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Satellite observation of abnormal yellow haze clouds over East China during summer agricultural burning season

Minghui Tao [a,b], Liangfu Chen [a,*], Zifeng Wang [a], Jinhua Tao [a], Lin Su [a]

[a] State Key Laboratory of Remote Sensing Science, Jointly Sponsored by Institute of Remote Sensing and Digital Earth of Chinese Academy of Sciences and Beijing Normal University, Beijing 100101, China

[b] University of Chinese Academy of Sciences, Beijing 100049, China

HIGHLIGHTS

- We present a new view of extreme regional pollution event over East China.
- The role of agricultural burning in regional pollution was examined.
- Strict measures in agricultural burning should be extended to normal seasons.

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ABSTRACT

Durative haze clouds with unusual yellow color appeared in East China in agricultural burning period during June 8–12 in 2012, causing extreme air pollution in densely populated regions including Jiangsu, Hubei, and the Yangtze River Delta. The spatial variation, vertical structure, optical properties, as well as formation process, were investigated using combined multiple satellite observations, ground measurements, and meteorological data. Different from previous studies, our analysis reveals that the yellow haze clouds were caused by mixing and interaction among airborne dust, fire emissions, and urban pollution under humid conditions. The pollution layers were 3–5 km thick, and their vertical structures were very inhomogeneous, with dust mostly distributed in the upper part and mixing of fires smoke and urban haze concentrated near surface. Compared with fire smoke, the dust-like haze clouds exhibited different optical properties with higher volume depolarization ratio and notable increase in coarse mode aerosols. Although fire emissions and urban pollution may play a more important role in surface pollution, we conclude that dust transport and high humidity were the main reason that the haze pollution was much heavier than that in previous years. In addition, regional concentrated fires only occurred in several days, and fire count was inconsistent with regional average aerosol loading. The long-range transport of fire emissions can be overestimated. In order to avoid such regional pollution event, our results also suggest that the strict measures in fire management should be extended from special periods to normal season.

1. Introduction

Biomass burning is a worldwide phenomenon that exerts substantial influences on regional climate and air quality. Widespread agricultural fires for deforestation, soil nutrient, and land clearing seasonally circle and prevail in tropical and sub-tropical regions (Crutzen and Andreae, 1990). Intense natural fires occur frequently in forest regions such as that in North America and Russia during the dry season. These dense fires emit large amounts of aerosol particles such organic carbon (OC) and black carbon (BC) as well as gaseous pollutants, which can form continental brown clouds over the land (Gustafsson et al., 2009). The smoke clouds not only threaten public health near surface, but also modify clouds (Koren et al., 2004) and the hydrological cycle (Menon et al., 2002).

Recently, increased agricultural fires in East China, one of the most populated and fastest developing regions of the world, have drawn much attention due to its marked influence on air quality (Huang et al., 2012; Li et al., 2010) and regional climate (Cheng et al., 2010; Fan et al., 2010). During the summer harvest season, agricultural burning prevails in North China (42°N–30°N, 111°E–123°E) (Fig. 1), when wheat straws are burned for land clearing. Meanwhile, large numbers of anthropogenic emissions over East China, driven by diverse sources and meteorological conditions (Li

* Corresponding author. Jia No. 20 North, Datun Road, Chaoyang District, P.O. Box 9718, Beijing 100101, China. Tel.: +86 10 64836589.
E-mail address: minghuit@gmail.com (M. Tao).

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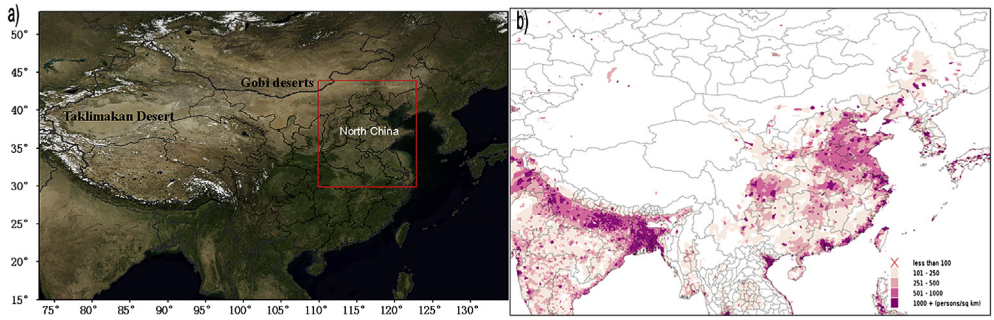

Fig. 1. a) MODIS true color image of China from Blue Marble of NASA; b) Population density from Land Atmosphere Near real-time Capability for EOS (LANCE). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

et al., 2011; Zhang et al., 2009), frequently lead to inhomogeneous haze clouds (Tao et al., 2012). Fire emissions in this high polluted region can result in serious air pollution and complex interactions with urban/industrial pollutants (Li et al., 2010; Wang et al., 2011). However, previous studies are mostly based on measurements in sparse ground sites, with less attention being paid to how the fire smoke change over space and time. Knowledge of regional variation and optical properties of the fire smoke as well as its interactions with background pollutants is essential in improving regional climate and chemical models but still not well understood.

Abnormal yellow haze clouds, seen neat the surface, covered East China for several days during the agricultural burning period in the first half of June in 2012, causing extremely severe air pollution in corresponding city clusters. In megacities such as Nanjing and Wuhan, surface hourly concentration of $PM_{2.5}$ exceeded 500 $\mu g\ m^{-3}$ and visibility was lower than 1–3 km (http://www.hbepb.gov.cn). The government and previous studies directly attributed this heavy regional pollution to emissions of agricultural fires (Huang et al., 2012). However, these works neither explain the unusual dust-like color of the haze clouds nor answer why the regional pollution was much heavier than those in previous years (Li et al., 2010; Wang et al., 2011). In particular, essential characteristics of the haze clouds, including their extent, variation, and optical properties are still unclear due to lack of large-scale comprehensive observations.

To reduce these harmful haze clouds and evaluate their climate effects, it is urgent to have a clear understanding of the formation process of the haze clouds and the potential role of fire emissions in the regional pollution over East China. Different from chemical analysis that may only capture partial information of inhomogeneous regional pollution, here we conduct a large-scale comprehensive study to the formation mechanism of the extreme haze clouds in June 2012 and the role of agricultural burning in regional pollution using combined multiple satellite observations and ground measurements.

2. Data and method

2.1. Satellite data sets

The A-train satellite constellation is composed of several satellites such as Aqua, CALIPSO, and Aura, each of which crosses the equator in ascending node at around 1:30 p.m. local time on the same track. The multi-sensor view provides unprecedented chances to observe aerosols and clouds in one place simultaneously from a wide range of parameters. Combined with meteorological data and ground-based measurements, the A-train satellite observation can provide a unique regional view of optical properties and formation process of the haze clouds (Tao et al., 2012).

Moderate Resolution Imaging Spectroradiometer (MODIS) on the morning satellite Terra (crosses the equator in descending node at around 10:30 a.m. local time) and afternoon satellite Aqua detects properties of the atmosphere and land by radiances from 36 spectral bands in 0.4–14.4 μm. With a large swath width of 2330 km, MODIS can provide twice daily coverage in East China. Collection 5.1 MODIS 10 km aerosol optical depth (AOD) data with errors in $\pm(0.05 + 15\%)$ were used to analyze variations in regional pollution (Levy et al., 2010). We used fire data from MODIS Fire Information for Resource Management System (FIRMS) to study the agricultural burning in North China during wheat harvest season (from May 20 to June 20) in 2003–2012. MODIS fire retrieval results have different confidence depending on intensity, scale, and burning time of the fires (Giglio et al., 2003). We considered both the total fire number and high-confidence (possibility of 80% to be true) fire counts.

The Ozone Monitoring Instrument (OMI) onboard Aura satellite detects tropospheric pollutants by measuring reflected solar radiance of the Earth–atmosphere system in the visible and ultraviolet spectra (270–500 nm) with a swath width of 2600 km. UV Aerosol Index (UVAI) is one widely used parameter that detects the existence of elevated UV-absorbing aerosols such as airborne dust and biomass burning smoke (Torres et al., 2007). UVAI is very sensitive to the altitude of the UV-absorbing aerosols (>2 km), but rather insensitive to surface type (Ahn et al., 2008). Therefore, it can be used over both land and ocean and in cloud-free and cloudy scenes. We used OMI Level 2 grid data of UVAI with resolution of 0.25° in this study.

Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) aboard the CALIPSO satellite provides high-resolution vertical profiles and depolarization measurements of aerosol and cloud layers (Liu et al., 2008). Both daytime and nighttime CALIPSO V3.02 data were used in the study. Daytime data was mainly used for reference due to the noise of solar radiance. CALIPSO detection classifies aerosols into six subtypes including smoke, dust, polluted dust (dust + smoke), clean and polluted continental, and clean marine according their altitudes, size, and optical information (Omar et al., 2009). Linear depolarization at 532 nm of CALIPSO is especially sensitive to non-spherical particles such as pure dust (Mielonen et al., 2009). Biomass burning also emits fine smoke particles with non-spherical shape, but its volume depolarization ratio (VDR) is much smaller than that of dust (Liu et al., 2008).

2.2. Ground measurements and meteorological data

A CIMEL sun photometer in Taihu (31.42N, 120.22E) from NASA's Aerosol Robotic Network (AERONET) provides retrievals of aerosol optical properties such as AOD, Single Scattering Albedo (SSA), and size distribution (Holben et al., 1998), which can be used to validate satellite observations. In this study, level 2.0 SSA and size