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Effect of aerosols on evapo-transpiration

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HIGHLIGHTS

- Aerosol radiative forcing (ARF) from model and direct observations compared.
- ARF reduces latent (LE) and sensible heat (H) fluxes by 14% and 16% respectively.
- Less reduction in LE is attributable to diffuse radiation-enhanced-photosynthesis.
- LE compensates ARF by 52% for wet soil and by 37% for dry soil.
- LE is more sensitive to saturation moisture deficit for a given ARF when SSA is low.

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ABSTRACT

Aerosol direct radiative forcing (ARF) at surface is estimated from instantaneous, simultaneous observations of global radiation and aerosol optical depth (AOD) during winter, pre-monsoon and monsoon seasons over a tropical Indian station at the south-eastern end of Indo Gangetic basin. A comparison of observed and model derived ARFs is made and possible reasons for mismatch are discussed. Aerosol-induced reduction in solar visible (0.4–0.7 μm) spectrum energy (SW_{vis}), contributing 44% to total broad band (0.3–3.0 μm) energy (SW), and its effect on surface energy fluxes are discussed in this study. Aerosols on an average reduce SW_{vis} at surface by ~27%. SW_{vis} reduces by 14.5 W m^{-2} for a 0.1 increase in AOD when single scattering albedo (SSA) is 0.979 where as it reduces by 67.5 W m^{-2} when SSA is 0.867 indicating the significant effect of absorbing aerosols. Effect of ARF on net radiation, Rn, sensible heat flux, H and latent heat flux/evapo-transpiration, LE are estimated using the observed ratios of Rn/SW, H/Rn and LE/Rn, having reasonably good correlation. Observed Rn/SW varies between 0.59 and 0.75 with a correlation of 0.99 between them. LE, calculated by energy balance method, varies from 56% to 74% of Rn but with a lesser correlation, the possible reasons are discussed. For a given ARF, LE decreases by ~14% and Rn by ~15% with respect to observed LE and Rn respectively. The reduction in LE increases from 37% to 54% of ARF when LE increases from 220 W m^{-2} to 440 W m^{-2}, suggesting that wet soil induces relatively larger reduction in evaporation. The results agree with earlier model sensitivity studies that Rn reduces more with increase in aerosol absorption which is compensated by proportionate reductions in H and LE depending on soil and atmospheric conditions.

1. Introduction

Effects of aerosols on environment are studied extensively at different space and time scales and their various effects on weather and climate. Probably the direct effect through radiative forcing is the most long-lived as it is easily perceptible (eg. Sokolik and Toon, 1996 to Murphy, 2013). Global warming by increased greenhouse gases at least partly gets compensated by global dimming due to aerosols (Kondratyev, 1996). While the total concentration matters more for greenhouse gases, in the case of aerosols, their optical nature, i.e. scattering or absorbing type, profile, size distribution, and their high spatiotemporal variability and coupling with dynamics modifies the thermal, optical and chemical properties of atmosphere. Thus aerosols interfere with the global environment in multiple ways and can have decisive impact when local effects predominate.

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Aerosol radiative forcing (ARF) has been majorly calculated using aerosol optical depth (AOD) derived through instruments such as sun photometer and sun–sky radiometer or through satellite observations and using the same with appropriate other inputs in a suitable radiative transfer model (RT) (eg. SBDART, Ricchiazzi et al., 1998). Some other researchers (Jayaraman et al., 1998; Satheesh and Ramanthan, 2000) have also employed direct radiation measurements concurrent with AOD; however this method though nearer to truth (due to no model bias) is quite difficult to maintain for long term for the need of recurrent observer interference and need of many parameters like water vapor, ozone, and CO_2 to get statistically significant results.

Reduction in energy reaching the surface in turn modifies the surface fluxes, boundary layer evolution and temperature/humidity profiles that effects stability/convection, cloud formation, precipitation etc. Ramanathan et al. (2001) warned about the possible negative effects on hydrological cycle. There have been sensitivity studies on the effects of solar dimming caused by aerosols on boundary layer, especially with thrust on their absorbing nature by Yu et al., (2002). Actual observations were employed to initialize ABL model in a similar sensitivity study (Pandithurai et al., 2007) by varying single scattering albedo. Jiang and Feingold (2006) through their large eddy simulation studies revealed that aerosols modify the cloud properties to a much larger extent through dynamical coupling of the radiative processes than moderations through microphysical interactions stressing the key role of surface processes. Terrestrial photosynthesis and transpiration changes due to effect of aerosols are studied through a climate–biosphere model by Steiner and Chameides (2005).They found that aerosols thermal effects can sometimes alleviate the midday decrease in photosynthesis and though not dominant, is an important feedback in the climate–biosphere interactions and net primary productivity. An observation similar to the temperature response of plant canopy by increased photosynthesis activity on restoration of radiation after an intense reduction is observed by Latha et al. (2013) in connection with solar eclipse over a cassava canopy.

The objective of the study is to present observational quantification of aerosol only effect on evapo-transpiration over a heterogeneous land surface that is generally the case of non-cultivated land, i.e. not exclusively over plant canopy, apparently attempted for the first time. An investigation is made into the impact of aerosols on evaporation through direct radiative effects using measurements of aerosol optical properties, latent heat flux and incoming solar radiation. Aerosols induce negative direct radiative forcing which is partially offset by positive diffuse radiative forcing. Increase in diffused radiation is found to increase transpiration by means of enhanced photosynthesis depending on the type of plants; it favors tall forest canopy but may affect grass lands negatively (Wild et al., 2011). Similarly, Wang et al., 2008 studied effect of clouds and aerosols on transpiration over plant canopy. They reported an increase in transpiration over vegetation canopy due to aerosols as well as cloud-induced enhancement in diffuse radiation that helped increase photosynthesis rate. Latent heat flux, the net effect of surface evaporation and transpiration, gets modified due to these two processes with the former depending on radiation, soil moisture, wind and moisture deficit in the atmosphere. Instantaneous global radiation (0.3–3.0 μm) and aerosol optical depth from skyradiometer, corrected for air mass variations, are used to calculate aerosol radiative forcing efficiency. Apart from sensitivity studies, few studies reported the effect of radiative forcing on surface fluxes by actual observations; hitherto limiting the field observations to the radiative forcing only. In the current study we present the simultaneous ARF and resultant modification of surface evapo-transpiration over the station Ranchi, a tropical plateau region south of Indo Gangetic Plain.

2. Site, data and meteorology

Ranchi (85.3 °E, 23.5 °N, 650 m AMSL) is situated in the mining belt, on the eastern side of India. This region may be classified as a per-humid region under meteorological category and falls in the most precipitating region of eastern end of monsoon trough. The observation station is set up in the campus of Birla Institute of Technology, Mesra campus with skyradiometer and meteorological observatory. Fig. 1 shows the deployment of skyradiometer and 32 m meteorological tower.

Aerosol optical properties derived from skyradiometer model POM1-L (PREDE Inc, Japan make) for the year 2011 are considered for this study. These skyradiometers are used world wide and have well documented comparison with the other skyradiometer of CIMEL make (eg. Estelles et al., 2012). It measures sky radiances directly and that of aureole to derive aerosol properties through inversion algorithm (used in SKYNET aerosol-radiation network; http://atmos.cr.chiba-u.ac.jp/aerosol/skynet). An analysis of opto-chemical parameters of this station for this period is presented in Latha et al. (2013) while technical description and function of skyradiometer is provided in Aoki and Fujiyoshi (2003). It measures both direct solar irradiance (every 1 min) and diffuse sky radiation at 10 min time interval at 7 wavelengths (0.315, 0.4, 0.5, 0.675, 0.87, 0.94, 1.02 μm). The measured sun and sky radiances are inverted using the inversion algorithm viz. SKYRAD.pack ver.4.2. It uses improved Langley method (Nakajima et al., 1996) taking into account the AOD variations to get a more accurate calibration. Moreover the instrument, POM1L is an improvised version used for this study, also considers solar zenith angle variation while an aerosol scan by the skyradiometer is in progress though it takes only about a minute to complete it and scans both sides of the solar disc thus assuring better cloud screening. Procedure elaborated by Nakajima et al. (1996) and Boi et al. (1999) for this instrument is followed for calibration, data reduction and quality checks.

Solar radiation is measured by net radiometer (Kipp & Zonen) that consists of short wave (SW) (0.3–3.0 μm) incoming and reflected as well as long wave (LW) (3.0–60 μm) incoming and outgoing radiation. Net radiation is the summation of all 4 components i.e., Net Rad = SW (incoming-reflected) + LW (incoming-outgoing). Solar radiation is sampled at 1 s interval and 1-min mean values are stored. Multi-level measurements of wind, temperature and humidity (Vaisala make) are collected from the micrometeorological

Fig. 1. Field view of micrometeorological tower with inset showing sun–sky radiometer installation.