DISSERTATION

on

"***Statistical Analysis of Aerosol Optical Depth (AOD) Over Indian Subcontinent Using Observed MODIS Data and Comparison with CMIP6 Models***"

Submitted in partial fulfilment of the requirement
for the award of degree of
Master of Science (Technology)
In
Geophysics
SESSION: 2023-2024

Under the guidance of:
Dr. Barunava Mondal
Assistant Professor

Submitted by:
Aafaque Ahmad
M.Sc. (Tech.) Final Year

DEPARTMENT OF GEOPHYSICS
INSTITUTE OF SCIENCE
BANARAS HINDU UNIVERSITY
VARANASI-221005 (INDIA)

Exam Roll No: 21419GEP001

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CANDIDATE’S DECLARATION

I **Aafaque Ahmad Ansari** student of M.Sc. (Tech.) Geophysics (Semester-VI) Department of Geophysics, Institute of Science, Banaras Hindu University, Varanasi, hereby declare that this project work entitled “***Statistical Analysis of Aerosol Optical Depth (AOD) Over Indian Subcontinent Using Observed MODIS Data and Comparison with CMIP6 Models***” has been carried out by me at Department of Geophysics, Banaras Hindu University from June 15, 2023 to April 25, 2024. The literature described and matter reported herewith is an authentic record of my own work. This dissertation issubmitted for the partial fulfillment of the degree of M.Sc. (Tech.) in Geophysics Department of Geophysics, Institute of Science, Banaras Hindu University, Varanasi, Uttar Pradesh.

Dated:
Place: Varanasi

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I take this opportunity to acknowledge my deep and sincere thanks to my family members and my colleagues for their continuous support and immense help through my dissertation work. And also, I would like to thank my friends and all the staffs of Department of Geophysics, BHU who have helped in one or the other way in completing this project successfully.

Dated:

Place: Varanasi

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ABSTRACT

The Indian Subcontinent is among the areas most impacted by atmospheric aerosols, mostly as a result of the northern region's industrial activity and frequent vehicle exhausts. The primary cause of the alteration in the energy budget that powers the climate system is these aerosols. Additionally, based on aerosol optical depth (AOD), a thorough description of the temporal and spatial aerosol features is provided. The examination of AOD variability, trends, and performance of various models in the Coupled Model Inter-comparison Project (CMIP6) and their mean in relation to satellite observations from the Moderate Resolution Imaging Spectroadiometer (MODIS) over India throughout the year is the main emphasis of this work. In order to do this, TERRA-MODIS DTB and the AOD (550 nm) data of seven CMIP6 models are collected between 2000 and 2020.

A range of statistical methods, such as regression, correlation, standard deviation, bias, root mean square error, and simple mean, were employed for validation. Additional trends and time series analyses are conducted to assess the AOD fluctuations over the area. The results show that the AOD mean is high in northern Indian towns like Delhi. All things considered, minimal regression was found and there was good agreement with MODIS for the MRI-ESM2-0, CESM2, and ACCESS-ESM1-5. INM-CRS-5 shows lower RMSE and negative Correlation values. It is also demonstrated that the AOD trends and variability are higher in Northern India.

Chapter-1

Introduction

1. Introduction

The mixture of tiny solid and liquid particles suspended in the atmosphere, known as aerosols, dramatically affects the earth's and the atmosphere's overall energy balance (Fan et al. 2021). In addition to changing cloud characteristics, the water cycle, ecosystems, environments, and agriculture, these particles may have a significant impact on the climate system and, most significantly, human health Furthermore, a number of studies have suggested that aerosols are the primary cause of global climate change highlighting the fact that the Indian subcontinent plays a significant role in the world's atmospheric aerosols, both naturally occurring and caused by humans, in the Northern Hemisphere.

Summertime in Northern India is usually when the concentrations of aerosols from natural occurrences, particularly from vehicle exhausts, are highest. In contrast, the primary sources of anthropogenic aerosols in this area were building sites, oil and gas enterprises, and traffic pollution (Khodeir et al. 2012). Understanding the concentration, characteristics, and kinds of aerosols as well as how they interact with the earth's climate system is therefore essential in this area.

An essential metric for measuring aerosol loading in the atmosphere and fully characterizing its climatic effects is aerosol optical depth (AOD). Typically, model simulations, satellite remote sensing, and ground-based stations are used to gather AOD data. Ground-based station networks, both global and regional, that use Sun photometers to monitor the AODs over various regions globally include AERONET, AEROCAN, GAW PFR, BoM, SKYNET, NOAA/ESRL, CARSNET, and SONET.

Owing to limitations, the current network of ground-based stations is unable to provide extensive worldwide coverage for measurements of aerosol optical depth (AOD). Satellites with near-polar orbits and large-swath capability can give regular aerosol data across the whole world to solve this problem (King et al., 1999). Numerous sensors, including VIIRS, MERIS, TOMS, OMI, MISR, SeaWiFS, and MODIS, are the source of these satellite-derived AOD products (Liu et al., 2014; Kosmale et al., 2017; Torres et al., 2002, 2007; Kahn et al., 2011; Sayer et al., 2012; Remer et al., 2005; Levy et al., 2013).

Satellite AOD retrievals involve assumptions about aerosol kinds and surface properties and are based on radiance observations. In order to evaluate the accuracy of these satellite-derived products, they are modelled and validated against data from ground-based stations. Furthermore, aerosol features, such as AOD fluctuation and trends over certain time periods, may be predicted by climate models. The various effects of aerosols on anticipated changes have been covered in a number of climate change assessments, including reports from the Intergovernmental Panel on Climate Change (IPCC), which frequently depend on the output of climate model simulations.

Aerosols and greenhouse gases are the two main sources of "global emissions trajectories" in the framework of the CMIP6 research. Both trajectories illustrate the relative contributions of both emissions to the global climate system. Despite their inherent flaws, climate models are regarded as reliable tools for assessing long-term climate projections and understanding AOD behaviours in specific regions.

1.1 Aerosols and Climate

Aerosols have a major effect on the radiative balance of the atmosphere and cloud formation processes, both of which have an impact on Earth's climate system. These microscopic particles scatter and absorb both incoming solar energy and outgoing terrestrial radiation, changing the atmosphere's temperature directly. The warming or cooling effect of this direct radiative impact can be caused by the aerosol's size, composition, and dispersion. In addition, aerosols serve as cloud condensation nuclei (CCN) or ice nuclei (IN), giving rise to the surfaces where water vapor condenses to form cloud droplets or ice crystals.

Aerosols have a more significant role in cloud formation than just being CCN or IN. They can alter lifespan and albedo (reflectivity), two characteristics of clouds, by indirect radiative impacts. Cloud reflectance is enhanced by more numerous but smaller cloud droplets that are frequently produced by increased aerosol concentrations. This mechanism, also referred to as the "cloud indirect effect" or "cloud albedo effect," helps to chill the atmosphere. The intricacy of these collateral consequences highlights the continuous investigations aimed at augmenting comprehension of aerosol-cloud dynamics.

Moreover, regional-scale effects on climate dynamics are caused by aerosol emissions from many sources, such as dust storms, burning of biomass, and industrial activity. Variations in aerosol characteristics and concentrations can cause climatic feedbacks that can either increase or decrease the impact of other climate forcing, including greenhouse gas emissions. For instance, by increasing cloud reflectivity and lowering incoming solar radiation, higher aerosol emissions may partially balance the warming brought on by greenhouse gases.

To effectively forecast future climate change and assess the effects of human activity on the Earth's climate system, a thorough knowledge of the interactions between aerosols and climate is necessary. Aerosol-climate interactions are incorporated into climate models to improve future climate scenario forecasts and guide climate policy choices. Research projects are ongoing to improve our knowledge of how aerosols affect the climate and their wider consequences on the environment and society.

India's aerosol pollution problem is complex and has both natural and human-caused causes. High concentrations of aerosols are found across the region as a result of a combination of human activity, such as burning biomass, industrial emissions, and vehicle exhaust, and natural sources including dust storms and wildfires. Significant risks to visibility, public health, and climate dynamics are posed by this pollution, which also affects respiratory health, transportation, and local climate patterns, such as the monsoon. To solve this complex environmental concern and protect human health and environmental sustainability, mitigation efforts concentrate on regulatory measures, enhanced monitoring, and promotion of clean energy technology.

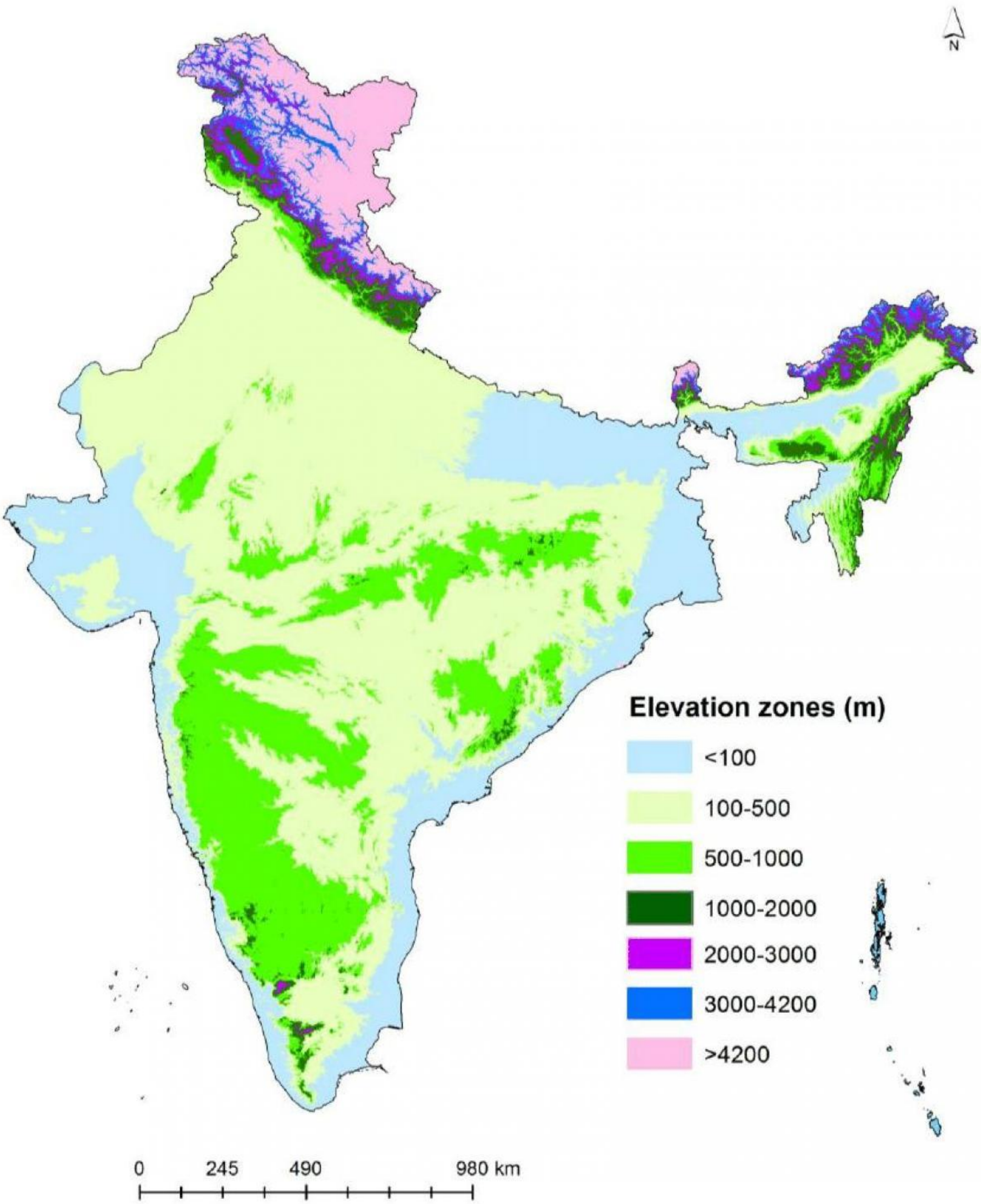
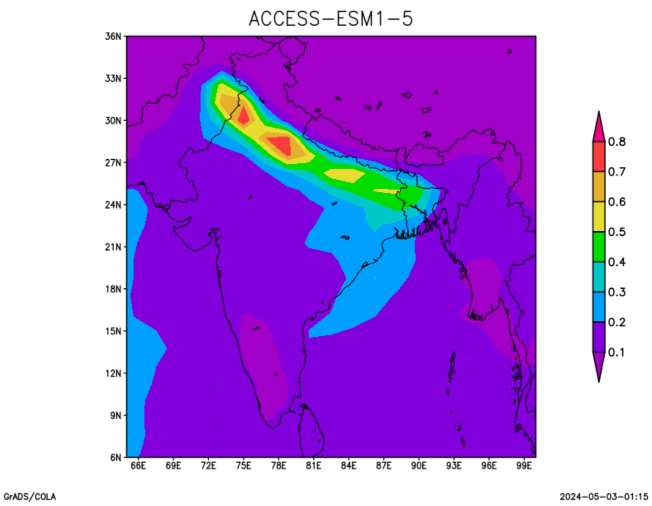
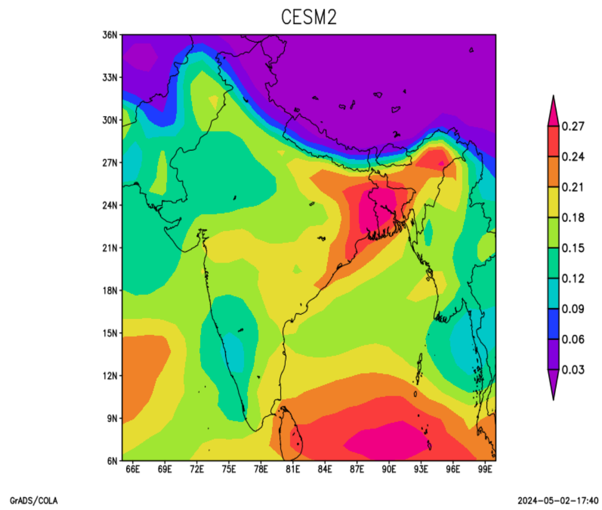
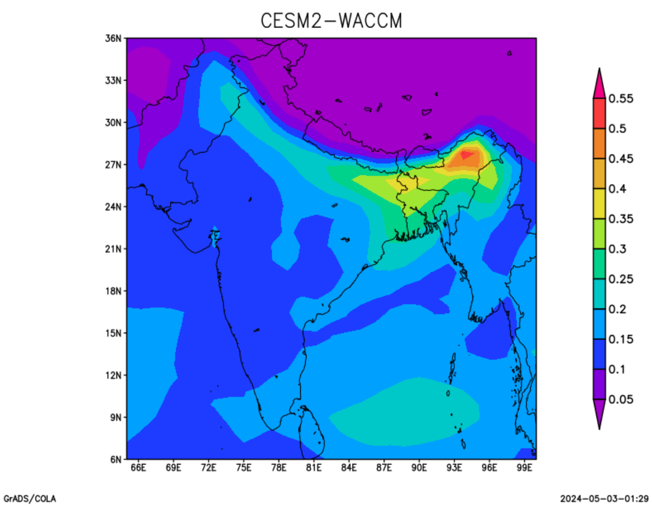


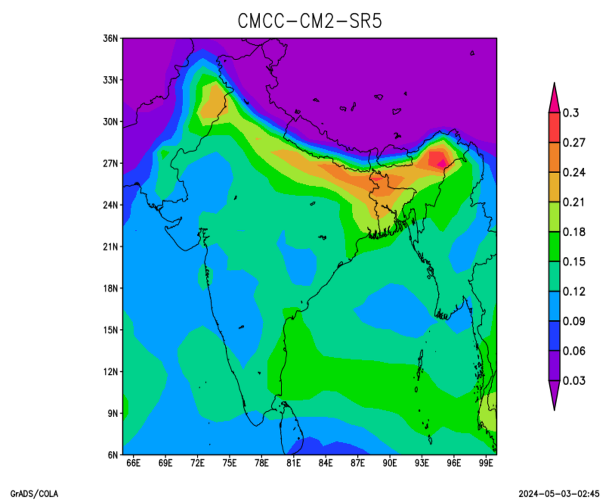
Figure 1.1 Topographical Map of India showing Elevation Zones (Study Area).

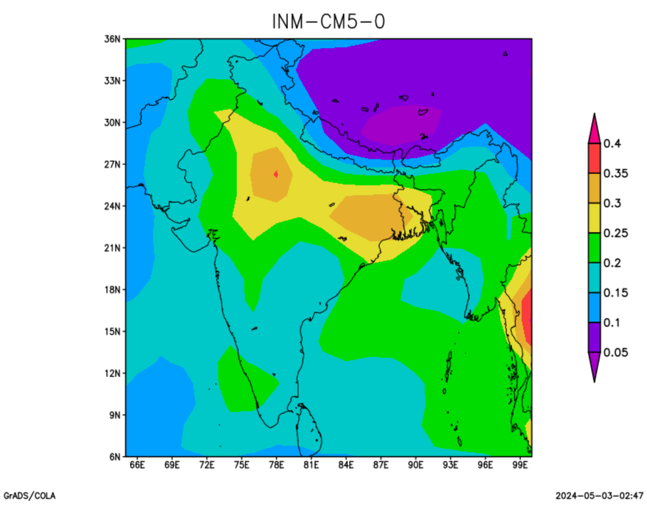
1.2 Distribution of Aerosol Optical Depth Over Indian Subcontinent











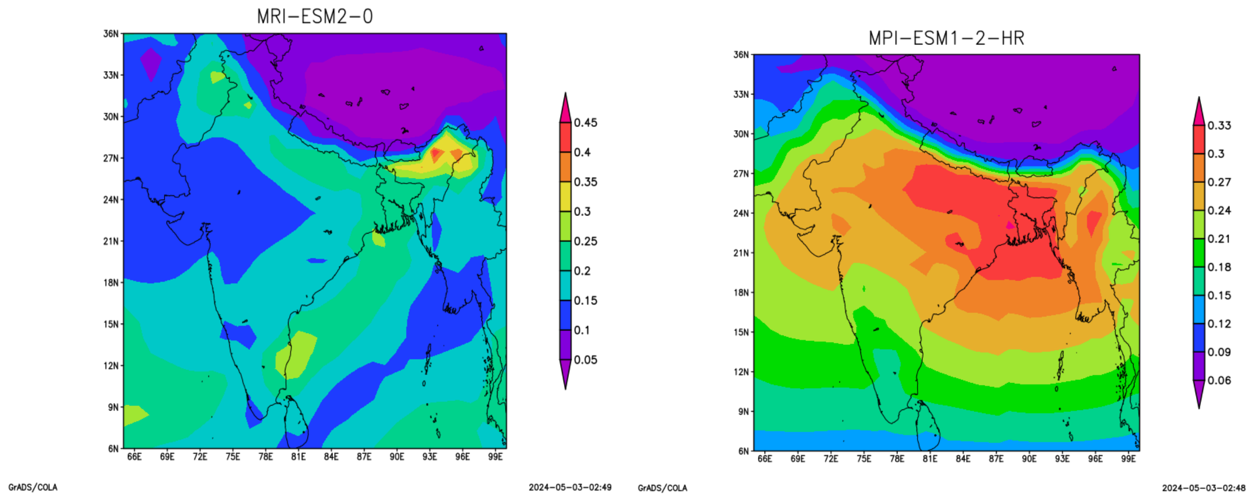


Figure 1.2 Geographic AOD generated from CMIP6 models over Indian Subcontinent during year 2000-2020.

Figure 1.2 displays the geographic changes in AOD for CMIP6 models from 2000 to 2020.

The distribution of MODIS AOD trends indicates slight increases in the north and fluctuating trends in the northeast of the Indian Peninsula. Among models, ACCESS-CSM1-5 shows slight increases in the northern regions and lower increases along the coast. ACCESS-ESM1-5 displays decreasing trends over a large area, with higher increases in the west. CESM2 exhibits notable increases in the northeast and lower increases elsewhere. INM-CM2-SR5 shows increasing trends in the northeast and varying increases in the north and southeast. CMCC-CM2-SR5 indicates higher increases in the northeast and minimal increases in the west and central regions. MPI-ESM1-2-HR shows higher trends across the Peninsula. MPI-ESM2-0 indicates higher trends in the northeast and lower trends in the southwest. CESM2-WACCM shows significant increases in the east and lower increases in the central and west. Overall, ACESS-ESM1-5 and MPI-ESM2-0 trends closely resemble MODIS, with notable increases attributed to dust transport and industrialization.

1.3 General Circulation Models (GCMs)

A kind of climate model is a general circulation model (GCM). It makes use of a mathematical model of a planet's atmosphere or ocean's overall circulation. It makes use of thermodynamic concepts for different energy sources (latent heat, radiation) in the Navier-Stokes equations on a spinning sphere. These formulas serve as the foundation for computer systems that mimic the seas or atmosphere of Earth. Studying the effects of past, current, and future climate changes at the global or synoptic scale is a common use of general circulation models (GCMs), which are created by several modeling groups worldwide under the auspices of the coupled model intercomparison project (CMIP).

General Circulation Models (GCMs) integrate aerosols into their simulations to study their impact on Earth's climate system. These models simulate aerosol distribution, transport, interactions, and radiative effects, accounting for their influence on temperature, precipitation, atmospheric circulation, and cloud formation. GCMs also evaluate feedback mechanisms and uncertainties, providing insights into the role of aerosols in climate change.

General Circulation Models (GCMs) are vital tools for studying aerosol optical depth (AOD) and its impact on Earth's climate. they consider physical processes such as emission, transport, transformation, and removal mechanisms. GCMs also account for aerosol chemical composition, size distribution, and interactions with clouds. Additionally, they help evaluate uncertainties and validate their simulations against observations to improve accuracy. Overall, GCMs contribute significantly to our understanding of AOD and its role in shaping the Earth's climate system.

Chapter-2

Data and Methodology

2.1 Data

Here we use the aerosol optical depth during summer monsoon season of ACCESS-ECSM-5, CESM2, CESM2-WACCM, CMCC-CM2-SR5, INM-CMS-5, MPI-ESM1-2-HR and MRI-ESM2-0 with experiment ID historical runs (2000-2014), ssp245 (2015-2020) and simulation variant (r1i1p1f1) from Climate Model Inter-comparison Project 6 (CMIP6) with MODIS/terra DTB 550nm Monthly data product.The approach combines the deep blue (DB) and dark target (DT) algorithms (Levy et al. 2013).

2.2 Satellite Observed Data

The aerosol product of MODIS is used in this study because to the effective AOD pixels (Georgoulias et al. 2016). The MODIS sensor is installed on board both the Terra (1999–2002, North–South orbit, crossing at 10:30 am local time) and Aqua (2002–2002, South–North orbit, crossing at 01:30 pm local time) spacecraft. Investigating aerosol characteristics and their distribution across an atmosphere is the main goal of MODIS. The sensor is capable of capturing outgoing long wave radiations in 36 spectral bands (0.4–14.4 µm), in addition to three bands of spatial resolution (250 m, 500 m, and 1 km).

In this study, we used the TERRA-MODIS DTB monthly AOD (550nm) output, which combines the deep blue (DB) and dark target (DT) algorithms. (Levy et al. 2013).

"NASA Giovanni" is the source of this information. Visit this URL (https://giovanni.gsfc.nasa.gov/giovanni/) for further information.

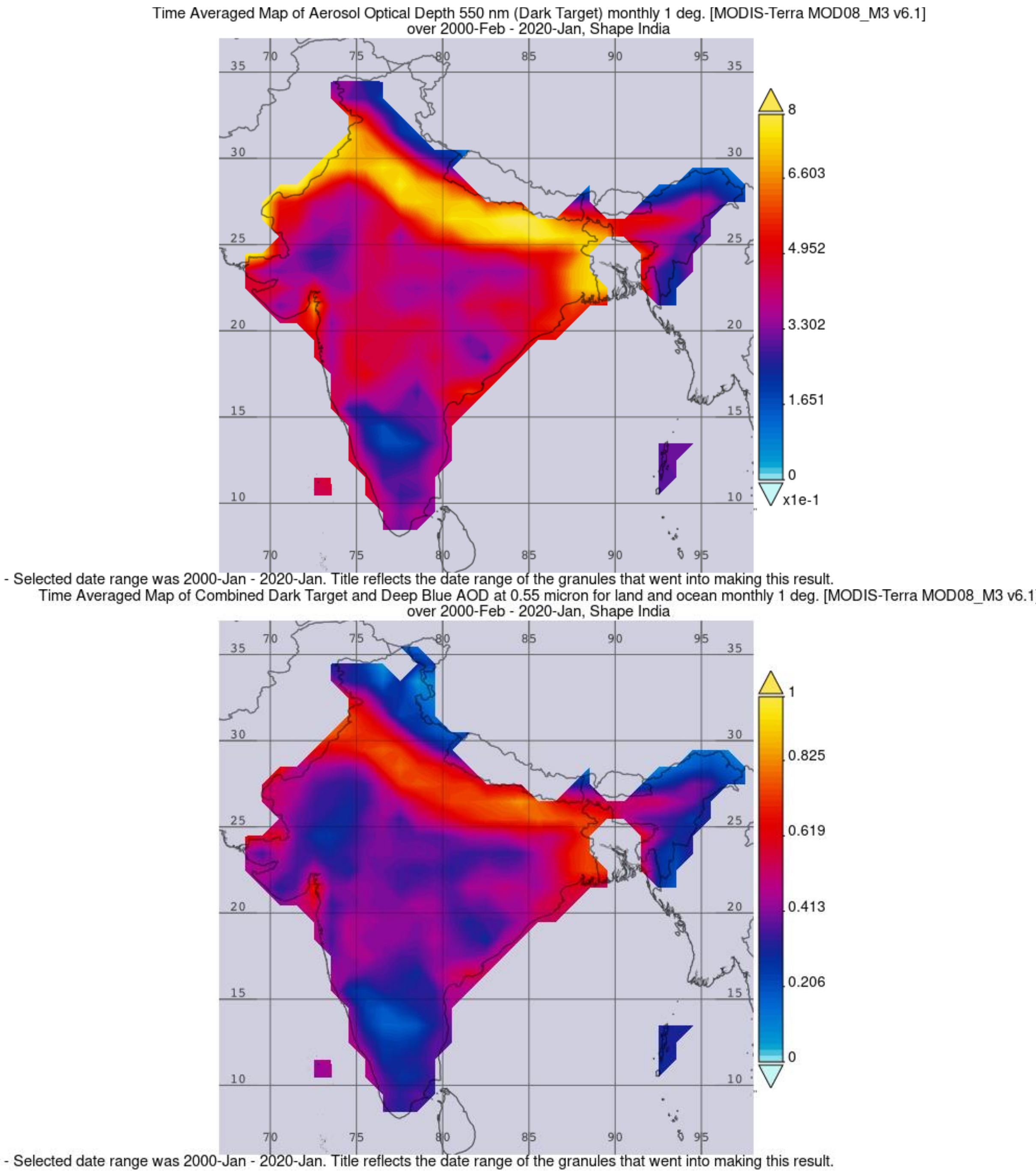


Figure-2.2 Observed Data from MODIS/terra for
(a) Aerosol Optical Depth 550nm (dark target) for India over 2000-2020
(b) Combined Deep Blue AOD at 0.55 micron for India over 2000-2020

2.3 CMIP6 Model Data

Through WCRP, the CMIP6 has been gradually made available (https://esgf-data.dkrz.de/search/cmip6-dkrz//search/cmip6/). Eleven GCMs from the CMIP6 were utilized to evaluate the precipitation availability (Eyring et al., 2016). With the exception of the E3SM-1-0 model, which concluded in 1999, the CMIP6 historical simulations spanned the years 1850–2014.

Here we used monthly data sets from CMIP6 with horizontal resolution 100km, A CCESS-ECSM-5, CESM2, CESM2-WACCM, CMCC-CM2-SR5, INM-CMS-5, MPI-ESM1-2-HR and MRI-ESM2-0 with horizontal resolution 100 km, experiment ID historical run (2000-2014) and ssp245 (2015-2020) and simulation variant (r1i1p1f1) from Climate Model Inter-comparison Project 6 (CMIP6) over India.

The data have downloaded from Germany, DKRZ
- https://esgf-data.dkrz.de/search/cmip6-dkrz/

Several research institutes from across the world have contributed to CMIP6, the most recent iteration of the Coupled Model Inter-comparison Project, each of which is creating a unique global climate model. These models replicate the interactions between the atmosphere, ocean, land surface, and cryosphere all key elements of Earth's climate system. They aid in our knowledge of climate dynamics and variability by conducting simulations for a variety of objectives, such as future predictions, historical reconstructions, and sensitivity studies.

Table 1. An overview of the CMIP6 models used in this work is provided, along with a comparison and validation of the models against MODIS (Terra) DTB satellite observation data over the Indian Subcontinent.

SR. No	Models	Institution	Country	Resolution
1	ACCESS-ECSM1-5	Australian Research Council Centre for Excellence for Climate System Science	Australia	1.87°x1.25°
2	CESM2	Community Earth System Model	USA	0.9° × 1.3°
3	CESM2-WACCM	Whole Atmosphere Community Climate Model	USA	0.9375°x1.25°
4	CMCC-CM2-SR5	Euro-Mediterranean Centre on Climate Change	Italy	0.94°x1.25°
5	INM-CR5-0	Institute of Numerical Mathematics	Russia	2°x1.5°
6	MP1-ESM1-2-HR	Max Plank Institute for Meteorology	Germany	1.875°x1.875°
7	MRI-ESM2-0	Meteorological Research Institute	Japan	1.125°x1.125°

2.4 Methodology

We used a variety of techniques in this study to accomplish our goals. The following is a detailed description of the applied methodology:

1. To see the AOD characteristics validation of climate models, we see the mean aerosol optical depth 550nm for study period of 2000-2020 from the raw output of ACCESS-ECSM-5, CESM2, CESM2-WACCM, CMCC-CM2-SR5, INM-CMS-5, MPI-ESM1-2-HR and MRI-ESM2-0 from CMIP6 with respect to the observed MODIS data for the study period 2000-2020.

2. First, analysis of the time series for mean AOD for period 2000-2020 for CMIP6 models with respect to observation data has been done.

3. Using the interpolation approach, the MODIS observed and seven CMIP6 model outputs were interpolated to confirm the identical resolution (1°). Additionally, all models percent bias is computed for the purpose of comparing AOD over the Indian subcontinent.

4. The seven CMIP6 models data are assessed using a range of statistical techniques in comparison to the MODIS across the Indian Region. Simple mean, standard deviation, root mean square error, mean absolute error, and correlation approaches were used to assess the data.

2.4.1 Mean

The mean of a data collection is its arithmetic average. Additionally, it measures a finite collection of numbers' central tendency. Stated otherwise, the total number of values (data sets) divided by the sum of all the values (data sets).

$$Mean = \frac{\sum \mathrm{Ki}}{\mathrm{N}}$$

Xi = number of datasets

N = total number of datasets

2.4.2 Standard deviation

The standard deviation, which is computed as the square root of the variance, is a statistic that assesses how dispersed a dataset is in relation to its mean. By figuring out how different each data point is from the mean, the square root of variance is computed.

$$\text{STD} = \sqrt{\sum_{i=1}^{n} \frac{(X_i - \bar{X})^2}{n}}$$

$\bar{x}$ = mean value of data sets

2.4.3 Root Mean Square Error

The average difference between the values predicted by a statistical model and the actual values is measured by the root mean square error, or RMSE. In terms of math, it is the residuals' standard deviation. The gap between the regression line and the data points is represented by residuals.

$$\text{RMSE} = \frac{1}{\mathrm{n}}\sqrt{\sum_{\mathrm{i}=1}^{\mathrm{n}} (\mathrm{MODEL} - \mathrm{MODISDTB})^2}$$

2.4.4 Bias

In statistics, a systematic departure from the true value is referred to as bias. Given that the sample size cannot be decreased by a simple increase, the sampling process may provide the researcher with some significant issues. The discrepancy between the parameter's actual value and its predicted value is known as bias.

$$Bias = x - \bar{x}$$

2.4.5 Mean Absolute Error

The mean absolute error (MAE) in statistics is a measurement of the discrepancies between paired observations that represent the same phenomena. The total of the absolute errors is used to compute MAE.

$$\mathrm{MAE} = \frac{1}{\mathrm{n}} \sum_{\mathrm{i}=1}^{\mathrm{n}} |\mathrm{MODEL} - \mathrm{MODISDTB}|$$

2.4.6 Regression

A statistical method known as regression establishes a relationship between a dependent variable and one or more independent (explanatory) variables. It is possible to determine if changes in one or more of the explanatory variables are related to changes in the dependent variable using a regression model.

$$R = \frac{\sum_{i=1}^{n} (X_i - \bar{X}) \left(Y_i - \bar{Y} \right)}{\sqrt{\sum_{i=1}^{n} (X_i - \bar{X})} \sum_{i=1}^{n} \left(Y_i - \bar{Y} \right)}$$

Chapter-3

Results and Discussions

3.1 Results

Fig. 3.1.3 displays the geographic distributions of the mean AOD across India for the years 2000–2020, derived from CMIP6 and MODIS DTB. The MODIS DT mean indicates a high AOD (0.6–0.8) in the northern parts, whereas the mean is lower (0.1–0.4) throughout the India's southern and north eastern sections. Furthermore, the AOD mean (0.7–0.8) is higher in Delhi's northern sections and lower (< 0.2) in its middle and southern regions, according to the ACCESS-ESM1-5 model. However, the eastern regions' CESM2 has a high AOD mean range of 0.2 to 0.3, whereas the coastal regions in the south display a lower mean (0.09–0.12).

Furthermore, the north eastern area has a high mean AOD (0.5–0.6), whereas the western regions have a lower mean (< 0.2), according to the CESM2-WACCM model. The CMCC-CM2-SR5 model's geographical distributions once more reveal that the north eastern area has the greatest mean (0.2–0.3), while the mean in the middle and northern regions vary between 0.1 and 0.2. Regarding the INM-CM5-0 model, the Delhi region had a high average AOD mean (0.35-0.4), whereas the southern portion of the subcontinent demonstrated low average values (0.15–0.25).

Furthermore, the eastern portions of Bengal exhibit the greatest values (0.3-0.33) in the MPI-ESM1-2-HR AOD mean study, whilst the southern and central regions have the lowest values (0.12-0.24). Additionally, the MRI-EMS2-0 model shows that the northern regions of the Sea have substantial mean variability (0.4–0.45), whereas the remainder of the Indian subcontinent has minimal mean variance (0.1–0.3).

3.1.1 Time Series Analysis for AOD MODIS and CMIP6 Data

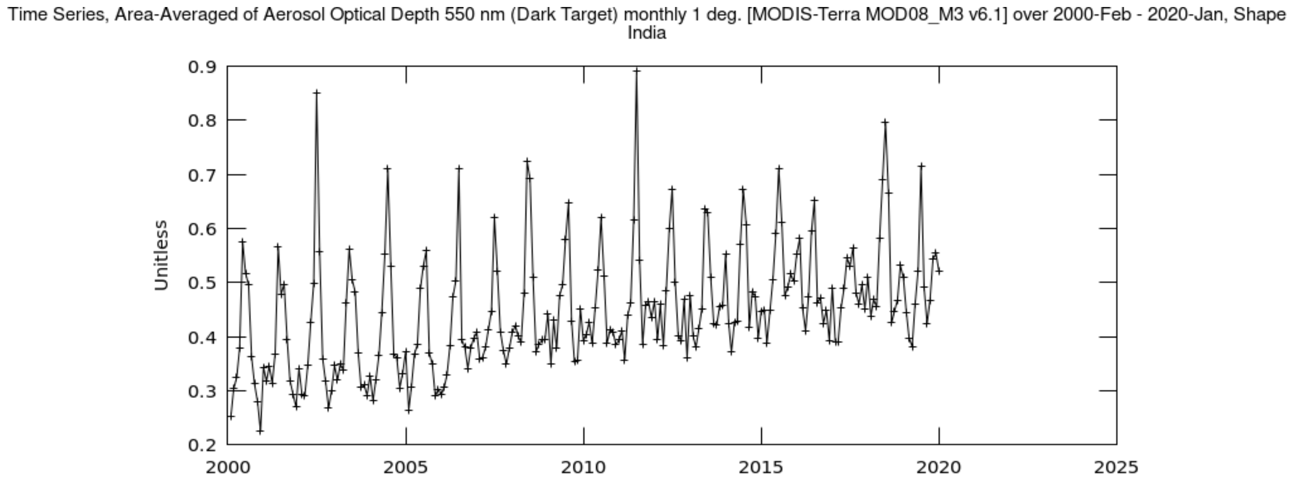
Here we will compare the mean Indian AOD 550nm for each year for the study period of 2000-2020 from ACCESS-ECSM-5, CESM2, CESM2-WACCM, CMCC-CM2-SR5, INM-CMS-5, MPI-ESM1-2-HR and MRI-ESM2-0 with observed MODIS data.

Time series analysis for MODIS data with CMIP6 models involves assessing the temporal patterns and trends of Aerosol Optical Depth (AOD) measurements over a specified period, alongside corresponding data from CMIP6 climate models. This process typically includes data collection, exploration, statistical analysis, model fitting, comparison, and interpretation to understand the relationship between observed AOD trends and model projections.

Time series graph representing the aerosol optical depth (550 nm) over India, measured monthly from January 2000 to January 2020. Here's a brief explanation:

1. Aerosol Optical Depth (AOD): AOD is a measure of how much sunlight aerosols prevent from reaching the ground. It's a dimensionless number that represents the level of atmospheric particles.
2. Data Source: The data comes from the MODIS-Terra MOD08_M3 v6.1 instrument, which is a satellite-based sensor used to monitor Earth's atmosphere.
3. Variations Over Time: The graph shows fluctuations in AOD values, with peaks indicating higher aerosol concentrations. These could be due to various factors like pollution, dust storms, or forest fires.
4. Area-Averaged: This graph specifically represents an area-averaged view over India, meaning it reflects the average AOD values across the entire country.

Time Series Analysis



- Selected date range was 2000-Jan - 2020-Jan. Title reflects the date range of the granules that went into making this result.

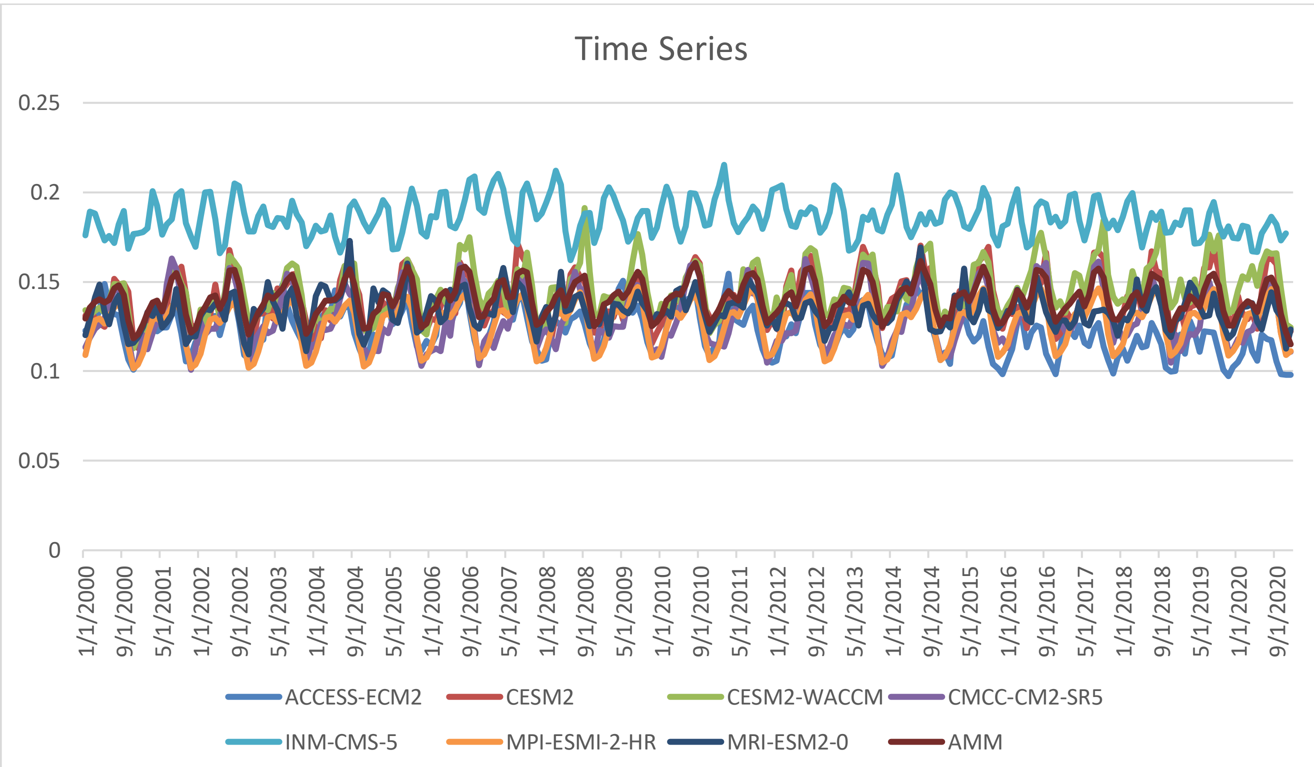


Figure 3.1.1 Time Series Analysis for AOD Variability for MODIS Observed data and CMIP6 Models

3.1.2 CMIP6 models compare MODIS in terms of Pbias, RMSE, and Standard Deviation (STD).

Models	CORRELATION	MEAN	PBIAS
ACCESS-ECSM1-5	0.005656	0.123034	0.21695
CESM2	0.17343	0.139936	1.42712
CESM2-WACCM	0.068473	0.144479	1.45756
CMCC-CM2-SR5	0.276182	0.129434	1.510036
INM-CR5-0	-0.45484	0.186401	1.276697
MP1-ESM1-2-HR	0.17502904	0.12625	1.51831
MRI-ESM2-0	-0.0268853	0.134258	1.492623

Table 2. AOD mean, percentage bias and correlation co-efficient of all CMIP6 models derived over India.

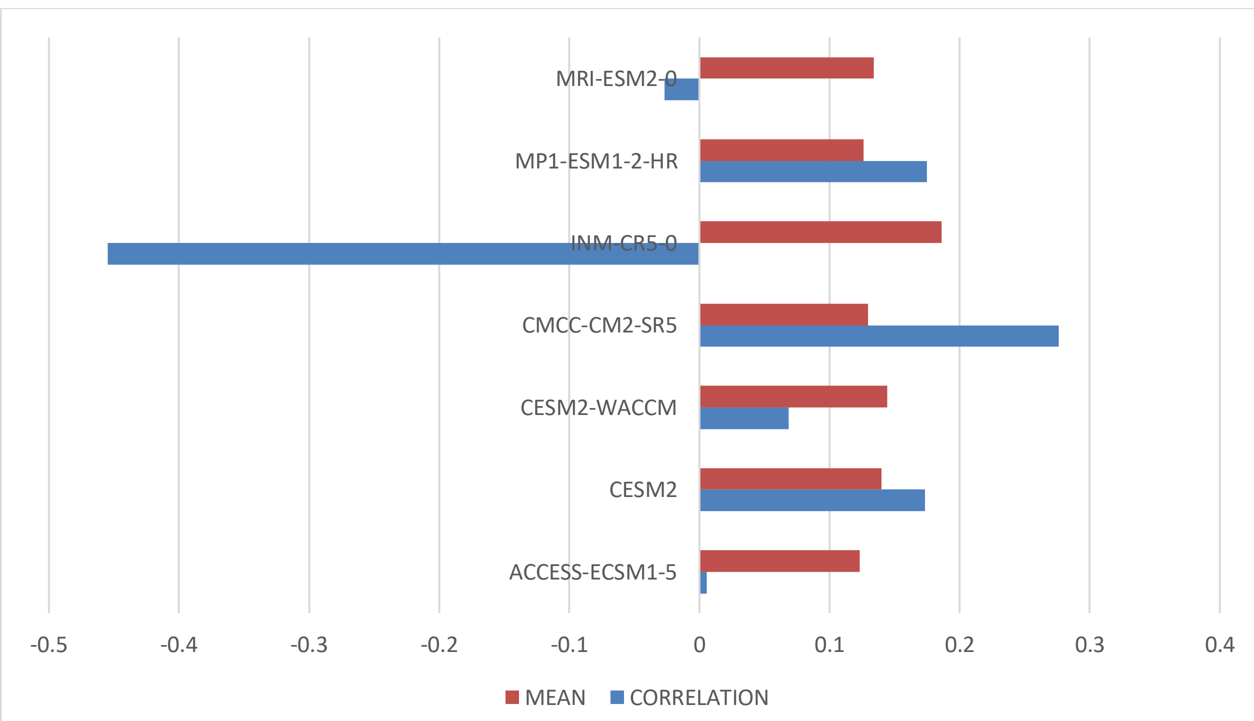


Figure 3.1.2(a) Mean and Correlation variability of all CMIP6 Models.

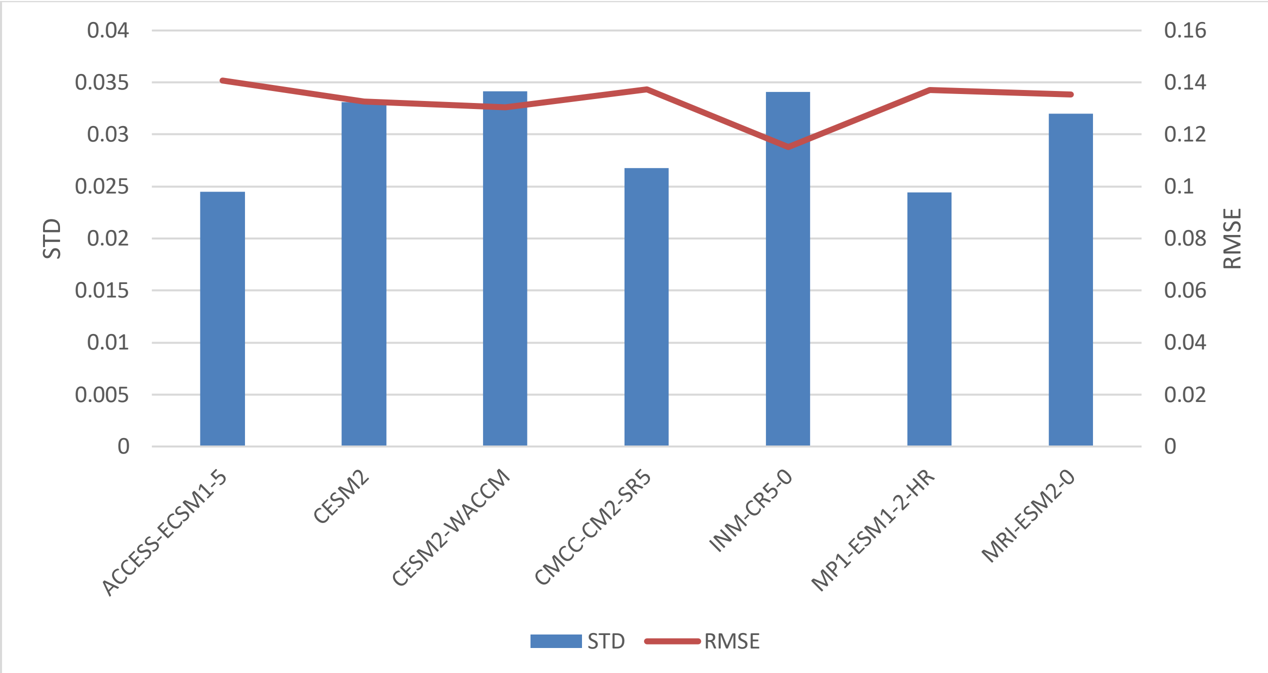
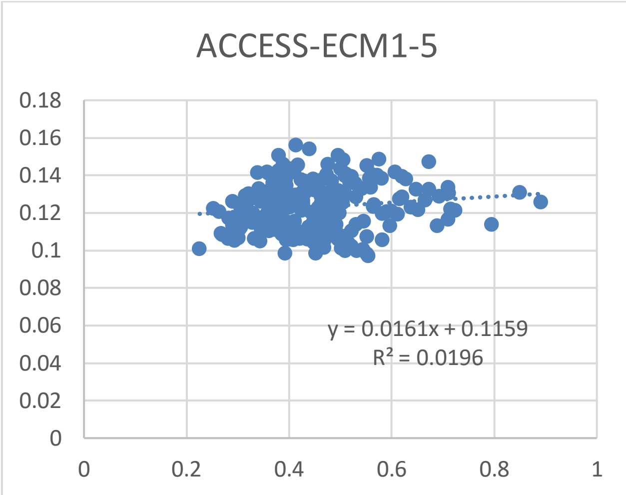
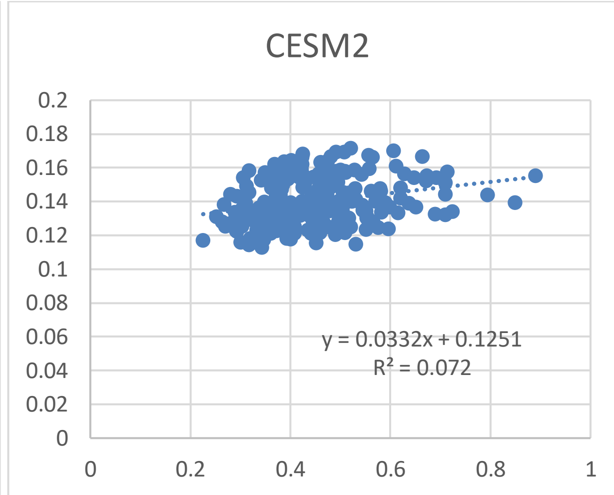


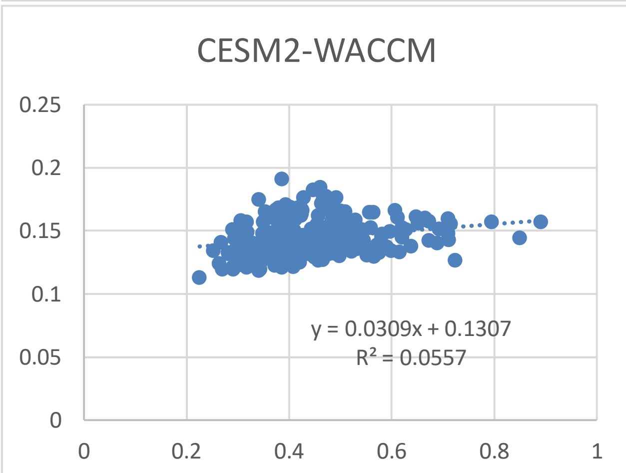
Figure 3.1.2(b) Root Mean Square Error (RMSE) and Standard Deviation (STD) for all CMIP6 Models

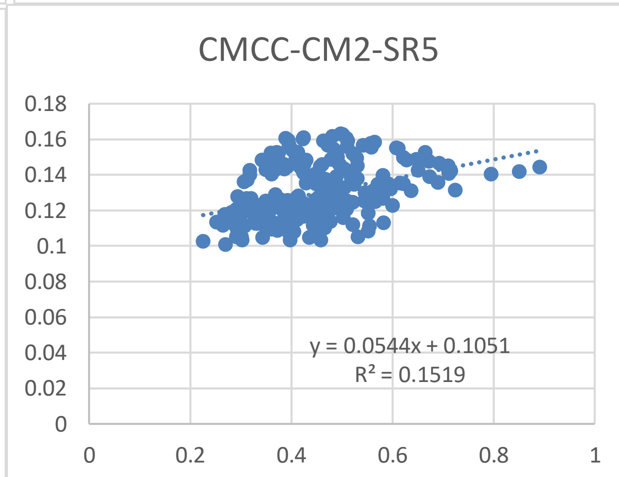
Figure 3.1.2(c) Percentage Bias for all CMIP6 Models

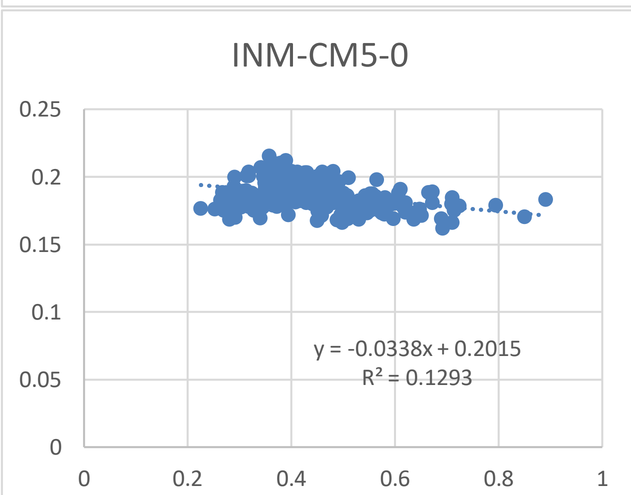
Figure 3.1.2(d) Regression Trends of all CMIP6 Models

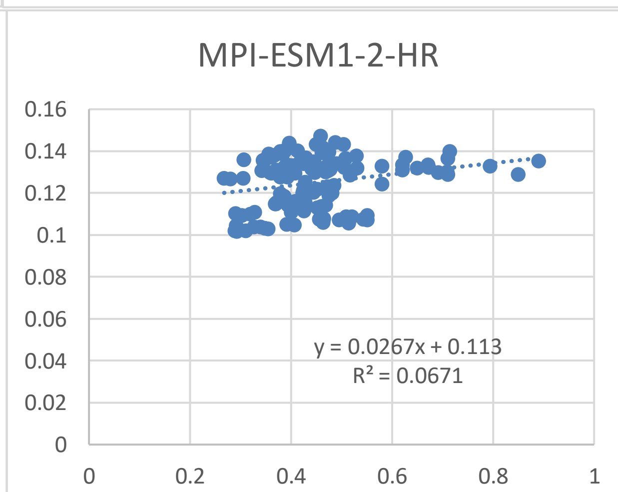

ACCESS-ECM1-5
y = 0.0161x + 0.1159
R² = 0.0196

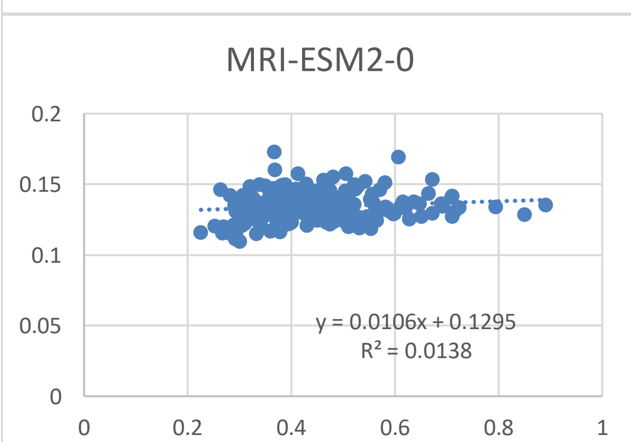

CESM2
y = 0.0332x + 0.1251
R² = 0.072


CESM2-WACCM
y = 0.0309x + 0.1307
R² = 0.0557

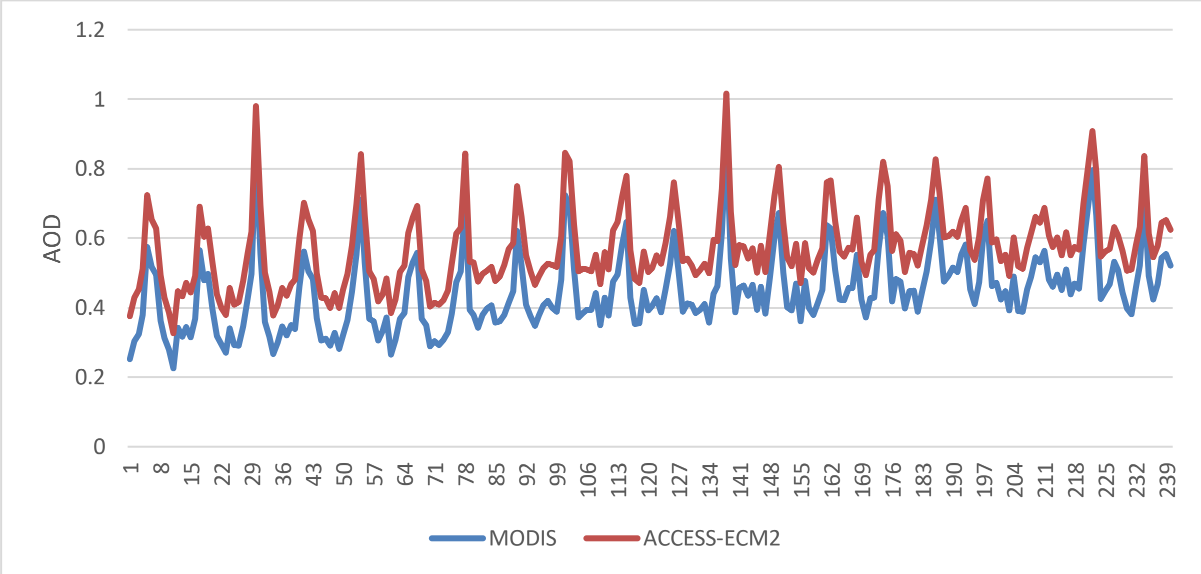

CMCC-CM2-SR5
y = 0.0544x + 0.1051
R² = 0.1519

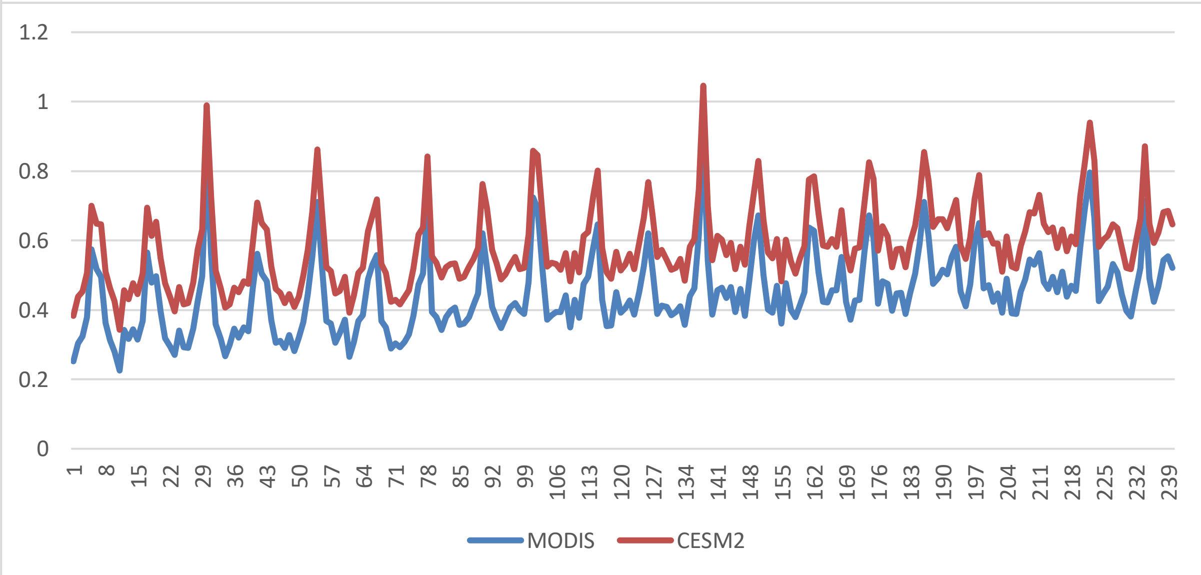

INM-CM5-0
y = -0.0338x + 0.2015
R² = 0.1293

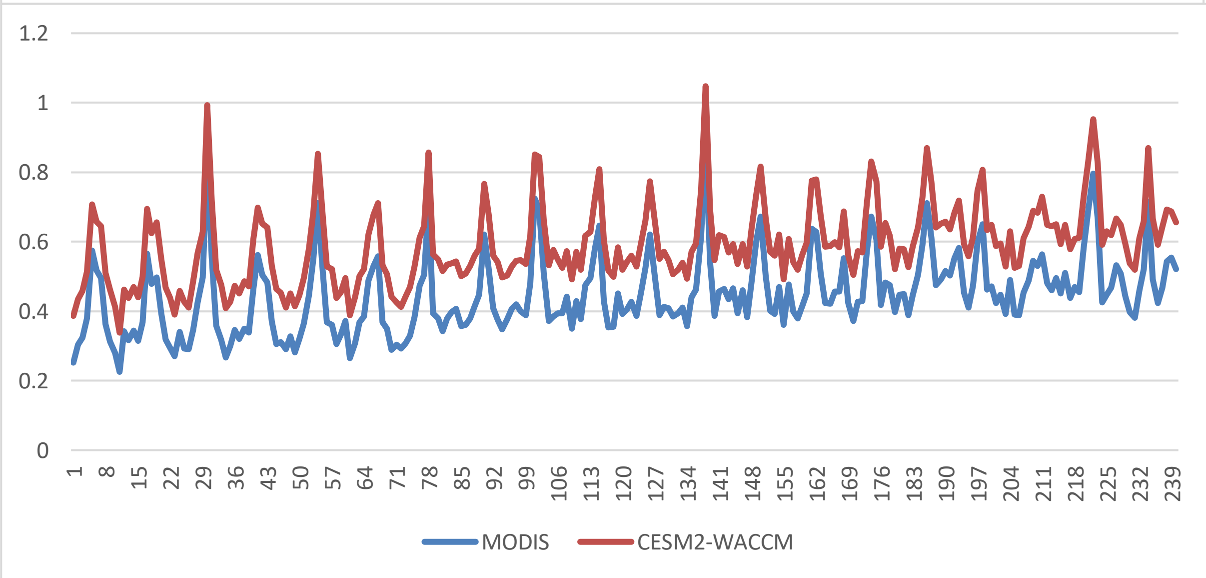

MPI-ESM1-2-HR
y = 0.0267x + 0.113
R² = 0.0671

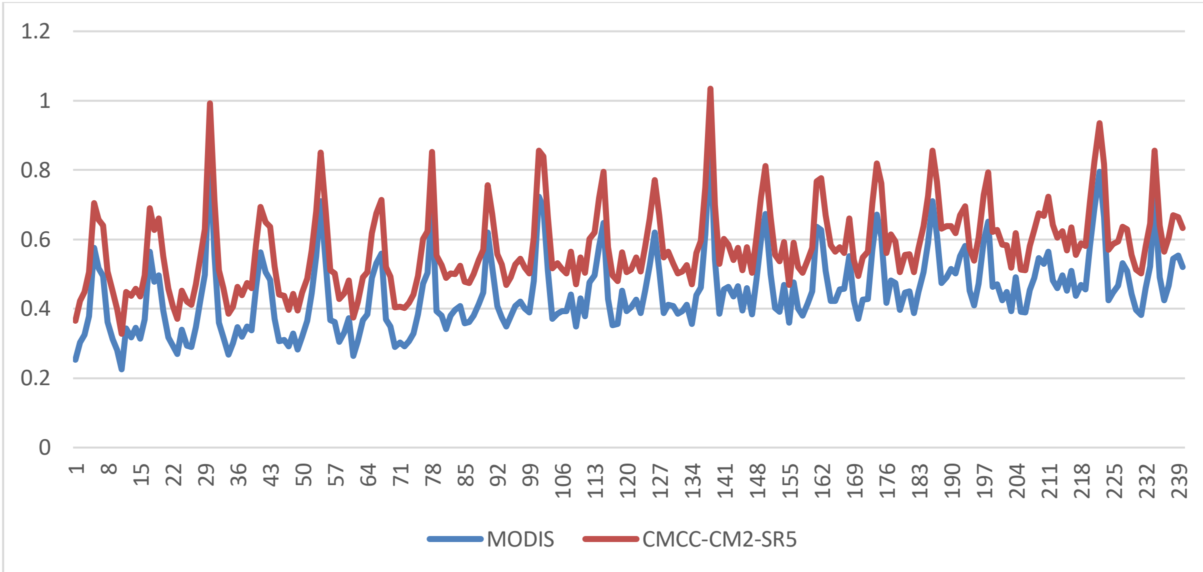

MRI-ESM2-0
y = 0.0106x + 0.1295
R² = 0.0138

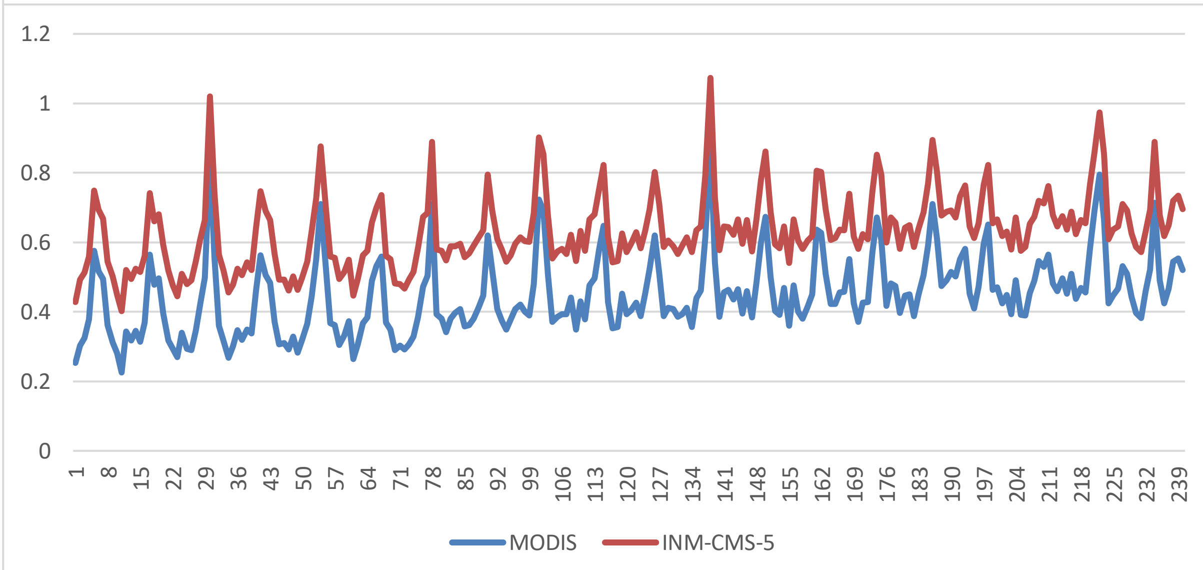
3.1.3. Comparison of MODIS data with CMIP6 Models

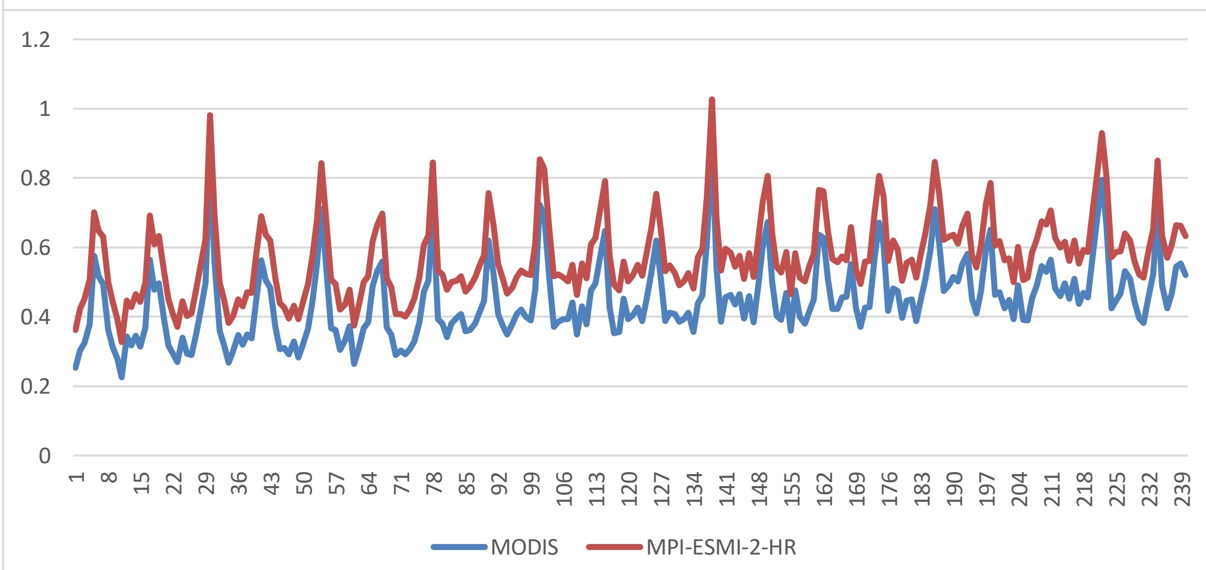







1.2
1
0.8
0.6
0.4
0.2
0
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134 141 148 155 162 169 176 183 190 197 204 211 218 225 232 239
MODIS
CMCC-CM2-SR5


1.2
1
0.8
0.6
0.4
0.2
0
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134 141 148 155 162 169 176 183 190 197 204 211 218 225 232 239
MODIS
INM-CMS-5


1.2
1
0.8
0.6
0.4
0.2
0
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134 141 148 155 162 169 176 183 190 197 204 211 218 225 232 239
MODIS
MPI-ESMI-2-HR

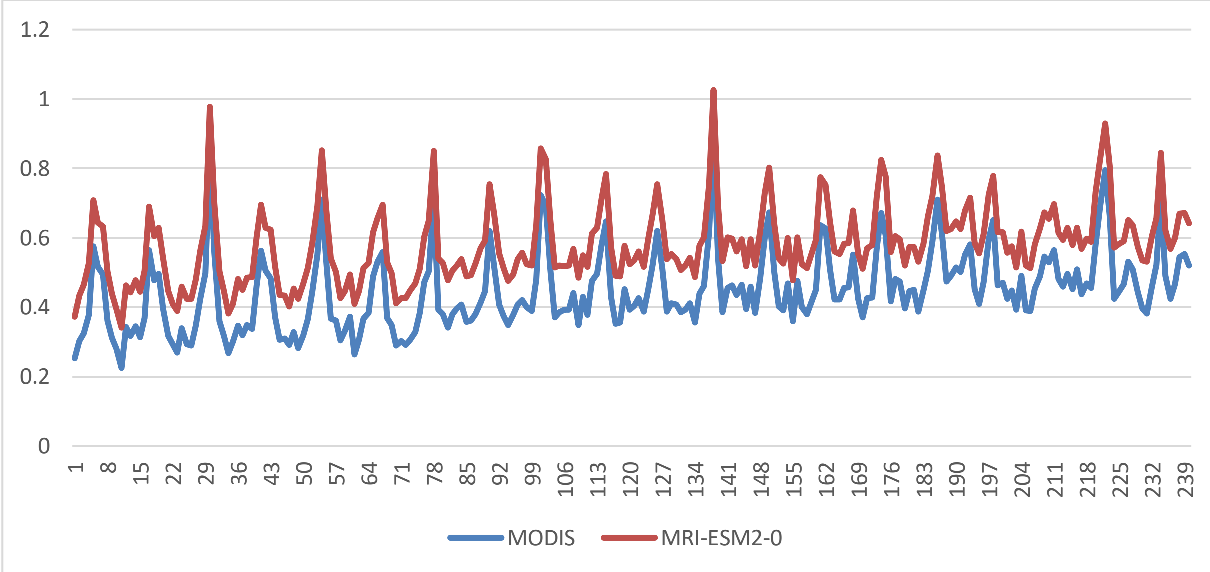


Figure 3.1.3 Comparison of all CMIP6 Models with Observed MODIS data.

The AOD variability of the CMIP6 and MODIS models over India from 2000 to 2020 are displayed in Figure 3.1.3. Whereas MODIS's AOD variability range from 0.2 to 0.6, the ACCESS-ECM2 has large variability, ranging from 0.4 to 0.8. In contrast to MODIS, the ACCESS-ESM has modest AOD variability. The MODIS and ACCESS-ESM display values that are closer at first, but they later diverged. Furthermore, for the chosen time, the CMCC-CM2 shows smaller AOD variability (0.3–0.6) than MODIS. When comparing the time series of CESM2 and MODIS, it can be shown that ACCESS-ECM2 fluctuates more, at 0.4–0.8, than MODIS. Additionally, when compared to other models, the ACCESS-ECM2 AOD variability pattern shows values that are closer to MODIS, whereas the INM-CMS displays significantly larger variability in the region of 0.4–1.2 when compared to MODIS. Furthermore, AOD variability (0.4–1.0) on the MPI-ESM2-HR is larger than on MODIS. The AOD variability (0.4–0.6) of the MRI-ESM2 model usually stays in phase and deviates somewhat from the MODIS pattern. Furthermore, the Regression shows that the AOD pattern and MODIS variability are rather comparable.

Chapter-4

Conclusions

Conclusion

The study evaluates each seven individual CMIP6 models against observed MODIS DTB data covering the period 2000–2020 across the Indian Subcontinent, with a focus on analyzing AOD variability, trends, and model performance during the summer season. Various statistical methods are utilized for this assessment. The average AOD variability throughout the region is represented by the summer mean, and MODIS AOD data is used in time series analysis to compare each model and mean.

Models are considered effective if their phase and range closely match that of MODIS data. Furthermore, statistics like bias, correlation coefficient, standard deviation are used.

Spatial AOD trends highlight regional AOD variability, while comparing model, Mean, and MODIS trend patterns offers insights into the reliability of future forecasts. Using regression analysis and AOD trends and coefficient of determination, the link between each model, Mean, and MODIS is explained. According to the study, the northern and southern portions of the Indian subcontinent have greater mean AOD levels, respectively, based on MODIS measurements. Time series analysis shows that although CESM2-WACCM CMCC-CM2-SR5, INM-CMS-5, and MPI-ESM1-2-HR exhibit low bias and error metrics coupled with strong correlation coefficients relative to MODIS, ACCES-ESM1-5, CESM2, and MRI-ESM2-0 closely match with MODIS data. Overall, the study finds that there is strong agreement between ACCESS-ESM1-5 and MRI-ESM2-0 and MODIS DTB data, and it emphasizes increased AOD variability and trends in the Indian region.

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