DOE/SC-ARM-14-011

Ganges Valley Aerosol Experiment (GVAX) Final Campaign Report

VR Kotamarthi

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Office of Science, Office of Biological and Environmental Research

Acronyms and Abbreviations

AERI	Atmospheric Emitted Radiance Interferometer
AGU	American Geophysical Union
AMF	ARM Mobile Facility
AMSL	above mean seal level
AOS	Aerosol Observing System
ARIES	Aryabhatta Research Institute of Observational Sciences
ARM	Atmospheric Radiation Measurement
BC	black carbon
CAPE	convective available potential energy
CCN	cloud condensation nuclei
COSPAR	Committee on Space Research
DOE	U.S. Department of Energy
GVAX	Ganges Valley Aerosol Experiment
INDOEX	Indian Ocean Experiment
ISM	Indian Summer Monsoon
km	kilometer(s)
m	meter(s)
MPL	micropulse lidar
nm	nanometer(s)
PBL	planetary boundary layer
PSAP	particle soot absorption photometer
µm	micrometer(s)

Contents

1.0 Introduction

In general, the Indian Summer Monsoon (ISM) as well as the and the tropical monsoon climate is influenced by a wide range of factors. Under various climate change scenarios, temperatures over land and into the mid troposphere are expected to increase, intensifying the summer pressure gradient differential between land and ocean and thus strengthening the ISM. However, increasing aerosol concentration, air pollution, and deforestation result in changes to surface albedo and insolation, potentially leading to low monsoon rainfall. Clear evidence points to increasing aerosol concentrations over the Indian subcontinent with time, and several hypotheses regarding the effect on monsoons have been offered. The Ganges Valley Aerosol Experiment (GVAX) field study aimed to provide critical data to address these hypotheses and contribute to developing better parameterizations for tropical clouds, convection, and aerosol-cloud interactions. The primary science questions for the mission were as follows:

What effect do increasing aerosols in the Ganges Valley have on the ISM?

- Does the increase in mid tropospheric aerosols act as a heat pump and drive moist air over from the Indian Ocean to the northern parts of India and Tibet, thus extending the monsoons and causing earlier onset?
- Does the increase in mid tropospheric aerosol cause increasing cloud heating rates and lead to evaporation of clouds and decreased rainfall?
- What are the vertical profiles of the chemical, physical, and optical characteristics of the aerosols that cause one of the above to be true?

What effect does the diurnal planetary boundary layer (PBL) cycle in the Ganges Valley have on the atmospheric distribution of aerosols?

- Does the diurnal cycle in the PBL transport smaller and radiatively more active particles for mixing into the mid troposphere and regional-scale transport?
- Does the diurnal mixing of aerosols in the atmospheric column have an impact on measured cloud properties?

What effect do aerosols have on deep convective activity over the northern plains and the Ganges Valley region and how does this affect cloud formation?

- What effect do the changes in heating rates in the PBL have on convection?
- Does the PBL have a “lifted” profile as a result of aerosol heating, as proposed during the Indian Ocean Experiment (INDOEX) studies?
- What effect does the additional heating have on convective available potential energy (CAPE) in the PBL?
- What is the CAPE at cloud level as compared to the PBL?

2.0 Background

The Ganges Valley is one of most rapidly developing and densely populated regions in the Indian subcontinent. In recent decades, this area has been heavily exposed to air pollution arising from fossil fuel and biomass burning as well as mineral dust from the Thar Desert (Chinnam et al. 2006). Past studies (Bollasina, Ming, and Ramaswamy 2011; Meehl, Arblaster, and Collins 2008; Lau and Kim 2006; Ramanathan et al. 2005) suggest that the increased air pollution over this region has the ability to modify the annual Indian monsoon rainfall. This is explained as the increased aerosols tend to increase the surface temperature, which in turn could intensify the summer pressure gradient between land and ocean and hence strengthen the ISM (Hu et al. 2000). However, a recent study by Ganguly et al. (2012) indicates that the continuous increase of human-influenced aerosol emissions from local and distant sources over the Indian subcontinent reduce the mean monsoon precipitation. This is explained as the response of increased absorption of sunlight by these aerosols, which in turn produces a warming effect that reduces the cloud cover and weakens the monsoon rains in South Asia. Studies by Bollasina, Ming, and Ramaswamy (2011) and Wu (2005) also indicate similar weakening of Indian monsoon rains from increased aerosol concentration, but is due to the outcome of the slowdown in tropical meridional circulation that must be driven to counteract the energy imbalance forced by aerosols between the Northern and Southern Hemispheres. In addition to the region-specific impact of aerosols on climate, aerosols also perturb the incoming solar and outgoing longwave radiation by means of scattering and absorption—a direct effect. Absorbing aerosols such as black carbon (BC) tend to heat up the atmosphere and reduce the cloud cover—a semi-direct effect. Increased aerosol concentration leads to increased cloud condensation nuclei (CCN), leading to clouds of smaller droplet size. Due to their smaller size, these clouds are less efficient converting into raindrops—an indirect effect. Thus, aerosols affect the monsoonal climate system in a variety of ways, and it is more likely that the climate impact from aerosols in this region depends on more than one factor (Ganguly et al. 2012).

GVAX was a U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility deployment at the northern Indo-Gangetic Plain over the high-altitude site of Manora Peak, Nainital, from late June 2011 to March 2012. This complex field study used the ARM Mobile Facility (AMF) to measure radiative, cloud, convection, and aerosol characteristics over the mainland for a 10-month period. All of the AMF instrumentation was situated atop a building at, and operated from, the Aryabhatta Research Institute of Observational Sciences (ARIES) Observatory at Nainital.

The measurements were conducted at Manora Peak in Nainital (29° 21' 33.84" N, 79° 27' 29.27" E), about 280 kilometers (km) northeast of New Delhi, India. The site is located at 1980 meters (m) above mean sea level (AMSL) in the foothills of the Himalayan mountain range—far from major pollution sources from industries or cities. To the south and southwest of the site are regions of low elevation that merge with the vast Ganges Basin.

The AMF started operation in Nainital on 21 June 2011 and collected data until 31 March 2012, with a wide variety of in situ and remote sensing instrumentation. The aerosol observations performed from the Aerosol Observing System (AOS), included a 3-wavelength particle soot absorption photometer (PSAP; 470, 528, and 660 nanometers [nm]) to measure the particle absorption coefficient, a 3-wavelength nephelometer (450, 550, and 700 nm) to measure the total particle scattering and hemispheric backscattering coefficients, a condensation particle counter to measure the total number concentration of particles in the size range of 10 nm to 3 micrometers (μm) diameter, a single column CCN counter to measure total number concentration of particles in the size range of 1 µm to 10 µm diameter. The PSAP and nephelometer switch between aerosol particles of size <10 µm and <1 µm every 30 minutes. Other measurements of interest for this study included radiosondes launched every 6 hours, a state-of-the-art passive Atmospheric Emitted Radiance Interferometer (AERI), a multi-filter rotating shadowband radiometer that was operational for the entire sampling period, and a micropulse lidar (MPL) that operated between February and March 2012. In addition, various in situ sensors to obtain 1-minute statistics of surface meteorology such as temperature, relative humidity, precipitation, wind speed and wind direction were also used. A full list of instruments deployed and details of each instrument and their uncertainty corrections can be found at: http://www.arm.gov/sites/amf/pgh/instruments.

3.0 Preliminary Results

As a result of GVAX, the reason for the discrepancy between models and measurements of absorbing aerosols over this region is better idea understood. We can establish that a) most of the models underestimate because of the problems in the model representing aerosols in the boundary layer (2 km and below); b) an underestimate of the contribution of absorbing aerosols from agriculture residue burning; c) not accounting for absorbing aerosols of sizes >1 µm in the model calculation of absorption in this region; and d) the presence of brown carbon as a significant contributor to absorption. The last two points may prove to be quite important not only for this region but also for many other regions of the globe and is potentially the biggest outcome from the project.

4.0 Campaign Details

Campaign Duration and Location

June 10, 2011–March 30, 2012
Nainital, India

Collaborating Agencies

U.S. Department of Energy
Indian Space Research Organization

Project Leads

Dr. V. Rao Kotamarthi, Argonne National Laboratory
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Team Members

Prof. Sethu Raman, North Carolina State University
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Dr. Ram Sagar, Aryabhatta Research Institute of Observational Sciences, Nainital, India

5.0 GVAX Campaign Publications

5.1 Journal Articles and Manuscripts

Dumka et al. "Aerosol characterization at Nainital (1958 m AMSL) using the Atmospheric Radiation Measurement Mobile Facility (AMF-1)." Submitted.

Feng, Y, VR Kotamarthi, and R Coulter. 2014. "Modeling radiative impact of aerosols over S Asia constrained by observation of vertical distribution." In preparation.

Govardhan, G, RS Nanjundiah, SK Satheesh, KK Moorthy, and VR Kotamarthi. 2013. "Validation of the online chemistry transport model WRF-CHEM over Indian region." *Journal of Geophysical Research*. Submitted.

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Manish, N, VR Kotamarthi, N Singh, P Kumar, UC Dumka, R Kumar, N Ojha, P Bhardhwaj, and S Lal. "Surface observations of aerosols and vertical ozone profiling: Influence of the Indo Ganegtic Plain, biomass burning and LRT." In preparation.

Manoharan, VS, VR Kotamarthi, Y Feng, and M Caddedu. 2013. "Increased absorption by giant aerosol particles over the Gangetic-Himalayan region." *Atmospheric Chemistry and Physics Discussion* 13: 19837–19852. doi:10.5194/acpd-13-19837–2013.

Ojha, N, M Cadedu, VR Kotamarthi, and R Kumar. "Influence of aerosols on radiation budget at Nainital during GVAX." *Journal of Geophysical Research*.

Sahai, S, M Naja, N Singh, DV Phanikumar, UC Dumka, V Pant, A Jefferson, P Pant, R Sagar, SK Satheesh, KK Moorthy, and VR Kotamarthi. 2013. "Evidence of perturbed aerosol physico-chemistry over Central Himalayas caused by post-harvest biomass burning in Punjab region during autumn season." *Environmental Science & Technology*. In press.

5.2 Meeting Abstracts/Presentations/Posters

Feng, Y, VR Kotamarthi, A Jefferson, EM Wilcox, K Pistone, PS Praveen, RM Thomas, and V Ramanathan. 2012. "Observation-constrained estimation of aerosol climate impacts over S Asia." Presented at the American Geophysical Union (AGU) Fall Meeting. San Francisco, California.

Gogoi, M, S Babu, V Nair, S Satheesh, M Naja, and VR Kotamarthi. 2012. "Aerosol scattering and absorption properties over the Central Himalayan location Nainital: results from GVAX." Presented at the AGU Fall Meeting. San Francisco, California.

Govardhan, GR, RS Nanjundiah, S Satheesh, K Krishnamoorthy, and VR Kotamarthi. 2012. “Simulations of aerosols during pre-monsoon and post-monsoon periods over Indian region.” Presented at the AGU Fall Meeting. San Francisco, CA.

Kafle, DN, and RL Coulter. 2012. “Studies of aerosol vertical profiles during GVAX campaign using micropulse lidar.” Presented at the AGU Fall Meeting. San Francisco, California.

Manoharan, V, and M Cadeddu. 2012. “Influence of aerosol loading, water vapor and surface topography trends on the regional hydrology of the Indo-Ganges basin.” Presented at the AGU Fall Meeting. San Francisco, California.

Naja, M, N Singh, P Bhardwaj, UC Dumka, P Pant, R Sagar, S Satheesh, K Krishnamoorthy, P Kumar, and VR Kotamarthi. 2012. “Meteorological soundings during GVAX-RAWEX in the Central Himalayas: variabilities in trace species and role of dynamics.” Presented at the AGU Fall Meeting. San Francisco, California.

Pant, V, R Sagar, P Pant, K Krishnamoorthy, DV Phanikumar, and UC Dumka. 2012. “Measurement of aerosol physical properties at a high altitude station in Central Himalayas during RAWEX-GVAX.” Presented at the 39th COSPAR Scientific Assembly. Mysore, India.

Sahai, S, R Sagar, P Pant, K Krishnamoorthy, DV Phanikumar, UC Dumka, V Pant, N Singh, VR Kotamarthi, M Naja, and SK Satheesh. 2012. “Tracing the impacts of regional and local sources on the aerosols over Central Himalayan region during GVAX.” Presented at the 39th COSPAR Scientific Assembly. Mysore, India.

Singh, N, MK Naja, UC Dumka, DV Phanikumar, P Pant, R Sagar, S Satheesh, K Krishnamoorthy, and VR Kotamarthi. 2012. A41F-0040. Presented at the AGU Fall Meeting, December 2012. San Francisco, California.

Singh, N, MK Naja, UC Dumka, DV Phanikumar, P Pant, R Sagar, S Satheesh, K Krishnamoorthy, and VR Kotamarthi. 2012. “Local boundary layer, vertical motions measured with 1290 MHz profiler and Ceilometer cloud heights over a high altitude location in the central Himalaya.” Presented at the AGU Fall Meeting. San Francisco, California.

Shukla, KK, R Sagar, DV Phanikumar, UC Dumka, V Pant, N Singh, and S Sahai. 2012. “Preliminary observations of Doppler LIDAR.” Presented at the 39th COSPAR Scientific Assembly. Mysore, India.

Umesh, CD, M Naja, N Singh, DV Phanikumar, P Pant, R Sagar, SK Satheesh, K Krishnamoorthy, VR Kotamarthi, and A Jefferson. “Optical properties of aerosols from the Central Himalayas during RAWEX-GVEX field campaign.” Presented at the AGU Fall Meeting. San Francisco, California.

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Ganguly, D, PJ Rasch, H Wang, and J Yoon. 2012. "Climate response of the South Asian monsoon system to anthropogenic aerosols." *Journal of Geophysical Research* 117(D13209): 15, doi:10.1029/2012JD017508.

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