Preface to special section on East Asian Studies of Tropospheric Aerosols: An International Regional Experiment (EAST-AIRE)

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[1] Papers published in this special section report findings from the East Asian Study of Tropospheric Aerosols: An International Regional Experiment (EAST-AIRE). They are concerned with (1) the temporal and spatial distributions of aerosol loading and precursor gases, (2) aerosol single scattering albedo (SSA), (3) aerosol direct radiative effects, (4) validation of satellite products, (5) transport mechanisms, and (6) the effects of air pollution on ecosystems. Aerosol loading is heaviest in mideastern China with a mean aerosol optical depth (AOD) of 0.5 and increasing to 0.7 around major cities that reduced daily mean surface solar radiation by $\sim$30–40 W m^{-2}, but barely changed solar reflection at the top of the atmosphere. Aerosol loading, particle size and composition vary considerably with location and season. The MODIS AOD data from Collection 5 (C5) agree much better with ground data than earlier releases, but considerable discrepancies still exist because of treatments of aerosol SSA and surface albedo. Four methods are proposed/adopted to derive the SSA by means of remote sensing and in situ observation, which varies drastically with time and space. The nationwide means of AOD, Ångström exponent, and SSA (0.5 μm) in China are 0.69 ± 0.17, 1.06 ± 0.26, and 0.89 ± 0.04, respectively. Measurements of trace gases reveal substantial uncertainties in emission inventories. An analysis of aircraft measurements revealed that dry convection is an important mechanism uplifting pollutants over northern China. Model simulations of nitrogen deposition and impact of ozone pollution on net primary productivity indicate an increasing threat of air pollution on the ecosystem.

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1. Motivation of the EAST-AIRE

[2] A key to understanding the direct and indirect radiative forcing of aerosols, which are the largest uncertainties in climate research [*Intergovernmental Panel on Climate Change*, 2007], is quantitatively characterizing aerosol properties on a region-by-region basis because both aerosol loading and properties exhibit drastic spatial and temporal variations. East Asia is a region where high aerosol concentrations are common, as is clearly shown by the Moderate Resolution Imaging Spectroradiometer (MODIS) aerosol optical depth (AOD) product [*Kaufman et al.*, 2002; *Z. Li et al.*, 2007a], as well as from ground-based observations [*Nakajima et al.*, 2003]. According to worldwide systematic measurements of AOD from the Aerosol Robotic Network (AERONET) [*Holben et al.*, 1998], the annual mean AOD in east Asia and Asia as whole is about 0.36, ranking second highest in the world next to Africa (Table 1). Coexistence of dust, industrial pollutants, and smoke over this vast area complicates satellite retrievals [*Li*, 2004]. At present, there are few ground stations measuring aerosol loading and properties in most of the world's aerosol-laden regions, including Asia.

[3] Increasing evidence suggests that the influence of aerosols on the energy and water cycles of the Earth's system is significant [*Ramanathan et al.*, 2001]. Atmospheric circulation may be altered which influences monsoons [*Lau et al.*, 2006; *Lau and Kim*, 2006] and severe storms [*Zhang et al.*, 2007]. Despite the rapid increase in the number of studies dealing with aerosol issues in recent years, it remains a daunting task to determine the extent of the influence exerted by aerosols, especially those produced

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Table 1. Long-Term and Regional Means of Aerosol Optical Depth (AOD) and the Ångström Exponent Measured in Different Continental Regions of the World From the AERONET

Region	Africa	Asia	Australia	Europe	North America	South America
AOD	0.44	0.36	0.11	0.21	0.15	0.22
AE	0.62	1.11	0.87	1.27	1.34	1.17

by human activities, on weather, climate and ecosystem. Unraveling this question is urgent in this heavily populated and rapidly developing region of the world, where more than half of the world's population resides. Changes in weather patterns and climate would affect the well being of billions of people.

[4] Over the past few decades, the climate in China has changed at an unprecedented rate. Perhaps the change most noticeable to the general public is a 35% reduction in visibility from the 1960s to the 1980s. During this period, the amount of direct solar radiation reaching the ground decreased by about 8.6% in China [*Luo et al.*, 2000; *Liang and Xia*, 2005], while total solar radiation decreased by about 4.6% per decade [*Shi et al.*, 2007]. The decrease in solar radiation reaching the ground is at odds with a general decreasing trend in annual mean cloud cover (1–3%/decade) and rainy days (1–4%/decade) observed at most ground stations in central, eastern, and northeastern China [*Kaiser*, 1998; *Liang and Xia*, 2005], which is consistent with an analysis using the more reliably observed frequencies of cloud-free sky and overcast sky [*Qian et al.*, 2006]. Using direct radiation measurements made at the surface, *Luo et al.* [2001] inferred a general increase in AOD of about 25% from 1960s to 1980s. This increase in AOD is likely the major cause for the cooling trend in central eastern China, while the rest of the country experiences significant warming [*Xu et al.*, 2006]. Changes in patterns of precipitation are also considerable with a general tendency of "south wetting and north drying." On the basis of model sensitivity tests, *Menon et al.* [2002] hypothesized the observed change in the precipitation pattern were caused by the aerosol direct effect. However, they had to assume an aerosol single scattering albedo (SSA) of 0.85. This assumed value is lower than the majority of those estimated from ground and satellite measurements across China [*Lee et al.*, 2007].

[5] The aerosol direct effect may contribute to the weakening of the Asian monsoon system. Analyzing wind data in China, *Xu et al.* [2006] found that the surface wind speed associated with the east Asian monsoon has significantly weakened in both winter and summer seasons during the past three decades. From 1969 to 2000, annual mean wind speeds over China have decreased steadily by 28%, and the prevalence of windy days (daily mean wind speed >5 m/s) has decreased by 58%. They also found that the monsoon wind speed to be highly correlated with incoming solar radiation at the surface, which is very sensitive to aerosol loading.

[6] These changes in monsoonal winds are not surprising because the monsoon circulation is mainly driven by differential heating between the land and ocean. The dimming effect of aerosols [*Wild et al.*, 2005] reduces the inhomogeneous heating between land and ocean, and thus diminishes the temperature difference, which helps weaken the monsoon [*Lau et al.*, 2007]. The weakening of the east Asian monsoon system tends to decrease water vapor transport from the south to the north, prolonging the rain belt in the south, and reinforcing the trend of "south wetting and north drying."

[7] Fewer investigate aerosol semi-indirect and indirect effects on cloud and precipitation because of the dearth of in situ measurements of coincident aerosol and cloud properties in this part of the world. Analyzing long-term trends of precipitation and sounding data along with short-term trends of MODIS AOD, *Zhao et al.* [2006] argued that the reduction in rainfall is caused by increasing atmospheric stability due to aerosol-induced heating of the atmospheric boundary layer, and proposed a positive feedback: more aerosols → less precipitation → more aerosols. The aerosol indirect effect was examined using MODIS aerosol and cloud products in China and other parts of the world [*Li and Yuan*, 2006; *Yuan et al.*, 2007]. They found that aerosols tend to reduce cloud particle size in northern China but increase cloud particle size in southern China. This finding agrees with *Storelvmo et al.* [2006] who investigated the aerosol indirect effect using the Global Climate Model CAM-Oslo. *Rosenfeld et al.* [2007] reported a correlation between rainfall reduction and air pollution over a hilly region in western China, and thus proposed that pollutant aerosols decreased cloud droplet size and reduced precipitation in that region.

2. EAST-AIRE Goals, Objectives, and Observation Activities

[8] Fully accounting for aerosol effects on climate requires extensive measurements of aerosol optical, physical (size), and chemical (composition and hygroscopic) properties. A handful of international aerosol experiments have already taken place in the east Asian region surrounding China, such as the Asian-Pacific Regional Aerosol Characterization Experiment (ACE-Asia) [*Huebert et al.*, 2003], the NASA Global Tropospheric Experiment Transport and Chemical Evolution Over the Pacific (TRACE-P) [*Christopher*, 2003], the Asian Atmospheric Particle Environment (APEX) [*Nakajima et al.*, 2003], and the Atmospheric Brown Clouds-East Asian Regional Experiment (EAREX) (T. Nakajima et al., Overview of the ABC EAREX 2005 regional experiment and a study of the aerosol direct radiative forcing in east Asia, submitted to *Journal of Geophysical Research*, 2007, hereinafter referred to as Nakajima et al., submitted manuscript, 2007). Very few experiments have taken place inside or near mainland China. In order to gain a basic knowledge of the characteristics of aerosols and gases and an understanding of their climatic effects, the East Asian Studies of Tropospheric Aerosols: an International Regional Experiment (EAST-AIRE) was established as a US-China joint research endeavor with the following primary goals: (1) to acquire and understand the physical, chemical and optical properties of dominant natural and anthropogenic aerosols and their precursor gases in China and (2) to gain insights into the direct and indirect effects of these aerosols on radiation, cloud, precipitation, atmospheric circulation and the environment.

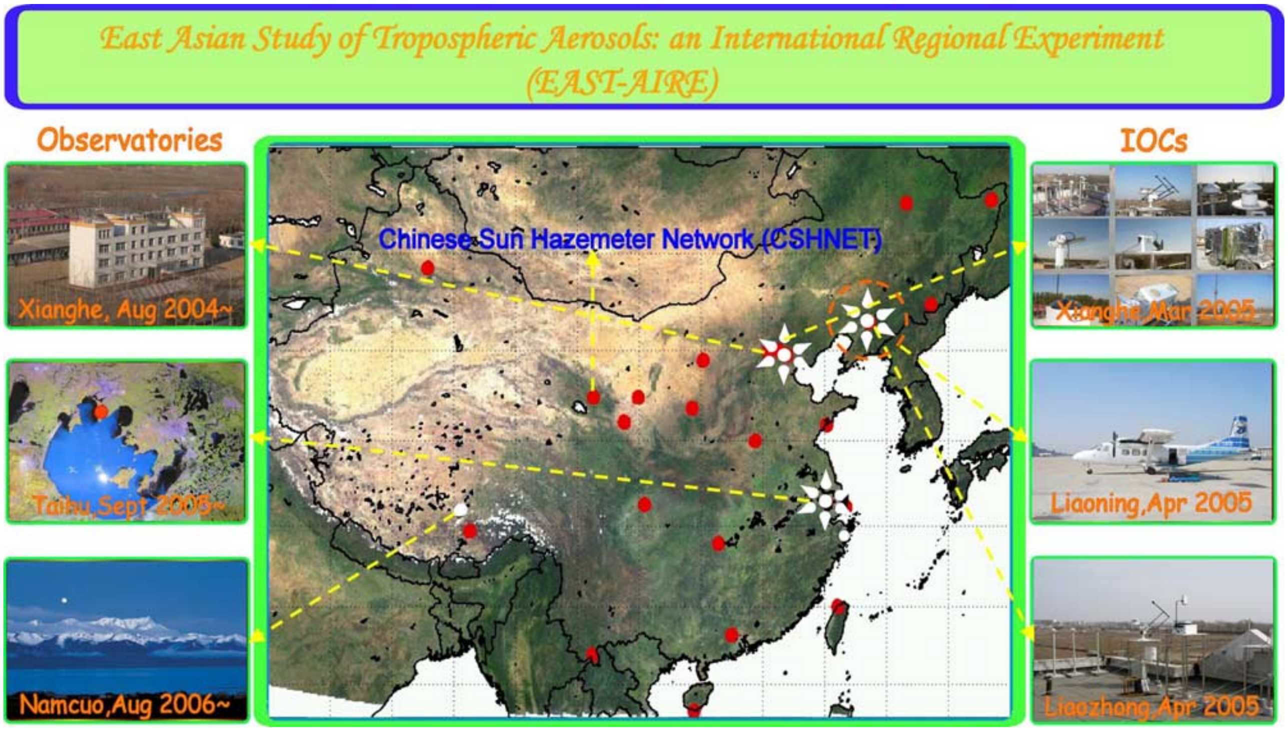

Figure 1. Overview of observational activities conducted under the auspices of the EAST-AIRE, including a nationwide aerosol observation network (CSHNET), observatories with extensive instrumentation, and intensive observation campaigns (IOC).

[9] In the first phase of the study, focus has been placed on obtaining in situ and remote sensing measurements of aerosols and pollutant gases near or down wind of major source regions throughout inland China. Both routine and intensive observation campaigns (IOC) have been conducted utilizing ground-based and airborne measurements. The majority of the studies presented in this special section (13 articles) made extensive use of measurements made from three types of observation programs: 2 baseline stations measuring aerosol, cloud and radiation quantities in heavy anthropogenic aerosol emission regions in northern and southern China; 25 stations measuring AOD at multiple wavelengths; and ground-based and airborne IOCs measuring the physical and chemical properties of aerosol particles and precursor gases, as well as cloud and radiation quantities. Major observation activities are highlighted in Figure 1. For more details of the project and viewing the data, visit the EAST-AIRE homepage: http://www.atmos.umd.edu/∼zli/EAST-AIRE/station.htm. Tables 2 and 3 list some of the instruments deployed for routine observations and the IOCs.

2.1. Baseline Observation Stations

[10] Two baseline observatories were established: Xianghe (70 km southeast of Beijing) in September 2004 and Taihu Lake (100 km west of Shanghai) in September 2005. At these stations, extensive measurements are made and include (1) radiative quantities (direct, diffuse and total shortwave (SW) fluxes, longwave (LW) fluxes, ultraviolet (UV), photosynthetically active radiation (PAR), ultraviolet (UV) radiation and spectral irradiances) using broadband and narrowband radiometers, and spectrometers; (2) cloud properties (cloud fraction and height, optical depth);

Table 2. Instruments Used for Routine Aerosol, Radiation, and Cloud Measurements at the EAST-AIRE Supersites

Instruments	Manufacturer	Parameters
CM21 radiometer and CM22 radiometer	Kipp & Zonen Inc., Bohemia, New York	total (CM21) and diffuse radiation (CM22) with a ventilation system (CV2); all placed on an EKO solar tracker
8–48 B&W radiometer, normal incidence pyrheliometer, and precision infrared radiometer	Eppley Lab	diffuse and direct solar radiation, with ventilator (VEN) attached to the 8–48 radiometer
MFR-7 rotating shadow band radiometer and TSI 440A 2 Total Sky Imager	Yankee Environment Sys., Turners Falls, MA	direct and diffuse spectral radiation; cloud fraction; cloud optical depth; cloud effective radius; total sky image and animation movie
Cimel CE-318 Sun photometer	CIMEL Electronique, Paris, France	direct spectral radiance; AOD, SSA, and aerosol size distribution

Table 3. Instruments Deployed During the Intensive Observation Campaign of Spring 2005

Instruments	Manufacturer	Model	Parameters
MPL lidar[a]	NASA/GSFC		aerosol extinction profile, cloud height
Microwave radiometer[a]	NASA/GSFC		cloud liquid water path, precipitable water
High-volume aerosol sampler[a]	U. of Miami		aerosol samples (TSP)
Aerosol optical sampler[b]	NASA/GSFC		aerosol samples for chemical composition and optical property analysis
Pulsed fluorescence SO_2 analyzer[b]	Thermo Electron Inc.	TEI 43C	sulfur dioxide concentration
Gas filter correlation CO analyzer[b]	Thermo Electron Inc.	TEI 48C	carbon monoxide concentration
UV photometric O_3 analyzer[b]	Thermo Electron Inc.	TEI 49C	ozone concentration
Integrating nephelometer[b]	TSI, Inc	3563	aerosol light scattering at 450, 550 and 700 nm
Particle/soot absorption photometer[b]	Radiance Research, Inc		aerosol light absorption at 565 nm
MetOne particle counter[b]	MetOne, Inc.	9012	aerosol size distribution 0.3–1.0 μm
Condensation particle counter[b]	TSI Inc.	3007	total aerosol number concentration (<1.0 μm)
Rosemont pressure transducer[b]	Rosemont, Inc	2008	ambient pressure
Garmin GPS 90[b]	Garmin, Inc.	90	position

[a]Just employed on the ground.
[b]Deployed both on the ground and in aircraft.

(3) aerosol optical quantities retrieved from Cimel Sun photometers and multifilter rotating shadowband radiometers (MFRSR); and (4) physical and chemical properties from aerosol impactor samples. The quality of the data is monitored daily both locally and remotely. Redundant measurements made with independent instruments help discover data anomalies and fixing them promptly [*Xia et al.*, 2007b]. The data are uploaded automatically on a daily basis via the Internet for prompt quality inspection at the University of Maryland and the Institute of Atmospheric Physics in Beijing. The Xianghe site became the first Chinese site accepted into the Baseline Surface Radiation Network (BSRN) and the data are archived at the BSRN data center in Switzerland. Since its commencement, quality-controlled data have been collected continuously without interruption. Data plots are automatically generated and can be viewed online at the EAST-AIRE homepage. In addition to these two sites there is a partially finished site at Namco in Tibet.

2.2. Nationwide Aerosol Observation Network

[11] A nationwide aerosol observation network, the Chinese Sun Hazemeter Network (CSHNET), was established in August 2004, providing daily continuous measurements of aerosol optical depths at 3 wavelengths (405 nm, 500 nm, 650 nm) at over 25 stations across China. In addition to initial in-house calibrations conducted in the United States, the handheld Sun photometers were further calibrated against the Cimel Sun photometers at Xianghe and Tibet by means of both instrument intercomparisons and the Langley method [*Xin et al.* 2007]. The Cimel Sun photometer at Xianghe is calibrated annually. This is a pioneering effort at making direct aerosol measurements across China using a well-documented and quality-controlled procedure.

2.3. Intensive Observation Campaigns (IOC)

[12] Two consecutive IOCs were conducted in the spring of 2005: during March on the ground in Xianghe and during April from both aircraft and ground in the Liaoning province, 650 km northeast of Beijing. These IOCs took place in conjunction with the EAREX that was conducted simultaneously in the downstream region of Gosan Island off the coast of Korea (Nakajima et al., submitted manuscript, 2007). In addition to routine measurements acquired at the EAST-AIRE baseline station, observations were supplemented with IOC measurements of clouds using microwave radiometers, a micropulse lidar, and various aerosol and gas analyzers (see Tables 2 and 3).

[13] For aerosols and gases, the following extensive parameters were measured: (1) aerosol optical depth, scattering and absorbing coefficients, vertical attenuation profiles, and absorption (using a Cimel Sun photometer, nephelometer, aethalometers, PSAP); (2) aerosol physical quantities (size distribution, mass and condensation number) using aerosol filter samplers, cascade impactors, particle sizers; (3) aerosol composition using the OC/EC analyzer, aerosol filters and sample analyzers; and (4) precursor gases (ozone, NO, NO_x, NO_y, CO, SO_2) using gas analyzers.

[14] Eight research flights were made under various weather conditions. Some ideal conditions were encountered, enabling the measurements of major emission sources and the mechanisms responsible for the lofting and transport of gases and particles [*Dickerson et al.*, 2007], thus enabling the study of their impact on regional climate.

3. Major Findings of the EAST-AIRE

[15] This special section presents studies reporting major scientific findings concerning the following specific scientific questions: (1) What are the spatial and temporal distributions of general aerosols, carbonaceous aerosols and precursor gases over inland China? (2) What is the SSA of aerosols over China? (3) What is the magnitude of aerosol direct radiative forcing over China? (4) How can direct observations from EAST-AIRE help validate and improve satellite retrievals? (5) How do aerosols and precursor gases transport out of the source regions over continental China? (6) What are the effects of increasing atmospheric pollutants on the ecosystems of China, and what are the effects of urbanization on weather and climate?

3.1. Question 1: What Are the Spatial and Temporal Distributions of General Aerosols, Carbonaceous Aerosols, and Precursor Gases Over Inland China?

[16] Prior to the EAST-AIRE, some observational efforts were made to measure aerosols and precursor gases in China, including a nationwide environmental monitoring

network distributed over 300 cities [*Hao and Wang*, 2005]. Many of these studies focused on in situ aerosol mass concentrations and chemical composition, shedding light on the heavy aerosol loadings and complex aerosol sources near the surface [e.g., *Chan et al.*, 2005; *Sun et al.*, 2005; *Yao et al.*, 2002]. Studies lasting 1 year (a) or longer disclosed seasonal changes in aerosol concentrations and origins, emphasizing the importance of dust aerosols during spring, secondary aerosols during summer, carbonaceous aerosols during biomass burning seasons, and contributions from combustion for heating during winter [e.g., *Yang et al.*, 2005; *Zheng et al.*, 2005]. Short-term experiments measured aerosol optical properties, providing critical information such as aerosol size distributions, SSA, and the hygroscopic growth factor [*Bergin et al.*, 2001; *Xu et al.*, 2002, 2004; *Xia et al.*, 2005]. Other studies monitored traces gases, uncovering the processes related to pollutant emissions and photochemical smog formation [e.g., *Wang et al.*, 2002, 2004]. In addition, sporadic aircraft and lidar measurements, characterized three-dimensional distributions of aerosols and trace gases [e.g., *Hatakeyama et al.*, 2005; *Zhang et al.*, 2006]. These studies provide invaluable information regarding aerosol properties over east Asia, mostly on a case-by-case basis, with limited spatial and temporal coverage. Satellite observations [e.g., *Li et al.*, 2003] have better coverage than in situ measurements, but are subject to errors due to inaccurate assumptions concerning surface reflectance and aerosol models [*Levy et al.*, 2007a, 2007b]. Studies analyzing surface solar radiation measurements provide a gross account of the long-term trends and spatial distributions of AOD over China [*Luo et al.*, 2001; *Qiu*, 1998; *Shi et al.*, 2007], but calibration of instruments has always been an issue [*Li*, 2004].

[17] *Xin et al.* [2007] analyzed 1 a worth of AOD data from the CSHNET and found a wide range of aerosol loadings over different regions in China, with AOD at 500 nm ranging from ~0.15–0.2 over remote locations like Tibet to more than 0.5 in urban and suburban areas. Overall, annually averaged AODs over the eastern part of China are ~0.5 and show little difference between urban and rural agricultural stations, suggesting the existence of a widespread haze layer over this more developed and populated area. Handheld Sun photometers with multiple channels provide additional information about particle size and aerosol types, which vary greatly with space and time, implying complex aerosol compositions and sources. AERONET observations at the two EAST-AIRE supersites [*Z. Li et al.*, 2007b; *Xia et al.*, 2007a, 2007b] near urban centers in northern and southern China also found high aerosol loadings of mixed origins, with the mean AOD exceeding 0.6 and Ångström exponents fluctuating from zero to almost 2.

[18] By providing year-round measurements of AOD, the aerosol observation network established under the EAST-AIRE also enables the investigation of the temporal change in aerosol loadings and properties over China with unprecedented coverage. While seasonal variations in aerosol loadings and compositions due to changes in land surface, weather conditions (humidity and temperature), and human activities were noticed, the observed seasonal changes were dwarfed by dramatic day-to-day oscillations found at all stations over the eastern part of China [*Xia et al.*, 2006; *Z. Li et al.*, 2007b; *Mi et al.*, 2007; *Xia et al.*, 2007a]. Fast transitions between heavily polluted episodes (AOD up to 4) and relatively clean conditions (AOD ~0.2) occurred in a matter of a few days in northern China. Such changes in aerosol levels on a synoptic timescale were also observed through ground [*Chaudhry et al.*, 2007; *Dickerson et al.*, 2007; *C. Li et al.*, 2007] and aircraft in situ measurements of aerosols and trace gases during the spring 2005 IOCs. Changes in weather conditions accompanying the passages of midlatitude cyclones influenced pollutant dispersion, and were responsible for the observed synoptic variations in aerosols [*C. Li et al.*, 2007]. Diurnal changes in aerosol optical properties, associated with the evolution of the planetary boundary layer (PBL) and local emission sources were also well documented during the IOCs [*Chaudhry et al.*, 2007; *C. Li et al.*, 2007].

[19] In addition to aerosol optical measurements, *Cao et al.* [2007] analyzed the organic and elemental carbon (OC and EC) components from daily $PM_{2.5}$ samples collected at 14 cities across China. Both OC and EC concentrations reach a maximum in winter and a minimum in summer for all cities with the mean concentration ranging from 13.8 to 38.1 μg m^{-3} for OC and from 3.6 to 9.9 μg m^{-3} for EC. OC is better correlated with EC more closely in winter than summer. Carbonaceous matter accounts for about 44.2% and 38.8% of the total $PM_{2.5}$ in winter and summer, respectively. Primary and secondary OC and EC account for 47.5%, 31.7% and 20.8%, respectively, of total carbon emitted in Chinese cities, with over two thirds emitted as particles.

[20] Aircraft [*Dickerson et al.*, 2007] and lidar measurements [*Chaudhry et al.*, 2007] also added to the very limited database of aerosol and trace gas vertical distributions over inland China. They found aerosol layers at different altitudes with distinct size distributions may exist at different levels, e.g., anthropogenic particles in the PBL and dust transported at higher altitudes. The vertical profile measurements contributed to the investigation of pollution transport mechanisms as described below.

3.2. Question 2: What Is the Single Scattering Albedo (SSA) of Aerosols in China?

[21] As a measure of the capability of aerosols to absorb photons, the SSA is a critical parameter defining the signs (warming or cooling) of the net climate effects of aerosol radiative forcing. Prior to the EAST-AIRE, short-term in situ measurements and ground remote sensing were conducted to determine SSA at a handful of locations over China, including different urban and suburban areas in the eastern part of China (Guangzhou in the south [*Andreae et al.*, 2005], the Yangtze Delta Region (YDR) [*Xu et al.*, 2002], and Beijing in the north [*Xia et al.*, 2006; *Bergin et al.*, 2001]), as well as a desert source region in northwestern China [*Xia et al.*, 2005; *Xu et al.*, 2004]. Overall, the SSA in the visible band over China was found to be low, with values in Beijing (0.81 from in situ measurements and 0.90 from ground remote sensing) and Guangzhou (0.85) lower than those determined in the YDR (0.93) and near deserts (0.92). Using broadband surface solar irradiance measurements, *Qiu* [2000] also retrieved rather low SSAs for aerosols over six cities in northern China. There still exist large inconsistencies in the reported values of SSA.

[22] Much effort has been made in the EAST-AIRE to determine SSA over China. Four different approaches have been used to determine the SSA from (1) sky radiances as estimated from Cimel Sun photometers [*Dubovik and King*, 2000]; (2) a combination of spectral direct transmittance and total solar fluxes [*Zhao and Li*, 2007]; (3) a combination of ground-based spectral direct transmittance and spaceborne spectral reflectance [*Lee et al.*, 2007]; and (4) optical analyses of in situ aerosol samples in labs [*Chaudhry et al.*, 2007].

[23] Following the method of *Dubovik and King* [2000], the three AERONET sites under the aegis of the EAST-AIRE provided SSA retrievals for the whole atmospheric column over long periods of time. The average AERONET-retrieved SSA is about 0.9 in the visible wavelength range at all stations, confirming the presence of aerosols with strong absorbing properties, which was suggested by previous studies [*Eck et al.*, 2005; *Xia et al.*, 2006], but not as low as was found in other studies [e.g., *Qiu*, 2000]. The AERONET approach requires scanning the sky with a robotic Sun photometer. SSA was also retrieved from downwelling surface shortwave fluxes together with spectral direct radiances [*Zhao and Li*, 2007]. Their 1-a SSA retrievals using data from Xianghe have accuracies and uncertainties comparable to colocated AERONET retrievals (0.891 versus 0.886). This algorithm can be applied to CSHNET stations instrumented with both handheld Sun photometers and pyranometers, thus enhancing the potential of obtaining SSA information over a large area at a relatively low cost. Unfortunately, few CSHNET stations were equipped with pyranometers; the deployment of this instrument at more sites is planned for the future. Another approach used to estimate the SSA utilizes coincident measurements of direct transmittance made with handheld Sun photometers on the ground and reflected radiance at the top of the atmosphere from the spaceborne MODIS [*Lee et al.*, 2007]. This approach is particularly suitable for China as aerosol loading is generally high so the sensitivity to surface albedo is reduced enough to obtain SSA with reasonable accuracies. By applying the method to all CSHNET station data, SSA was derived across China for all months, leading to a gross knowledge about the spatial and temporal variations of SSA for the first time [*Lee et al.*, 2007]. The nationwide average SSA is 0.89. Relatively low SSA is found in northeastern China, central-north China and western China during winter seasons. In the heart of a major industrial zone in eastern China, SSA is somewhat higher (0.90–0.92). This fundamental information on aerosol property is critical for determining aerosol radiative forcing at the top and bottom of the atmosphere across the region.

[24] During the ground-based IOC carried out in Xianghe in 2005, in situ measurements of SSA were also made from a combination of aerosol scattering and aerosol absorption measurements [*C. Li et al.*, 2007]. SSA values at 500 nm derived from these in situ measurements were typically 0.8–0.85, but ranged as low as 0.7 at times. These values are similar to the in situ measurements made by *Bergin et al.* [2001] in Beijing but significantly lower than the colocated AERONET retrievals, presumably reflecting the sampling difference between in situ instruments (near ground) and Cimel Sun photometers (whole atmospheric column), although measurement uncertainties play a role. If aerosols at ground level are indeed much more absorbing than those at higher altitudes, as suggested by these studies, the resulting vertically differential aerosol radiative heating may influence atmospheric stability, weather patterns, and the evolution of the PBL [*Yu et al.*, 2002].

[25] Changes in the SSA with height are also thought to be the major cause for the discrepancies between SSA measured from daily aerosol samples and inferred from the AERONET at the Xianghe site where Nuclepore filters were collected for the first 5 months of 2005 [*Chaudhry et al.*, 2007]. From these samples, both mass concentration in various bins and SSA in different spectral bands were measured in the NASA/GSFC lab and compared with those retrieved from AERONET Sun photometers. The ground-based measurements compare favorably with AERONET retrievals in cases of vertical homogeneity in aerosol concentrations observed by lidars. When there existed multiple layers of aerosols, the two sets of measurements deviate and their disparity tends to increase with increase in aerosol loading. In general, ground-based measurements produces lower values of SSA than AERONET retrievals; consistent with the finding of *C. Li et al.* [2007] based on collocated PSAP and nephelometer measurements.

3.3. Question 3: What Is the Magnitude of Aerosol Direct Radiative Forcing in China?

[26] In previous studies, shipboard [*Markowicz et al.*, 2003] and ground-based radiometers [*Kim et al.*, 2005], aerosol transport-radiation models [*Takemura et al.*, 2003], in situ measured aerosol data and radiative transfer models [*Conant et al.*, 2003], and satellite radiance measurements [*Nakajima et al.*, 2003] were used to estimate the aerosol radiative forcing at the surface and at the top of the atmosphere (TOA) over the western Pacific and east Asia, an area under frequent influence of plumes from upwind aerosol source regions. At the surface, these studies generally found strong direct negative radiative forcing of more than 10 W/m^2 due to aerosol scattering and absorption. Relatively less has been done to quantify the aerosol radiative forcing over the inland areas of China. Many existing studies focusing on aerosol radiative forcing in China are based on model simulations rather than actual observations [e.g., *Giorgi et al.*, 2002; *Qian et al.*, 2003].

[27] A key step in differentiating the radiative effects of aerosols and clouds is to identify cloudy, hazy, and clean scenes. This poses a serious challenge over China because very high aerosol loadings can be difficult to distinguish from cloudy conditions. In this special section, *Z. Li et al.* [2007b] and *Xia et al.* [2007a] demonstrate the successful application of a number of cloud screening techniques combining direct/diffuse shortwave radiation measurements, temporal derivatives of shortwave fluxes, lidar measurements, and sky images. Aerosol reduction of surface shortwave irradiance was estimated at about 30 W/m^2 at the Liaozhong site in northeastern China, during the observation period from April to June 2005 [*Xia et al.*, 2007a]. At the Xianghe site near Beijing, the annual and daily (24 hours) mean aerosol radiative effect at the surface

(24 W/m^2) was only moderately lower than the cloud radiative effect (41 W/m^2) [*Z. Li et al.*, 2007a; *Xia et al.*, 2007b]. At the TOA, the aerosol radiative effect was only one tenth of that at the surface, suggesting strong heating of the atmosphere by aerosols [*Z. Li et al.*, 2007b]. At the Taihu site in southeastern China, the annual mean aerosol radiative effect amounts to 38.4 W m^{-2}. Heavy aerosol loading in this region leads to reductions of 112.6 W m^{-2} and 45.5 W m^{-2} in direct and global solar radiation, respectively, and an increase of 67.1 W m^{-2} in diffuse radiation reaching the surface [*Xia et al.*, 2007c].

3.4. Question 4: How Can EAST-AIRE Observations Help Validate and Improve Satellite Retrievals?

[28] The Moderate Resolution Imaging Spectroradiometer (MODIS), a well-calibrated multiwavelength satellite sensor, has been providing high-quality global aerosol products since 2000. Over land, MODIS retrievals are subject to errors originating primarily from inaccurate assumptions concerning surface reflectance and aerosol models. AERONET-observed AOD products have been extensively used to validate MODIS aerosol products around the world [e.g., *Chu et al.*, 2002; *Levy et al.*, 2005; *Ichoku et al.*, 2002; *Remer et al.*, 2005]. Prior to the EAST-AIRE, few comparisons were done over China [e.g., *Xia et al.*, 2004].

[29] Taking advantage of data from the two Chinese AERONET sites established under the aegis of the EAST-AIRE, *Mi et al.* [2007] made a detailed examination of MODIS Collection 4 (C004) and Collection 5 (C005) aerosol products over China. It was found that over northern China, errors in land surface reflectance resulted in substantial errors in C004 AOD. Over southern China where the land surface more closely matches the assumptions in the C04 retrievals, errors due to the preassumed SSA of 0.85 compared to 0.9 (retrieved from AERONET) dominated. With the incorporation of significantly improved land surface models and aerosol models into the retrieval algorithm [*Levy et al.*, 2007a, 2007b], the C005 MODIS aerosol products over China compare much better with AERONET observations.

[30] Compared to AERONET measurements, aerosol observations made by the CSHNET handheld Sun photometers provide less spectral information but offer much larger spatial coverage. The CSHNET data allow for validation of MODIS aerosol products over a range of distinct types of land surfaces. Similar to *Mi et al.* [2007], *Z. Li et al.* [2007a] found that the performance of MODIS C005 aerosol products were in much better agreement with ground aerosol measurements than MODIS C004 products. However, the performance of the MODIS C005 product varied greatly with surface and aerosol types, with overestimation of AOD over bright surfaces (deserts, semideserts, and urban areas) and underestimation of AOD over dark surfaces (forest). Smaller discrepancies were generally found when the MODIS-assumed surface reflectance was similar to the surface reflectance corrected under clean and clear sky conditions. Such comparisons provide further insight into the possible error sources of satellite retrievals and can thus help improve aerosol products in the future.

[31] SO_2 retrievals from the Ozone Mapping Instrument (OMI) onboard the Earth Observing System (EOS)/Aura satellite have also benefited from the EAST-AIRE data set. SO_2 profiles obtained during the EAST-AIRE aircraft IOC were used to correct the air mass factor (AMF) in OMI operational SO_2 retrievals, leading to substantially better agreement between aircraft-observed and OMI-retrieved SO_2 column amounts (N. Krotkov et al., OMI SO_2 validation over eastern China using in situ aircraft measurements, submitted to *Journal of Geophysical Research*, 2007). Improved OMI SO_2 retrievals successfully tracked a SO_2 plume originating from the flight area of the aircraft experiment, and gave reasonable estimates of SO_2 lifetimes [*Dickerson et al.*, 2007].

3.5. Question 5: How Are Aerosols and Precursor Gases Transported Out of the Source Regions?

[32] With the potential of lifting pollutants out of the PBL in a relatively short time, convection [e.g., *Dickerson et al.*, 1987] and the warm conveyor belt (WCB, the large-scale isentropic upward motion within the warm sector of a midlatitude wave cyclone) [e.g., *Bey et al.*, 2001] have been proposed as major mechanisms responsible for long-range transport of aerosols and precursor gases. Both processes are well characterized over North America and the north Atlantic through extensive aircraft measurements [e.g., *Bertram et al.*, 2007]. To date, most of the aircraft measurements investigating pollutant plumes out of east Asia were conducted over the western Pacific, downwind of the major emission sources in China. These studies generally emphasized the role of WCB in pollutant transport from east Asia [e.g., *Cooper et al.*, 2004; *Mari et al.*, 2004] because convection is often localized and its effects are not readily discernable in downwind regions.

[33] During the April 2005 EAST-AIRE aircraft IOC, eight research flights were made under a variety of weather conditions in northeastern China centered over Shenyang, a large industrial city 650 km northeast of Beijing. Vertical profiles of trace gases and aerosol optical properties were obtained in both warm and cold sectors of midlatitude cyclones, showing distinct chemical characteristics ahead versus behind cold fronts. Substantial amounts of pollutants were found well above the PBL during the flight on 5 April [*Dickerson et al.*, 2007]. Trajectory analysis and satellite observations suggest that the enhanced pollutant levels at higher altitudes were likely convectively lifted in the regions west of Shenyang and then transported by westerly winds. The WCB did not effectively vent pollutants out of the PBL over land, but intensified once the cyclone moved off the Chinese coast. In this particular case, over land, dry (nonprecipitating) convection may be more efficient in lifting pollution out of the PBL. There was large-scale lifting of pollutants associated with a cyclone on 11 April. However, in this case, the pollutants only ascended to a limited height over land (within the PBL) and had little potential for long-range transport, confirming the episodic nature of trans-Pacific transport.

[34] Such case studies shed light on the mechanisms of long-range pollutant transport out of east Asia. A better understanding the relative roles of WCB and convective processes under different situations necessitates an integral approach incorporating in situ measurements, satellite observations, and model simulations so that knowledge

about which transport mechanisms are most important in particular situations. To this end, it is necessary to analyze various satellite data sets, conduct more field experiments and run more model simulations.

3.6. Question 6: What Are the Effects of Increasing Atmospheric Pollutants on the Ecosystems of China and What Are the Effects of Urbanization on Weather and Climate?

[35] While much attention has been paid to the health and climatic effects of aerosols and trace gases, there is accumulating evidence suggesting the effects of air pollutants on ecosystems. Through interactions with radiation, aerosols may perturb the carbon budget [e.g., *Gu et al.*, 2003] and reduce agricultural yields [*Chameides et al.*, 1999a]. An essential nutritional element for plant growth, nitrogen deposition in the form of nitrogen-containing aerosols and gases may also alter the functioning of ecosystems [e.g., *Tian et al.*, 2003]. Ozone, an important gas pollutant closely related to the generation of secondary particles, may adversely affect ecosystems and decrease crop yields [*Aunan et al.*, 2000; *Chameides et al.*, 1999b].

[36] Using available precipitation chemistry measurements and ambient trace gas monitoring, *Lü and Tian* [2007] estimated wet and dry deposition of nitrogen over China from 1990 to 2003. They found the mean nitrogen deposition rate over south-central China was higher than in the Unites States and Europe, probably because of rapid industrialization in that region. Large areas in China with sensitive ecosystems, such as coniferous forests, grasslands and deserts, are under the risk of nitrogen saturation or even acidification. A rise of 7–8% in nitrogen dry deposition was found over China, by comparing the averaged dry deposition fluxes during 1999–2003 and 1990–1994. Consequently, air pollution in China may pose threat to a range of ecosystems. Another paper [*Ren et al.*, 2007] estimated the influence of ozone on net primary product and carbon storage in terrestrial ecosystems in China, highlighting a possible link between air pollution and the carbon cycle. Their simulation results showed that elevated O_3 could result in a mean 4.5% reduction in NPP and 0.9% reduction in total carbon storage nationwide from 1961 to 2000. The O_3 effects on carbon fluxes and storage are dependent upon environmental factors. The effects of O_3 should thus be taken into account in order to accurately assess the regional carbon budget in China.

[37] It has long been recognized that temperatures over urbanized areas are commonly higher than over the surrounding rural areas, the so-called "urban heat island" (UHI) effect [*Oke*, 1976]. On local scales, the effects of urbanization on climate may be comparable to or even greater than those directly associated with greenhouse gas accumulation. Utilizing MODIS-retrieved land surface temperature/emissivity, vegetation indices, BRDF/Albedo, and land cover products, *Wang et al.* [2007] identified the prominent UHI effect of the Beijing metropolitan area, where the daytime temperature difference between the city center and suburban areas can be more than 10°C in summer, although distinctive diurnal and seasonal variations exist. Less evaporation over the urban region, different thermal parameters between urban and rural areas, and anthropogenic heat fluxes from the urban area were proposed as major factors controlling the seasonal and diurnal patterns in the UHI effect.

4. Summary

[38] East Asia with China at its heart is one of major aerosol source regions in the world. While aerosols of natural origin (e.g., dust) continue to be a severe problem for this area, particles of anthropogenic origin (e.g., sulfates) have significantly increased over the past few decades. Aerosol impacts are likely substantial, but these effects are not well identified or quantified because of insufficient knowledge and understanding of the interactions of aerosols with ecosystems and climate.

[39] Through a cooperative research endeavor between Chinese and American institutions, a coordinated observation program was initiated, providing continuous high-quality measurements across China. It consists of twenty stations and two supersites making measurements on a routine basis over diverse climate zones and ecosystems within China. Intensive ground-based and airborne observation campaigns augmented the observational database. Some major findings during the first 3 a of the EAST-AIRE are reported in this special section. While previous observations confirm the existence of a haze layer over eastern China, the extensiveness of the EAST-AIRE network provides more detailed information about the temporal and spatial features of key aerosol properties and precursor gases. Simultaneous measurements of aerosols and irradiance has enabled the quantification of aerosol radiative effects, as well as development of few new SSA retrieval algorithms. Expanding high-quality ground-based aerosol observation networks (AERONET and CSHNET) to different regions in China enabled validation of and improvements in satellite retrievals useful for climate and ecosystem modeling. The vertical profiling capabilities of lidar and instrumented aircraft added to our knowledge of the vertical variations of aerosols and precursor gases essential for investigating aerosol effects on atmospheric stability and understanding the mechanisms of pollutant transport. Case studies with aircraft data shed some light on the potential role of dry convection on long-range transport of pollutants over east Asia. Aircraft-measured SO_2 profiles also helped improve satellite retrievals of this important pollutant. The effects of aerosols and trace gases on ecosystems and the carbon cycle were estimated using observational data. Satellites detected prominent urban heat island effects over Beijing, which was attributed to changes in the land surface due to the process of urbanization.

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