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AEROSOLS AND CLOUDS INTERACTIONS IN AN URBAN ATMOSPHERE

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ABSTRACT
Aerosols create great uncertainties in studying climate change under global warming and atmospheric dynamics. To understand the impacts of aerosols on cloud properties in Madurai, we have analyzed an extensive collection of aerosol and cloud properties, obtained from the Moderate resolution Imaging Spectroradiometer (MODIS) data, over the study site during 2012-2013. Monthly, seasonal and annual variations of aerosols and clouds studied along their interactions and impacts on climate. Considering annual averages for all these parameters, most often the year 2012 was dominated with a higher presence of AOD, COD, CER, CTT, CTP whereas rainfall and CF were found to be dominated in 2013. The presence of higher CF in 2013 may be a cause for the higher rainfall and the lower level of CF in 2012 may be a cause for less rainfall. High aerosol loading in this area is due to biomass burning and urban air pollution which may significantly suppress precipitation. Increased aerosols and the local aerosol emissions may reduce the precipitation efficiency, which is responsible for the precipitation reduction and vice-versa.

1. INTRODUCTION

Indian summer monsoon is the biggest source of freshwater resource and more than 70 % of the annual precipitation over India occurs during the monsoon season. Indian monsoon rainfall is critical to food and water security. Aerosol is known to impact the formation and the life cycle of clouds and sometimes it is known to influence the rainfall. Higher aerosol concentrations may decrease the cloud droplet size, suppressing rainfall and enhancing the retention of liquid water by the cloud. Hence increasing the lifetime of the cloud and also the total cloud cover (Albrecht, 1989). Smaller cloud droplets are less efficient at producing rainfall than larger ones; an enhanced aerosol population will lead to a longer cloud life (Rosenfeld, 2000). Longer cloud life results in a lower rate of surface evaporation, a more stable and drier atmosphere, and consequently a reduction in cloud formation (Hansen *et al*., 1997). The interaction between aerosols, cloud and precipitation can be in two ways; (i) presence of more number of aerosols leads a smaller droplet formation with less coalescence and contributes cooling effect and (ii) abundant smaller cloud droplets have a tendency to reduce precipitation they alter cloud cover with increase cloud lifetime and albedo (Devara and Manoj, 2013). Changes in aerosol, cloud properties cause an uneven distribution of rainfall associated with flash flood or prolonged drought. The changes resulted in major loss of human lives and damages to crops and properties with devastating societal impacts. The studies of aerosols are very important because due to lack of understanding of aerosol properties and their spatial and temporal variations, their effects will be indefinite and vast aerosols withstand in the atmosphere (Gunaseelan *et al*., 2014).

2. METHODOLOGY

2.1 MODerate resolution Imaging Spectroradiometer (MODIS)

MODerate resolution Imaging Spectroradiometer (MODIS) is a key instrument aboard the Terra - Earth Orbiting System (EOS AM) and Aqua (EOS PM) satellites. The MODIS aerosol algorithm has two components, one adapted for retrieval over land (Kaufman *et al*., 1997), and the other for retrieval over ocean (Tanré *et al*., 1997). The daily mean of aerosol optical depths (AOD) derived from the MODIS with level 3 and the collection version of 5.1 with grid size of 1° x 1° at 550 nm aerosol data product from the Terra platform is used in the present work. AODs which are above 0 and less than 1.0 are only considered. This limit is imposed on the assumption that AOD value greater than 1.0 would have resulted most likely due to cloud contamination (Chung *et al*., 2005).

2.2 Study area/ site description

Madurai (9.98º N, 78.21º E) is a semi-arid region on the banks of river Vaigai. It has an average elevation of 100 m. Madurai has the typical climate of the Deccan plateau and remains hot and humid during most of the year with very bright sun shines during summer season manifested by the temperature ranging from 27 °C to 40 °C. Therefore, the climate is quite hot during the summer, winter starts from December and lasts till February with the temperatures ranging between 20 °C and 30 °C. Madurai experiences similar monsoon pattern with Northeast monsoon and Southwest monsoon, with the most rain during October to December. Rainfall is very frequent in the city and it receives the major share of rainfall between the months of July and October. The city is mainly utilized for agricultural activities and the major crop is paddy. Agricultural and biofuel burning practices, heavy transportation and high dense population are the main source of the environmental pollution in this Madurai city.

3. RESULTS

3.1 AEROSOL AND CLOUD INTERACTIONS

The aerosol, cloud and rainfall interaction play an important role in atmospheric dynamics, climate change, radiation budget. Troposphere clouds and scattering aerosols tend for cooling the earth's surface, whereas clouds in the high altitude and absorbing aerosols tend to arming effect (IPCC, 2013). AOD during 2012 and 2013 at 550 nm were taken to study the cloud and rainfall interactions in the Madurai city. AOD oscillated between 0.27 to 0.79 for 2012, whereas for 2013 the values fluctuate from 0.27 to 0.60 and the annual averages are 0.46 ± 0.16 (2012) and 0.39 ± 0.10 (2013.) Maximum AOD peak throughout the two years was noticed in May and minimum AOD was in January (2012) and in February (2013). Maximum concentration in the study site is due to the high temperature and also due to a local religion festival which takes place in a particular month. The city covered with mushroom population, generator usage for the festival, traffic related issues with lots of fireworks. Usage of crackers and also people from outside of the festival use open burning for their usages. Differences in temperature are also attributed to aerosol loadings in the different seasons because the circulation shifts are associated with the monsoon system. Minimum AOD may be due to cold temperature and winter manifested reversal of the spatial gradient of aerosol loading. During this period spatial gradient of aerosol shows comparatively much low levels over entire Indian peninsula (Indira *et al.,* 2013).

Monthly, seasonal and annual variations of cloud parameters and rainfall along with Pearson correlation were studied. Cloud Parameters such as Cloud Optical Depth (COD), Cloud Fraction (CF), Cloud Effective Radius (CER), Cloud Top Temperature (CTT) and Cloud Top Pressure (CTP) data were collected from the satellite data.

COD during 2012, varies from 2.18 to 11.08, maximum is noticed in October whereas minimum is in May. In 2013, the COD values set as 3.50 to 7.50, upper limit values are noticed on December and lower limit values are noticed on May. Considering the seasonal variations of the two years, during 2012 ceiling of COD was in post monsoon and low limit was in the monsoon. In 2013, the ceiling limit was noticed in winter and lower limit was in summer. By Studying the annual variation between the two years 2012 dominated with huge COD than 2013. Correlation analysis gives that in both the years the AOD and COD show a strong negative relationship. Moisture density is more important for the COD, the heavy rain in 2013 might have produced more moisture content in the city with significant COD.

The variations of CF was studied, in 2012 the values swings from 0.36 to 0.92, the highest peak was noticed in August and low peak was in January meanwhile in 2013 the values rise and fall as 0.49 to 0.98 and the maximum durations were noted in June, July along the minimum variations in January. Considering the seasonal variations, presence of higher and lower CF was observed on the monsoon and winter for both the years. Comparing the both years for annual variations more CF was noted in 2013 than in 2012. CF and AOD correlation demonstrates that the relationship between them throughout the study period is a strong positive correlation. Presence of number of particles in the aerosols act as CCN and they are capable to produce more new clouds i.e. directly increases the cloud fraction.

Monthly CER for 2012 oscillates from 12.71 µm to 23.04 µm, it dominates in the November and least was in September. In 2013, the monthly CER values rolled among 14.31 µm to 19.60 µm, bare minimum was in February and utmost CER peak noticed on November. Huge CER whereas minimum CER was noticed on monsoon in 2012 and in 2013 it was in summer. Annual variations resulted that CER dominated in 2012 when compared to that of 2013. The correlation between CER and AOD during 2012 was positively correlated whereas in 2013 it was correlated negatively. Reduction of CER during monsoon and summer may be due to the microphysical effects of aerosols over clouds and also due to the changes in the atmospheric circulation patterns.

CTT values were found to be ceiling in January and found to be small in October and their level diverges from 244.99 ºC to 278.02 ºC for 2012. CTT during 2013 ranged between 244.09 ºC to 275.61 ºC and higher and lower variations are noticed in February and July. The seasonal variations outcome shows that elevated CTT was perceived during winter for both the years (2012 and 2013). Least amount of CTT was in the post monsoon during 2012 whereas in 2013, minimum CTT was in the monsoon. CTT for annual variations showed that minimum crest noted in 2013 and the maximum crest was in 2012. CTT and AOD relationship during 2012 was quite strongly negative relation whereas in 2013 these parameters were moderately correlated with a negative relationship. Two physically possible mechanisms can relate AOD with CTT and rainfall. During 2013, the invigoration effect might have taken place in Madurai. This effect is most significant for the deeper clouds and has the ability to enhance the convection and may produce heavy rainfall. Microphysical effect may take place in the study region during 2012 which cause for the size reduction of the cloud particle, rainfall rate and further leads for precipitation suppression.

Monthly CTP values are varied from 244.99 hPa to 278.02 hPa, the elevated level was in November and bare minimum was in September. CTP monthly values for 2013 vary from 378.34 hPa to 722.37 hPa the monthly maxima and minima are noted in February and July. Seasonal deviation results show that throughout the study period, CTP was found maximum in winter and minimum in monsoon. Yearly consideration of CTP outcome represents that CTP is highly dominated during 2012 when compared with 2013. Low CTP is necessary for most prominent clouds for producing rainfall than high CTP. Low CTP in 2012 and 2013 monsoon in the study site helps for mature and well-formed clouds for precipitation formation and it could be the likely reason for elevated rainfall in 2013. A strong negative relationship was noticed between AOD and CTP throughout the research period, increasing in aerosol enhancement may decrease the CTP.

The statistical approach Pearson's correlation was carried was out between AOD, cloud parameters and rainfall during the study periods. During 2012, AOD is positively correlated with CF and CER it suggests that this relationship is due to an inverse aerosol indirect effect. AOD values are negatively correlated with COD, CTT, CTP and with rainfall and the results are correlated significantly. Since the year receives less rainfall and also the wet removal will be negligible and hence aerosols are dominated. For the period 2013, a significant positive correlation was noticed between AOD and CF. Negative correlation was noticed between AOD and CER, COD, CTT, CTP, rainfall and the indirect radiative effects of aerosols are the most probable cause. During this year, the study site might dominate by giant aerosols, it can lead to form larger droplets rapidly than CCN does and it accelerates the onset of precipitation. Considering annual averages for all these parameters, most often the year 2012 was dominated with a higher presence of AOD, COD, CER, CTT, CTP whereas rainfall and CF were found to be dominated in 2013. The presence of higher CF in 2013 might be a cause for the higher rainfall and the lower level of CF in 2012 may be a cause for less rainfall. Throughout both the years, AOD was correlated in a same manner, but the changes in CER between the two years might be a probable reason for the drought and monsoon conditions. In Madurai during 2012 and 2013, variations in CF and CER play an important role in the formation and obstruction of rainfall. The possible reason for low rainfall is due to the abundance of aerosols in 2012. Apart from aerosols, clouds and meteorological parameters, location of the study site, the dominance of the aerosol types and other parameters also play an important role. Since various natural and anthropogenic activities may happen at any cost of time and it is impossible to predict the situation in any location. Man-made emissions induce the brighter clouds with less rainfall and affect the particle size distribution. Increase of aerosol in the atmosphere changes the radiative balance, reduction in visibility (Zhou *et al*., 2014) and health impacts. Smoke aerosols can be a possible reason to suppress precipitation and decrease cloud droplets. The open burning of crop wastes and forests contribute to the aerosol concentration over this region. It was concluded that the role of aerosols with cloud and rainfall are extremely complex phenomena and also unpredictable.

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