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Aerosol radiative effects over an urban location and a remote site in western India: Seasonal variability

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ABSTRACT

Seasonal variability in radiative effects due to aerosols in the shortwave and longwave regions is studied utilizing measured aerosol optical properties and models over two distinct environments, namely, Ahmedabad (urban, industrialised location) and Gurushikhar (high altitude remote site) in western India. Top of the atmosphere (TOA) forcing in shortwave varies from positive to negative over Ahmedabad, while over Gurushikhar it is negative throughout the year because of lower surface reflectance and higher single scattering albedo (SSA). Aerosol radiative forcing at the surface (SFC) is >-30 Wm^{-2} over Ahmedabad. In Gurushikhar SFC forcing increases from winter (-7 Wm^{-2}) to premonsoon (-14 Wm^{-2}), which is attributed to the increase in the amount of dust aerosol loading. Aerosol radiative forcing in the atmosphere (ATM) peaks during postmonsoon with a value of 54 Wm^{-2} over Ahmedabad, while ATM warming over Gurushikhar peaks during premonsoon (9 Wm^{-2}). Shortwave heating rate is >0.9 K d^{-1} over Ahmedabad while it is an order of magnitude lower over Gurushikhar.

Aerosols produce a positive TOA and SFC forcing in the longwave and cool the atmosphere. Anthropogenic influence is evident from the aerosol radiative effects obtained over Ahmedabad and Gurushikhar. The abundance of fine (coarse) mode aerosols over Ahmedabad (Gurushikhar) results in higher (lower) aerosol optical depth, lower (higher) SSA, and higher (lower) aerosol radiative forcing. Owing to the dissimilar nature of shortwave and longwave radiative effects of aerosols, when coarse mode aerosols are abundant over a region, longwave radiative effects can balance shortwave atmospheric warming produced by aerosols.

1. Introduction

Atmospheric aerosols from both natural and anthropogenic sources exert a cooling effect on the Earth's climate through direct and indirect effects which partially offset the warming caused due to greenhouse gases (Solomon et al., 2007). The potential for aerosol forcing of climate can vary according to regional differences in aerosol columnar concentration, chemical composition and the age of the air mass (Spencer et al., 2008). Manmade pollutant emissions can change the atmospheric composition contributing to climate change, and climate change in turn through changes in temperature, dynamics, the hydrological cycle, atmospheric stability, and biosphere–atmosphere interactions can alter the atmospheric composition (Isaksen et al., 2009). Aerosols exhibit regional signatures and depending on their chemical composition can either warm (black carbon) or cool (sulfate) the atmosphere. Aerosols still remain a major source of uncertainty in the prediction of climate change due to inadequate information on the variabilities of aerosol characteristics at regional and temporal scales. This uncertainty can be reduced by documenting the seasonal variations in aerosol radiative forcing over different locations in a region governed by different aerosol sources. This paper reports the seasonal variations in shortwave and longwave aerosol radiative forcing over two environmentally distinct locations in western India. Measured aerosol characteristics are utilized in conjunction with aerosol optical properties and radiative transfer models to estimate the aerosol radiative forcing. The results will serve as useful inputs for characterizing the radiative effects of aerosols over an aerosol source region, and becomes important in the context of regional and global climate change.

2. Study locations and meteorology

Ahmedabad (23.0°N, 72.5°E) is a densely populated (~5.8 million), industrialized, urban location in western India with several small and large scale industries including two power plants (Ramachandran and Kedia, 2010) (Fig. 1). Gurushikhar (24.6°N,

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72.8°E) in Mount Abu is a remote site located on a mountain top (~1.7 km above mean sea level (AMSL)) and lies north-east of the Thar desert. Ahmedabad and Gurushikhar, though are located in the same longitudinal belt, their environments are distinctly different. While Ahmedabad is a densely populated urban regime, Gurushikhar is a cleaner region devoid of any low altitude atmospheric pollution and has a population of only about 50,000. A comparison of results obtained from the two stations will help delineate the anthropogenic influence on aerosol radiative forcing.

Surface level synoptic winds during winter (December–January–February, DJF) are calm, north/northeasterly and are from the polluted northern hemisphere over the study locations. Temperatures are colder and relative humidity (RH) is less than 40% (Fig. 1). In premonsoon (March–April–May, MAM) winds originate and travel from/through a less polluted west (arid/marine); temperatures increase and RH differs only slightly when compared to winter. During monsoon (June–July–August–September, JJAS) winds are stronger, moist and are from the marine and western regions; both temperature and RH are high during this season, however, the increase in RH is more significant (Fig. 1c). During postmonsoon (October–November, ON) wind patterns start shifting in direction from south-west to north-east. Seasonal mean temperatures are similar to monsoon while RH reduces to about 40%. On the basis of meteorology, the results are grouped into four major seasons of winter, premonsoon, monsoon, and postmonsoon, and discussed.

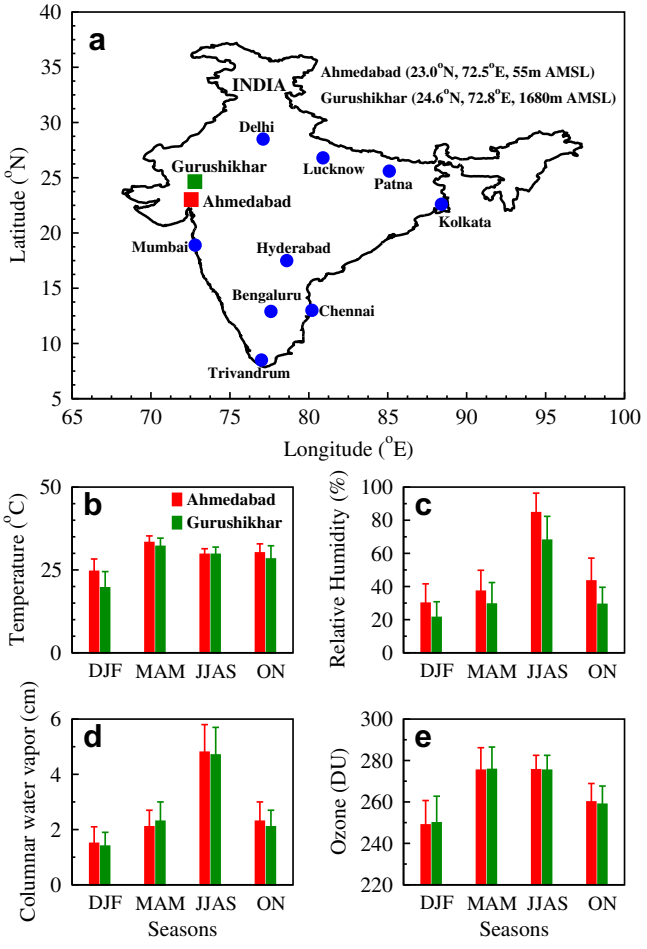

Fig. 1. (a) The study locations in western India – Ahmedabad and Gurushikhar, in addition to a few major cities in India. Latitude, longitude and altitude of both the study locations above mean sea level (AMSL) in meters are given. Seasonal mean (b) temperature, (c) relative humidity, (d) columnar water vapor concentration (cm) and (e) column ozone (Dobson Unit (DU)) over Ahmedabad and Gurushikhar. Vertical bars represent $\pm 1\sigma$ variation from the mean during each season.

3. Estimation of aerosol radiative forcing

3.1. Necessary inputs: aerosol optical properties

The principal input parameters required for calculating aerosol radiative forcing are aerosol optical depth (AOD), single scattering albedo (SSA) and asymmetry parameter (g). Aerosol optical depth is directly proportional to aerosol loading and the size distribution of aerosol mass burden in the atmospheric column; typically in an aerosol size distribution submicron aerosols will be orders of magnitude higher than supermicron particles. The size distribution is crucial to determine the SSA, as the value of SSA (whether high or low) is determined by the ratio of the number of absorbing to scattering particles in the aerosol size distribution. Asymmetry parameter depends both on the size distribution and chemical composition of aerosols. Single scattering albedo and asymmetry parameter also vary as a function of relative humidity. Thus, optical (aerosol optical depths), physical (mass concentration and/or size distribution), and chemical (composition) characteristics of aerosols are necessary to determine aerosol radiative forcing.

3.1.1. Aerosol optical depth

Aerosol optical depths (AODs) were measured in the wavelength range of 0.4–1.02 μm at 0.4, 0.5, 0.675, 0.875 and 1.02 μm over Ahmedabad and Gurushikhar using a hand held sun photometer (October, 2006–December, 2007), and a pair of Microtops-II sun photometers (Solar Light Co., USA) (January–December, 2008) at the wavelength bands centered around 0.38, 0.44, 0.50, 0.675, 0.87 and 1.02 μm (Morys et al., 2001). An inter comparison of AODs measured simultaneously with the hand held sun photometer and Microtops-II sun photometers everyday at an hourly basis during November 2007–February 2008 over Ahmedabad showed a very good agreement in the entire wavelength range ($R^2 > 0.94$) (Kedia and Ramachandran, 2011). Daily mean AODs in the 0.4–1.02 μm wavelength region measured during 2006–2008 are used to determine the seasonal mean.

3.1.2. Single scattering albedo

Over Ahmedabad SSA values are calculated from the ground-based measurements of scattering and absorption coefficients. Scattering and absorption coefficients of aerosols over Ahmedabad were measured using a 3-wavelength (0.45, 0.55 and 0.70 μm) integrating nephelometer (*3563, TSI Inc., USA*) and a 7-wavelength (0.37, 0.47, 0.52, 0.59, 0.66, 0.88 and 0.95 μm) aethalometer (*AE-47, Magee Scientific, USA*) respectively. Measurements of scattering and absorption coefficients of aerosols were conducted in a continuous mode in Ahmedabad during 2006–2008 at 5-min interval. The uncertainty in scattering coefficient taking into account the noise, calibration and truncation error is estimated to be a maximum of 15% (Ramachandran and Rajesh, 2008). The cumulative uncertainty in absorption coefficient due to changes in filter scattering caused due to aerosol loading, underestimation of aethalometer signal with increasing filter load, flow rate, filter spot area and detector response is found to be 10% (Ramachandran and Kedia, 2010). Absorption coefficient β_{abs} at three wavelengths (0.45, 0.55 and 0.70 μm) are calculated using the absorption coefficients measured at the 7 wavelengths mentioned above, following the wavelength dependence of aerosol absorption expressed as $\beta_{abs} = K\lambda^{-\alpha}$, where K and α are the absorption Ångström coefficient and α is a measure of spectral dependence of aerosol absorption. β_{abs} at