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Aerosols: Production and Effects

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Abstract:

Aerosol plays a major and vital role in the climate change and it also affects the human life. It is found that the tiny particles of dust, smoke and the various gases emitted by industrial activities goes into the atmosphere and they cause the asthmatic problems for the human life. The same thing appears during the cutting and cleaning the crop, cleaning the houses during the time of Indian festivals like Diwali and other occasions. Similarly, biomass burning also plays a major role in these activities, even a complicated compound (chapdi) used to seal the envelope and packets create a very serious problem in breathing in the human and animal life.Aerosol affects the climate in the form of cooling as well as heating. By keeping the above factors in mind a review paper about aerosol, their productions and effect are written. This paper will help in understanding a basic idea about the aerosol.

Keywords

Aerosol, Climate change, Atmosphere, Pollution

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1. Introduction

The planet on which human activities exist in a well-established manner is earth. The earth's atmosphere supports it due to the different composition of gases, which are essential for the survival of the organism. These gases are very important because these are related to human activities in the direct or indirect way. The earth's atmosphere is a thin layer of gases; it contains several kinds of most abundant gases like major gases, 78% nitrogen, 21% oxygen, 0.93% inert gas like argon, in volume. Some small amount of other types of gases, like carbon dioxide, 0.038% in volume and other trace and inert gases are also available in the atmosphere [1]. In addition to it, particulate matter (PM) i.e., aerosols are present, which are widely variable in space and time. The word aerosol was introduced about 90 years ago as an excuse to the term hydrosol, a stable liquid suspension of the solid particle [2].

The atmospheric aerosols are actually atmospheric molecules and the ion chemical species in one cubic centimetre of air; also contain a substantial number of other suspended particles in liquid, solid, gas as well as fluid phases varying in size from a few nanometers to several microns depending on the climate condition. In clean air, the size of it is about 1 nanometer to 100 micrometres and in the polluted air, their size can be 10,000 microns or more including bacteria, dust and industrial waste [3].

There are several types of aerosols; smoke, haze and fog are some most common examples of them. Smoke is a cloud of particles produced by burning wood, coal, oil and other carbonaceous fuels [4]. The haze is a system of particles, grown to large size by water vapour condensation on it and it reduces the visibility; and fog is a collection of the small liquid droplet containing water. These particles on colliding and combining together form large droplets and their radius become greater than 100 micrometres, they appear as drizzle or even as rain [5, 6]. Smoke and fog on combining together form a new type of aerosol, known as smog [7]. In this way, the fog is an example of natural aerosols and haze, dust, particulate air pollutants and smoke are the examples of artificial aerosols [2]. Thus the atmospheric aerosols are characterised by extensive variation in composition, size, physical characteristics, latitudinal and altitudinal distributions [8-10].

2. Sources of Aerosol Production

The sources of atmospheric aerosols can be terrestrial and extra-terrestrial. The extra-terrestrial source contributes mainly in the stratosphere [11]. Aerosols originate in the atmosphere from terrestrial sources are of natural processes and anthropogenic (man-made) activity. The natural, primary or directly sources of aerosols include interplanetary dust (meteorites), terrestrial dust, sea-salt aerosols, volcanic aerosols and biogenic aerosol production. Indirect sources or secondary sources include the chemical reactions, converting the natural and man-made anthropogenic gaseous species into solid or liquid particle from gas to particle conversion process and their size is below about 0.2 micrometres

in diameter. On a global scale, the natural sources of aerosols are three to four times larger than anthropogenic aerosols, but on regional- scale, anthropogenic emission can be significant [12].

2.1. Soil Dust

The fine soil and sand particles are the major contributor to aerosol loading, especially in the subtropical and tropical region and are found all around the world. The main sources of dust are the region of desert, dry lake beds, semi-arid desert fringes and the areas, where vegetation has been reduced by the industrialization and other human activities [13]. The dust particles are transported from these regions to thousands of kilometers away when the wind exceeds a threshold velocity, which is a function of particle size, soil mixture and surface roughness elements. Dust events are often triggered by thunderstorm outflows passing topographic depressions fulfilled by dust accumulated over a long time. Figure 1 shows a picture showing the dust uptake into the atmosphere [14].

Figure 1. Dust uptake into the atmosphere

The process of the uptake of dust and sand particles from the soil depends on the near-surface dynamics (see Figure 2) [15, 16]. The picking of dust is controlled by the wind intensity, the soil wetness, the soil texture and the land cover. Scientists observed that wind speed greater than 0.5 m/s is enough for picking up and keeping the airborne soil particle as large as 2 micrometres in radius [17]. The threshold value of wind increases with the size of the particles because they are heavier and therefore more difficult to lift up due to gravity. If the particles are small the threshold wind value is high, since it has to break rather strong cohesion force keeping small particles together.

It has been estimated that up to 50% of the current atmosphere dust load originates from the disturbed soil surface and therefore it might be considered as anthropogenic origin [18].

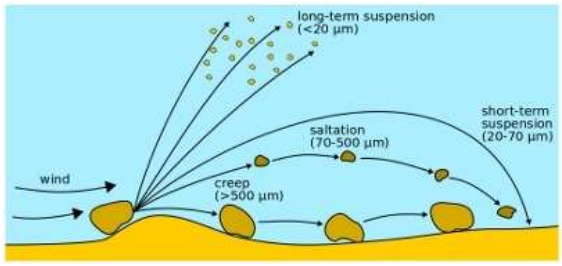

Figure 2. Process of particle motion

Within the uptake process, there are three modes of aeolian particle motion identified [19], which are a creep (the largest particles are moving by rolling motion), saltation (particles in the size range from 70-500 micrometre) and suspension (the smallest particles are wafting due to turbulent diffusion).

2.2. Sea-Salt Aerosol

The sea-salt aerosol is mainly produced by bursting of air bubbles entrained in the ocean surface during white cap formation [20-26]. Investigators found that about 30% of the global aerosol burden are due to sea-salt aerosol [23, 27]. It is very difficult to estimate the production rate of this aerosol because it depends on wind speed, salinity and the sea state. This aerosol is mainly dominant in the region of the marine atmosphere, where wind speed is high or where the other sources of aerosol are very weak [28, 29]. Figure 3 shows the breaking waves on a beach in Hawaii, it also shows the white cap [30].

Figure 3. Breaking waves on a beach in Hawaii

2.3. Volcanic Aerosol

This is also a natural source of aerosols, which are ejected into the atmosphere by strong volcanic eruptions and it leads to the short-term change in the climate [31]. Several gases evolved during the volcano, which undergoes gas to particle conversion and these particles injected into the stratosphere, rapidly disperse around the globe by the large-scale atmospheric waves.

Figure 4. Iliamna Volcano in Alaska

Aerosols produced from the gases remained several years in the atmosphere [32-35]. In Figure 4 lliamna volcano is shown, which was seen in Alaska [36].

2.4. Biogenic Aerosol

Biogenic aerosols are produced by oxidation of biogenic emissions like terpenes [37]. The primary biogenic aerosol consists of plant debris and microbial particles. They are present, particularly in densely vegetated region, i.e., in forest [38].] These aerosols are characterized by low molecular weight hydrocarbon and different dicarboxylic acids and aromatic acid [39, 40]. The presence of humid-like substance makes this aerosol light absorbing in the UV-B region and there is evidence that primary biogenic particles may be able to act to form both as cloud droplet and ice nuclei [41-43].

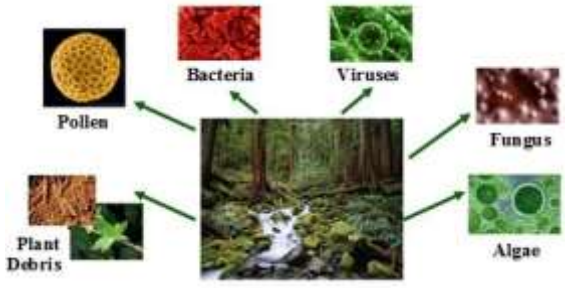

Figure 5. Primary biological aerosol particles

2.5. Aerosol from forest fire/biomass burning

This source of aerosols is globally important and it plays a major role during the summer season when the dry leaf of trees automatically burned up due to temperature [44]. Africa has the greatest intensity of this source, where 40% of the total biomass burning is found. In the tropical regions, the burning of fuel wood and agricultural waste is a main source of energy. Biomass burning produces both primary aerosol particle and precursor gases for secondary aerosol formation [45, 46]. About 70% of the mass of particulate matter released is a fine carbon-containing particle and out of it, 20% occur as black carbon or elemental carbon, known as soot. The magnitude of black carbon emitted from biomass burning is similar to that from fossil fuel burning [47, 48]. Ethane, propane, acetylene and methyl chloride are the main organic gaseous compound released during biomass burning. At low saturation values, these compounds condense easily and react with each other to form aerosol particles. The presence of polar functional groups makes the many of the organic compound aerosol water-soluble and allows them to participate in cloud droplet nucleation [49]. Figure 6 shows the forest fires and burning of the field in the topic, which creates the biomass burning aerosols [50].

Figure 6. Biomass burning, including forest fires and the burning of fields in the tropics

Black carbon (BC) is particulate pollutant species produced from the incomplete combustion of any carbon-containing material like fossil fuels, biofuel and biomass in the absence of oxygen [51]. It is well estimated that about 8 million tonnes of BC and 37 million tonnes of organic carbon are emitted worldwide annually [52, 53].

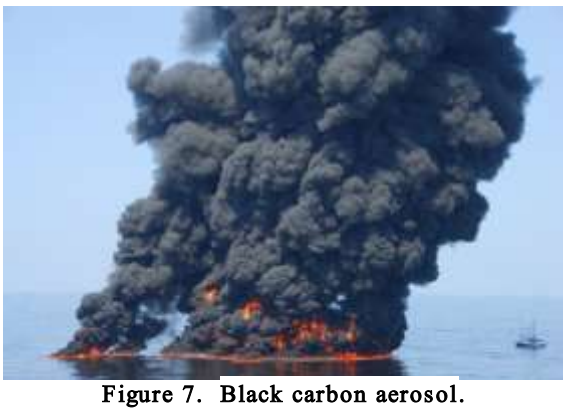

Figure 7. Black carbon aerosol.

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It is found that 40% of BC is emitted from coal and oil burned in industrial and mobile sources, 18% of residential bio-fuel for heating and cooking (wood, agricultural and animal waste) and 42% from open biomass burning worldwide [54]. The Recent study on BC shows that the majority of BC emissions are from developing countries [55] and this trend is expected to increase [56]. For black carbon, aerosol see Figure 7 [57].

2.6. Sulfate and Nitrate Aerosol

The sulfate aerosols are produced by chemical reactions involving gaseous precursors (SO2) from anthropogenic sources and volcanoes [58]. The main contribution of atmospheric sulfate is due to fossil fuel combustion and industry and therefore the source distribution and magnitude of this trace gas are fair and well known and they do not differ by an amount about 20% to 30% [59]. The major sulfur compounds in the atmosphere are sulfur dioxide, hydrogen sulfide, carbon disulfide, carbonyl sulfide and dimethyl sulfide. The oxidations of these compounds are photochemically induced and depend on the amount of UV radiation. Since UV radiation is mainly available in the stratosphere, so photo-oxidation of these compounds is likely in the stratosphere and in troposphere these are oxidized mainly by the OH radical. While the main sources of nitrate aerosol are soil release, fossil fuel combustion and agricultural activities. Ammonia is also emitted from agricultural activities [4]. Since the removal mechanism such as rain does not affect the stratosphere, so these aerosols remain in the atmosphere for several years. Anthropogenic activities produce nitrogen bearing gases. The major nitrogen compound in the atmosphere is nitrous oxide, which decomposes into nitrogen and nitric oxide. Nitric oxide gets quickly oxidized to nitrogen dioxide by reacting with ozone and finally, nitrogen dioxide react with OH and forms nitric acid [58, 60]. The formation of the sulfate-nitrate-ammonium aerosol is shown in Figure 8.

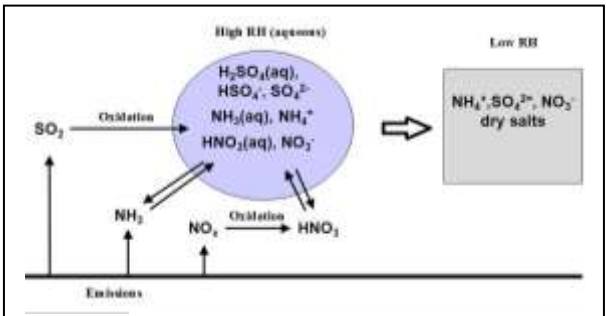

Figure 8. Formation of Sulfate-Nitrate-Ammonium Aerosol.

3. Effects of aerosols

3.1. Effects of aerosols on climate conditions

The solar energy influences the earth's atmosphere. On an annual average basis, the incoming solar flux should be equal to the outgoing terrestrial radiation at the top of the atmosphere and aerosol plays an important role in modulating the radiative balance between the incoming solar and outgoing terrestrial radiation and hence it affects the earth-atmosphere radiation budget. The imbalance in the net irradiance at any level in the atmosphere due to any species in the atmosphere in units of watts per square meter is known as radiative forcing [47, 61-63]. Its negative value shows a loss of energy and results in a cooling effect, while its positive value represents a gain of energy, indicating a warming effect. The aerosols can absorb as well as scatter the radiation and hence it is an important species and has the significant impact on the earth's atmosphere radiation budget [64]. The scattering and absorbing properties of aerosol depend on the size, refractive index and their chemical composition. Since the aerosol can reduce the radiation reaching the earth's atmosphere and hence it leads to a cooling of the surface and their effect varies with altitude [48. 65]. Since most of the aerosols scatter more than 90% of the visible light and therefore the primary direct effect of aerosols is the increase in the albedo and the primary indirect effects of aerosols on clouds include an increase in cloud brightness, change in precipitation and possibly an increase in lifetime [66], thus the overall net impact of aerosols is an enhancement of the shortwave albedo, this effect reduces the sunlight reaching the Earth's surface, producing a net climatic cooling, as well as a redistribution of the radiant and latent heat energy deposited in the atmosphere.

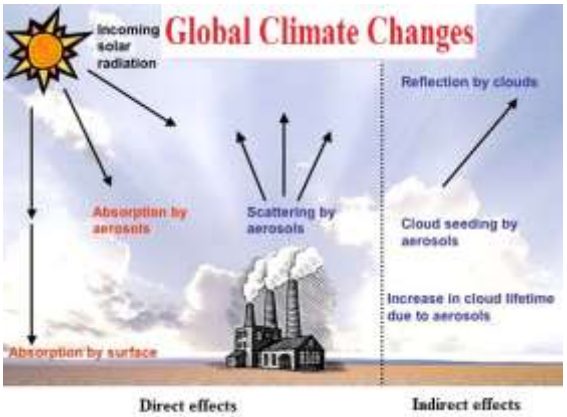

Figure 9. Direct and indirect effects of aerosol.

These effects can alter the atmospheric circulation and the water cycle, including precipitation patterns, on a variety of spatial and temporal scales [67]. The direct and indirect effects of aerosol on climate change are shown in Figure 9 [68].

Lots of researchers' studies on aerosol radiative forcing from the 1970s at different parts of the globe [69-82] and on the basis of their research IPCC published a report. A Summary of the estimates of global average aerosol radiative forcing due to aerosols reported by IPCC [47, 48 and 83] is given in Figure 10.

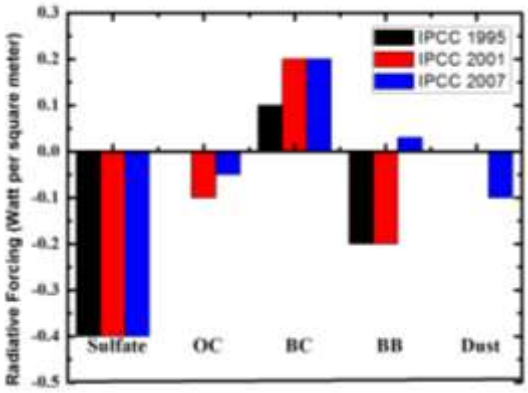

Figure 10. Estimates of global radiative forcing due to different aerosols

On the basis of this figure, it is found that the direct radiative forcing of the individual aerosol species is less than the total direct radiative forcing. The recent estimates of mean and uncertainty of the different constituents are: sulfate, –0.4 (±0.2) W/m^2; fossil fuel organic carbon, –0.05 (±0.05) W/m^2; fossil fuel black carbon, +0.2 (±0.15) W/m^2; biomass burning, +0.03 (±0.12) W/m^2; nitrate, –0.1 (±0.1) W/m2 and mineral dust, –0.1 (±0.2) W/m^2. For sulfate aerosols, the mean aerosol radiative forcing values remained same for all the assessments, while its uncertainty got reduced in the higher forcing values. It is very interesting to see that the sign of the biomass burning aerosols reversed in the 2007 assessment report, it indicates that the low scientific understanding of the microphysical properties of biomass burning aerosols [84] and the vertical distribution of aerosols relative to the clouds [85, 86]. It is also found that the regional climate impacts of atmospheric aerosols depend on the vertical distribution of radiant energy absorbed by the aerosols [87].

The recent studies showing that there is a decadal change in the surface reaching solar radiation and it varies significantly from one region to another region of the globe. The decadal decrease or increase in the surface reaching solar radiation is generally referred to as "global dimming" or "global brightening" [88-90]. The net reduction in shortwave radiation at the surface due to the direct and indirect effects of aerosols is estimated in the range −1.8 W/m2 to −4 W/m2 [91-93]. Researchers also show that the reduction in net solar radiation reaching the surface may be partly balanced by a reduction of evaporation. It is found that about 60 to 70 percent of the absorbed solar radiation at the ocean surface is balanced by evaporation and this would lead to the decrease in the water vapour content in the atmosphere and reduce the precipitation. About 37 percent of the energy input to the atmosphere occurs by the release of latent heat from water vapour that condenses into cloud drops and ice crystals [94]. It is found that absorbing aerosols not only cool the Earth's surface, but also warms the atmosphere resulting in a reduction in the atmospheric lapse rate leading to increased atmospheric stability [95].

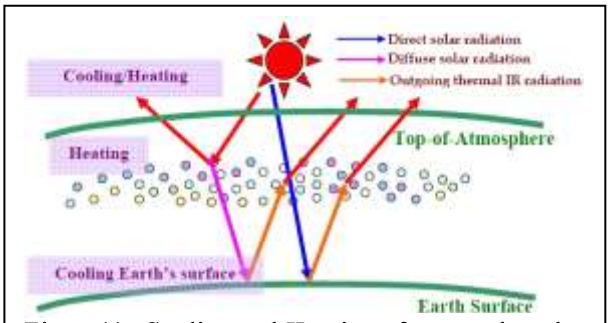

Figure 11. Cooling and Heating of atmosphere by aerosols.

Globally, radiative cooling in the atmosphere is balanced by latent heat release through precipitation. It is found that the high anthropogenic aerosol loading decreases the rainfall locally. Rosenfeld [96] has reported large suppression in rainfall due to the air pollution and forest fire. Hence the aerosol forcing pathways have the significant impact on the hydrological cycle. In addition, the changes in the water cycle and synoptic-scale circulations are likely to change the aerosol transport, modulate dry and wet deposition processes and alter the physical and chemical environments in which mixing of different aerosol species may take place.

3.2. Effects of atmospheric aerosols on air quality and human health

Besides the above effects, aerosols also have environmental issue such as degradation of air quality and implying health hazardous. If the soot particles are very large in the atmosphere, then it causes considerable risks to public health and for agriculture. The study performed by researchers on aerosol during the past two decades shows that the pollutions due to aerosol in most urbanized regions of the world cause severe health effects, including premature death in people with heart or lung disease,

aggravation of respiratory and cardiovascular disease, impaired lung function and increased respiratory symptoms [96, 97]. It is very well established that the deposition of particulate pollutants with acidic nature can speed up the declination of building materials, harm vegetation, damage the aquatic ecosystem, causes breathing problems and even increases the death rate among humans [98]. The smaller particle can penetrate deeper into the lung during the breathing process and hence their potential adverse health effect is much higher [99]. These particles have a larger surface-to-volume ratios and are generally produced from combustion processes, which are known to produce carcinogens such as polycyclic aromatic hydrocarbons. The elevated particulate air pollution has been associated with declining in lung function and increased respiratory syndromes [100, 101]. It is found that every 10 µg/m3 elevation in fine particulate air pollution was associated with approximately 6 percent increased the risk of cardiopulmonary and 8 percent lung cancer mortality. These particulate emissions also affect the agriculture. Several studies estimated that the reduction in sunlight from regional "dimming" from soot, sulfate, and other particles in Asia might diminish crop yields by about 10 percent or more [102].

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5. References

[1] Salby, M.L., "Fundamentals of Atmospheric Physics",.Academic Press, San Diego, California., 1996.

[2] Hinds, W., "Aerosol technology: Properties, behavior, and measurement of airborne particles", Wiley: New York., 1999.

[3] Twomey, S., "Atmospheric Aerosols", Elsevier Scientific Publishing Co., New York., 1977.

[4] Seinfeld, J.H. and Pandis, S.N., "Atmospheric Chemistry and Physics: From Air Pollution to Climate Change", New York; Chichester, John Wiley & Sons., 1998.

[5] Roach, W.T., "On the effect of radiative exchange on the growth by condensation of a cloud or fog droplet", Quart. J. Roy. Meteor. Soc., 102, pp. 361–372, 1976, doi:10.1002/qj.49710243207.

[6] Jensen, J.B. and Nugent, A.D., "Condensational Growth of Drops Formed on Giant Sea-Salt Aerosol Particles", Journal of the atmospheric sciences, 74, pp.669-697, 2017, doi: 10.1175/JAS-D-15-0370.1.

[7] Sturges, K., " Atmospheric Environment - Fifty Years of Endeavour", Atmospheric Environment, 43, 1, pp 1-218, 2009.

[8] Junge, C.E., "Air Chemistry and Radioactivity", Academic Press Inc., New York, USA, pp. 111-208, 1963.

[9] Prospero, J.M., et al., "The atmospheric aerosol system", Rev. Geophys. Space Phys., 21, pp. 1607–1629, 1983.

[10] Jaenicke, R., "Aerosols and their climatic effects", A Deepak publishing, Virginia, USA, 1984.

[11] D'Almeida, G.A., Koepke, P., and Shettle, E.P., "Atmospheric aerosols-global climatology and radiative characteristics", A. Deepak Publishing, Hampton, Virginia, USA., 1991.

[12] Charlson, R.J., Schwartz, S.E., Hales, J.M., Cess, R.D., Coakley., J.A. et al., "Climate forcing by anthropogenic aerosols", Science, 255, pp. 423-430, 1992.

[13] Kusky, T., "Climate Change: Shifting Glaciers, Deserts and Climate Belts", Infobase Publishing, ISBN: 1438118457, 2008.

[14] https://www.wmo.int/pages/prog/arep/wwrp/new/source.html.

[15] Goudie, A.S., Middleton, N.J., "Desert Dust in the Global System" Springer Berlin Heidelberg New York, ISBN: 3540323546, 2006.

[16] https://www.wmo.int/pages/prog/arep/wwrp/new/source.html.

[17] Gillette, D.A., "A Wind tunnel simulation of the erosion of soil: Effect of soil texture, sandblasting, wind speed, and soil consolidation on the dust production", Atmos. Environ., 22, 1735, 1978.

[18] Tegen, I., and Fung, I., "Contribution to the Atmospheric Mineral Aerosol Load from Land Surface Modification", J. Geophys. Res., 100, pp. 18707–18726, 1995.

[19] Bagnold, R., "The Physics of Blown Sand and Desert Dunes" *in Proceedings of the Royal Society* A 225 49, 1954.

[20] Blanchard, D.C., and Woodcock, A.H., "The production, concentration, and vertical distribution of sea-salt aerosol", Ann. N.Y. Acad. Sci. 388, pp. 330-347, 1980.

[21] Blanchard, D.C., "The Oceanic Production of Atmospheric Sea Salt", J.Geophys. Res., C1, 1985, doi:10.1029/JC090iC01p00961, 961-963.

[22] Hoppel, W.A., Fitzgerald, J.W., Frick, G.M., and Larson, R.E., "Aerosol size distribution and optical properties found in the marine boundary layer over the Atlantic ocean", J. Geophys. Res., 95, pp. 3659-3686, 1990.

[23] Fitzgerald, W.J., "Marine aerosols: A review", Atmos. Environ., 25A, 3-4, pp. 533-546, 1991, doi: 10.1016/0960-1686(91)90050-H.

[24] Parameswaran, K., Vijayakumar, G., Murthy, B.V.K., and Moorthy, K.K., "Effect of wind speed on mixing region aerosol concentrations in a tropical coastal environment", J. Appl. Meteorol., 34, pp. 1392-1397, 1995, doi: 10.1175/1520-0450(1995)034<1392:EOWSOM>2.0.CO;2.

[25] Moorthy, K.K. and Satheesh, S.K., Characteristics of Aerosols over a Remote Island, Minicoy in the Arabian Sea: Optical Properties and Retrieved Size Characteristics. Quart. J. Roy. Meteor. Soc. 126, 562, pp. 81-109, 2000, doi: 10.1002/qj.49712656205.

[26] Sokhi, R.S., "World Atlas of Atmospheric Pollution, Anthem Press, U.K.", 2008

[27] Srivastava, N. and Satheesh, S.K., "Modulation in Direct Radiative Forcing Caused by Wind Generated Sea-Salt Aerosols ", Aerosol and Air Quality Research, 16, pp. 2869–2883, 2016, doi: 10.4209/aaqr.2015.07.0462.

[28] Grythe, H., Ström, J., Krejci, R., Quinn, P., and Stohl, A., "A review of sea-spray aerosol source functions using a large global set of sea salt aerosol concentration measurements", Atmos. Chem. Phys., 14, pp. 1277–1297, 2014, doi:10.5194/acp-14-1277-2014.

[29] Chu, Y., Sheng, L., Liu, Q., Zhao, D., Jia, N., and Kong, Y., "Size Distributions and Source Function of Sea Spray Aerosol over the South China Sea", Journal of Ocean University of China. 15, pp. 569–576, 2016, doi: 10.1007/s11802-016-2856-5.

[30] http://www.windows2universe.org/earth/Atmosphere/sea_salt_aerosol.html

[31] Zanchettin, D., Timmreck, C., Graf, H.F., Rubino, A., Lorenz, S., Lohmann, K., Krüger, K., and Jungclaus, J.H., "Bi-decadal variability excited in the coupled ocean–atmosphere system by strong tropical volcanic eruptions", Climate Dynamics, 39, pp. 419–444, 2012.

[32] Hoffmann, D.J., and Rosen, J.M., "Stratospheric sulphuric acid fraction and mass estimate for the 1982 eruption of El Chichon", Geophys. Res. Lett., 10, pp. 313-316, 1983.

[33] Bluth, G.J.S., Doiron, S.D., Schnetzler, C.C., Krueger, A.J., and Walter, L.S., "Global tracking of the SO2 clouds from the June, 1991 Mount Pinatubo eruptions", Geophys. Res. Lett., 19, 2, pp. 151-154, 1992, doi:10.1029/91GL02792.

[34] Hansen, J., Lacis, A., Ruedy, R., and Sato, K., "Potential climate impact of Mount Pinatubo eruption", Geophys. Res. Lett., 19, pp. 215-218, 1992.

[35] Moorthy, K.K., Nair, P.R., Murthy, B.V.K., and Satheesh, S.K., "Time evolution of the optical effects and aerosol characteristics of Mt. Pinatubo origin from ground based observations", J. Atmos. Terr. Phys., 58, pp. 1101-1116, 1996.

[36] https://www.pinterest.com/AtriaSpringdale/volcanoes-in-alaska/

[37] Flores, R.M., "Terpene and Terpenoid emissions and secondary organic aerosol production", *Dissertation, Michigan Technological University*, 2013.

[38] Fuzzi, S. , Baltensperger, U. , Carslaw, K. , Decesari, S. , Denier van der Gon, H. , Facchini, M.C. , Fowler, D., Koren, I., Langford, B., Lohmann, U., Nemitz, E., Pandis, S., Riipinen, I., Rudich, Y., Schaap, M., Slowik, J.G., Spracklen, D.V., Vignati, E., Wild, M., Williams, M., and Gilardoni S., "Particulate matter, air quality and climate", Atmos. Chem. Phys., 15, pp. 8217–8299, 2015, doi:10.5194/acp-15-8217-2015.

[39] Jaoui, M., and Kamens, R.M., "Gas and particulate products distribution from the photooxidation of α-humulene in the presence of NOx, natural atmospheric air and sunlight", J. Atmos. Chem, 46, 1, pp. 29-54, 2003, doi: 10.1023/A:1024843525968.

[40] Falkovich, A.H., Graber, E.R., Schkolnik, G., Rudich, Y., Maenhaut, W., and Artaxo, P., "Low molecular weight organic acids in aerosol particles from Rondonia, Brazil, during the biomass-burning, transition and wet ˆ periods", Atmos. Chem. Phys., 5, 781–797, 2005.

[41] Schnell, R.C. and Vali, G., "Biogenic ice nuclei: Part I. Terrestrial and marine sources", J. Atmos. Sci., 33, pp. 1554-1564, 1976.

[42] Havers, N., Burba, P., Lambert, J., and Klockow, D., "Spectroscopic characterization of humic like substances in airborne particulate matter", J. Atmos. Chem., 29, pp. 45-54, 1998.

[43] Després, V.R., Huffman, J.A., Burrows, S.M., Hoose, C., Safatov, A.S., Buryak, G., Nowoisky, J.F., Elbert, W., Andreae, M.O., Pöschl, U., and Jaenicke, R., "Primary biological aerosol particles in the atmosphere: a review", Tellus B: Chemical and Physical Meteorology, 64, 1, 15598, 2012, doi: 10.3402/tellusb.v64i0.15598.

[44] Liveira, P.F., Artaxo, P., Pires, C., Lucca, S.D., Procopio, A., Holben, B., Schaffer, J., Cardoso, L.F., Wofsy, S.C., Rocha, H.R., "The effects of biomass burning aerosols and clouds on the CO_2 flux in Amazonia", Tellus B: Chemical and Physical Meteorology, 59, 3, pp. 338-349, 2007, doi: 10.1111/j.1600-0889.2007.00270.x

[45] Roberts, G., Wooster, M.J., and Lagoudakis, E., "Annual and diurnal African biomass burning temporal dynamics", Biogeosciences, 6, pp. 849–866, 2009.

[46] Van Leeuwen, T.T., van der Werf, G.R., Hoffmann, A.A., Detmers, R.G., Rücker, G., French, N.H.F., Archibald, S., Carvalho, Jr., J.A., Cook, G.D., de Groot, W.J., Hély, C., Kasischke, E.S., Kloster, S., McCarty, J.L., Pettinari, M.L., Savadogo, P., Alvarado, E.C., Boschetti, L., Manuri, S., Meyer, C.P., Siegert, F., Trollope, L.A., and Trollope, W.S.W., "Biomass burning fuel consumption rates: a field measurement database", Biogeosciences, 11, pp. 7305–7329, 2014, doi:10.5194/bg-11-7305-2014.

[47] IPCC, Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the IPCC, edited by J.T. Houghton, et al. Cambridge: Cambridge University Press, 2001.

[48] IPCC, Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth

Assessment Report of the Intergovernmental Panel of Climate Change 129, 132, 2007.

[49] Sinha, P., Hobbs, P.V., Yokelson, R.J., Bertschi, I.T., Blake, D.R., Simpson, Gao, S., Kirchstetter, T.W., and Novakov, T., "Emissions of trace gases and particles from savanna fires in southern Africa", Journal of Geophysical Research, 108, D13, 8487, doi:10.1029/2002JD002325, 2003.

[50] https://www.nasa.gov/images/content/159505main_biomass_burn_lg.jpg

[51] Nussbaumer, T., "Overview on Technologies for Biomass Combustion and Emission Levels of Particulate Matter", Verenum Langmauerstrasse 109 CH – 8006 Zürich Switzerland, 2010, ISBN: 3-908705-21-5

[52] Bond, T.C., Streets, D.G., Yarber, K.F., Nelson, S.M., Woo, J.H., and Klimont, Z., "A technology-based global inventory of black and organic carbon emissions from combustion", J. Geophys. Res., 109, D14203, 2004, doi:10.1029/2003JD003697.

[53] Paliwal, U., Sharma, M., and Burkhart, J.F., "Monthly and spatially resolved black carbon emission inventory of India: uncertainty analysis", Atmos. Chem. Phys., 16, pp. 12457–12476, 2016, doi:10.5194/acp-16-12457-2016.

[54] Delucchi, M. "A Lifecycle Emissions Model (LEM): Lifecycle Emissions from Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity Use, Heating and Cooking Fuels, and Materials". *Institute of Transportation Studies*. UC Davis: Institute of Transportation Studies (UCD), 2003. Retrieved from: http://escholarship.org/uc/item/9vr8s1bb.

[55] Bond, T.C., Bhardwaj, E., Dong, R., Jogani, R., Jung, S., Roden, C., Streets, D.G., and Trautmann, N.M., "Historical emissions of black and organic carbon aerosol from energy related combustion, 1850–2000", Global Biogeochem Cycles, 21, GB2018, 2007, doi:10.1029/2006GB002840.

[56] Jacobson, M.Z., "Testimony for the Hearing on Black Carbon and Arctic, House Committee on Oversight and Government Reform", 2007, http://oversight.house.gov/documents/20071018110606.pdf.

[57] http://www.noaanews.noaa.gov/stories2011/images/controlledburnuscg.jpg.

[58] Kondratyev, K.Y., Ivlev, L.S., Krapivin, V.F., and Varostos, C.A., Atmospheric Aerosol Properties: Formation, Processes and Impacts, Springer-Verlag Berlin Heidelberg New York, ISBN 978-3-540-26263-3, 2006.

[59] Lelieveld, J., Roelofs, G.J., Ganzeveld, L., Feichter, J., and Rodhe, H., "Terrestrial surfaces and distribution of atmospheric sulphur", *Phil. Trans. R. Soc. Lond. B.*, 352, pp. 149-158, 1997.

[60] Boucher, O., "Atmospheric Aerosols: Properties and Climate Impacts", Springer Customer Service Center Gmbh, 2016, ISBN: 9789401778008.

[61] Jacobowitz, H., Soule, H.V., Kyle, H.L., and House, F. B., "The Earth Radiation Budget (ERB) Experiment: An overview", J. Geophys. Res., 89(D4), pp. 5021–5038, 1984, doi:10.1029/JD089iD04p05021.

[62] Seinfeld, J.H., et al., "A Plan for a Research Program on Aerosol Radiative Forcing and Climate Change", National Research Council, 1996, ISBN: 0309588871.

[63] Remer, L.A., Chin, M., DeCola, P., Feingold, G., Halthore, R., Kahn, R.A., Quinn, P.K., Rind, D., Schwartz, S.E., Streets, D., and Yu, H., "Executive Summary, in Atmospheric Aerosol Properties and Climate Impacts, A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research". [Mian Chin, Ralph A. Kahn, and Stephen E. Schwartz (eds.)]. National Aeronautics and Space Administration, Washington, D.C., USA, 2009.

[64] Ramachandran, S., Rengarajan, R., and Sarin, M.M., "Atmospheric carbonaceous aerosols: issues, radiative forcing and climate impacts", Current Sci. 97, 1, pp. 18-20, 2009.

[65] Haywood, J., and Boucher, O., "Estimates of the direct and indirect radiative forcing due to tropospheric aerosols: A review", Rev. Geophys., 38, 4, pp. 513–543, 2000, doi:10.1029/1999RG000078.

[66] Chin, M., "Atmospheric Aerosol Properties and Climate Impacts", DIANE Publishing, 2009, ISBN: 9781437912616.

[67] Zhang, Y., Liu, P., Queen, A., Misenis, C., Pun, B., Seigneur, C., and Wu, S.-Y., "A Comprehensive Performance Evaluation of MM5-CMAQ for the Summer 1999 Southern Oxidants Study Episode, Part-II. Gas and Aerosol Predictions", Atmos. Environ., 40, pp. 4839-4855, 2006.

[68] http://physicalsciences.ucsd.edu/molecules/multimedia/ images/aerosols.climate.change.jpg

[69] Kiehl, J.T., and Briegleb, B.P., "The relative roles of sulfate aerosols and greenhouse gases in climate forcing", Science, 260, pp. 311-314, 1993.

[70] Rasch, P.J., Barth, M.C., Keihl, J.T., Schwartz, S.E., and Benkowitz, C. M., "A description of the global sulphur cycle and its controlling processes in the NCAR CCM3", J. Geophys. Res., 105, pp. 1367-1386, 2000.

[71] Vinoj, V., Babu, S.S., Satheesh, S.K., Moorthy, K.K., and Kaufman, Y.J., "Radiative forcing by aerosols over the Bay of Bengal region derived from shipborne, islandbased, and satellite (Moderate-Resolution Imaging Spectro-radiometer) observations", J. Geophys. Res., 109, D05203, 2004, doi:10.1029/2003JD004329.

[72] Dey, S., Sarkar, S., and Singh, R.P., "Comparison of aerosol radiative forcing over the Arabian Sea and the Bay of Bengal", Adv. Sp. Res, 33, 7, pp. 1104–1108, 2004, doi:10.1016/S0273-1177(03)00737-3.

[73] Sarkar, S., Chokngamwong, R., Cervone, G., Singh, R.P., and Kafatos, M., "Variability of aerosol optical depth and aerosol forcing over India", Adv. Sp. Res, 37, 12, 2005 doi:10.1016/j.asr.2005.09.043.

[74] Bellouin, N., Boucher, O., Haywood, J., and Reddy, M., "Global estimates of aerosol direct radiative forcing from satellite measurements", Nature, 438, pp. 1138-1140, 2005.

[75] Moorthy, K.K., Babu, S.S., and Satheesh, S.K., "Aerosol characteristics and Radiative Impacts over the Arabian Sea during the Intermonsoon Season: Results from ARMEX Field Campaign", J. Atmos. Sci., 62, pp. 192-206, 2005.

[76] Jayaraman, A., Gadhavi, H., Ganguly, D., Misra, A., Ramachandran, S., and Rajesh, T.A., "Spatial variations in aerosol characteristics and regional radiative forcing over India: Measurements and modeling of 2004 road campaign experiment, Atmos. Environ., 40, pp. 6504-6515, 2006.

[77] Nair, S.K., Rajeev, K., and Parameswaran, K., "Interannual variability in the shortwave aerosol direct radiative forcing over the oceanic areas around the Indian subcontinent during dry season", *Proc. SPIE*, Vol. 6408, 640812, 2006; doi:10.1117/12.694027.

[78] Bates, T.S., Anderson, T.L., Baynard, T., Bond, T., Boucher, O., Carmichael, G., Clarke, A., Erlick, C., Guo, H., Horowitz, L., Howell, S., Kulkarni, S., Maring, H., McComiskey, A., Middlebrook, A., Noone, K., O'Dowd, C.D., Ogren, J., Penner, J., Quinn, P.K., Ravishankara, A.R., Savoie, D.L., Schwartz, S.E., Shinozuka, Y., Tang, Y., Weber, R.J., and Wu, Y., "Aerosol direct radiative effects over the northwestern Atlantic, northwestern Pacific, and North Indian Oceans: estimates based on in situ chemical and optical measurements and chemical transport modeling", Atmos. Chem. Phys., 6, pp. 1657-1732, 2006.

[79] Yu, H., Kaufman, Y., Chin, M., Feingold, G., Remer, L., Anderson, T., Balkanski, Y., Bellouin, N., Boucher, O., Christopher, S., DeCola, P., Kahn, R., Koch, D., Loeb, N., Reddy, M.S., Schulz, M., Takemura, T., and Zhou, M., "A review of measurement based assessments of aerosol direct radiative effect and forcing", Atmos. Chem. Phys., 6, pp. 613-666, 2006.

[80] Babu, S.S., Moorthy, K.K., and Satheesh, S.K., "Temporal heterogeneity in aerosol characteristics and the resulting radiative impacts at a tropical coastal station – Part 2: Direct short wave radiative forcing", Ann. Geophys., 25, pp. 2309-2320, 2007, doi:10.5194/angeo-25-2309-2007.

[81] Satheesh, S.K., Vinoj, V., and Krishnamoorthy, K., "Assessment of Aerosol Radiative Impact over Oceanic Regions Adjacent to Indian Subcontinent Using Multisatellite Analysis", Adv in Meteorol, ID 139186, 2010, doi:10.1155/2010/139186.

[82] Singh, S., Soni, K., Bano, T., Tanwar, R.S., Nath, S., and Arya, B.C., "Clear-sky direct aerosol radiative forcing variations over mega-city Delhi", Ann. Geophys., 28, pp. 1157–1166, 2010.

[83] IPCC, Climate Change 1994: Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emission Scenarios [Houghton, J.T., et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1995, ISBN: 0521550556.

[84] Abel, S.J., Haywood, J.M., Highwood, E.J., Li, J., and Buseck, P.R., "Evolution of biomass burning aerosol properties from an agricultural fire in southern Africa", Geophys. Res. Lett., 30, 15, 1783, 1983, doi:10.1029/2003GL017342.

[85] Keil, A., and Haywood, J.M., "Solar radiative forcing by biomass burning aerosol particles over marine clouds during SAFARI-2000", J. Geophys. Res, 108 (D13), 8467, 2003, doi:10.1029/2002JD002315.

[86] Abel, S.J., Highwood, E.J., Haywood, J.M., and Stringer, M.A., "The direct radiative effect of biomass burning aerosol over southern Africa, Atmos. Chem. Phys. Discuss., 5, pp. 1165–1211, 2005.

[87] Chung, C.E., and Zhang, G.J., "Impact of absorbing aerosol on precipitation: Dynamic aspects in association with convective available potential energy and convective parameterization closure and dependence on aerosol heating profile", J. Geophys. Res., 109, D22103, 2004, doi:10.1029/2004JD004726.

[88] Stanhill, G., and Cohen, S., "Global dimming: a review of the evidence for a widespread and significant reduction in global radiation with discussion of its probable causes and possible agricultural consequences", *Agricultural and Forest Meteorology*, 107, pp. 255-278, 2001.

[89] Padma Kumari, B., Londhe, A.L., Daniel, S., and Jadhav, D.B., "Observational evidence of solar dimming: Offsetting surface warming over India, *Geophys. Res. Lett.*, 34, L21810, 2007, doi:10.1029/2007GL031133.

[90] Martin, W., "Enlightening Global Dimming and Brightening", American Meteorological society, pp. 27-37, 2012, doi: 10.1175/BAMS-D-11-00074.1.

[91] Ramanathan, V., Crutzen, P.J., Lelieveld, J., Mitra, A.P., Althausen, D., Anderson, J., Andreae, M.O., Cantrell, W., Cass, G.R., Chung, C.E., Clarke, A.D., Coakley, J.A., Collins, W.D., Conant, W.C., Dulac, F., Heintzenberg, J., Heymsfield, A.J., Holben, B., Howell, S., Hudson, J., Jayaraman, A., Kiehl, J.T., Krishnamurti, T.N., Lubin, D., McFarquhar, G., Novakov, T., Ogren, J.A., Podgorny, I.A., Prather, K., Priestley, K., Prospero, J.M., Quinn, P.K., Rajeev, K., Rasch, P., Rupert, S., Sadourny, R., Satheesh, S.K., Shaw, G.E., Sheridan, P., and Valero, F.P.J., "Indian Ocean experiment: An integrated analysis of the climate forcing and effects of the great Indo-Asian haze, J. Geophys. Res., 106 (D22), 28, pp. 371–28,398, 2001, doi:10.1029/2001JD900133.

[92] Liepert, B.G., Feichter, J., Lohmann, U., and Roeckner, E., "Can aerosols spin down the water cycle in a warmer and moister world?", Geophys. Res. Lett., 31, L06207, 2004, doi:10.1029/2003GL019060.

[93] Lohmann, U., and Feichter, J., "Global indirect aerosol effects: a review, Atmos. Chem. Phys., 5, pp. 715-737, 2005.

[94] Trenberth, K.E., Fasullo, J.T., and Kiehl, J., "Earth's global energy budget, Bull. Amer. Meteor. Soc., doi:10.1175/2008BAMS2634.1, 311-323, 2009.

[95] http://www.iitk.ac.in/infocell/iitk/newhtml/story/fig1snt.jpg

[95] Rosenfeld, D., "Suppression of rain and snow by urban and industrial air pollution", *Science*, 87, pp. 1793-1796, 2000.

[96] Sario, M. De, Katsouyanni, K., and Michelozzi, P., "Climate change, Extreme weather events, air pollution and

respiratory health in Europe", European Respiratory Journal, 42, pp. 826-843, 2013, doi: 10.1183/09031936. 00074712.

[97] https://www.rabbitair.com/pages/our-children-at-risk.

[98] Seinfeld. J.H.. and Pandis.. S.N., "Atmospheric Chemistry and Physics", 1326, 1998.

[99] Rothen-Rutishauser, B.M., Schürch, S., Haenni, B., Kapp, N., and Gehr, P., Interaction of Fine Particles and Nanoparticles with Red Blood Cells Visualized with Advanced Microscopic Techniques", Environ. Sci. Technol., 40, 14, pp. 4353–4359, 2006, doi: 10.1021/es 0522635.

[100] Pope, C.A., Dockery, D.W., and Schwartz, J., "Review of Epidemiological Evidence of Health Effects of Particulate Air Pollution", Inhalation Toxicology 7, 1, 1995, doi:10.3109/08958379509014267.

[101] Pope, C A 3rd, Bates, D.V., and Raizenne, M.E., "Health effects of particulate air pollution: time for reassessment?", Environ Health Perspect., 103, 5, pp. 472-480, 1995.

[102] Chameides, W.L., Yu, H., Liu, S.C., Bergin, M., Zhou, X., Mearns, L., Wang, G., Kiang, C.S., Saylor, R.D., Luo, C., Huang, Y., Steiner, A., and Giorgi, F., "Case study of the effects of atmospheric aerosols and regional haze on agriculture: An opportunity to enhance crop yields in China through emission controls?", Proceeding of the National Academy of Sciences of the USA, 96, 24, pp. 13626–13633, 1999, doi: 10.1073/pnas.96.24.13626.

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