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Analysis of the origin of peak aerosol optical depth in springtime over the Gulf of Tonkin

Xiaoli Shan[1,2], *Jun Xu*[2,*], *Yixue Li*[1], *Feng Han*[3], *Xiaohui Du*[4], *Jingying Mao*[5], *Yunbo Chen*[2], *Youjiang He*[2], *Fan Meng*[2], *Xuezhi Dai*[2]

1. *College of Resources and Environment, Shandong Agricultural University, Taian 271000, China. E-mail:* sxlgis@foxmail.com
2. *State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences, Beijing 100012, China*
3. *College of Environmental Science and Engineering, Taiyuan University of Technology, Taiyuan 030024, China*
4. *College of Geography and Environment, Shandong Normal University, Jinan 250014, China*
5. *Environmental Protection Research Institute of Guangxi, Nanning 530022, China*

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A B S T R A C T

By aggregating MODIS (moderate-resolution imaging spectroradiometer) AOD (aerosol optical depth) and OMI (ozone monitoring instrument) UVAI (ultra violet aerosol index) datasets over 2010–2014, it was found that peak aerosol loading in seasonal variation occurred annually in spring over the Gulf of Tonkin (17–23°N, 105–110°E). The vertical structure of the aerosol extinction coefficient retrieved from the spaceborne lidar CALIOP (cloud-aerosol lidar with orthogonal polarization) showed that the springtime peak AOD could be attributed to an abrupt increase in aerosol loading between altitudes of 2 and 5 km. In contrast, aerosol loading in the low atmosphere (below 1 km) was only half of that in winter. Wind fields in the low and high atmosphere exhibited opposite transportation patterns in spring over the Gulf of Tonkin, implying different sources for each level. By comparing the emission inventory of anthropogenic sources with biomass burning, and analyzing the seasonal variation of the vertical structure of aerosols over the Northern Indo-China Peninsula (NIC), it was concluded that biomass burning emissions contributed to high aerosol loading in spring. The relatively high topography and the high surface temperature in spring made planetary boundary layer height greater than 3 km over NIC. In addition, small-scale cumulus convection frequently occurred, facilitating pollutant rising to over 3 km, which was a height favoring long-range transport. Thus, pollutants emitted from biomass burning over NIC in spring were raised to the high atmosphere, then experienced long-range transport, leading to the increase in aerosol loading at high altitudes over the Gulf of Tonkin during spring.

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Introduction

The region of Southeast Asia (SEA), which neighbors Southern China, is considered one of the hotpots for the global atmospheric brown cloud study (Ramanathan et al., 2008). As a result of vigorous economic growth for the last 3 decades, especially the rapid expansion of process and manufacturing industries, anthropogenic emissions have experienced rapid

* *Corresponding author*. E-mail: xujun@craes.org.cn (J. Xu).

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increases in SEA (Ohara et al., 2007). After adding in emissions from seasonal biomass burning (Reid et al., 2009), these emissions may affect other countries or regions through long-range transport, in addition to deteriorating local air quality.

Compared with long-range transport issues in Northeast Asia (Carmichael et al., 2002; Kim et al., 2011), transport of Indo-China Peninsula (IC) emissions to surrounding countries or areas has raised relatively less concern. Even in the international joint project 7SEAS (7-Southeast Asian Studies), which is focused on the SEA region, few research works related to transport of IC emission have been carried out (Reid et al., 2013). This could be partly due to its complicated transport pattern driven by monsoon climate (Chang et al., 2011), low latitude synoptic systems and topographic effects (Lin et al., 2009a). Additionally, the transport between IC and the surrounding regions would probably be mutual. In terms of the effects of transport of pollutants from IC, there have been studies attributing episodic decreasing of air quality over the Pearl River Delta region (Deng et al., 2008) and the enhancement of tropospheric ozone over Hong Kong (Chan et al., 2000) to transport of pollutants from IC in spring. By analyzing aerosol measurements in spring at Mountain Lulin in Taiwan Province, Chuang et al. (2014) attributed high level carbonaceous aerosols to the air masses originating from IC biomass burning.

The Gulf of Tonkin (shown in Fig. 1), which is bordered by IC and South China, is much closer to IC compared with the receptors mentioned above. Additionally, it is mostly covered by ocean. Local emissions are significantly low, making this region an ideal receptor area to study regional transport. However, there have been few studies reported in the literature pertaining to the study of aerosol characteristics at the regional scale over the Gulf of Tonkin, and even the status in terms of the long-term average is relatively unknown.

The development of satellite remote sensing enables the understanding of global or regional distribution, origin and transportation of pollutants (Huang et al., 2008; Ma et al., 2013; Ramanathan and Feng, 2009; Warner et al., 2014; Yu et al., 2010). For SEA, satellite images are often susceptible to clouds and underlying surface conditions (Reid et al., 2013). This restricts the effective utilization of short-term satellite data for studying pollution episodes. However, from a long-term perspective, data averaged for certain regions has found extensive application. This is especially true of the emergence of synergistic earth observations based on application of multiple platforms, sensors, detecting bands and publicly available datasets, such as the "A-Train" (Stephens et al., 2002). The datasets could complement and be verified by each other. Thus, making use of long-term averaged datasets in research is more reliable.

In this study, the characteristics of seasonal variations of aerosol loading in terms of multi-year averages over the Gulf of Tonkin are analyzed, and its origins are also explored. First, the seasonal variation characteristics of aerosol loading are described, followed by analyzing aerosol vertical structure detected by CALIOP (cloud-aerosol lidar with orthogonal polarization). Then, the origins of aerosol loading over the Gulf of Tonkin are analyzed by comparing climatology wind fields at different layers, investigating emissions from different source over IC, and exploring aerosol vertical structure over the source region. Finally, the uplift mechanism of pollutants at low atmosphere is discussed. All of the above was mainly achieved using multiple remote sensing datasets from satellite, long-term meteorology data and emission inventory data over IC and the surrounding areas.

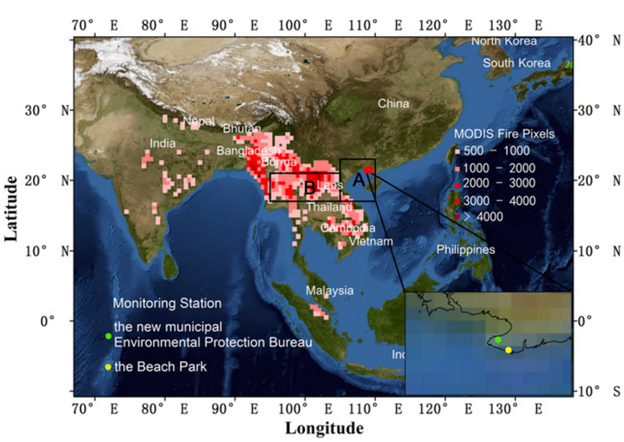

Fig. 1 – Research domain and major region of CALIOP (cloud-aerosol lidar with orthogonal polarization) data analysis, including the Gulf of Tonkin delimited as rectangle A and the Northern Indo-China Peninsula (NIC) delimited as B. Ground monitoring sites were located at Beihai, Guangxi Province, over the Gulf of Tonkin for validation of retrieved results. MODIS (moderate-resolution imaging spectroradiometer) fire counts during March to April in 2010–2014 are overlapped.

1. Data and methods

1.1. Satellite data

A total of 5 years (2010–2014) of satellite datasets from sensors such as a moderate-resolution imaging spectroradiometer (MODIS), ozone monitoring instrument (OMI), CALIOP and an atmospheric infrared sounder (AIRS) were used in the study. Given the long time series and global coverage, MODIS aerosol optical depth (AOD) has been widely used to investigate the characteristics of regional distributions of aerosols as long-term averages. The level 3 daily product with horizontal resolution of 1 × 1 degree was used here.

The OMI ultra violet aerosol index (UVAI) is retrieved from OMI detections of two channels in ultraviolet spectra (Torres et al., 1998). It has excellent ability to identify absorbing aerosols, especially aloft aerosol layers such as smoke. In this paper, the level 3 monthly product of UVAI with horizontal resolution of 1 × 1 degree was used.

CALIOP is a primary payload onboard the cloud-aerosol lidar and infrared pathfinder satellite observations (CALIPSO) satellite, which provides detailed detection of vertical structure and distribution of aerosols and clouds along the orbit track. A 532 nm aerosol extinction coefficient (AEC) contained in the CALIOP level 3 product was mainly used in this study,

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