold of ±0.5 °C (defining El Niño if Niño3.4 ≥0.5 °C), and those in (b) represent the threshold of ±0.46 °C (defining the Central Pacific type if EMI ≥0.46 °C). EMI = El Niño Modoki Index; IODMI = Indian Ocean dipole model index (Pan et al., 2018).*

The IOD has the potential to cause significant climate anomalies over the Asian-Australian monsoon regions, so it's worth investigating whether it changed in concurrently with the El Niño regime shift (Saji & Yamagata, 2003; Meyers et al., 2007; Cai et al., 2009. At this time, the specific relationship between the IOD and the two forms of El Niño (EP and CP) is still unidentified.

According to Stibig et al. (2013) among the most prominent drivers of forest change in Southeast Asia has been recognised as the conversion of forests to cash crop plantations (also known as "forest to cash crop plantations"). Selection logging that is not environmentally sustainable has been identified as the second most important driver of change. Forest change in Southeast Asia has been ranked third in terms of importance, with the conversion of natural forest canopies to fast growing tree plantations (for example, Acacia mangium on Sumatra and Borneo), or to rubber plantations (for example, in Cambodia, Laos, and Thailand) being the most significant factor. Land-cover and fire-fighting techniques represent two important temporal changes.

1.There are changes in land-use systems as a result of governmental changes, such as new land rights in Vietnam and Laos' post-socialist economies.

2.There are significant seasonal differences in the vegetation burned as a result of agricultural production strategies.

Furthermore, due to industrial emissions and other anthropogenic sources like fossil fuel burning, accumulation level of carbonaceous aerosols are rising over time. These changes have been profound in some regions, like Vietnam. Growing market connections between this region and consumers across the worldwide have ramifications for the use of fire, land clearing, and agricultural waste burning.

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Vulnerable Peatlands of SEA

Release of carbon dioxide from damaged peatlands in Southeast Asia. Tropical peatlands are a unique ecosystem in Southeast Asia because of their high water tables and deep layers of organic matter (OM). Because of their high water tables and deep layers of organic matter (OM), tropical peatlands frequently separate plant root networks from underlying parent materials in their pristine condition (Mishra et al.,2021). With the granting of timber concessions in the 1980s, commercial exploitation of peat swamp forests increased (Dommain et al., 2016). Because tropical peatland is a significant carbon storage on a global scale, large-scale conversion and degradation result in significant carbon emissions. Figure 10 discusses the mechanisms by which these carbon losses occur in order to have a better understanding of how conversion and degradation affect the peatland C cycle. With changing land use in peatland ecosystems, the oxidation of organic matter (OM) that has collected over decades typically results in a shift in the peatland carbon balance from a net sink to a net source of atmospheric carbon (Miettinen et al., 2017). Such loss of carbon now responsible for roughly 78 percent of SE Asia's total GHG emissions from managed land cover (i.e., 146 Mt/C year; Cooper et al., 2020; Miettinen et al., 2017). The redox potential of the peat and the long-term positioning of the water table have a significant impact on the CO2 vs. CH4 emissions balance (Couwenberg et al., 2010).

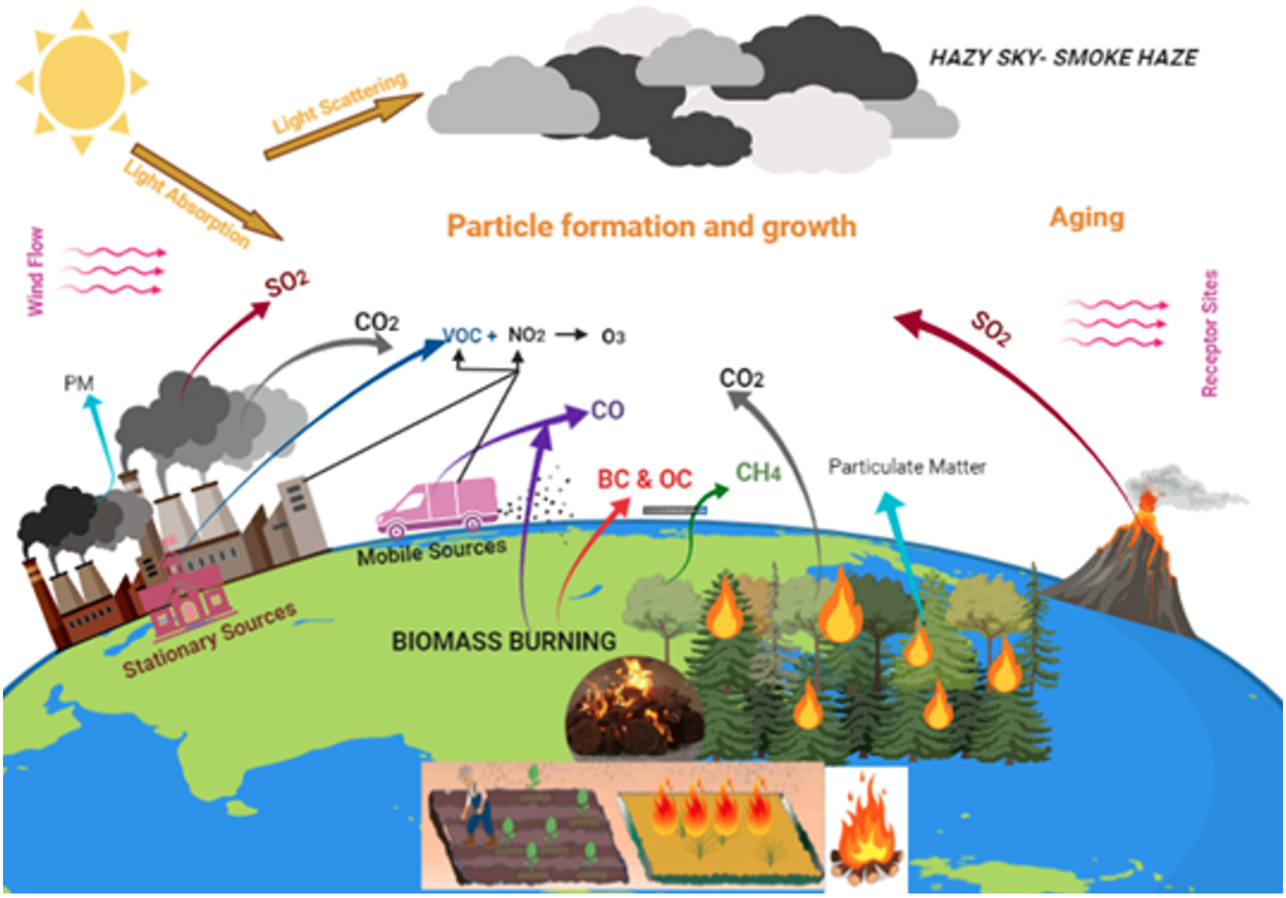

Figure 9. *Depiction of the carbon gains and losses from Intact and degraded peatlands. The width of the arrows indicates the intensity of flux in Intact versus degraded peatlands. (OM= organic matter; C=carbon) (Mishra et al., 2021).*

Thus, water-table depletion increases significantly during peat forest degradation and peatland conversion, and it has been demonstrated that this causes a significant increase in CO2 fluxes while simultaneously decreasing CH4 emissions (Cooper et al., 2020; Jauhiainen et al., 2005; Wright et al., 2013; Mishra et al., 2021).

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Palm oil Plantation

Oil palm trees can grow exclusively in tropical regions, 10 ° south and north of the equator. These tree could flourish where other species of trees suffer to survive. Due to the strong need for low-cost vegetable oil, Production of palm oil in tropical region is a major industry in. Palm oil production and export has been elevated at a 9% per year rate, owing to the expanding biofuel industries. The palm oil sector, on the other hand, has been linked to major environmental problems such as forest degradation, biomass burning and peat land exploitation, all of which contribute to global climate change by emitting carbon dioxide (CO2). Malaysia & Indonesia known to produces highest palm oil, generates ≈43 million tonnes per year and contributing for 87% of global production. Since 1990, these two nations have harvested 6.5 million hectares of oil palm. Even if only a half of the oil palm increase resulted in forest loss, between 1990 and 2010, oil palm accounted for more than 10% of overall forest degradation in Indonesia & Malaysia (Koh et al., 2011). Since 1990, its plantation have been linked to a 2.5 Gigatonne carbon (Gt C) reduction in tropical peat lands (Miettinen et al., 2017).

Because of Oil palm production there has been large scale degradation and transformation of natural tropical peat swamp which has resulted in total carbon reduction from peat and biomass of 427.2 90.7 t C ha^{-1} and 17.1 3.6 t C ha^{-1} year, consecutively, over the last 25 years. Peat loss accounts for approximately 63 percent of total carbon loss globally, highlighting the necessity of developing mitigation strategies to prevent tropical peat swamps from land conversion and thereby reduce greenhouse gas emissions. (Hergoualc'h & Verchot, 2011).

Effects of Biomass burning

Haze episodes. Haze is a phenomenon that develops when the atmosphere contains a sufficient number of aerosols that scatter visible light, resulting in a detectable loss in visual range. The regional haze in Southeast Asia is a recurring environmental disaster caused primarily by forest fires, and it is typically associated with dry weather and draughts caused by the El Nino Southern Oscillation phenomenon, which occurs every year between June and September Haze is linked to excessive levels of air pollutants; it decreases visibility and has a negative impact on human health in the SEA countries impacted (Radojvic, 2003). Agriculture strategies such as "slash - and - burn," forest destruction, and the emergence of oil palm plantations on peat lands have been identified as major contributors to high-intensity combustions that cause trans boundary haze in Malaysia and Indonesia, notably in Sumatra and Kalimantan. The physical and chemical properties of emissions from forest fires and the resulting haze play a role in the numerous environmental and health effects of haze from biomass fires, particularly in terms of respiratory and cardiovascular health. There seems to be an upsurge in fire incidents in the equatorial SEA region during the south - west monsoon season (June to September). It is possible for pollutants to be transported across borders from Indonesian burning areas in Sumatra and Kalimantan to Peninsular Malaysia and Malaysian Borneo as a result of the predominant southerly and south-westerly winds that blow in these regions. The worst haze outbreaks in Southeast Asia occurred in 1997 and 1998, respectively (Radojvic, 2003). Hospitalizations for chronic obstructive pulmonary disease, upper respiratory infections, asthma, and rhinitis have all increased in response to haze events, as per studies. Haze occurrences caused a 19% increase in respiratory mortality the health effects of haze are more likely to affect children and the elderly. There have been a lot of fire aerosols in the air in Southeast Asia's major cities over the last decade. In Bangkok, 38 percent of the low visibility events (visibility 10 km) have been caused by fire aerosols in the last 10 years. In Kuala Lumpur, 35 percent of the low visibility events have been caused by fire aerosols in the last 10 years (Lee et al., 2016). Trans-boundary haze has been linked to agricultural practises such as "slash-and-burn," forest destruction, and the establishment of oil palm plantations on peat lands, all of which have been linked to high-intensity burning. Peatland fires are estimated to contribute 60% of the total smoke and haze produced, while converted forests contribute 18%.

Health. Non-communicable diseases (NCDs), including heart disease, stroke, chronic obstructive pulmonary disease (COPD), and lung cancer, are linked to air pollution, which accounts for 24% of all adult deaths from heart-related diseases, 25% from stroke, 43% of COPD deaths, and 29% of lung cancer deaths (WHO, 2018). According to a new study, people who live close to urban highways and power plants are more likely to acquire dementia and other neurological illnesses. (Underwood, 2017)

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Trans-boundary haze is often caused by combustion-associated smoke emissions, which contain significant amounts of particulate matter that is small enough to be transported into the atmosphere. The great majority of the particles (PM2.5) are less than 2.5 microns in size, and as a result, they may readily be suspended in wind currents for extended periods of time. They are also tiny enough to penetrate deep into the body the respiratory tract of a human being (Pavagadhi et al., 2012; Cheong et al., 2019). In an acute situation, these seasonal haze events may aggravate asthma symptoms and other respiratory-related problems; however, the long-term health consequences of occasional intense bouts of seasonal haze exposure are still unknown. Certain research has indicated an elevated risk of chronic illnesses such as lung cancer, however they have only been conducted in the setting of long-term exposure to the substance (Khan et al., 2016).

Exposure Mitigation. Crop wastes burned in open, slash-and-burn agricultural activities, peat land fires & forest, and other factors contribute to Biomass Burning smoke enhanced haze in the various regions of Southeast Asia (SEA). Because of the various spatio-temporal and socio-political scales at which challenges with Trans - border pollution of air, such as BB-induced smoke haze, emerge, environmental governance of these challenges is hard. Association of Southeast Asian Nations (ASEAN) which is a group form 10 Asian countries. Working together can solve it on a provincial level. In fact, in 2002, ASEAN ratified the Trans boundary Haze Pollution Agreement. The Agreement, on the other hand, did not worked effectively in reducing the frequency of haze incidents the region. Emissions form Particulate Matter which comes from the sources of biomass burning could impact health of humans in three ways: by ingesting, skin exposure, and inhalation.

The aggregation of agricultural residues (e.g. Oil palm biomass, wood combustion, crop residue) in a region is a key reason that might lead to forest and land fires. This issue can be addressed by recycling residues into useful products using sustainable approaches.

- For instance, Wastes generated via land clearance could be converted into lump charcoal, compost bio char, which are highly valued & viable.
- Another option is to convert the waste from biomass left over from land clearance or plants into bio-products of high value that may be used for energy generation.

Conclusion and Future research directions

Crop residue open burning emissions are concentrated in populated areas and primarily occur during months of low precipitation, which lead high pollution levels in Southeast Asia. As a result, they may have significant health and environmental consequences in the community. Destruction and alteration of a naturally occurring tropical peat swamp due to oil palm production has led to an extreme carbon reduction from peat and biomass. Peat loss accounts for roughly 63 percent of global carbon loss, showcasing the need for mitigation strategies to save tropical peat swamps and reduce greenhouse gas emissions. Due to of human activities and climate change, vegetation and peatlands burning, there has been tremendous increase in the release of smoke haze in the air. This happens mostly in Indonesia (Sumatra and Borneo), but it affects the whole SEA. Smoke particles generated by biomass burning could significantly change the radiation balance of earth by dispersing and absorbing radiation from sun, potentially resulting in less solar heating at the earth's surface and drastically affected meteorological conditions. The various emissions from biomass burning may have widely different effects on the environment (global warming from CO2 and CH4, health implications from suspended particles and so on). The following are some of our suggestions:

Incentives should be provided to encourage logging practices that result in sustainable output of producing forests, and mechanical land clearance should be carried out. A familiarity with various strategies for the prevention and mitigation of fires, as well as the proper institutional frameworks for coordinating efforts pertaining to mitigation on the national, regional, and international levels. It would be beneficial to make the early warning system a little bit more proactive so that it can better estimate the danger of fires and convey this information in a timely way to the central, provincial, and district authorities, as well as to the community as a whole. Both the key stakeholders, along with government agencies and indigenous peoples, must be actively involved in the development and implementation of any efforts to improve the restoration of degraded peatlands and to control forest degradation. However, because of the close relationship between poverty and fire at the village level, the current policy push for village development may provide opportunities

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to reversing this trend. While central and district policies, as well as regional economic growth, have all generally contributed to a voracious degradation of the environment, it is important to take into account the consequences of flames on the local people. Regarding the time and meteorological conditions for burnings near the conclusion of the dry season in Southeast Asia, a plan or collective action should be established in order to reduce the risk on public health. An inclusive management and rehabilitation strategy to tropical peatlands is extremely important in the context of achieving the 2030 United Nations Sustainable Development Agenda and the Paris Climate Agreement's climate change targets. Finally, identification of critical research and management gaps, if addressed, would provide critical information on how to cope more effectively with Biomass burning issue in Southeast Asia. However, to actually see the change, both the people and the government must work together.

References

ADAM M., CHIANG A., BALASUBRAMANIAN R. (2019) Insights into characteristics of light absorbing carbonaceous aerosols over an urban location in Southeast Asia. Environmental Pollution, 257, 113425. https://doi.org/10.1016/j.envpol.2019.113425

AIKEN S.R. (2004) Runaway Fires, Smoke-Haze Pollution, and Unnatural Disasters in Indonesia, Geographical Review, 94(1):55-79. https://doi.org/10.1111/j.1931-0846.2004.tb00158.x

ANDREAE M.O., MERLET P. (2001) Emission of trace gases and aerosols from biomass burning. Global Biogeochemical Cycles, 15(4), 955-966. https://DOI.ORG/10.1029/2000GB001382

ANDREAE M., ROSENFELD D., ARTAXO P., COSTA A., FRANK G., LONGO K., SILVA-DIAS M. (2004) Smoking Rain Clouds over the Amazon. Science, 303(5662):1337-1342. https://doi.org/10.1126/science.1092779

ANDREAE M., GELENCSÉR A. (2006) Black carbon or brown carbon? The nature of light-absorbing carbonaceous aerosols. Atmospheric Chemistry And Physics, 6(10), 3131-3148. https://doi.org/10.5194/acp-6-3131-2006

ASHOK K., BEHERA S., RAO S., WENG H., YAMAGATA T. (2007) El Niño Modoki and its possible teleconnection. Journal of Geophysical Research, 112(C11). https://doi.org/10.1029/2006jc003798

BARBER C.V. (2000) Trial by fire: Forest fires and forestry policy in Indonesia's era of crisis and reform. World Resources Institute, Forest Frontiers Initiative.

BUDISULISTIORINI S., RIVA M., WILLIAMS M., CHEN J., ITOH M., SURRATT J., KUWATA M. (2017). Light-Absorbing Brown Carbon Aerosol Constituents from Combustion of Indonesian Peat and Biomass. Environmental Science &Amp; Technology, 51(8):4415-4423. https://doi.org/10.1021/acs.est.7b00397

CHEONG N., MORGAN G., PEK T., LAI H., ET AL. (2019). Acute Health Impacts of the Southeast Asian Transboundary Haze Problem—A Review. International Journal Of Environmental Research And Public Health, 16(18):3286. https://doi.org/10.3390/ijerph16183286

COHEN J. (2014) Quantifying the occurrence and magnitude of the Southeast Asian fire climatology. Environ. Res. Lett., 9:114018.

COOPER H. V., EVERS S., APLIN P., CROUT N., DAHALAN M.P.B., SJOGERSTEN S. (2020). Greenhouse gas emissions resulting from conversion of peat swamp forest to oil palm plantation. Nature Communications, 11:407. https://doi.org/10.1038/s41467-020-14298-w

COUWENBERG J., DOMMAIN R., JOOSTEN H. (2010). Greenhouse gas fluxes from tropical peatlands in south-east Asia. Global Change Biology, 16:1715–1732. https://doi.org/10.1111/j.1365-2486.2009.02016.x

DEFRIES R., HANSEN A., NEWTON A., HANSEN M. (2005) Increasing isolation of protected areas in tropical forests over the past twenty years. Ecological Applications, 15(1):19-26. https://doi.org/10.1890/03-5258

DOMMAIN R., DITTRICH I., GIESEN W., WIBISONO I. (2016) Ecosystem services,

DOI: 10.6092/issn.2281-4485/15539

degradation and restoration of peat swamps in the South East Asian tropics. In Peatland Restoration and Ecosystem Services: Science, Policy and Practice. Ecological Reviews (pp. 253–288).

DUC H., BANG H., QUAN N., QUANG N. (2021) Impact of biomass burnings in Southeast Asia on air quality and pollutant transport during the end of the 2019 dry season. Environmental Monitoring And Assessment, 193(9). https://doi.org/10.1007/s10661-021-09259-9

CULLIS C., NORRIS A. (1972). The pyrolysis of organic compounds under conditions of carbon formation. Carbon, 10(5):525-537. https://doi.org/10.1016/0008-6223(72)90092-9

EKADINATA E, VAN NOORDWIJK M, BUDIDARSONO S, DEWI S. (2013) Hotspots in Riau, haze in Singapore: the June 2013 event analysed. ASB Policy brief 33. Nairobi: ASB Partnership for the Tropical Forest Margins. Link: https://www.asb.cgiar.org/PDFwebdocs/ASB%20PolicyBrief%2033-Hot%20spots%20in%20Riau,%20Haze%20in%20Singapore%20Events%20analyzed.pdf

EVERS S., YULE C., PADFIELD R., O'REILLY P., VARKKEY H. (2017) Keep wetlands wet: the myth of sustainable development of tropical peatlands - implications for policies and management. Global Change Biology, 23(2):534-549. https://doi.org/10.1111/gcb.13422

FREDERICK, W. H. AND LEINBACH, THOMAS R. (2020). Southeast Asia. Encyclopedia Britannica. https://www.britannica.com/place/Southeast-Asia.

FULLER D., MURPHY K. (2006) The Enso-Fire Dynamic in Insular Southeast Asia. Climatic Change, 74(4);435-455. https://doi.org/10.1007/s10584-006-0432-5

GIGLIO L., CSISZAR I., JUSTICE C. (2006) Global distribution and seasonality of active fires as observed with the Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) sensors. Journal Of Geophysical Research: Biogeosciences, 111(G2). https://doi.org/10.1029/2005jg000142

GOLDAMMER J.G. (1999) Forests on Fire. Science, 284 (5421):1782-1783.

GUHARDJA E., FATAWI M., SUTISNA M., MORI T., OHTA S (2003) Rainforest Ecosystems of East Kalimantan, El Nino, Drought, Fire and Human Impacts, Ecological Studies. Springer, New York, 140331 pp.

HANSEN M., STEHMAN S., POTAPOV P., LOVELAND T., TOWNSHEND J., DEFRIES R. ET AL. (2008) Humid tropical forest clearing from 2000 to 2005 quantified by using multitemporal and multiresolution remotely sensed data. Proceedings Of The National Academy Of Sciences, 105(27):9439-9444. https://doi.org/10.1073/pnas.0804042105

HARRISON M.E., PAGE S.E., LIMIN S.H. (2009) The global impact of Indonesian forest fires. Biologist 56:156-163.

HE C., MILJEVIC B., CRILLEY L., SURAWSKI N., BARTSCH J., SALIMI F. ET AL. (2016) Characterisation of the impact of open biomass burning on urban air quality in Brisbane, Australia. Environment International, 91:230-242. https://doi.org/10.1016/j.envint.2016.02.030

HERGOUALC'H K., VERCHOT L. (2011) Stocks and fluxes of carbon associated with land use change in Southeast Asian tropical peatlands: A review. Global Biogeochemical Cycles, 25(2). https://doi.org/10.1029/2009gb003718

HOOIJER A., PAGE S., CANADELL J., SILVIUS M., KWADIJK J., WÖSTEN H., JAUHIAINEN J. (2010). Current and future CO2 emissions from drained peatlands in Southeast Asia. Biogeosciences, 7(5):1505-1514. https://doi.org/10.5194/bg-7-1505-2010

JAENICKE J., ENGLHART S., SIEGERT F. (2010) Monitoring the effect of restoration measures in Indonesian peatlands by radar satellite imagery. Journal Of Environmental Management, 92(3):630-638. https://doi.org/10.1016/j.jenvman. 2010.09.029

JAUHIAINEN J., TAKAHASHI H., HEIKKINEN J.E.P., MARTIKAINEN P.J., VASANDER H. (2005) Carbon fluxes from a tropical peat swamp forest floor. Global Change Biology, 11:1788–1797. https://doi.org/10.1111/j.1365-2486.2005.001031.x

DOI: 10.6092/issn.2281-4485/15539

KANABKAEW T., KIM OANH N.T. (2011) Development of Spatial and Temporal Emission Inventory for Crop Residue Field Burning. *Environmental Modeling & Assessment*, *16*(5):453–464. https://doi.org/10.1007/s10666-010-9244-0

KAO H., YU J. (2009) Contrasting Eastern-Pacific and Central-Pacific Types of ENSO. Journal of Climate, 22(3):615-632. https://doi.org/10.1175/2008jcli2309.1

KHAN M., LATIF M., SAW W., AMIL N., NADZIR M., SAHANI M. ET AL (2016) Fine particulate matter in the tropical environment: monsoonal effects, source apportionment, and health risk assessment. Atmospheric Chemistry And Physics, 16(2):597-617. https://doi.org/10.5194/acp-16-597-2016

KETTERINGS Q.M., TRI WIBOWO T., VAN NOORDWIJK,M., PENOT E. (1999) Farmers' perspectives on slash-and-burn as a land clearing method for small-scale rubber producers in Sepunggur, Jambi Province, Sumatra, Indonesia. Forest Ecology and Management, 120(1-3):157–169. https://doi.org/10.1016/s0378-1127(98)00532-5

KIM OANH N.T., PERMADI D.A., HOPKE P.K., SMITH K.R., DONG N.P., DANG A.N. (2018). Annual emissions of air toxics emitted from crop residue open burning in Southeast Asia over the period of 2010–2015. Atmospheric Environment, 187:163–173. https://doi.org/10.1016/j.atmosenv.2018.05.061

KIRONO D., TAPPER N., McBRIDE J. (1999) Documenting Indonesian rainfall in the 1997/1998 El Nino event. Physical Geography, 20(5):422-435. doi: https://doi.org/10.1080/02723646.1999.10642687

KLEIN S., SODEN B., LAU N. (1999) Remote Sea Surface Temperature Variations during ENSO: Evidence for a Tropical Atmospheric Bridge. Journal Of Climate, 12(4):917-932. https://doi.org/10.1175/1520-0442(1999)012<0917:rsstvd>2.0.co;2

KOE L.C.C., ARELLANO A.F., McGREGOR J.L. (2001) Investigating the haze transport from 1997 biomass burning in Southeast Asia: its impact upon Singapore. Atmospheric Environment 35:2723e2734.

KOH L., MIETTINEN J., LIEW S., GHAZOUL J. (2011) Remotely sensed evidence of tropical peatland conversion to oil palm. Proceedings of the National Academy of Sciences, 108(12):5127-5132. https://doi.org/10.1073/pnas.1018776108

KUMARI S., LAKHANI A., KUMARI K. (2021) Variation of carbon monoxide at a suburban site in the Indo-Gangetic Plain: Influence of long-range transport from crop residue burning region. Atmospheric Pollution Research, 12(9):101166. https://doi.org/10.1016/j.apr.2021.101166

KUG J., JIN F., AN S. (2009) Two Types of El Niño Events: Cold Tongue El Niño and Warm Pool El Niño. Journal Of Climate, 22(6):1499-1515. https://doi.org/10.1175/2008jcli2624.1

LASKIN A., LASKIN J., NIZKORODOV S. (2015) Chemistry of Atmospheric Brown Carbon. Chemical Reviews, 115(10):4335-4382. https://doi.org/10.1021/ cr5006167

LI P., FENG Z., JIANG L., LIAO C., ZHANG J. (2014) A Review of Swidden Agriculture in Southeast Asia. Remote Sensing, 6(2):1654-1683. https://doi.org/10.3390/rs6021654

LIT.,WANGB.,CHANGC.,ZHANGY.(2003)ATheory for the Indian Ocean Dipole–Zonal Mode. Journal of The Atmospheric Sciences, 60(17):2119-2135. https://doi.org/10.1175/1520-0469(2003)060<2119:atftio>2.0.co;2

LOHMAN D.J., BICKFORD D., SODHI N.S. (2007) ENVIRONMENT: The Burning Issue. Science, 316(5823):376. https://doi.org/10.1126/science.1140278

MALTBY E., C.P. IMMIRZI C.P., SAFFORD R.J. (Eds) (1996) Tropical lowland peatlands of Southeast Asia. IUCN, Gland, Switzerland.

MARLIER M., DEFRIES R., KIM P., GAVEAU D., KOPLITZ S., JACOB D. ET AL. (2015).Regional air quality impacts of future fire emissions in Sumatra and Kalimantan. Environmental Research Letters, 10(5):054010. https://doi.org/10.1088/1748-9326/10/5/054010

DOI: 10.6092/issn.2281-4485/15539

MEYERS G., McINTOSH P., PIGOT L., POOK M. (2007) The Years of El Niño, La Niña, and Interactions with the Tropical Indian Ocean. Journal Of Climate, 20(13):2872-2880. https://doi.org/10.1175/jcli4152.1

MENON S., HANSEN J., NAZARENKO L., LUO Y. (2002) Climate Effects of Black Carbon Aerosols in China and India. Science, 297(5590):2250-2253. https://doi.org/10.1126/science.1075159

MIETTINEN J., LIEW S. (2010) Status of Peatland Degradation and Development in Sumatra and Kalimantan. AMBIO, 39(5-6):394-401. https://doi.org/10.1007/ s13280-010-0051-2

MIETTINEN J., HOOIJER A., VERNIMMEN R., LIEW S., PAGE S. (2017) From carbon sink to carbon source: extensive peat oxidation in insular Southeast Asia since 1990. Environmental Research Letters, 12(2):024014. https://doi.org/10.1088/1748-9326/aa5b6f

MUNROE D., WOLFINBARGER S., CALDER C., SHI T., XIAO N., LAM C., LI D. (2008) The relationships between biomass burning, land-cover/-use change, and the distribution of carbonaceous aerosols in mainland Southeast Asia: a review and synthesis. Journal of Land Use Science, 3(2-3):161-183. https://doi.org/10.1080/ 17474230802332241

MURDIYARSO D.T., TSURUTA H., ISHIZUKA S., HAIRIAH K., PALM C.A. (2005). Green house fluxes slash and burn and alternative land uses practices in Sumatra, Indonesia. Slash and burn agriculture: the search of alternatives. Colombia University Press, New York, United States.

NATALI C., BIANCHINI G., CREMONINI S., SALANI G.M., VIANELLO G., BROMBIN V., FERRARI M., VITTORI ANTISARI L (2021) Peat soil burning in the Mezzano Lowland (Po Plain, Italy): triggering mechanisms and environmental consequences. GeoHealth, 5:1-16. https://doi.org/10.1029/2021GH000444

OTHMAN M., LATIF M. (2013) Dust and Gas Emissions from Small-Scale Peat Combustion. Aerosol and Air Quality Research, 13(3):1045-1059. https://doi.org/10.4209/aaqr.2012.08.0214

PAGE S., RIELEY J., BANKS C. (2011) Global and regional importance of the tropical peatland carbon pool. Global Change Biology, 17(2):798-818. https://doi.org/10.1111/j.1365-2486.2010.02279.x

PAVAGADHI S., BETHA R., VENKATESAN S., BALASUBRAMANIAN R., HANDE M. (2012) Physicochemical and toxicological characteristics of urban aerosols during a recent Indonesian biomass burning episode. Environmental Science and Pollution Research, 20(4):2569-2578. https://doi.org/10.1007/s11356-012-1157-9

PERMADI D.A., KIM OANH N.T. (2012) Assessment of biomass open burning emissions in Indonesia and potential climate forcing impact, Atmospheric Environment, http://dx.doi.org/10.1016/j.atmosenv.2012.10.01

QI L., WANG S. (2019) Fossil fuel combustion and biomass burning sources of global black carbon from GEOS-Chem simulation and carbon isotope measurements. Atmospheric Chemistry And Physics, 19(17):11545-11557. https://doi.org/10.5194/acp-19-11545-2019

QUAH E. (2002) Transboundary Pollution in Southeast Asia: The Indonesian Fires. World Development, 30(3):429–441. https://doi.org/10.1016/s0305-750x(01)00122-x

RADOJEVIC M. (2003) Chemistry of Forest Fires and Regional Haze with Emphasis on Southeast Asia. Pure And Applied Geophysics, 160(1-2):157-187. https://doi.org/10.1007/s00024-003-8771-x

RASTOGI N., SINGH A., SINGH D., SARIN M. (2014) Chemical characteristics of PM2.5 at a source region of biomass burning emissions: Evidence for secondary aerosol formation. Environmental Pollution, 184:563-569. https://doi.org/10.1016/j.envpol.2013.09.037

RAMANATHAN V., CARMICHAEL G. (2008) Global and regional climate changes due to black carbon. Nature Geoscience, 1(4):221-227. https://doi.org/10.1038/ngeo156

RERKASEM K., RERKASEM B. (1995) Montane Mainland South-East Asia: agroecosystems in

DOI: 10.6092/issn.2281-4485/15539

transition. Global Environmental Change, 5(4):313-322. https://doi.org/10.1016/0959-3780(95)00065-v

SAJI N., YAMAGATA T. (2003) Structure of SST and Surface Wind Variability during Indian Ocean Dipole Mode Events: COADS Observations*. Journal of Climate, 16(16):2735-2751. https://doi.org/10.1175/1520-0442(2003)016<2735:sosasw>2.0.co;2

SAJI N., GOSWAMI B., VINAYACHANDRAN P., ET AL. (1999) A dipole mode in the tropical Indian Ocean. Nature, 40:360–363 https://doi.org/10.1038/43854

SAMSUDDIN, N., KHAN, M., MAULUD, K., HAMID, A., MUNNA, F., & RAHIM, M. ET AL. (2018). Local and transboundary factors' impacts on trace gases and aerosol during haze episode in 2015 El Niño in Malaysia. Science Of The Total Environment, 630: 1502-1514. https://doi.org/10.1016/j.scitotenv.2018.02.289

SANCHEZ P.A., PALM C.A., VOSTI S.A., TOMICH T.P., KASYOKI J. (2005) Alternatives to slash and burn: challenge and approaches of an international consortium. Slash burn agriculture: the search for alternatives. Columbia University Press, New York, United States.

SCHOTT F., XIE S., McCREARY J. (2009) Indian Ocean circulation and climate variability. Reviews Of Geophysics, 47(1). https://doi.org/10.1029/2007rg000245

SHIKWAMBANA L. (2019). Long-term observation of global black carbon, organic carbon and smoke using CALIPSO and MERRA-2 data. Remote Sensing Letters, 10(4):373–380.

SIEGERT F., RUECKER G., HINRICHS A., HOFFMANN A. (2001) Increased damage from fires in logged forests during droughts caused by El Niño. Nature, 414(6862):437-440. https://doi.org/10.1038/35106547

SILVIUS, M., AND DIEMONT, H. (2007). Deforestation and degradation of peatlands. Peatlands international 2:32–34.

SINGH N., BANERJEE T., DEBOUDT K., CHAKRABORTY A., KHAN M.F., LATIF M.T. (2021). Sources, Composition, and Mixing State of Submicron Particulates over the Central Indo-Gangetic Plain. ACS Earth and Space Chemistry, 5(8):2052–2065.

SINHA V., KUMAR V., SARKAR C. (2014) Chemical composition of pre-monsoon air in the Indo-Gangetic Plain measured using a new air quality facility and PTR-MS: high surface ozone and strong influence of biomass burning. Atmospheric Chemistry and Physics, 14(12):5921–5941.

SODHI N., POSA M., LEE T., BICKFORD D., KOH L., BROOK B. (2010) The state and conservation of Southeast Asian biodiversity. Biodiversity and Conservation, 19(2):317-328. https://doi.org/10.1007/s10531-009-9607-5

STREETS D., BOND T., CARMICHAEL G., FERNANDES S., FU Q., HE D. ET AL. (2003) An inventory of gaseous and primary aerosol emissions in Asia in the year 2000. Journal Of Geophysical Research: Atmospheres, 108(D21). https://doi.org/10.1029/2002jd003093

Sun, Y., Jiang, Q., Xu, Y., Ma, Y., Zhang, Y., Liu, X., Li, W., Wang, F., Li, J., & Wang, P. (2016). Aerosol characterization over the North China Plain: Haze life cycle and biomass burning impacts in summer. *Journal of Geophysical Research: Atmospheres*, *121*(5), 2508–2521.

Targino, A. C., Harrison, R. M., Krecl, P., Glantz, P., de Lima, C. H., & Beddows, D. (2019). Surface ozone climatology of South Eastern Brazil and the impact of biomass burning events. *Journal of Environmental Management*, *252*, 109645. https://doi.org/10.1016/j.jenvman.2019.109645

TAYLOR D. (2009) Biomass burning, humans and climate change in Southeast Asia. Biodiversity and Conservation, 19(4):1025-1042. https://doi.org/10.1007/ s10531-009-9756-6

TIPAYAROM A., KIM OANH N. (2020) Influence of rice straw open burning on levels and profiles of semi-volatile organic compounds in ambient

DOI: 10.6092/issn.2281-4485/15539

air. Chemosphere, 243:125379. https://doi.org/10.1016/j.chemosphere.2019.125379 125379

TURETSKY M., BENSCOTER B., PAGE S., REIN G., VAN DER WERF G., WATTS A. (2015) Global vulnerability of peatlands to fire and carbon loss. Nature Geoscience, 8(1):11-14. https://doi.org/10.1038/ngeo2325

UNDERWOOD E. (2017) The polluted brain. Science 355: 342 -345.

VAN DER WERF G., RANDERSON J., GIGLIO L., COLLATZ G., MU M., KASIBHATLA P. ET AL. (2010). Global fire emissions and the contribution of deforestation, savanna, forest, agricultural, and peat fires (1997–2009). Atmospheric Chemistry And Physics, 10(23):11707-11735. https://doi.org/10.5194/acp-10-11707-2010

VAKKARI V., BEUKES J.P., DAL MASO M., AURELA M., JOSIPOVIC M., VAN ZYL P.G. (2018) Major secondary aerosol formation in southern African open biomass burning plumes. Nature Geoscience, 11(8):580–583.

VONGRUANG P., PIMONSREE S. (2020) Biomass burning sources and their contributions to PM10 concentrations over countries in mainland Southeast Asia during a smog episode. Atmospheric Environment, 228:117414. https://doi.org/10.1016/j.atmosenv.2020.117414

WEBSTER P., MOORE A., LOSCHNIGG J. ET AL. (1999) Coupled ocean–atmosphere dynamics in the Indian Ocean during 1997–98. Nature 401:356–360. https://doi.org/10.1038/43848

WOOSTER M., PERRY G., ZOUMAS A. (2012) Fire, drought and El Niño relationships on Borneo (Southeast Asia) in the pre-MODIS era (1980–2000). Biogeosciences, 9(1):317-340. https://doi.org/10.5194/bg-9-317-2012

WÖSTEN J., CLYMANS E., PAGE S., RIELEY J., LIMIN S. (2008) Peat–water interrelationships in a tropical peatland ecosystem in Southeast Asia. Catena, 73(2): 212-224. https://doi.org/10.1016/j.catena.2007.07.010

WRIGHT E.L., BLACK C.R., TURNER B.L., SJÖGERSTEN S. (2013) Environmental controls of temporal and spatial variability in CO2 and CH4 fluxes in a neotropical peatland. Global Change Biology, 19:3775–3789.

XIE S., ANNAMALAI H., SCHOTT F., McCREARY J. (2002) Structure and Mechanisms of South Indian Ocean Climate Variability*. Journal Of Climate, 15(8): 864-878. https://doi.org/10.1175/1520-0442(2002)015<0864:samosi>2.0.co;2

YIN Y., CIAIS P., CHEVALLIER F., VAN DER WERF G., FANIN T., BROQUET G. ET AL. (2016) Variability of fire carbon emissions in equatorial Asia and its nonlinear sensitivity to El Niño. Geophysical Research Letters, 43(19), 10,472-10,479. https://doi.org/10.1002/2016gl070971

ZACCONE, C., REIN, G., D'ORAZIO, V., HADDEN, R., BELCHER, C., & MIANO, T. (2014). Smouldering fire signatures in peat and their implications for palaeoenvironmental reconstructions. Geochimica Et Cosmochimica Acta, 137, 134-146. https://doi.org/10.1016/j.gca.2014.04.018

ZHAI, P., YU, R., GUO, Y., LI, Q., REN, X., & WANG, Y. ET AL. (2016). The strong El Niño of 2015/16 and its dominant impacts on global and China's climate. Journal of Meteorological Research, 30 (3), 283-297. https://doi.org/10.1007/s13351-016-6101-3