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ARM Mobile Facility Deployment in China 2008 (AMF-China)

Science Plan

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and

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Executive Summary

The ARM Mobile Facility deployment in China (AMF-China) is a field experiment designed to collect a comprehensive dataset that can be used to study the impact of heavy aerosol loading on radiative fluxes, clouds, and precipitation, as well as the general climate in China and downstream regions. The rapid pace of changes in the atmospheric environment provides a natural testbed for identifying and quantifying the direct and indirect effects of aerosols on climate. To date, little insight has been gained on both aerosol properties and their climatic effects due to a lack of observations. This represents a major source of uncertainties in the estimation of regional and global climate forcing.

The AMF-China mission includes the following observation campaigns:

- Deployment of the main AMF in Shouxian from March to December
- Deployment of the ARM Ancillary Facility (AAF) in northern China from March to May
- Enhancement of two from the East Asian Study of Troposheric Aerosols: An Internation Regional Experiment (EAST-AIRE) baseline sites from the
- Experimental in situ observation campaigns.

By analyzing the extensive observational data (including satellite products) in combination with modeling, we address the following scientific questions:

- What are the properties of both anthropogenic and natural aerosols in China?
- How different are cloud microphysics in heavily polluted regions from those in clean regions?
- How do aerosols influence cloud microphysics, liquid water content, drizzle formation, and rainfall?
- What are the impacts of aerosols emitted in China on the East Asian monsoon system, as well as on regional and global climate?

The overall objectives of the AMF-China are:

- To acquire essential cloud, aerosol, and meteorological parameters for the study of its climatic effects in China
- To understand the mechanisms of the AIE under the special conditions of the region
- To examine the roles of aerosols in affecting regional climate and atmospheric circulation with a special focus on the impact of aerosols on the East Asian monsoon system.

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1. Introduction

Asia accommodates over 60% of the world's population and is the largest source of aerosol emissions in the world. Attention must be paid to Asian aerosols and their climatic, environmental and health effects, given their complex properties, far-reaching impact, and rapid changes, especially over China (Li 2004; Li et al. 2007a) and India (Ramanathan et al. 2005). Emissions of fine-mode aerosol particles are particularly strong in these regions (Breon et al. 2002), presumably due to air pollution from fossil and biofuel combustions. Dust storms, which are particularly prevalent during spring in eastern Asia, are another significant source of warming agents in the atmosphere. The annual mean aerosol optical depth (AOD) measured across China is 0.43 (Xin et al. 2007), which is about 3 times the global mean value measured at all the Aerosol Robotic Network (AERONET) sites (Holben et al. 1998; Dubovik et al. 2002).

The annual and daily mean aerosol radiative effect (ARE) amounts to 25 Wm^{-2} at a site near Beijing (Li et al. 2007b). However, the ARE at the top of the atmosphere (TOA) is virtually nil, indicating that much of the reduced energy is trapped inside the lower atmosphere. The enhanced heating in the boundary layer may stabilize the atmosphere and suppress precipitation over China (Zhao et al. 2006; Rosenfeld et al. 2007).

The magnitude of AOD has shown a general increasing trend since the 1960s (Luo et al. 2001). The increase in aerosol loading is a likely cause for changes in several key climate variables. Perhaps the most noticeable change to the general public is a reduction of 35% 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% (Liang and Xia 2005), and global total solar radiation decreased by about 4.6% per decade (Shi et al. 2007). The decrease in solar radiation is at odds with a general decreasing trend in the annual mean cloud cover (1-3%/decade) and rainy days (1-4% /decade) observed at many ground stations (Kaiser 1998; Liang and Xia 2005), which is consistent with changes in the frequencies of cloud-free sky and overcast sky (Qian et al. 2006). The increase in AOD is likely the major cause for the cooling trend in central eastern China (Xu et al. 2006). Changes in precipitation are also considerable with a general trend of "south flood and north drought." Using model sensitivity tests, Xu. (2001) and Menon et al. (2002) attempted to attribute the change in the precipitation pattern to the aerosol direct effect.

The aerosol direct effect may contribute to the weakening of the Asian monsoon system. From an analysis of wind data in China, Xu et al. (2006) found that the surface wind speed associated with the East Asian monsoon has weakened significantly in both winter and summer during the past three decades. From 1969 to 2000, the annual mean wind speed over China has 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 is highly correlated with incoming solar radiation at the surface, which is very sensitive to aerosol loading. This is not surprising because the monsoon circulation is driven mainly by differential heating between the land and ocean. The dimming effect of aerosols (Wild et al. 2005) reduces the heating over land, and thus diminishes the temperature difference between the land and ocean and weakens the strength of the monsoon (Lau et al., 2008). The weakening of the East Asian monsoon system would be unfavorable for water vapor transportation from south to north, prolonging the stay of the rainbelt in the south, and thus exacerbating the trend of "south wetting and north drying." To unravel the complex interactions between aerosols and the Asian monsoon system, the "Asian

Monsoon Year-2008" (AMY08) initiative has been proposed and is endorsed by the Climate Variability and Predictability (CLIVAR) program and Global Energy and Water Experiment (GEWEX) as a major international collaborative project. The AMY08 will integrate ongoing and planned multi-national observational and modeling projects aimed at improving our understanding of the roles of radiation-monsoon-water cycle interactions for which aerosol is a key agent linking all three components.

Several previous international field experiments conducted in the Asian region, such as the Indian Ocean Experiment (INDOEX) and Aerosol Characterization Experiment (ACE)-Asia, led to many significant findings (Nakajima et al. 2003; Ramanathan et al. 2001; Huebert et al. 2003). However, few measurements were collected in or near source regions inside China. A breakthrough was achieved by the East Asian Study of Tropospheric Aerosols: an International Regional Experiment (EAST-AIRE) (Li et al. 2007a) that resulted in the acquisition of extensive measurements used to characterize aerosols and to determine their direct radiative effects (Li et al. 2007b; 2007c; Chaudhry et al. 2007; Xia et al. 2007), as well as their precursor gases (Li et al. 2007d). However, the experiment was not suited to address aerosol indirect effect (AIE) issues due to the lack of instruments to characterize aerosol hygroscopic properties, cloud condensation nuclei (CCN), and cloud microphysics. This hinders our understanding of the interactions between aerosols, clouds and precipitation. The deployment of the AMF will remedy this limitation to a considerable extent.

2. Overview of Observation Programs

2.1 Objectives

The overall objectives of the ARM Mobile Facility deployment in China (AMF-China) are to**:**

- Acquire essential cloud, aerosol and meteorological parameters for the study its climatic effects in China
- Understand the mechanisms of the AIE under the special conditions of the region
- Examine the roles of aerosols in affecting regional climate and atmospheric circulation with a special focus on the impact of aerosols on the East Asian monsoon system.

By combining the capabilities of the AMF and the East Asian Study of Troposheric Aerosols: An International Regional Experiment (EAST-AIRE), we will have an unprecedented opportunity to pursue studies concerning both direct and indirect effects of aerosols over this important climatic region. Figure 1 shows the locations of EAST-AIRE observation sites and AMF/ARM Ancillary Facility (AAF) deployment sites. Specific conditions at each observation site and instrumentation are given below. In addition to these ground observations, airborne and balloon field campaigns are also planned.

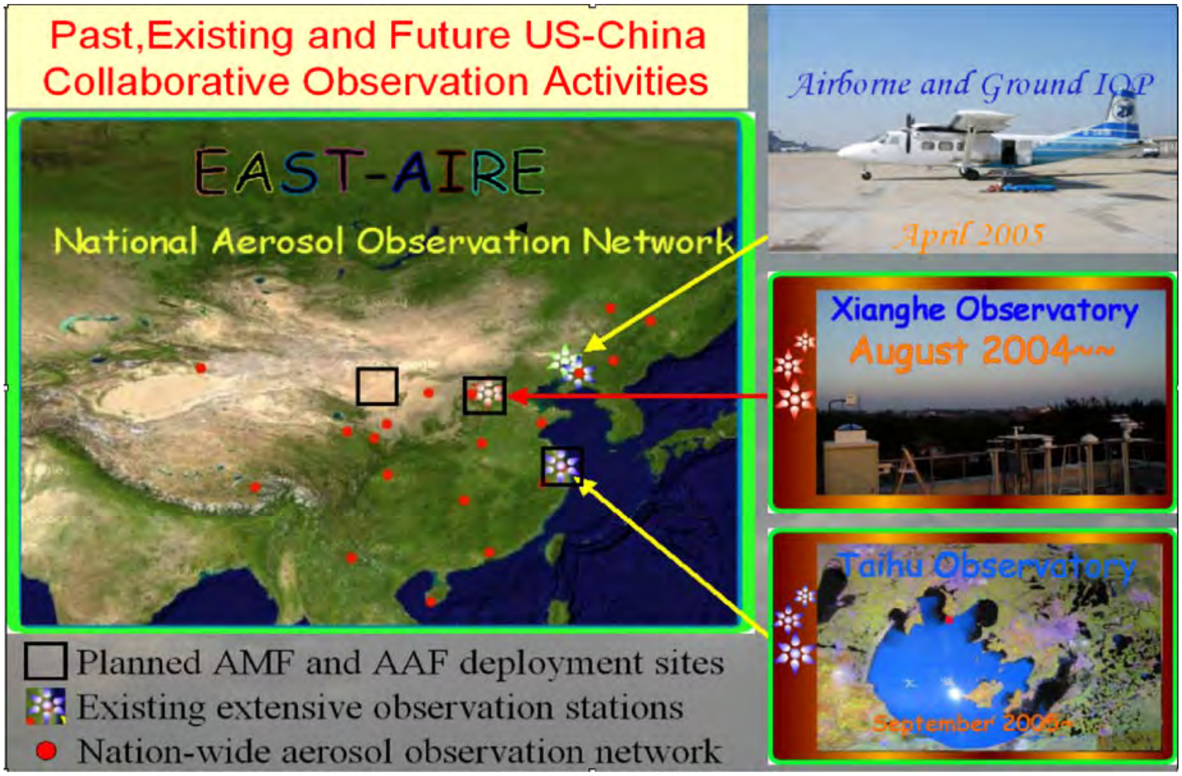

Figure 1. Locations of EAST-AIRE observation stations in China.

2.2 Observations

Observations include:

- Deployment of the AMF and the AAF in China for the acquisition of extensive measurements of aerosols, cloud, precipitation and radiation in northern and southern China, which are characterized by distinct climates and aerosol emissions
- Continued operation and enhancement of two EAST-AIRE baseline ground observation stations in Taihu and Shouxian and nation-wide aerosol survey stations so that major types of aerosols are characterized and their temporal and spatial variations across China are quantified.

The AMF and AAF will operate at three locations representing distinct climatic and environmental conditions, as illustrated in Figures 2 and 3. The AMF will be stationed in Shouxian (May-December) and Anhui in southeastern China. The AAF will be deployed in Zhangye (April-June) in northwestern China, in Xianghe (July-December) in northeastern China. A supplementary station will be operated at Taihu in southeastern China with substantially enhanced capability.

2.2.1 Southern Sites: Shouxian and Taihu

The primary AMF site will be located at Shouxian, approximately 500 km west of Shanghai, in the Jiang-Huan prairie region between the Huai and Yanzi rivers. The site is located at the edge of a rural town with a population of approximately 70,000 and is largely surrounded by farmland. The environment is somewhat similar to the Southern Great Plains (SGP) region, except with a much higher aerosol loading, as shown in Figure 4. The annual mean AOD is about 0.65 with the highest and lowest values occurring in summer and winter, respectively.

The first climate observatory established by the China Meteorological Adminstration (CMA) is located at Shouxian. The station was chosen for conducting several national and international meteorological experiments such as the Huaihe River Basin Energy and Water Cycle Experiment (HUBEX) under the aegis of GEWEX-Asian Monsoon Experiment (GAME), the Lower Atmosphere and Precipitation Study (LAPS), and two Chinese national basic research programs studying the mechanisms of flooding and other severe weather events. Thanks to these projects, dense observation networks have been established including manned and unmanned meteorogological stations, a Doppler radar network, and a hydrological network, in addition to the state-of-the-art infrastructure of the station.

The AMF consists of six instrument shelters, a baseline suite of instruments (see Tables 1 and 2 for a complete list) and equipment support, computers and data loggers for instrument access and data storage, computers for data communications, and computers and equipment in support of data systems. Instrument capabilities include standard meteorological instrumentation, a suite of broadband and spectral radiometers, and remote sensing instruments.

Figure 2. The various AMF and related sites: Shouxian (primary AMF site), Taihu (supplemental site), Zhangye and Xianghe (ARM Ancillary Facility) (Courtesy: U.S. Department of Energy's Atmospheric Radiation Measurement Program)

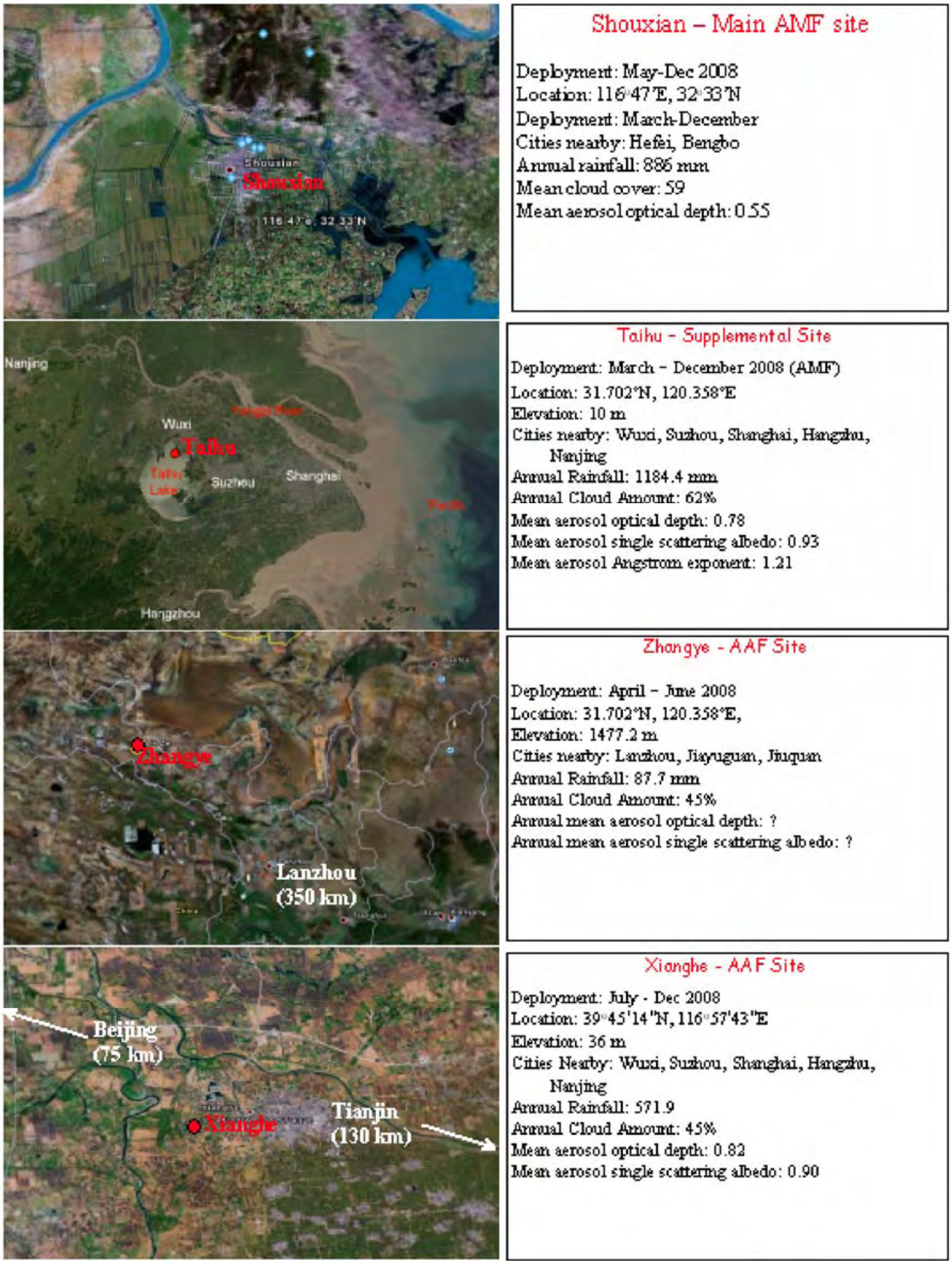

Figure 3. Geographic locations and meteorological conditions of four major ground observation stations used for AMF-China campaigns in 2008.

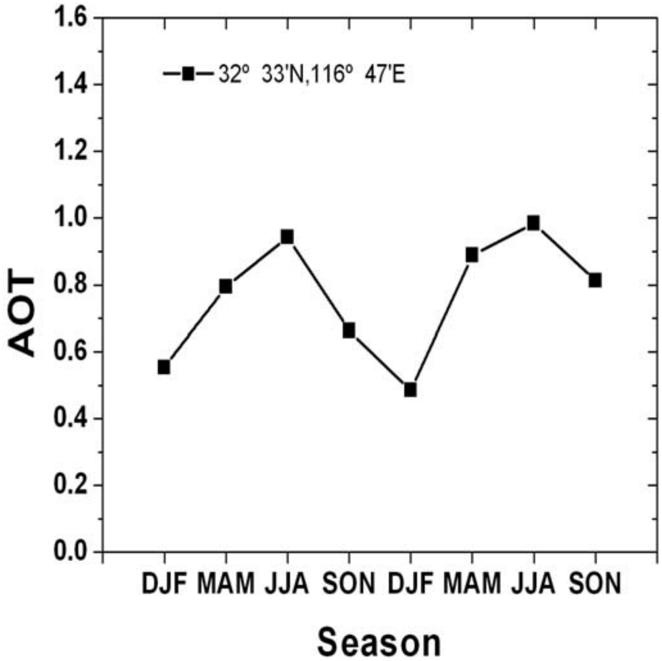

Figure 4. Aerosol optical depth at Shouxian retrieved from the moderate-resolution imaging spectroradiometer (MODIS).

Taihu is surrounded by several large cities in the Yangtze delta region: Shanghai, Hangzhou, Nanjing, Suzhou, and Wuxi (the closest). This is one of the fastest developing regions in China and probably also in the world, where the largest climatological discrepancy was found in satellite rainfall estimates from active and passive microwave rainfall sensors onboard the Tropical Rainfall Measuring Mission (TRMM) satellite. It was hypothesized that in the presence of high concentrations of sulfate aerosols, cloud particles would reduce in size to non-precipitating smaller sizes despite the high liquid water content (LWC). From the AMF campaign, we will be able to validate this hypothesis.

Separated by about 500 km, the two southern sites generally are influenced by similar weather/climate systems but different types of dominant aerosols. Figure 5 shows the dominant weather systems and circulation patterns in eastern and southern Asia. Shouxian and Taihu are located along the Meiyu front and the convergence zone of the eastern Monsoon system, where the moist southeasterly circulation driven by the subtropical high pressure in the western Pacific and the cold air from the north meet. They converge around the Jiang-Huai prairie region, producing a prolonged precipitation event called the Meiyu in the early summer season. Both locations abound in anthropogenic aerosols of differing types. At the heart of the industrial zone in the Yangtze delta region, Taihu is dominated by aerosols from industrial pollution, while Shouxian is more influenced by windswept soil and smoke from the burning of agricultural residues.

Table 1. Instruments and infrastructure of the AMF deployed at the Shouxian.

Instruments	Description
SKY Rads	Radiometers: (2 x PSP, pyranometer – global, diffuse – B/W) 2 x PIR (pyrgeometer), 1 x NIP (pyrheliometer)
SKY IRT	IR thermometer
GRD Rads	Radiometers: (1 x PSP, pyranometer – global, 1 x PIR pyrgeometer)
GRD IRT	IR thermometer
TRK	Solar tracker
MFRSR	Radiometer – multi-filter rotating spectral
SMET WD	Anemometer – wind direction
SMET T/RH	Temp/humidity
SMET BAR	Barometer
SMETORG (815)	Optical rain gauge
PWD	Present weather detector
TSI	Total sky imager (camera)
ECOR	Eddy correlation – surface flux
BBSS Digicora/Ant	Balloon borne sounding system - Digicora Rx, radiosondes, balloons, helium, antennas
CEIL	Ceilometer – cloud height boundary layer detection
MPL	Micropulse lidar – upper level cloud detector
MWR	Microwave radiometer – integrated cloud liquid and water vapor
MWRP	Microwave radiometer profiler
NFOV	Narrow field-of-view spectral radiometer
AERI	Interferometer – water vapor temperature profiles
WACR (95Ghz)	W-band ARM cloud radar
CIMEL	Sun photometer – spectral radiometer
RWP (1290Mhz)	Radar wind profiler
FRSR	Radiometer
MWR 10/190	Microwave radiometer
TSI nephelometer - Dry	TSI 3563 nephelometer at low RH
TSI nephelometer + humidograph	Nephelometer + humidograph system for scanning RH
RR PSAP	Radiance research 3 wavelength particle soot absorption photometer
CNC	TSI 3010 condensation nuclei counter
CCNC	DMT cloud condensation nuclei counter
Infrastructure	
GENSET	Stand-by power generator 1 x 20 ft sea container
Instrument shelters x 6	5 x 20 ft, 1 x 12 ft sea containers
Masts x 2	30 ft Meteorological, 40 ft Aerosol sampling.
Data system	Data logging storage and transmission

Table 2. Instruments deployed at Taihu, one of the EAST-AIRE stations.

Instrument	Manufacturer/Contact	Measurements
Kipp & Zonen 1. CM21 radiometer 2. CM11B radiometer 3. PAR-LITE 4. CV2 ventilator 5. EKO STR-22 solar tracker.	Kipp & Zonen (USA) Inc. 125 Wilbur Place Bohemia, New York 11716 USA om http://www.kippzonen.com	Total (CM21) and diffuse radiation (CM22) with a ventilation system (CV2). All are placed on solar-tracking system Deployed at our hazemeter network
Eppley 1. 8-48 B&W radiometer 2. Normal Incidence pyrheliometer 3. ventilator model VEN 4. Precision infrared radiometer (PIR)	Eppley Lab12 Sheffield Avenue PO Box 419 Newport Rhode Island 02840	Diffuse and direct solar radiation; and a ventilator to be attached to 8-48 radiometer
Campbell scientific logger (CR10X-4M)	Campbell Scientific Inc. 815 W. 1800N Logan, Utah 84321-1784	Data acquisition
MFR-7 Rotating shadow band radiometer TSI440 Total Sky Imager	Yankee Environment Sys. Mark Beaubien 101 Industrial Blvd. Turners Falls, MA	Direct and diffuse spectral radiation Cloud fraction Cloud optical depth Cloud effective radius
Cimel CE-318	CIMEL Electronique 172 rue de Charonne 75011 Paris, France	Direct spectral radiance, aerosol optical depth, single scattering albedo, & size distribution
Microwave radiometer profiles (12-channel)	Radiometric Corp. 2840 Wilderness Place #G Boulder, CO 80301 USA	Total liquid water path (LWP) All-weather profiles of water vapor and temperature
Micropulse lidar with polarization	Sigma Space Corp. 4801 Forbes Boulevard Lanham, MD 20706	Aerosol extinction profile Detection of spherical and non-spherical particles Cloud bottom height
High-resolution spectrometer FieldSpec3	ASD Inc. 2555 55th St. Boulder, CO 80301	Spectral radiance and irradiance at a particular zenith angle and whole-sky view

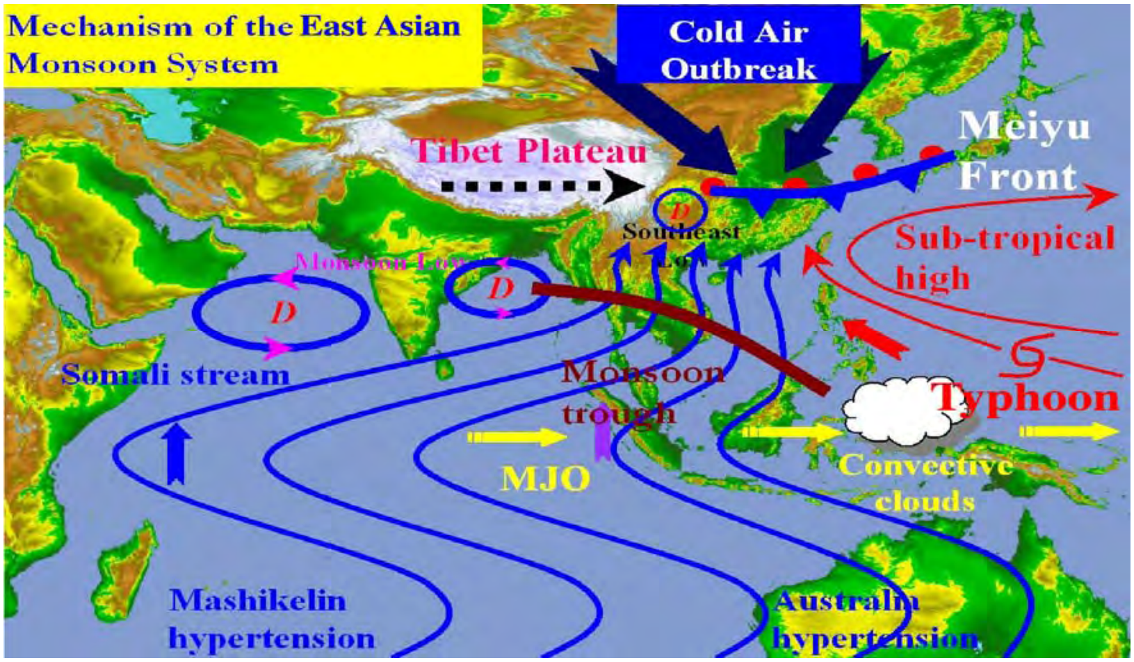

Figure 5. Schematic of the dominant weather systems and circulation patterns in eastern and southern Asia (Courtesy of Shouxian Climate Observatory).

2.2.2 Northern Sites: Xianghe and Zhangye

In addition to the AMF, the AAF will operate in sequence at two northern sites: Xianghe in the east and Zhangye in the west. Xianghe is the first station established under the aegis of EAST-AIRE and has been in continuous operation since 2004. Its observational capability will be considerably augmented by the AAF whose instruments are listed in Table 3.

These two northern sites are much drier and less cloudy than the two southern sites. This will enable the study of the AIE under different background conditions and, in particular, the role of aerosol swelling effects. Xianghe and Taihu are located in the center of China's most developed region but have drastically different precipitation regimes. In northern China, most of the precipitation falls during two summer months, while in southern China, precipitation is more uniformly spread throughout the year.

The Xianghe site is exposed much more frequently to episodes of coarse-mode aerosols, especially dust storms in early spring. Dramatic airmass changes occur frequently in the region and dictate the buildup, dispersion and transformation of aerosols, as seen in Figure 6. Such drastic episodic changes in aerosol conditions provide a unique opportunity to investigate the interactions between aerosols and the dynamic system.

The goal of deploying the AAF at the Zhangye site is to gain knowledge about dust aerosols. This site experiences very little precipitation, given its location in the Gobi Desert. Dust storms originating from this region can travel across China and the Pacific Ocean, reaching the North American continent. To date, few in situ measurements have been made from source regions of dust storms in China (Xuan and Sokolik 2002).

Table 3. AAF instrument package available for the 2008 field campaign.

Instrument	Serial Number	Measurement Range
Pyranometer	PSP, #32107F3	0.4~3 um
	PSP, #32188F3	0.7~3 um
	PSP, #32759F3	0.3~4 um
	PSP, #34252F3	0.3~3 um
	B/W, #21563	0.3~3 um
	CM21, #980563	0.3~3 um
	CM21, #980564	0.4~3 um
	CM21, #020992	0.7~3 um
	TSP, #9801-2	0.3~3 um
Pyrheliometer	NIP, #31823E6	0.3~3 um
	NIP, #33858E6	0.4~3 um
	NIP, #33875E6	0.7~3 um
	CH1, #000240	0.3~3 um
Pyrgeometer	PIR, #32193F3	4~50 um
	PIR, #32194F3	4~50 um
	CG4, #990005	4~25 um
UV	NELU-UV, #30	305, 312, 320, 340, 380, 400~700 nm
Sun photometer	Cimel, #	340, 380, 440, 500, 670, 870, 940, 1020 nm
	MFR, #401	414, 498, 614, 672, 866, 939, 400~1000 nm
	S3	340, 380, 440, 500, 670, 870h, 870v, 940, 1020, 1240, 1640, 2130 nm
Spectrometer	UV	0.28~0.45 um
	ASD, #6145	0.35~2.5 um
	MR100, #SZM4344W	3~20 um
Micropulse lidar	MPL 018	532 nm
Solar tracker	2AP	0~360 deg azimuth, 0~90 deg elevation
Sky imager	TSI440	RGB
Standard lamp	1800-02L, #ORC378	150W
Air pressure	CS105	600~1060 hPa
Temperature and RH	HMP45C	-40~60 C, 0~100 %
Water content sensors	CS615-L	
Wind speed/direction	Met One 034A, #Y2271	0~49 m/s, 0~360 deg
Optical rain gage	ORG-815-DA, #02030211	
Weather transmitter	WXT510, #A4010010	P, T, RH, Ws, Wd, rain rate
Tethered balloon	N/A	0~1.5 km
Aethalometer	AE16-HS-P3-F0, #500:0407	370, 430, 470, 520, 590, 700, 880 nm
APS	3321, #1329	0.5~20 um
Nephelometer	3563, #1088	450, 550, 700 nm
Nephelometer	M903, #393	530 nm
Nephelometer	M903, #394	531 nm

Table 3. (contd)

Nephelometer	M903, #395	532 nm
SMPS	3936L10, #70417455	0.01~1 um
TEOM aerosol chemistry	140AB244580302	PM1, PM2.5, PM10
Gase calibrator	146C-411405908	
CO_2 concentration	41C-509111189	1000 ppm
NO_x concentration	42C-77914-387	100 ppm
SO_2 concentration	43C-77808387	1 ppm
CO concentration	48C-77438-386	100 ppm
O_3 concentration	49C-77443-386	1 ppm

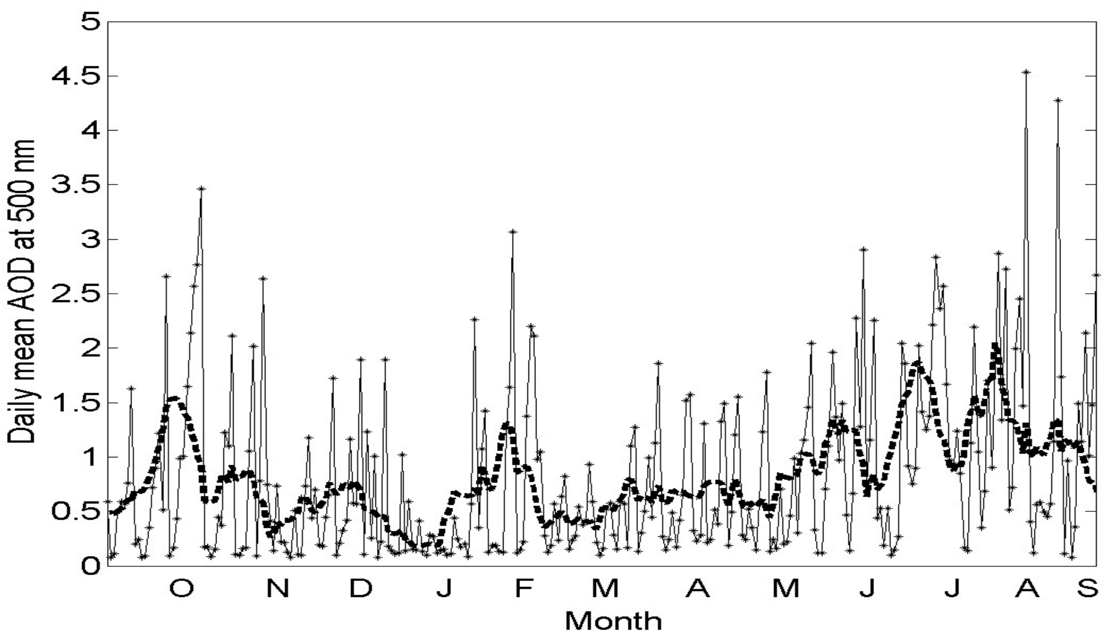

Figure 6. Daily mean aerosol optical depths measured by a Cimel sunphotometer from October 2004 to September 2005 at the Xianghe site. The dashed curve shows the 10-day running averages of the AOD (Li et al. 2007b).

3. AMF-China Science Questions

Four science questions will be addressed during the AMF-China deployment:

- What are the properties of both anthropogenic and natural aerosols in China?
- How different are cloud microphysics over heavily polluted regions from those found in clean regions?
- How do aerosols influence cloud microphysics, liquid water content, drizzle formation, and rainfall?
- What are the impacts of aerosols emitted in China on the East Asian monsoon system, as well as on regional and global climate?

3.1 What are the properties of both anthropogenic and natural aerosols in China?

To understand the climatic effects of heavy aerosol loading in China, we must first gain extensive knowledge regarding their physical, chemical, optical, and hygroscopic properties, both on the ground and throughout the atmospheric column. To this end, four observation sites are equipped with aerosol sensors of various types to measure aerosol optical depth, size distribution, scattering and absorption, and CCN. The vertical profiles of aerosol will be measured by a micro-pulse lidar (MPL).

China is a vast country with diverse sources of aerosol emissions of distinct properties. To a first order of approximation, aerosol sources fall into two broad categories: a natural source (mineral dust) and anthropogenic sources (from industrial and farming activities). The first source is located primarily in the dust regions of western and northwestern China. During the spring of 2008, the AAF will be deployed in western China for measuring mineral dust and dust storms. From June to the end of the year, it will be relocated to northern China for monitoring both dust and pollutants in northern China. The two southern sites are particularly suited to monitor aerosols from intensive industrial activities in the Yangtze delta region and intensive farming activities in Shouxian.

These ground-based measurements will be used to validate and improve satellite retrievals so that the spatial distribution of aerosols can be obtained with an acceptable accuracy for modeling studies. Several space-borne instruments have provided retrievals of aerosol properties (primarily optical thickness) from several Earth Observation System (EOS) platforms: the Moderate-Resolution Imaging Spectroradiometer (MODIS) on the Terra and Aqua platforms (Kaufman et al. 1997; Remer et al. 2005), the Multi-Imaging Spectroradiometer (MISR) on the Terra platform (Kahn et al. 2001), and the Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO). The majority of aerosol remote sensing studies have been restricted to dark surfaces (e.g., Kaufman et al. 1997). The combination of bright surfaces and absorbing aerosols often encountered in China makes the retrieval of aerosol optical thickness particularly cumbersome. The choice of an aerosol model plays a key role in the retrieval of AOD. Use of different aerosol models causes large discrepancies in the retrieved AOD products (Jeong and Li 2005; Jeong et al. 2005). While the new version of the MODIS aerosol product (Collection 5) is a substantial improvement over previous versions (Li et al. 2007c), use of only three aerosol models leads to large errors in the retrievals of AOD. In situ and ground-based aerosol measurements will help in the development of new aerosol models specific to the region. A key piece of critical information missing for studying AIE is the aerosol extinction vertical profile; this will be derived from ground-based lidars.

3.2 How different are cloud microphysics over heavily polluted regions from those found in clean regions?

There is growing evidence that aerosols can modify cloud microphysics, but the dearth of cloud microphysical observations in China has made it difficult to explore whether such a modification occurs in the heavy aerosol loading environment of China. Recent analyses of satellite-retrieved cloud and aerosol data indicate that an increase in aerosol loading may decrease or increase cloud droplet size, depending on atmospheric environmental conditions (Li and Yuan 2006; Yuan et al. 2008). The relationship between droplet effective radius and AOD shown in Figure 7 will be validated. To encompass the range of potential impacts of aerosols on cloud microphysics in China, four locations in northern and southern China with distinct climate regimes and aerosol types were chosen. By comparing cloud microphysics observed at these sites, as well as those from the U.S. ARM Climate Research Facility (ACRF) sites and European ACRF-like sites, the issue of differences in cloud microphysics over heavily polluted regions and over clean regions can be addressed.

Studying AIE requires knowledge of cloud location, optical depth, particle size, liquid water content/path, and lifetime. The AMF has several instruments whose data can be used to derive an array of cloud parameters, and include:

- W-band (95 GHz) Cloud Radar
- Micropulse Lidar (MPL)
- Vaisala Ceilometer (VCEIL)
- Microwave Radiometer (MWR) and Microwave Radiometer Profiler (MWRP)
- Sky Imager
- MultiFilter Rotating Shadowband Radiometer (MFRSR)
- The Surface Meteorology Station (SMET).

From the sky imager, a continuous record of the sky condition will be archived. From the combination of ceilometer and cloud radar measurements, good information on cloud bottom and top heights will be collected. Cloud liquid water path will be retrieved from microwave water radiometer (MWR) measurements and, from the MFRSR, cloud optical depth (COD), AOD, and precipitable water amount will be obtained. Combining the COD and LWP from the MWR, the cloud effective radius can be calculated (Min and Harrison 1996; Kim et al. 2003). From the mobile surface meteorological station, one-minute statistics of surface wind speed, wind direction, air temperature, relative humidity, barometric pressure, and rain rate will be obtained.

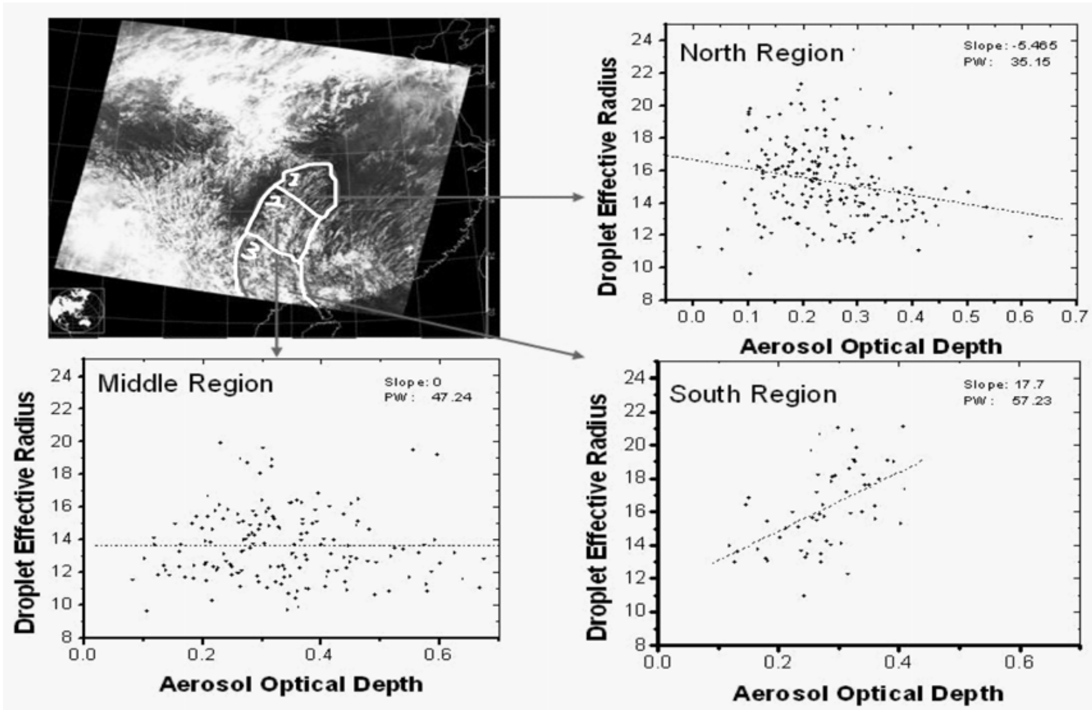

Figure 7. Dependence of cloud droplet size on aerosol optical depth over China.

Standard cloud variables (cloud-top height, column-integrated optical depth, droplet effective radius at cloud top, etc.) have been derived from multi-channel measurements made by MODIS (King et al. 2003). New and enhanced retrievals are also available, such as the cloud vertical structure for overlapped cirrus over water clouds (Chang and Li 2005a, b) and the cloud droplet effective radius (DER) profile for single-layer water clouds (Chang and Li 2002; 2003). Cloud vertical profiles can be verified directly against ARM value-added cloud products derived from a combination of ground-based radar and lidar data (Clothiaux et al. 2000). Validation of the DER profile needs to be constrained by the LWP retrieved from a ground-based MWR and cloud optical depth retrieved from the MFRSR (Min and Harrison 1996). In situ cloud microphysics data obtained from instrumented aircraft provide valuable direct measurements for validating ground-based and space-borne remote sensing products of cloud parameters. Measurements from the ground-based 95-GHz cloud radar data will be used to validate the retrievals of cloud geometric heights and layers that then can be used to study whether aerosols in the region have any impact on cloud development.

3.3 How do aerosols influence cloud microphysics, liquid water content, drizzle formation, and rainfall?

The wealth of information gained from the AMF will allow us to:

1. Identify the types of clouds that are distinctly affected by aerosols
2. Minimize the influence of atmospheric dynamics before relating cloud microphysics and aerosol parameters.

The Taihu site is ideally situated for testing this hypothesis. The site is surrounded by clusters of cities in the Yangtze delta region, one of the fastest developing regions in China. Berg et al. (2006) found indirect evidence of significant AIE on clouds and precipitation over the East China Sea next to this site. TRMM microwave imager data frequently indicate widespread light rain that is not detected by the precipitation radar. It was hypothesized that cloud particles would reduce in size to non-precipitating smaller sizes in the presence of high concentrations of sulfate aerosols despite the high liquid water content. Deployment of the MWR and MFRSR instruments at the Taihu site will provide an opportunity to test the hypothesis by virtue of the neighboring large water body over which cloud liquid path can be retrieved from satellite (AMSR-E) and compared to ground-based retrievals.

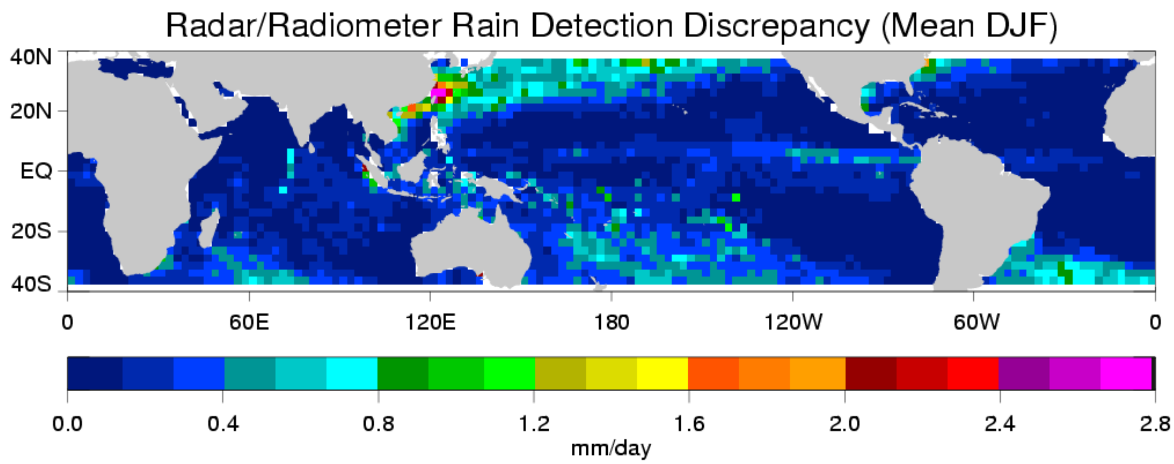

Figure 8. Climatological differences in rainfall detection between the TRMM microwave imager (TMI) and precipitation radar (PR) averaged during the winter over three years (Berg et al. 2006).

A key hypothesis to be tested is whether the presence of high sulfate aerosol concentrations in eastern China is responsible for the formation and maintenance of liquid water clouds with extremely high water contents, but little or no precipitation that often appear in satellite observations in the region (see Figure 8).

Analyses of various AMF datasets will lead to a better understanding of the connection between aerosol properties and the meteorological environment and will aid in quantifying aerosol impacts on the precipitation efficiency for warm clouds. This constitutes a necessary first step toward testing and improving process models.

Satellite data have been used to study the aerosol indirect effect on cloud microphysics (Kaufman et al. 1997; Nakajima et al. 2001) through the following ratios:

$$\mathrm{AIE} = -\Delta \ln r_e / \Delta \ln \tau_a \quad (1)$$

$$\mathrm{AIE} = -\Delta \ln r_e / \Delta \ln N_a \quad (2)$$

where r_e denotes the cloud DER. Aerosol optical depth and number concentration are represented by τ_a and N_a, respectively. N_a can be derived from MODIS or estimated from the product of τ_a and the Angstrom coefficient (Nakajima et al. 2001). A large range in the variation of the sensitivity of cloud microphysics to aerosols (a factor of 3 or more) was found

(Feingold et al. 2003). In this relationship, two critical assumptions are made that are subject to validation using the measurements made from the campaign:

1. τ_a a is a proxy of CCN
2. column-mean CCN is a proxy of CCN near the cloud bottom.

In situ measurements of aerosol and CCN to be made from an airborne campaign will help in evaluating these assumptions.

Detection and evaluation of the second AIE is more difficult than for the first AIE. Deployment of comprehensive remote sensing and in situ instruments provides opportunities to address the second AIE by coupling the approach used in Berg et al. (2006) with the theoretical analysis of Liu et al. (2004). Following similar approaches presented in Liu et al. (2005; 2006), the dependence of the threshold used to separate precipitating from nonprecipitating clouds in radar and TMI on the droplet concentration can be investigated with the AMF data. The results will be useful not only for addressing aerosol indirect effects, but also for improving remote sensing techniques.

3.4 What are the impacts of aerosols emitted in China on the East Asian monsoon system, as well as on regional and global climate?

In addition to alteration of cloud properties, aerosols in China may have an even stronger effect on atmospheric dynamics through which both precipitation intensities and patterns may be severely affected. Because the annual rainfall in northern China comes chiefly from precipitation associated with the summer monsoon, it is important to investigate whether aerosols have anything to do with the retreat or weakening of the monsoon system. Previous modeling studies of the Asian monsoon suffer from a lack of direct aerosol measurements. After sufficient data are collected by the AMF and other EAST-AIRE stations, the data can be used in a single column model (SCM), a global climate model (GCM), and a regional climate model (RCM) to evaluate the regional effects of aerosols on precipitation, radiation, cloud properties, and the Asian monsoon system.

To run an SCM, variational analysis (Zhang and Lin 1997) will be performed to take advantage of the frequent launches of radiosondes to derive a large-scale forcing dataset. The forcing data and AMF observations can be employed to test the implementation of 1) physically based schemes that treat droplet activation/nucleation in the Goddard Institute for Space Studies (GISS) SCM and GCM (Sednev et al. 2007); 2) a detailed aerosol microphysics scheme that can predict aerosol mass, number, and mixing state as described in Koch et al. (2007); and 3) prognostic equations for the prediction of cloud droplet number and ice crystal number, a bin-resolved cloud microphysics scheme (Khain and Sednev 1995) in the GISS SCM, and a two-moment cloud microphysics scheme (Morrison et al. 2005).

SCM and GCM simulations are tools to quantify the aerosol direct, semi-direct, and first and second indirect effects. In addition, model tests may be conducted to examine the roles that different dynamical regimes may play in modifying cloud responses to aerosols. Prior studies of aerosol effects over China, especially the monsoon response, assumed that absorbing aerosols constitute a relatively large proportion of total aerosols (Menon et al. 2002). The field measurements will provide information on the types of aerosols and their optical properties, as well as their vertical distribution, thus helping to quantify the role of absorbing aerosols on surface and atmospheric heating, energy fluxes (latent and sensible heating), and precipitation. The relative contribution of aerosols to the weakening or strengthening of the monsoon circulation then can be evaluated more realistically.

An RCM with parameterization schemes to cope with warm clouds, mixed-phase clouds, and the AIE (e.g., Cheng et al. 2007) will be used to study the effect of aerosol-cloud interactions on cloud microphysics. Observation data from the AMF will serve both as input data (e.g., sounding data, aerosol data) and validation data (e.g., cloud variables). For a tri-modal lognormal aerosol size distribution, prognostic equations are solved for the aerosol mass and water condensate (cloud and rain) droplet numbers, which includes consideration of the activation and deactivation of liquid condensates. AMF measurements in China will be used to evaluate the parameterizations similar to that done with ARM SGP data. The parameterizations will then be incorporated into regional climate models to study the aerosol indirect effect in the simulations of the East Asian summer monsoon and climate variability (Gong and Wang 2007; Zhang et al. 2007).

4. Concluding Remarks

The primary focus of the AMF-China deployment is to study the impact of aerosols on regional climate, especially on cloud, precipitation, and radiation and their dependence on aerosol type and regional meteorology, using ground-based observations from the AMF and auxiliary sites. In situ measurements of aerosol properties and their vertical distribution from ground-based lidar, airborne and balloon-borne experiments will be combined with measurements of cloud liquid water from the passive microwave radiometer and cloud droplet sizes from the W-band cloud radar to establish robust predictive relationships between cloud water, effective particle size, and aerosol concentration and the development of precipitation in warm clouds in a heavy aerosol loading environment. To account for the important dependence of these relationships on local meteorology, datasets from the full duration of the AMF deployment will be stratified using corresponding observations of the prevailing environmental conditions to establish the meteorological regimes that maximize the impact of aerosols.

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