Studies on Atmospheric Aerosols Using MODIS Satellite Data Over India from 2000-2020

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1.Introduction

Aerosols are microscopic particles that float in the air. Their size is insignificant, but their impact on the weather and climate is enormous. They are solid or larger particles that are dispersed in the air. Aerosols are now recognized as having the potential to act as climate's 'Atmospheric Switches.' Aerosols are important in acclimating the current climate to more unpredictable and chaotic weather patterns all over the world. The presence of particulate aerosols in the atmosphere has become a peculiar signature of the unusual weather changes that are being observed around the world. From causing a continental escalation of atmospheric/oceanic temperatures to global dimming, aerosols play an important role. Because of many new findings of their significant direct and indirect effects on climate (e.g., by altering temperature, cloud, radiation, and precipitation) and the large uncertainties in our estimates of aerosol forcing on climate, the aerosol is becoming a central theme in climate research. Many ground-breaking findings on a wide range of aerosol effects were reported in the following years referred to as the "exploratory phase" of aerosol research. Aerosols play a role in the suppression of precipitation and the slowing of hydrological cycles caused by dust storms, as well as air pollution and fire smoke plumes. Other noteworthy findings include a lower solar radiation budget at the surface than at the top of the atmosphere due to absorbing aerosols, as well as strong radioactive heating in the atmosphere due to the mixing state of black carbon.

Aerosols are created by mechanical disintegration processes that occur over land (e.g., dust lifting) and ocean (sea spray) or chemical reactions that occur in the atmosphere (e.g., conversion of Sulphur dioxide to sulphuric acid droplets). The different concentrations and compositions of these particles have a significant impact on changing the local and regional climates. Aerosols are frequently carried too far away from their source by wind after being produced at a specific location. Dust is transported in large quantities from Africa to the South Indian Ocean, West Asia to the Arabian Sea, China across the Pacific, and Australia to the Indian Ocean. The atmospheric aerosols have global implications due to their long-range continental origin and associated transport mechanisms. Aerosols can take anywhere from a few hours to a week to remove depending on their composition. These aerosols primarily originate at the surface and travel to the lower troposphere, where they settle. Aerosols from volcanic eruptions, on the other hand, can reach stratospheric levels. Most processes involving or initiated by aerosols are not well understood due to their diverse composition. As a result, it's critical to comprehend atmospheric aerosols' physical and chemical properties, as well as composition and forcing effects on a local scale.

Atmospheric aerosols play a critical role in many processes that affect human lives either directly (health) or indirectly (climate), with the most visible manifestation being atmospheric haze. The creation of clouds and fog by cloud condensation nuclei, as well as the scattering and absorption of solar radiation, are more fundamental. The sources, effects, and processes connected with atmospheric aerosols are depicted in Figure 1. The focus is on Black Carbon (BC), which absorbs solar energy substantially and contributes to forcing by partially concealing the surface from solar radiation. Because absorbing aerosols are more regionally concentrated and have life times on the order of a week, they may have a significant impact on regional climate.

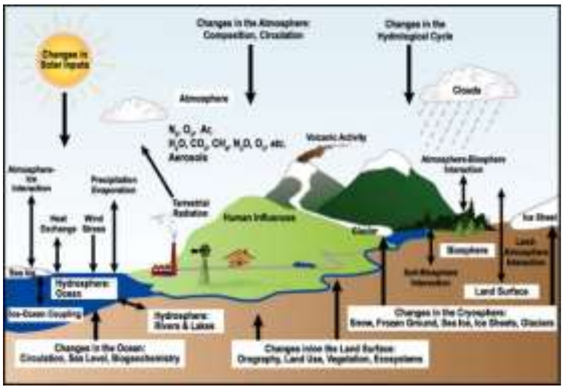


Fig.1. Main drivers of climate change. The radioactive balance between incoming shortwave radiation (SWR) and outgoing long wave radiation (OLR) is influenced by global climate 'drivers' (*Schematic View of the Components of the Climate System, Their Processes) (Download Scientific Diagram*, 2021)

The objective of the present investigation has been to study the characteristics of atmospheric (Tropospheric) aerosols in the urban environment. Optical investigations are carried out at several universities in South Asia using a Sun tracking multiple wavelength radiometers (MWR) and the data are analysed to study the various characteristics of atmospheric aerosols. Spatial homogeneity is very important in the context of using satellite data, studying cloud aerosol interaction, and estimating the influence of aerosol sources for a region. The spatial homogeneity of Atmospheric aerosols has been studied over south India using MODIS AOD. Variability of AOD over south India is studied using a statistical parameter -Coefficient of Variation. Seasonal variation of atmospheric aerosols has been studied using MODIS AOD and Aerosol Index from Ozone Monitoring Instrument (OMI). The source of high AOD during Monsoon is also investigated.

2. Experimental data: MODIS and AERONET data

(Bright & Gueymard, 2019) found that blending the two Aqua and Terra products, daily estimates of all Aerosol Optical Depth (AOD) products was more accurate. Each AOD product was validated similarly and distinctly. The most widely used solar resource assessment model, AOD550, performs poorly in equatorial climates (absolute root mean square error (RMSE) of 0.194) and well in temperate climates (RMSE of 0.126). The combined Aqua and Terra AOD550 have an absolute RMSE of 0.106 and a mean absolute error of 0.109 globally. The most common MODIS AOD retrievals range from 0.01 to 0.25, implying that the MODIS daily AOD products may introduce a significant source of uncertainty in modelled irradiance estimates and that other sources of input data should be used instead when high accuracy was required.

This study looked at the quality of satellite aerosol products about AERONET in Southeast Asian countries and highlighted a framework for air quality assessment across a large, complex region. (Wei et al., 2020) observed in areas with bright surfaces or that were dominated by human activity. The difficulty in estimating surface reflectance and the aerosol-type assumption was the main reasons for this. Furthermore, aerosol retrievals were overestimated in general, particularly in North America, Europe, and East Asia. Furthermore, estimation errors and uncertainties were strongly linked to changing surface and atmospheric aerosol conditions, becoming larger as surface brightness, aerosol loading, the angst om exponent, and single scattering albedo increase. To reduce estimation uncertainty, more algorithm improvements were needed, particularly for heterogeneous urban and bright surfaces.

AERONET, a NASA-founded ground-based remote sensing federation that was utilised to collect data for calibration, validation, and modelling, is discussed. The MODerate Resolution Imaging spectroradiometer (MODIS) was used to collect data on clouds, aerosols, and water vapour from satellites, which is also briefly described.

The main goal of this concept is to look at the impact of atmospheric aerosols over the Indian subcontinent using data from MODIS on board Terra Satellite for the years 2000 to 2020. The region between the co-ordinates 5°N to 40°N latitude and 65°E to 100°E Longitudes is selected for the study. The resolution of the data is 0.1° x 0.1° (approx. 10 km) of Collection 5.0 has been used. The region of interest is divided into 7225 grid boxes each of size 0.4°x 0.4°. Aerosol optical properties were investigated in six discrete wavelength regions using a hand-held sun photometer called AERONET (Aerosol Robotic Network). The optical properties of aerosols, as well as their day-to-day and seasonal variation, are studied using continuous monitoring of AOD on clear sky days. This paper discusses aerosol characterization, the relative dominance of different mode aerosols, number density, and its impact on radioactive forcing.

The Variability of Aerosol Content in the Atmosphere is influenced by various meteorological parameters. To determine the reasons for the variability, the magnitude of their impact must be investigated. MODIS on board Terra Level 2 AOD for a period of 20 years (2000-2020). The resolution of the data is 0.1° x 0.1° (approx. 10 km) of Collection 5.0

has been used. The region of interest is divided into 7225 grid boxes each of size 0.4°x 0.4°. The region between the coordinates 5°N to 40°N latitude and 65°E to 100° E Longitudes is selected for the study. Global Precipitation Climatology Project (GPCP) rainfall data for 2000-2020. The resolution of the data is 1°x 1°.

3. Seasonal variations of AOD

Plotting AOD over India in various seasons is used to investigate seasonal changes in AOD. The average of all AODs across the period of study was used to determine the Mean Aerosol Loading in each region of the Indian Subcontinent. With many Great Plains, mountain ranges, and plateaus, the Indian Subcontinent is divided into separate geographical areas. The Average Seasonal Variations of the AOD for the period of study is shown in Figure 2. AOD is significantly elevated in the northern section of India, and some eastern areas, the Indo Gangetic plain, North-Western areas of India. Southern peninsular India appears to have lower AOD than North India, which could be attributed to aerosol movement caused by land-sea winds. North India's population density is also higher than in the south (Census 2020), possibly leading to increased anthropogenic sources. India has a higher concentration of industries and thermal power plants. The Indo Gangetic plain's geography makes it difficult for aerosols to be transferred (the Himalayas in the North and Vindhya Range in the south obstruct the wind to transport Aerosols). Dust is transported from Rajasthan as well as other western portions of India. A large portion of Punjab, Chandigarh, and Rajasthan also have significant Aerosol concentration comparable to the Indian plain, which could be owing to desert dust transport from the Great Indian Thar desert. Aerosol Loading is moderate throughout a large part of Maharashtra, the Telangana area surrounding Hyderabad, and also some areas of Jharkhand (A. Gupta et al., 2021). Aerosol Loading is significant in sections of Maharashtra, Kerala, Hyderabad, and also some portions of Jharkhand. Internal sections of Kerala, Tamil Nadu, Andhra Pradesh, and a large part of Karnataka have lower AOD, while the coastal regions of these states have a moderate amount of Aerosol loading, which could be related to aerosols movement from nearby water bodies. The key result is that the AOD appears to be linked to topography. The AOD is low in many of the elevated areas, including a large part of southern Maharashtra, Karnataka, and western Andhra Pradesh. It is not an artefact because ground-based AOD readings within these areas agree with MODIS measurements. The reason could be that winds at greater elevations cause quick transportation. Compared to those closer to the land, the AOD over oceans far away from the land has less AOD, indicating significant Anthropogenic loading over the surface.

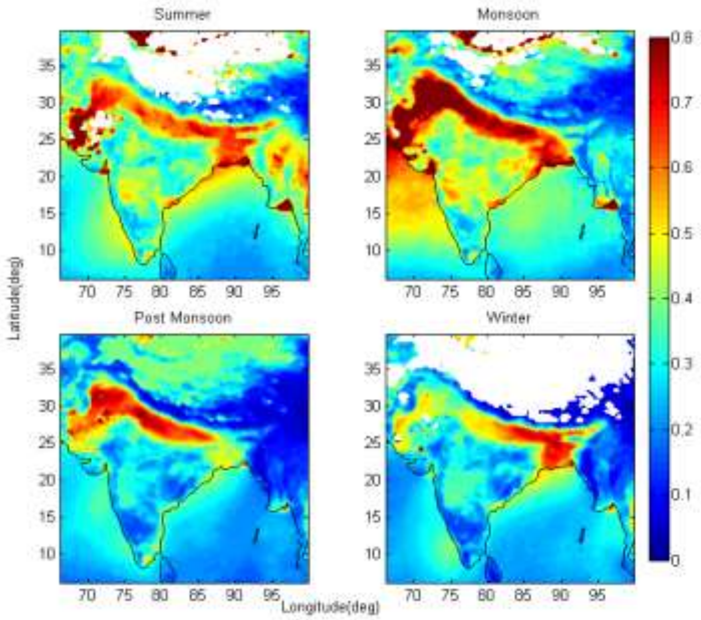
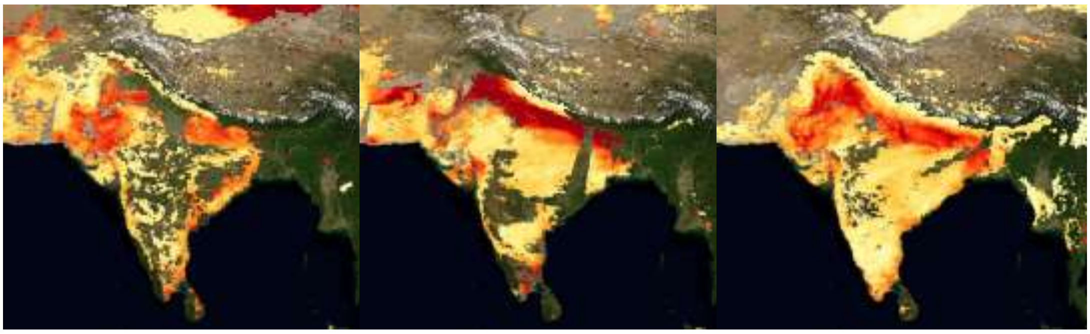


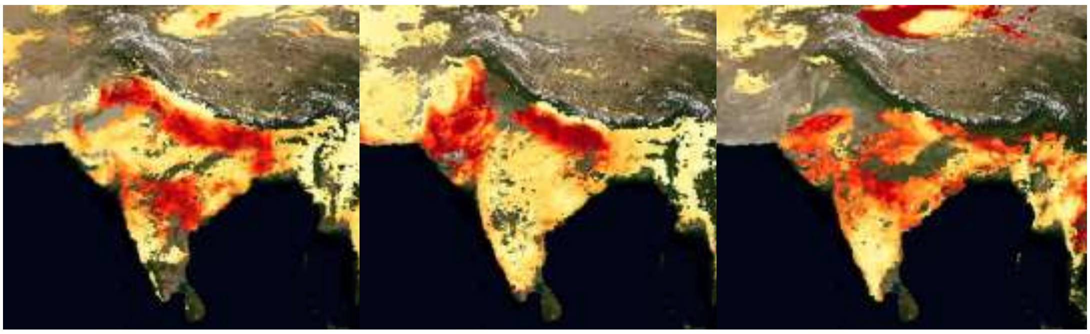
Fig. 2 Mean Seasonal variations of AOD over India for the period of 2000-2020

4. Yearly Variability of Atmospheric Aerosol over India

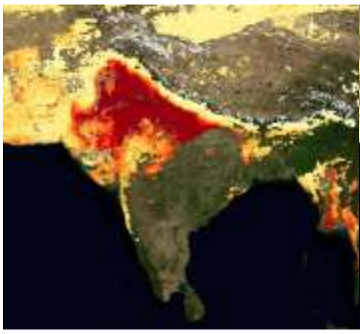
Aerosols have a very short life - span and are influenced by meteorological parameters. The current study looks into the effect of various parameters on the variability of aerosol optical depth.



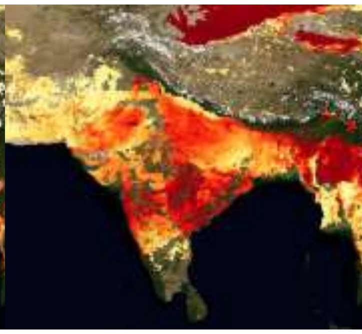
AOD Mean-2000 AOD Mean -2001 AOD Mean -2002



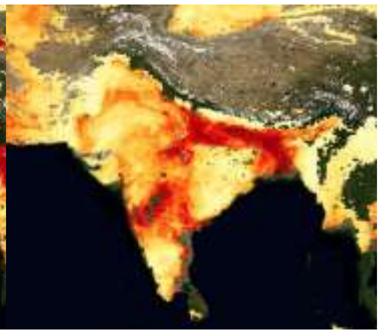
AOD Mean -2003 AOD Mean -2004 AOD Mean -2005



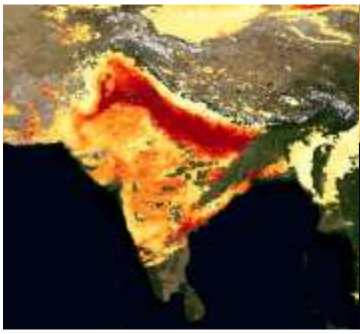
AOD Mean -2006



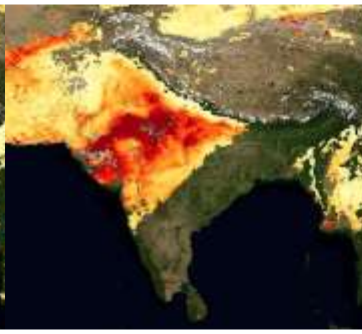
AOD Mean -2007



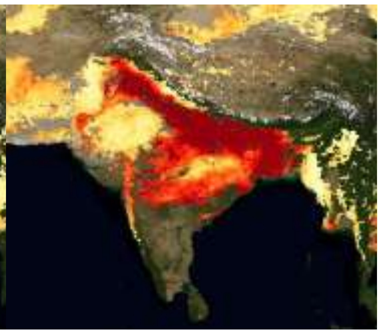
AOD Mean -2008



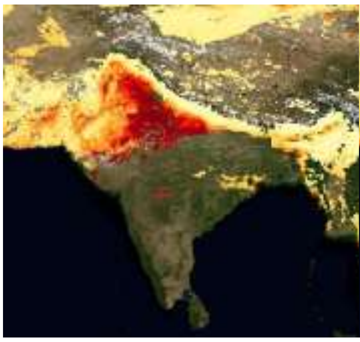
AOD Mean -2009



AOD Mean -2010

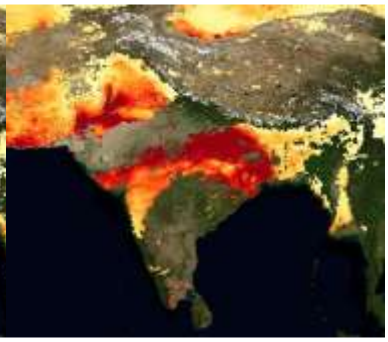


AOD Mean -2011

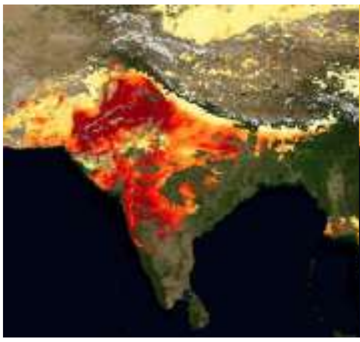


AOD Mean -2012

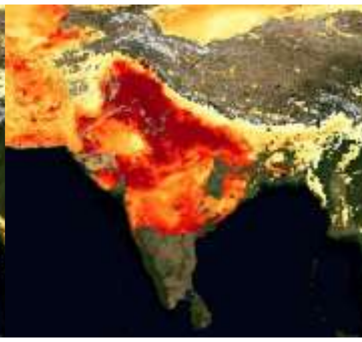
AOD Mean -2013



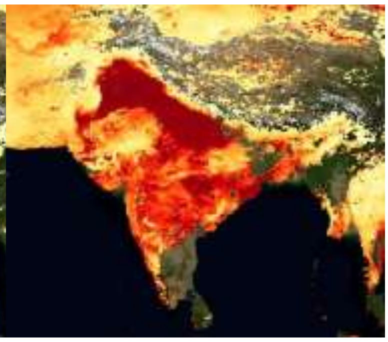
AOD Mean -2014



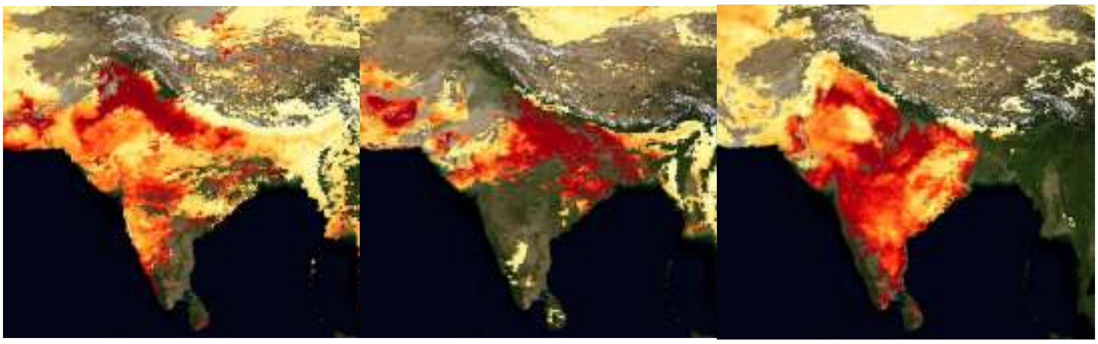
AOD Mean -2015



AOD Mean -2016



AOD Mean -2017



AOD Mean -2018 AOD Mean -2019 AOD Mean -2020

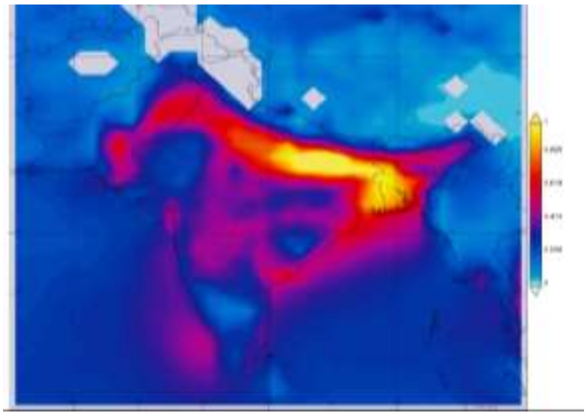
Fig. 3 Yearly Mean AOD over the Indian subcontinent for the period of twenty years i.e., 2000-2020

Figure 3 depicts the Yearly average optical depth of aerosols over entire period of study, i.e.. 2000-2020, When compared to southern part India, North West and north east portions of India are highly polluted with aerosols. The AOD along the east coast is also higher than along the west coast, which will be attributed to aerosol travel to Bay of Bengal. Regardless of season, the Indo-Gangetic plain is densely populated with aerosols (Kuttippurath et al., 2020). When compared to other regions, the southwestern peninsula has a very low AOD. AOD is high in central Maharashtra and western Madhya Pradesh. When compared to other regions, this region has a very high rainfall rate, and fast washout may be the purpose for less AOD (Aerosol Optical Depth).

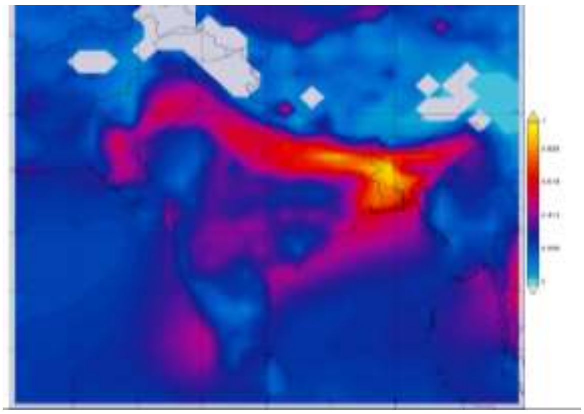
5.Monthly variation of AOD

`Monthly variations of Aerosol optical depth is studied by plotting Aerosol optical depth over India from 2000-to 2020. Figure 4 represents monthly mean variations of aerosol optical depth in 2000-2020. From 2000-2020 (a drought year), we observed heavy aerosol accumulation in July over IGP, central and eastern parts of India which results in the reduction of solar insolation reaching the Earth's surface, AOD is found to be very high (> .6) in Ganga basin with increasing aerosol concentration at a huge rate. The input of aerosols (mostly coarser fraction) from the Thar Desert and dry season during pre-monsoon cause high AOD in the Ganga basin. Fine soil dust from dry un-vegetated agricultural land during summer is another big source of aerosols in this region. The overall patterns of AODs show higher concentrations over the densely populated and highly industrialized Gangetic basin for both summer monsoon and winter seasons. During the winter monsoon, the AODs are larger over both the Arabian sea, the Indian Ocean, and the Indian subcontinent. As identified in numerous studies, the dominant sources for these aerosols are anthropogenic emissions (both biomass burning and fossil fuel combustion). The spatial gradient of AOD is showing an increase from the southern part of the BOB to the northern part up to the Himalayas (Lelli et al., 2020). Central India shows moderate AOD values. The Bay of Bengal (BOB) shows high AOD during the Monsoon season compared to the other seasons. The northern belt especially the central part of the Ganga basin suffered from very low rainfall. As a result, AOD was found to be much higher even during the monsoon season. Low aerosol loading is shown over entire India during November and February. Aerosol loading in the entire Indian region is low after monsoon rainfall as rainfall washes out most of the aerosol concentration due to which most of the study region including the Arabian sea, Indian ocean, and the BOB looks to be clean during November and February. The Winter season shows a reversal of the spatial gradient of aerosol loading (compared to pre-monsoon and monsoon season) which is low in the western zone to high in the eastern zone. Dust storm events begin at the end of March and drastically change the AOD distribution pattern during pre-monsoon and monsoon seasons (You et al., 2019). In general, AOD is less than 0.6 in most parts of the BOB during March except for some parts. Due to Westerly winds, the dust is transported from Arabian and African deserts to the Northern parts of India.

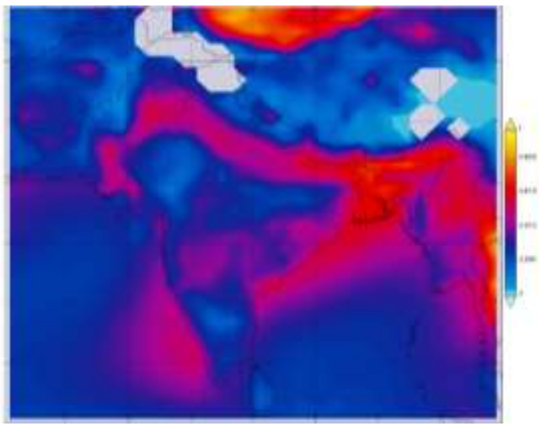
In the year 2000, we observed heavy aerosol accumulation in July over IGP, central and eastern parts of India which results in the reduction of solar insolation reaching the Earth's surface. As a result of this high pressure occurs over land which leads to less monsoon rainfall. And so, 2020 is a drought year. we observed heavy aerosol concentration in July over Eastern parts of Pakistan, Arabian sea, Indian ocean, Rajasthan, Gujarat, and IGP. High pressure was built up over oceans such that monsoon forcing was more overland leading to good monsoon rainfall.



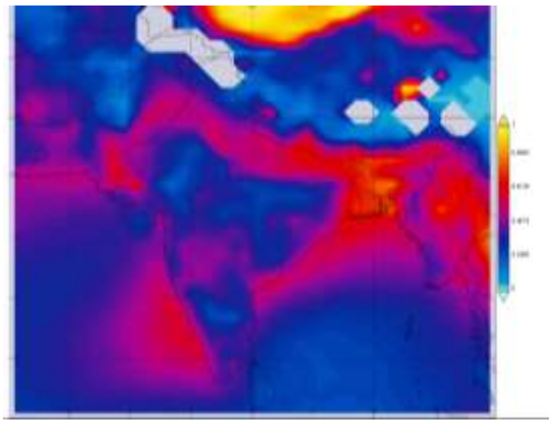
Jan (2000-2020)



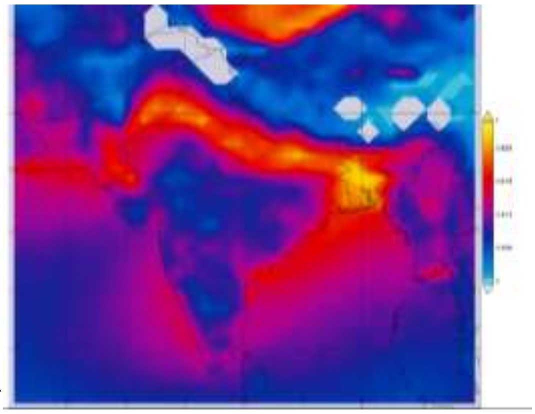
Feb (2000-2020)



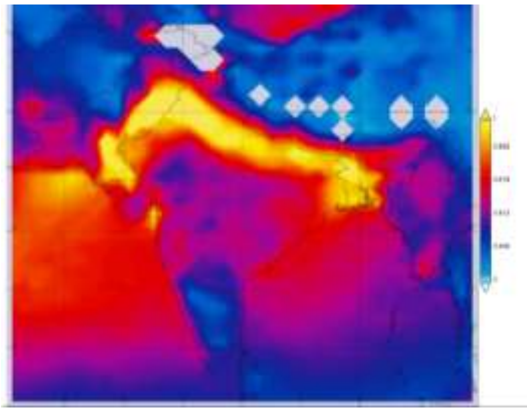
Mar (2000-2020)



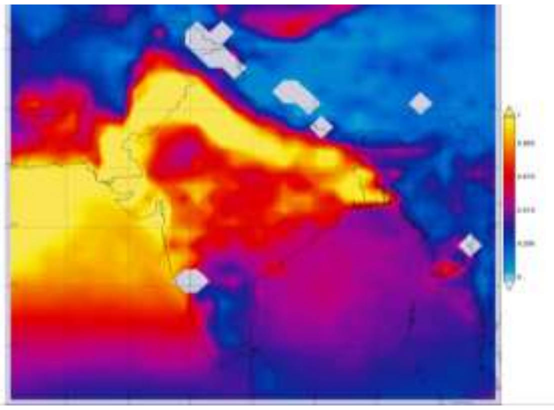
Apr (2000-2020)



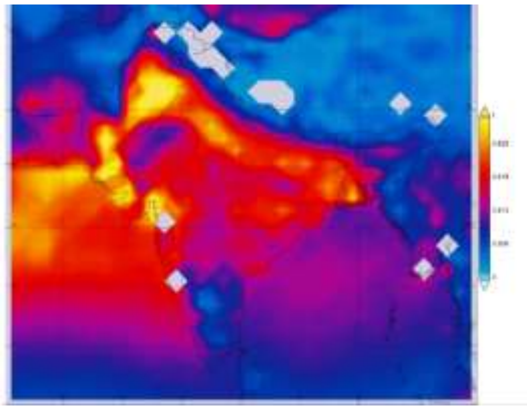
May (2000-2020)



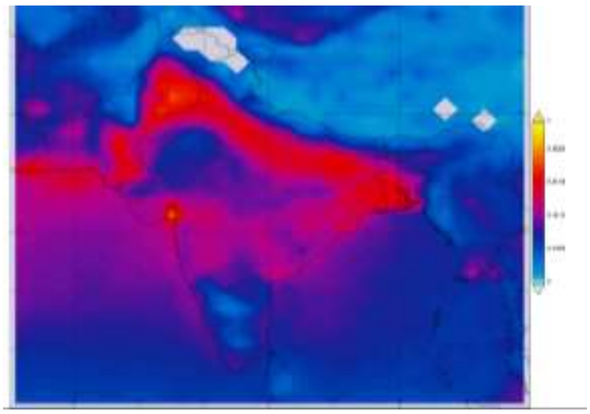
Jun (2000-2020)



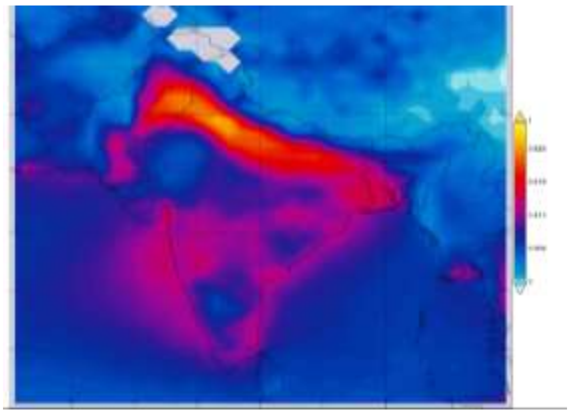
Jul (2000-2020)



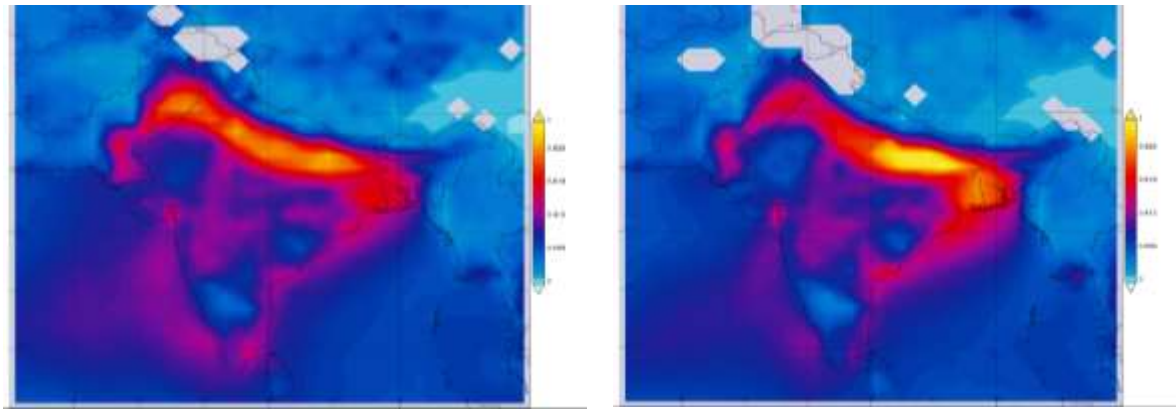
Aug (2000-2020)



Sep (2000-2020)



Oct (2000-2020)



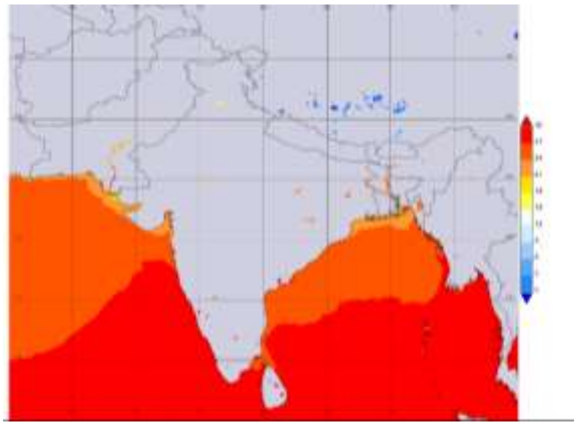
Nov (2000-2020) **Dec (2000-2020)**

Fig.4. Monthly Mean Variation of Aerosol Optical Depth (2000-2020) (Average combined Dark Target and Deep Blue AOD at 0.55 micron for land and ocean monthly 1 deg. [MODIS-Terra MODO8_M3 v6.1] for Every Months)

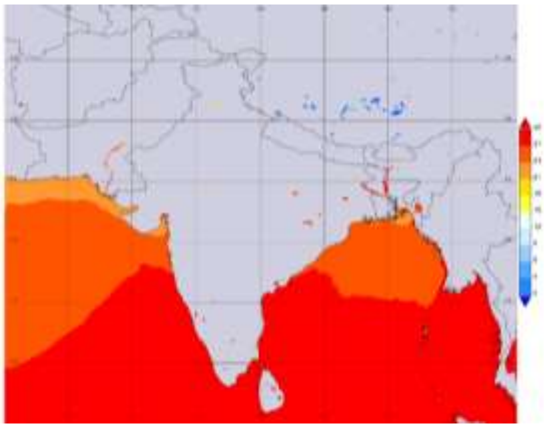
6.Monthly Variation of Sea Surface Temperature

It is observed that during March, April and May i.e., pre-monsoon season, a very warm episode is formed over the region covering the Arabian sea, Indian ocean, and the Indian subcontinent. This may be due to intense mixing or upwelling or due to a decrease in aerosol concentration which leads to the increase in solar insolation reaching the Earth's surface. The North Arabian Sea, and Indian ocean becomes the warmest area of the Oceans before the onset of the Southwest monsoon in June. It is noticed from the results that SST decreases during monsoon season compared to pre-monsoon season and the warm episode over the Arabian sea, the Indian ocean gets extended towards the Indian subcontinent. The Eastern equatorial Arabian sea, the Indian ocean is one of the active zones among the other oceans because it maintains warm temperatures of order 28^{o} C and even $29\ ^{o}$ C in some cases. The warming phase of the Arabian Sea, and the Indian ocean commences by February when it begins to extend on both sides of the equator and continues through April. The northern boundary of the warm episode merges with the south Indian coastline during April in the Indian subcontinent. The first signal of cooling is observed in the southern Arabian Sea and Indian ocean during May (Gohain et al., 2018). The summer monsoon cooling begins during June in the western equatorial Arabian sea, Indian ocean, and by July in the Arabian sea, Indian ocean, and continues through September. In the Indian subcontinent, sea surface temperature does not fall below $28\ ^{o}$ C during the summer. Soon after the withdrawal of the monsoon, secondary warming takes place in the Arabian Sea, and Indian ocean during October, and is followed by winter cooling of the Arabian Sea, and Indian ocean (north of the equator). The summer warming of the southern Arabian Sea, and Indian ocean and a warm episode in the BOB are part of the Arabian Sea, and Indian ocean and recede during October and November. The annual march of the Arabian Sea, and Indian ocean surface temperature shows the following four phases comprising warming from approximately February to May, cooling from May to Aug, warming from September to mid-November, and cooling from mid-November to January. This abnormal behavior of the Arabian Sea and Indian ocean is due to the influence of the SW monsoon which dominates the AS during the Northern Hemisphere summer.

Figure 5 represents monthly mean variations of sea surface temperature in 2000-2020. In 2000, the warming phase of the North Arabian Sea, Indian ocean starts in January, where the rest of it appears to have moderate SSTs. The warmness spread throughout the Indian subcontinent, the Arabian sea, Indian ocean from February through June. In July, SST decreases on account of rainfall. The secondary warming takes place from August through September. In October, again SST decreases, and in November, so many regions of the study area have less than moderate SST between 12 ^{o}-15 ^{o}C .In December, maximum SST is recorded throughout the study area probably the existence of aerosol particles is minimal due to the lack of rainfall. In 2010, many parts of the Arabian sea, Indian ocean have moderate SST, and warmth is spread over the whole Arabian sea, Indian ocean (Das et al., 2021). This continues through March. In April, the SST is spread throughout the study area. In May, again SST seems to decrease over the South Arabian Sea, Indian ocean, and Somali Coast. In June, warmness is extended from the Indian subcontinent. In July, a very low SST is recorded over the Northwestern Arabian Sea, Indian ocean, Somali Coast, and Equatorial Arabian Sea, Indian ocean. The patterns in August and September resemble those in March, and in November SST cools and falls to <22 ^{o} C. In December, it reaches 33 ^{o} C.



Jan (2000-2020)



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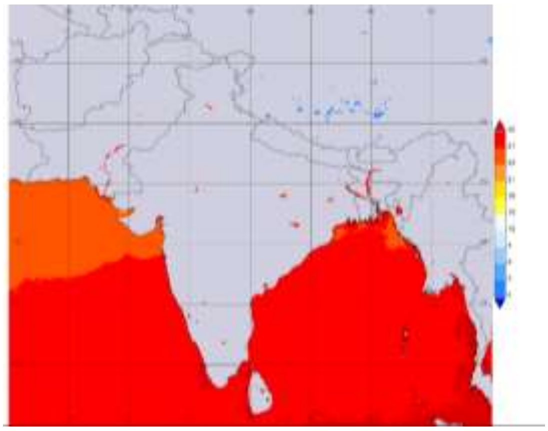

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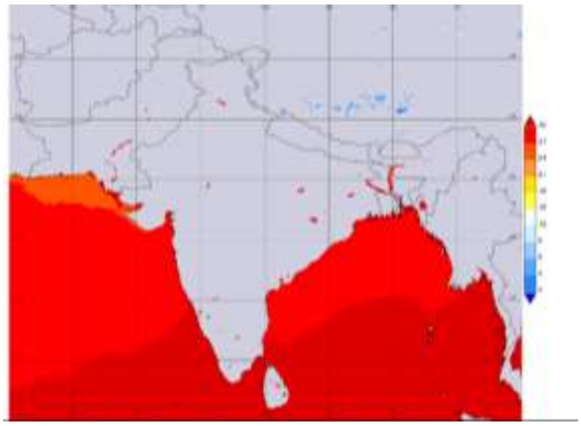

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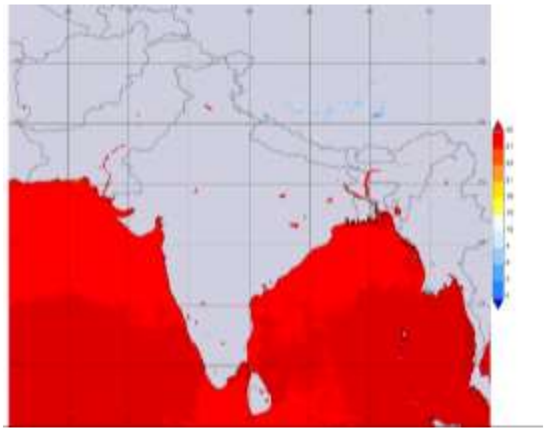

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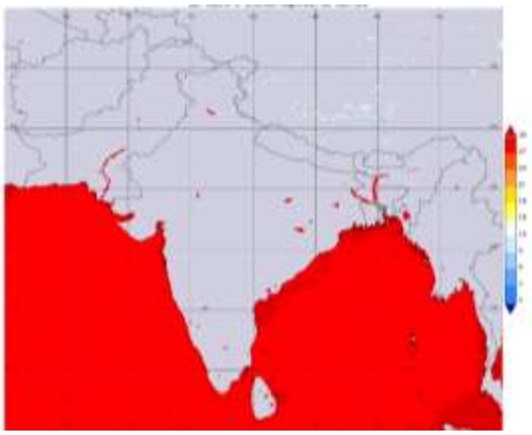
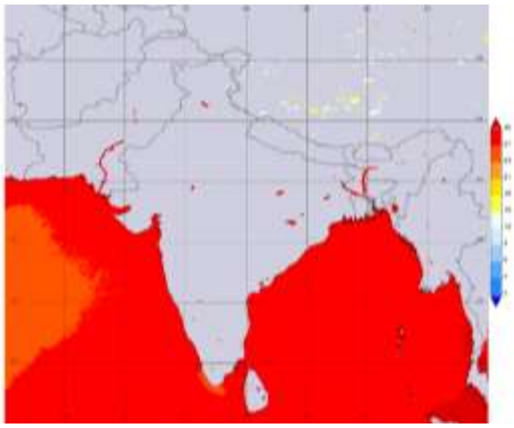
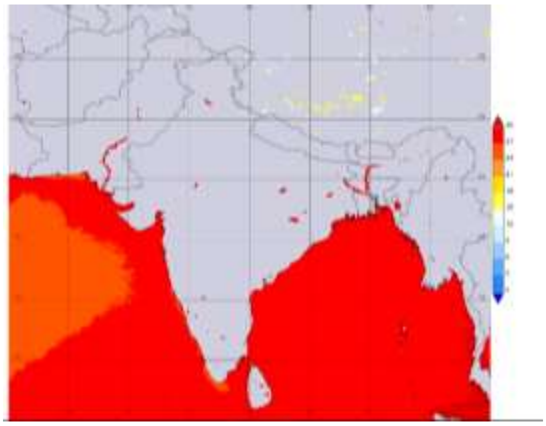


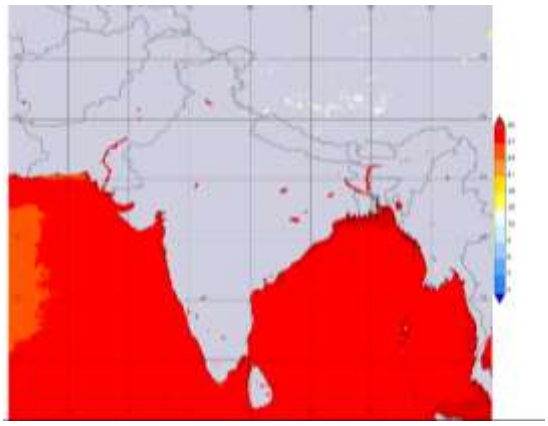
Jun (2000-2020)



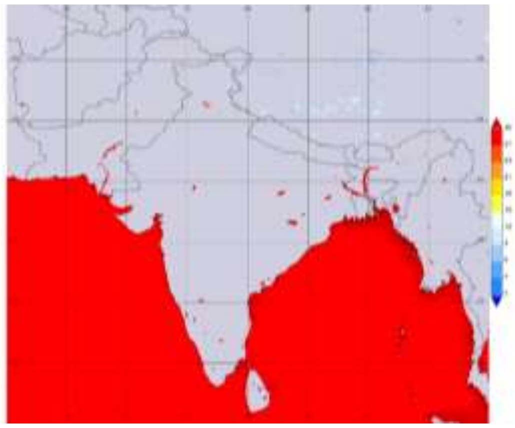
Jul (2000-2020)



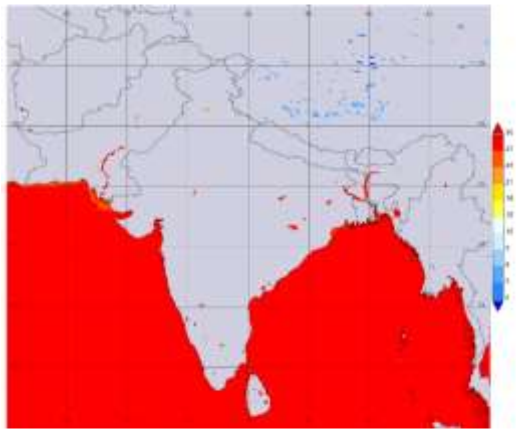
Aug (2000-2020)



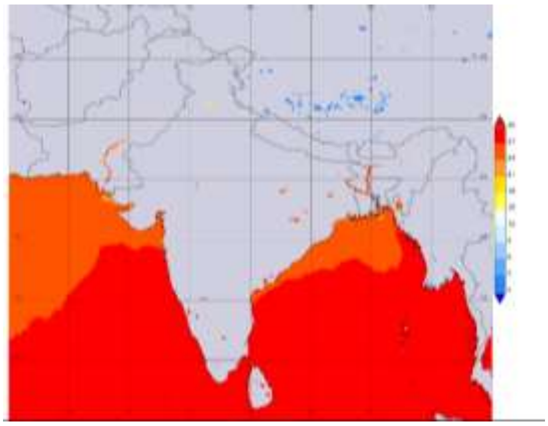
Sep (2000-2020)



Oct (2000-2020)



Nov (2000-2020)



Dec (2000-2020)

Fig.5. Monthly Mean Variation of Sea Surface Temperature (2000-2020) (Average Sea surface temperature at 11 microns (Day) monthly 4 km. [MODIS-Aqua MODISA_L3m SST monthly 4 km vR2019.0] for every months)

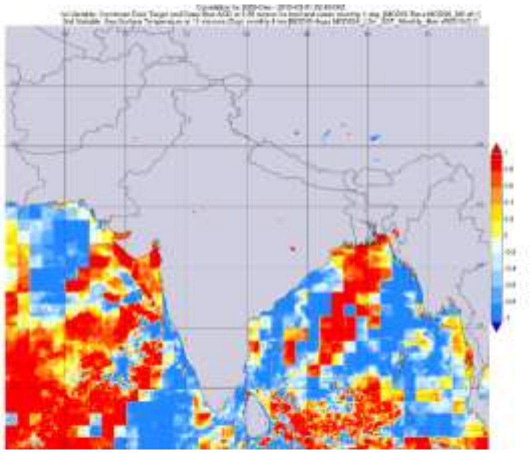
7.Seasonal Correlation of AOD and SST

Figures 6 and Figure 7 shows the seasonal correlation between AOD and SST for the year 2010 and 2020. And also, Figure 8 illustrates the Seasonal correlation between AOD and SST during 2000-2020 throughout the India. In the years 2010 and 2020, the correlation values between AOD and SST over the Equatorial Arabian Sea, and the Indian Ocean during summer are ranging from 0.2-to 0.6. The Northwest coast of Somalia is also showing the same values as above. The Southern BOB also has a positive correlation during the summer whereas over the Southern BOB and Somalia coast the correlation is highly negative. During the monsoon period, the spatial coverage of positive correlation over the Equatorial Arabian Sea, and Indian ocean had been reduced and it was turned negative over all other regions.

The year 2020 is also showing the same features as 2010 in summer except that it has more intensity in both negative and positive correlations. During monsoon season, the BOB and Somali coast show a positive correlation whereas the eastern Arabian Sea, and Indian ocean are negative. The year 2019 also resembles the same features during summer with almost a correlation of 0.6 over the Arabian Sea and the Indian ocean (Song et al., 2020.).. Seasonal correlation for AOD and SST is highly affected in the northern Arabian sea.

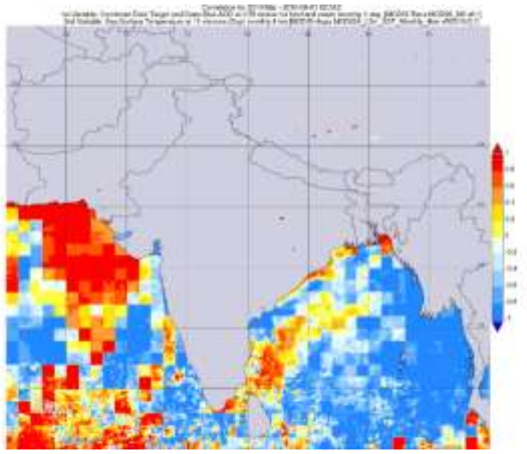
During monsoon, Northern BOB correlates with 0.8 whereas Southern BOB correlates with 0.4. All the cases Northern Arabian Sea, and Indian ocean is showing a negative correlation during monsoons and a positive correlation during summer. The equatorial Arabian sea and Indian ocean remain constant throughout summer and monsoon. The correlation over Somalia coast is been increasing from summer to monsoon showing higher correlation values during monsoon. During monsoon, the central BOB is showing high correlation, and the Equatorial Arabian Sea, Indian ocean, and west coast of Sumatra are showing positive correlation values. It is observed from the results that in the pre-monsoon season, SST and AOD are well correlated over the Arabian Sea, and Indian ocean whereas they are poorly correlated over the Arabian sea, Indian Ocean, and Indian subcontinent. The role of pre-monsoon aerosols over the Arabian Sea and the Indian Ocean region is expected to play a significant role in the monsoon features over the Indian subcontinent. The major fraction of aerosols over the Arabian Sea, and Indian ocean is desert dust of natural origin. The presence of aerosols over the Arabian Sea, and Indian ocean during the summer monsoon decreases the short-wave radiation arriving at the surface and increases the top of the atmosphere reflected radiation.

A positive correlation between AOD and SST may imply that the number of absorbing aerosols increases in the atmosphere, and atmospheric heating increases which further increases the temperature over land and sea. When aerosols are more, Cloud condensation nuclei increase which enhances the lifetime of clouds and hence leads to a decrease in precipitation. Due to the dispersion of clouds, the amount of rainfall is poor on land than on the sea which may lead to droughts (Dansie et al.,2021). High SSTs are recorded during drought years. A negative correlation between AOD and SST implies that if AOD increases then SST decreases. No correlation between AOD and SST implies that there is no influence of aerosols on sea surface temperature. During dry seasons (2010 and 2020), the wind areas are becoming easterlies, inhibiting the transmission of sea salt aerosols into to the atmosphere to cause amount of rain over the ocean and also reducing the transmission of moisture (via sea salt aerosols) onto land, resulting in drought-like scenarios.



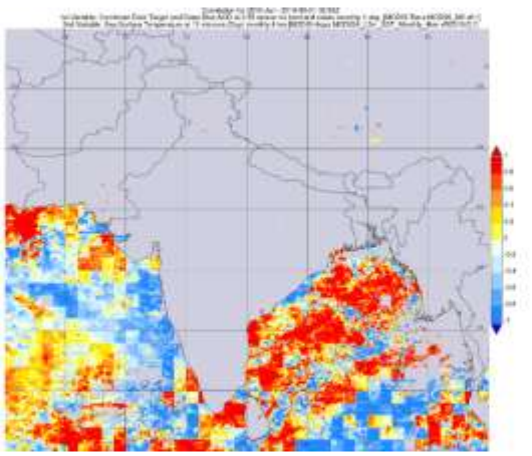
Winter

Correlation for 2009 Dec – 2010 Mar



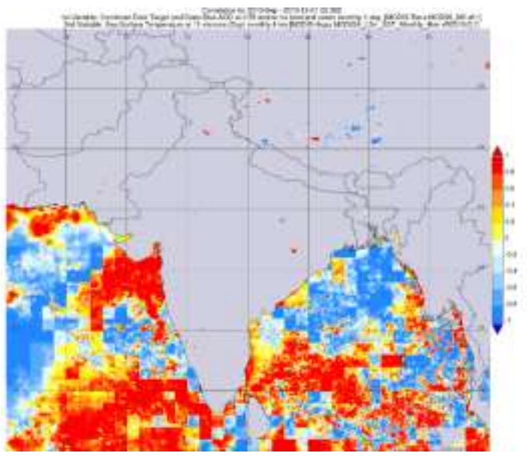
Summer

Correlation for 2010 Mar- 2010 Jun



Monsoon

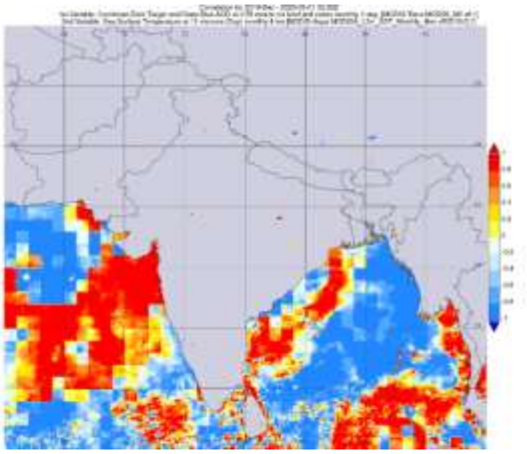
Correlation for 2010 Jun - 2010 Sep



Post Monsoon

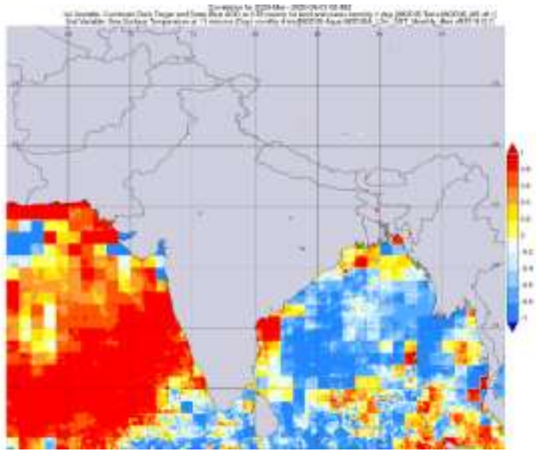
Correlation for 2010 Sep-2010 Dec

Fig 6. Seasonal Correlation for AOD and SST for the year 2010



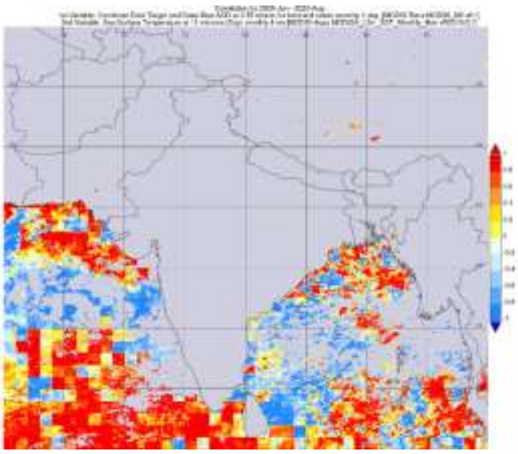
Winter

Correlation for 2019 Dec to 2020 Jan



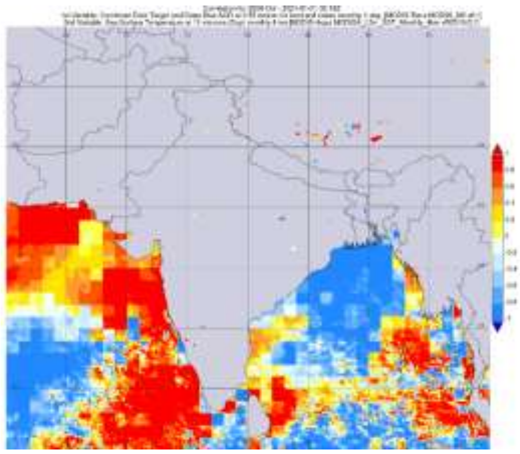
Summer

Correlation 2020 Mar – 2020 Jun



Monsoon

Correlation for 2020 Jun. – 2020 Sep



Post Monsoon

Correlation for 2020 Sep – 2020Dec

Fig.7. Seasonal Correlation for AOD and SST for the year 2020

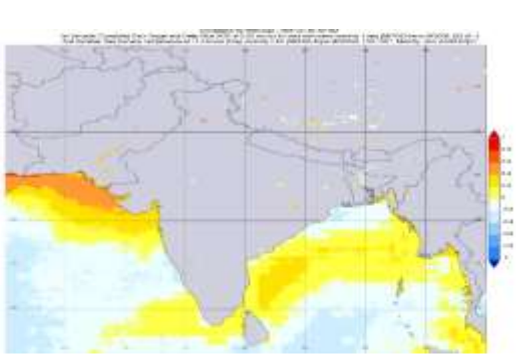


Fig. 8. Seasonal correlation for AOD and SST during 2000-2020

8.Summary &Conclusion

The impact of atmospheric aerosols over the Indian subcontinent using data from MODIS on board Terra Satellite for the years 2000 to 2020 is studied. The study focusses on SST on Indian Monsoon, Aerosol effects on SST, monthly and seasonal variations of AOD and SST. The main investigations are summarized below.

- AOD is found to be considerable in July, which is due to dust events in the northern portion of India from the Saharan desert, as well as dust occurrences in Pakistan's northwest.
- During the post-monsoon season, aerosols washout due to the rainfall that occurred during the monsoon season. Low AOD is observed over the Indian subcontinent, and the Indian Ocean throughout the year during the study period
- The transport of mineral dust from Arabia and North Africa by the Westerly winds, the enhancement in the production of sea salt by the strong westerly winds, and the humidity of the Southwesterly surface winds increase the aerosol size, which in turn, leads to an increase in scattering optical depth.
- During July, SST decreases drastically whereas it is high during the preceding months.
- During the entire study period SST is observed over the whole study area in December which may be due to no rainfall and poor aerosol overloading. A special feature observed in moderate rainfall years is no correlation between SST and AOD exists over the Equatorial Arabian Sea, and the Indian ocean in both summer and monsoon seasons.
- A positive correlation between AOD and SST may imply that the number of absorbing aerosols increases in the atmosphere, and atmospheric heating increases which further increases the temperature over land and sea. A negative correlation between AOD and SST implies that if AOD increases then SST decreases.
  - SST is found to be low over High AOD regions and this may be due to cooling by aerosols. The magnitude of SST over oceans has decreased from summer to that of monsoon and this may be due to rainfall cooling the Sea. AOD and SST are correlated well during drought years and negatively correlated during good monsoon years.
  - AOD and SST are negatively correlated during monsoon periods showing that high AOD can influence the SST and thus can influence the magnitude of the monsoon rainfall. High AOD and low COV are found in areas with high population density.

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