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Black Carbon and its Impacts on Climate

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Abstract
Black carbon, a form of fine particulate matter composed of soot and other carbonaceous particles, is generated through the incomplete combustion of fossil fuels, biomass, and biofuels. As a short-lived climate pollutant, black carbon has gained significant attention due to its detrimental effects on climate change and human health. This abstract aims to provide an overview of the key aspects surrounding black carbon and its impacts on the Earth's climate system. Black carbon exerts both direct and indirect influences on the climate. As a direct radiative forcing agent, it absorbs sunlight and traps heat in the atmosphere, contributing to the warming of the planet. Furthermore, black carbon particles deposited on snow and ice surfaces decrease their albedo, accelerating melting and reducing the Earth's overall reflectivity. These effects have implications for regional and global climate patterns, altering temperature profiles, precipitation patterns, and atmospheric circulation. In addition to its radiative properties, black carbon also plays a role in atmospheric chemistry. When emitted into the atmosphere, it interacts with other pollutants, modifying their lifetimes and impacts. Black carbon particles can act as cloud condensation nuclei, affecting cloud formation and properties, thus influencing the Earth's energy balance. Moreover, the deposition of black carbon on land and water surfaces can disrupt ecosystems and contribute to the acidification of oceans.

Key words: Black carbon, climate change, radiative forcing, optical depth

1.INTRODUCTION

Black carbon, A short-lived pollutant, which means that reducing it today will have an immediate impact on reducing the effects of climate warming. It is a soot emitted from unburnt fuels.it contains a portion of PM2.5 which is air pollutant .Black carbon is a pollutant that has a 3200-fold greater ability to cause climate change than carbon dioxide, so if we start reducing it and stop it from being released, the black carbon that is already in the atmosphere will settle out of the atmosphere, some of it falling on the ice and melting. Instead of waiting a few hundred years for black carbon dioxide to leave the atmosphere, for example, as you start to lower the source of black carbon emissions, we may have a direct and more immediate influence on reducing climate warming.so in my attempt to study optical depth of black carbon in different regions of Indian subcontinent and to calculate the radiative forcing of the black carbon. we know that radiative forcing of the black carbon depends on the optical depth, when the optical depth is dense there the absorption of solar radiation is also high so there there will be a energy imbalance which is an indicator of climate change. It is a powerful climate change that absorbs sunlight A short-lived pollutant that is the second largest contributor to global warming after carbon dioxide It affects visibility, damages ecosystems, affects crops and worsens global climate change. Its effect on humans is also noticeable causes premature deaths.

2. METHODOLOGY

The primary aim of this paper is to study black carbon with respect to climate change and also to identify the unique properties of black carbon with respect to climate change. Initially the emission rates of black carbon for different states in India is found by using the data available in the GAINS model. then optical depth of black carbon is calculated to find the concentration of black carbon for different Aero net stations in India then the radiative forcing of black carbon is derived and calculated for different aeronet stations in India

3. MATERIALS AND METHODS

A. GAINS MODEL

GAINS allows users to simulate the impact of various policy scenarios on greenhouse gas emissions, air pollution, and related health and environmental impacts. It also allows users to analyze the costs and benefits of different policy options and identify the most effective and cost-effective means of achieving mitigation and air quality goals. GAINS model

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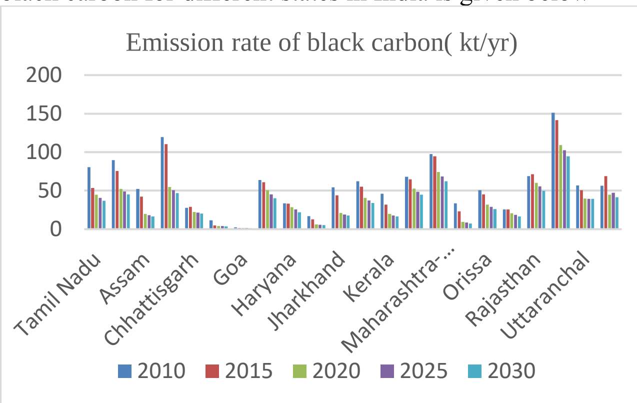
contains the emission rates of all greenhouse gases. it shows greenhouse gases of various sectors. the emissions rates of black carbon for different states in India is given below



B. OPTICAL DEPTH

Optical depth Soot optical depth refers to the measurement by which the number of soot particles (BC) in the atmosphere absorbs sunlight, reducing the amount of solar radiation reaching the Earth's surface. Optical depth is measured in units of a dimensionless quantity, with higher values indicating greater absorption of sunlight. Black carbon particles are small and absorb a wide range of wavelengths of solar radiation, greatly reducing the amount of solar energy reaching the earth's surface. The optical depth of soot is influenced by several factors, including the concentration of soot particles in the atmosphere, their size and shape, and the amount and type of solar radiation they are exposed to. The optical depth of black carbon has a significant impact on climate change as it contributes to atmospheric and surface warming. In addition, soot particles can penetrate deep into the respiratory tract, affecting air quality and human health. The optical depth is calculated to find the concentrations of black carbon for different Aeronet sites in india is given in the table below

Sites	Geolocation
Ahmedabad	23N72E
Amity University	28.54N 77.33E
Arm Ninital	28.54N 77.33E
Bareilly	28.39N 79.43 E
Bose Institute	22.57N 88.3E
Dharwar	15.5N 75.33
Dibrugarh	27.48N 94.90 E
Gandhi College	13.07N 80.2E
Goa	15.3N 74.0E
Gual Pahari	22.57N 78.90E
Iit Delhi	28.54N 77.19 E
Iit Kolkata	22.57N 88.41E
Jaipur	29.91N 75.81E
Kanpur	26.46N 80.3E
Karunya University	10.93N 76.76E
Nanital	29.29N 79.41E
New Delhi	28.6N 77.20E
Pantnagar	29.02N 79.48E
Pune	18.5N 78.35E
Trivandrum	8.48N 76.94E
Visakhapatnam	10.90N 78.36E

Hence in this study optical depth of black carbon is calculated at different regions in India. The total optical depth data ia obtained from AERONET VERSION 1.0 at different site locations in India. How ever it is tedious to calculate the calculate the optical de3pth of black carbon alone. It is possible to exclude all other optical depth expect black carbon hence optical depth of black carbon can be calculated. Hence to calculate the optical dust ration is required dust ratio is represented by μ. previous researchers separated the dust and non dust ratio by their depolarization values which is measured by LIDAR. So the depolarization values at 450,675,870 nm represents dust particles generated in various regions in India. So to calculate the dust ratio

$$\mu=\frac{(1+\sigma d)(\sigma_{1020}-\sigma nd)}{(1+\sigma_{1020})(\sigma d+\sigma nd)}$$

σd is the polarization of dust particles
σnd is the polarization of non dust particles
Hence the optical depth of dust particles can be calculated by

$$OD(D)= \mu \times OD(total)$$

There is a another factor called Angstrom exponent which describes the optical properties with respect to the wave length of light
Previous researches suggested the angstrom exponent of different region in India as 0.06±0.21 and 0.14±0.07.consequently aerosol optical depth at other wavelengths cane calculated by

$$OD(d)\lambda=OD_{(d)1020} \text{ x } \frac{1020nm}{\lambda}$$

λ is the wave length and the anstrong parameter is åD
Similarly the contribution of non dust particles to the total aerosal optical depth can now be calculated as

$$ODnd,\lambda = ODT,\lambda - ODd,\lambda$$

Other than this ώ is the spectral dependence i,e some portion of light may be scattered from the aerosals. So it is also an important factor to be considered because ώ increases with increase in wavelength studies shown that black carbon has more absorbtion spectra .So the equation becomes

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$$\dot{\omega}nd = \acute{\omega}T, \lambda - \frac{OD(d)\lambda}{OD(T)\lambda}\dot{\omega}(d) \text{ x } \frac{OD(d)\lambda}{OD(nd)\lambda}$$

Researchers calculated the spectral absorbance as 0.98,0.94,0.98 @450,675,870 wavelengths. There is also another aerosol called brown carbon which could absorb solar radiation so the contribution of brown carbon should also be excluded .Therefore to exclude brown the equation canbe

$$ODBrC,\lambda = ODnd,\lambda \times (1\text{-}\omega nd,\lambda) \times (1 - \omega BrC,\lambda)$$

With reference to the previous studies i used the brown carbon absorbtion spectra as 0.77,0.80,1.00 .Total optical depth data can be obtained by AERONET version 2.0

So the final equation for total solar radiation absorbed by black carbon wiabsorbed by black carbon with respect to the wavelength canbe calculated by

$$ODBC,\lambda = ODnd,\lambda - ODBrC,\lambda$$

C. RADIATIVE FORCING OF BC

Black carbon's radiative force may be described mathematically as:

$\Delta F = \alpha \times \Delta E$

where F denotes the radiative forcing, is the radiative efficiency, and E is the change in atmospheric energy due to the presence of black carbon.The radiative efficiency indicates the change in radiative forcing per unit change in black carbon content in the atmosphere. It is possible to compute it using the following formula:

$\alpha = (\ln(C/Co) - 1 + (Co/C) - \gamma) / Q$

The difference between the incoming solar radiation absorbed by black carbon and the outgoing longwave radiation released by the Earth determines the change in atmospheric energy E. The following formula may be used to compute the change in atmospheric energy:

$\Delta E = (1 - \alpha s) \times S0/4 \times (1 - \alpha) \times \tau$

where s is the surface albedo, S0 the solar constant, is the atmospheric albedo, and is the optical depth of black carbon.

Combining these equations yields the radiative forcing of black carbon:

$\Delta F = (\ln(C/Co) - 1 + (Co/C) - \gamma) / Q \times (1 - \alpha s) \times S0/4 \times (1 - \alpha) \times \tau$

This equation indicates that the radiative forcing of black carbon is affected by its atmospheric concentration, its radiative efficiency, and the surface and atmospheric albedos. The first step is to calculate total aerosol DRE at the top of the atmosphere (TOA) using the Loeb and Kato technique (2002).at top of the atmosphere aerosol DRE is defined on a particular day (d) and location at latitude (l) and longitude (t) by

F (d, θ, φ)= F na(d, θ, φ)- F a (d, θ, φ)

Where

Fna is the forcing of non aerosols

Fa is the forcing of aerosols

The forcing is calculated using instantaneous SS

TOA fluxes translated to daily averages across 1X 1 grids.

According to (Loeb and Kato, 2002 et al), Fa(d, θ, φ)and Fna (d,l,t,) are determined from diurnal albedo model(Diurnal variations of albedo are caused by the change of solar zenith angle with time of day and by changes of the atmosphere and surface through the day, primarily variations in cloudiness due to diurnal or synoptic processes) (Rutan and Smith 1997).The following step is to calculate the total radiative forcing of aerosal.

According to Boucher et al. (1998), Boucher and Tanré (2000), and Bellouin et al. (2003), the DRE/DRF of non- or weakly absorbing aerosols is proportional to (e-t-).

According to this empirical relationship,

D F (d, θ, φ)= D F ((d, θ, φ))(e -t NA - 1) /(e -t - 1),

This equation is used to determine total radiative force.

The next stage is to eliminate all additional black carbon forcings. we know that the aerosols are divided into five major components dust and non dust components, sulphates, organic carbon such as brown carbon ,blackcarbon. By subtracting the all other raditive forcings from the black carbon forcings . The radiative forcing of black carbon can be easily obtained.there for the final formula for calculating the radiative forcings of black carbon is Subtracting these components from DF(d, θ, φ) and the remaining is considered as a black carbon component DFBC(d, θ, φ).

4. RESULTS AND DISCUSSION

A . RESULTS OF OPTICAL DEPTH OF BC

As mentioned earlier the value 0.01 corresponds to an extremly clean atmosphere and a value greater than 0.4 corresponds to the extremly very hazy condition. From the above results it is found that the values are greater than 0.01 so the optical depth of black carbon is very dense, It is proved that black carbon absorbs more solar radiation from the above results the region around delhi has highest dense of black carbon and trivuvadrum has less dense black carbon. The optical depth of black carbon has a significant impact on climate change as it contributes to atmospheric and surface warming. In addition, soot particles can penetrate deep into the respiratory tract, affecting air quality and human health.

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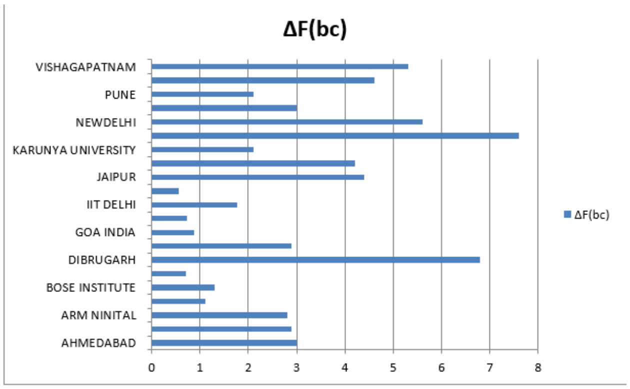
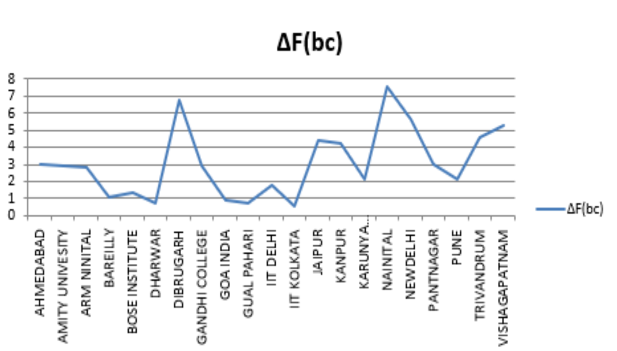
The optical depth of soot is influenced by several factors, including the concentration of soot particles in the atmosphere, their size and shape, and the amount and type of solar radiation they are exposed there fore by calculating the optical depth their concentration in their location canbe calculated. Optical depth is measured in a unit of a dimentionless quantity. Higher the value indicates the higher absorption of solar radiation



B. RESULTS OF RADIATIVE FORCING

Positive radiative forcing means earth receives more incoming energy from sun than it radiates in to space.From the above results it is found that in and around delhi there was a positive radiative forcings .Costal regions like pune and Kolkata have less positive effect when compared to mid regions .It is proved that radivative forcings depends on the parameters like optical depth and single scattering albedo,the regions where the optical depth is dense there the radiative forcing is also high (eg)delhi



5. CONCLUSION

The optical depth measurements are affected by the medium's characteristics and the wavelength of the incoming light. In a gas, for example, the optical depth is determined by the concentration of the absorbing molecules, their absorption cross-section, and the route length of the light through the gas. The optical depth of a solid or liquid relies on its density and thickness, as well as its composition and crystal structure.The optical depth may be used to investigate a wide range of physical processes, including light absorption by atmospheric gases, light scattering by dust particles, light attenuation in optical fibres, and light absorption by biological tissues.A gas's or aerosol's radiative forcing is determined by its concentration, absorption and scattering characteristics, and atmospheric lifespan.Radiative forcing has important consequences for climate change since it determines how much energy the Earth's climate system receives or emits. Positive radiative forcing may warm the climate system, whereas negative radiative forcing can chill it. We can better forecast the consequences of climate change and design mitigation methods by knowing the radiative forcing of various causes.

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