Atmospheric Research 122 (2013) 555–570

Contents lists available at SciVerse ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

Physical and optical characteristics of the October 2010 haze event over Singapore: A photometric and lidar analysis

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ARTICLE INFO

Article history:
Received 5 August 2011
Received in revised form 18 May 2012
Accepted 21 May 2012

Keywords:
Aerosols
Haze
Air quality
AERONET
MPLNET
South East Asia

ABSTRACT

Trans-boundary biomass burning smoke episodes have increased dramatically during the past 20–30 years and have become an annual phenomenon in the South-East-Asia region. On 15th October 2010, elevated levels of fire activity were detected by remote sensing satellites (e.g. MODIS). On the same date, measurements of fine particulate matter (PM2.5) at Singapore and Malaysia found high levels of fine mode particles in the local environment. All these observations were indicative of the initial onset of a smoke episode that lasted for several days. In this work, we investigate the temporal evolution of this smoke episode by analyzing the physical and optical properties of smoke particles with the aid of an AERONET Sun photometer, an MPLNet micropulse lidar, and surface PM2.5 measurements. Elevated levels of fire activity coupled with high aerosol optical depth and PM2.5 were observed over a period of nine days. Increased variability of parameters such as aerosol optical depth, Angstrom exponent number and its fine mode equivalents all indicated high levels of fine particulate presence in the atmosphere. Smoke particle growth due to aging, coagulation and condensation mechanisms was detected during the afternoons and over several days. Retrieved lidar ratios were compatible with the presence of fine particulate within the boundary/aerosol layer. Moreover, retrieved particle size distribution as well as single scattering albedo indicated the prevalence of the fine mode particulate regime as well as particles showing enhanced levels of absorption respectively.

1. Introduction

In an undisturbed environment i.e. without human intervention, fire activity is a rare occurrence in the humid tropical region of insular South-East Asia (SEA) (Goldammer, 2006). However, during the past century anthropogenic biomass burning has increased dramatically and over the past 20–30 years fire activity has become an annual phenomenon (Field et al., 2009). Fire is widely used for land preparation and forest clearance by plantation developers, shifting cultivators and small-holder farmers, often escaping and developing into uncontrollably burning wild-fires (Miettinen and Liew, 2009). The majority of fires take place between June and November coinciding with drier weather conditions. The environmental effects of fire activity in insular SEA are greatly exacerbated by the considerable numbers of fires taking place in peat land (Miettinen et al., 2011). Over 250,000 km^2 in Indonesia and Malaysia are covered by peat deposits estimated to contain around 70 Gt of carbon (Page et al., 2011). Degradation of peat land by human activities increases their vulnerability to yearly fires and enables severe fire episodes to take place occasionally.

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doi:10.1016/j.atmosres.2012.05.021

Fires in peat land areas not only produce serious trans-boundary haze emissions but they also release large amounts of carbon into the atmosphere (Page et al., 2002).

Biomass burning emissions are a potential and growing threat to human health and regional environmental quality (Balasubramanian et al., 1999; Siegert et al., 2001; Koe et al., Jul., 2001; Kunii et al., 2002; Balasubramanian et al., 2003) as well as to climate (Rosenfeld, 1999; Hamid et al., 2001; Tosca et al., 2010; Page et al., 2011). According the Global Fire Emissions Database (GFED), during the period 1997–2006, there were two major fire episodes in Indonesia (1997, 2006) and two minor episodes (2002, 2004). Before this period, records of severe biomass burning events are limited because of the absence of satellite data or any other high quality data records (Field et al., 2009). During the disastrous 1997 biomass burning episode (Page et al., 2002; Langenfelds et al., 2002; van der Werf et al., 2004; van der Werf et al., 2006), the equivalent of 13-to-40% of the mean annual global carbon emissions from fossil fuels were released into the atmosphere (Page et al., 2002) much of which contributed greatly to the largest annual increase in atmospheric CO_2 concentration (Langenfelds et al., 2002). In-situ observations suggested that the haze largely originated from smoldering peat fires in Sumatra and Kalimantan (Gras et al., 1999; Matsueda and Inoue, 1999; Sawa et al., 1999). Haze transport models (Koe et al., 2001) further identified the regions of Sumatra and Kalimantan to be the main sources of fire spots affecting the SEA region. Moreover, the severity of the 1997 event was magnified by the presence of El Niño Southern Oscillation (ENSO) which resulted in an enhanced seasonal drought around the SEA region (Chandra et al., 1998; Kita et al., 2000; van der Werf et al., 2004). The South-West monsoon caused a cross-equatorial transport of the haze from mainland Indonesia to the neighboring countries resulting in a persistent regional haze that produced aerosol concentrations high enough to significantly reduce visibility and increase health risk to the SEA population (Kunii et al., 2002; Heil and Goldammer, 1997; Wang et al., 2004). A second major fire episode occurred during the months of July to October 2006. The ENSO effect delayed the wet season, extending the seasonal drought and giving rise to severe fire episodes mostly on peat land areas located in Central Kalimantan, the Indonesian part of Borneo. Satellite images over Borneo captured by the Moderate Resolution Imaging Spectro-radiometer (MODIS) on NASA's Terra satellite detected "cores of fires" at Kalimantan province.[1] During this period, in-situ PM10 measurements recorded by Malaysia's Department of Environment (DOE) and Singapore's National Environment Agency (NEA) showed concentrations larger than 150 mg/m^3 (moderate to unhealthy risk) during the later days of October 2006 (Chew et al., 2008).

Unlike the 1997 and 2006 ENSO influenced biomass burning episodes, the year 2010 was characterized by a combination of moderate-to-strong El Niño for most of the first half of the year and transitioned to a moderate-to-strong La Niña conditions for the rest of the year (NOAA National Climatic Data Center, 2010). Although year 2010 might qualify as an ENSO neutral year, the global land surface temperature was the second warmest on record and marked by several notable extreme temperature events (NOAA National Climatic Data Center, 2010). Such a condition might have had some influence on the increased biomass burning activity observed on October 2010. On day 15th, smoke fire activity suddenly escalated over central Sumatra, particularly in the province of Riau (Fig. 1). The prevailing south-westerly to westerly winds carried in smoke from the fires in Sumatra over Singapore and peninsular Malaysia,[2] resulting in a substantial degradation of air quality and reduced visibility, specially during the period 16th to 24th October. According to Malaysia's Department of Environment (DOE), decline in air quality levels was first recorded around noon on Saturday, 16 October. According to a press release of NEA, on 19th October, the 24-h Pollutants Standard Index (PSI[3]) at 4 pm was 56 and classified as a moderate event. By 6 pm, the 3-h PSI has increased to 78 approaching unhealthy levels (levels above 100 are classified as unhealthy. Source: NEA Singapore). On the other hand, direct photometric observations captured during this period found elevated levels of aerosol loading as indicated by large values of aerosol optical depth (AOD) especially on days 16th, 20th and 24th respectively.

To study events such as the October 2010 trans-boundary smoke haze episode, an atmospheric radiation measurement super-site (Chew et al., 2009; Reid et al., 2013-this issue) has been recently deployed at the National University of Singapore (1.30° N, 103.77° E, 79 m above mean sea level). This atmospheric site was established as part of the cooperative framework of the Seven South East Asian Studies (7 SEAS) mission created in 2007 (Chew et al., 2009). The purpose of this framework is to engage the participating countries on a regional multi-year campaign set to study the regional aerosol, cloud and radiation environment (Reid et al., 2013-this issue). Since this super-site is situated off the southern part of the Malay Peninsula and north of the Indonesian Archipelago, it is ideally positioned for monitoring regional pollution events such as trans-boundary biomass burning emissions, clouds, local anthropogenic emissions and climate variability.

In this article, we discuss observations made through collocated passive and active remote sensing instruments such as from a Sun-Photometer and a micro-pulse lidar (MPL) complemented with in-situ PM2.5 particle concentration measurements and Moderate Resolution Infra-red Spectro-radiometer (MODIS) fire spot retrievals. We examine the temporal evolution of trans-boundary smoke generated by the biomass burning event of October 2010. Particular attention is given to the evolution of optical parameters such as AOD, Angstrom exponent number (AE), its derivative and their fine mode counterparts such as the fine mode AOD, fine mode AE, fine mode fraction (FMF) as well as the extinction-to-backscattering ratio (S) and extinction profiles obtained by combining lidar particulate backscatter and smoke AOD from photometric measurements.

[1] http://earthobservatory.nasa.gov.

[2] Regional Haze Map 20 October 2010, NEA.

[3] The 24-h PSI is a measure of the air quality over a period of 24 h. It is updated at 4 pm daily. The 3-h PSI reading is a measure of the air quality over a period 3 h. It is updated on the hour. Source: NEA Singapore.