Regional Atmospheric Radiation and Meteorological parameters in presence of Aerosol from CERES and MODIS: A Case Study of Observational Satellite Remote Sensing

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Abstract: This study focuses on the satellite observations from space-borne sensors and their usefulness in understanding atmospheric radiative changes in the presence of aerosol in a regional climate system. For this analysis, four years (2014–2017) of aerosol and flux products along with other meteorological parameters are used which are obtained from satellite remote sensing products. The radiative flux products available from Cloud and the Earth’s Radiant Energy System (CERES) along with the products pertaining to atmosphere thermodynamics available from Moderate resolution Imaging Spectroradiometer (MODIS) are included in this study. This study is an attempt to understand the possible effects of the presence of aerosol in perturbing the seasonal atmospheric dynamics and radiation budget, based on space borne observation systems. This study is aimed at atmospheric changes over Delhi, India, under different aerosol loading conditions. Significant changes have been observed in the atmospheric meteorological parameters and simultaneous modulation in radiation fluxes are perceived with the aerosol variation for 3 different seasons. The relationship between thermodynamic environment and its sensitivity in presence of aerosol has put forth a vital area for further studies. This analysis draws insight towards a merged hypothesis for the simultaneous roles of thermodynamics and aerosols in influencing the atmosphere dynamics and radiative effect modifying the energy budget and atmospheric processes on a local scale as well as a utility of space borne remote sensing in analysing environmental aspects.

Keywords: Aerosol, Radiation Flux, Meteorological parameters, CERES, MODIS, Delhi.

1. INTRODUCTION

The presence of aerosols in the atmosphere, affects the energy budget and thus influences the atmospheric processes both directly and indirectly by modulating the physical processes in clouds. Ample work has been carried out on understanding these effects. This influence is not only vital from meteorological or climate point of view but also very important towards society, environment and human health. Yet, the complete picture of these influential ways of aerosol on atmosphere has not been established. Nevertheless, through remote sensing, the area of research has quite been evolved in the last decade. The studies based on space based observations by the extensive amount of resources available through various satellites/sensors products have presented a useful tool to understand the aerosol and its impact in modifying the atmospheric dynamics and thermodynamics. The advantage of observing the atmosphere from space through satellites is having both global coverage and better understanding of spatio-temporal processes in the atmosphere (Satapathy and Jangid 2018;
There has been ample work carried out towards understanding the influence of aerosols on atmospheric dynamics and various environmental processes, especially on cloud properties (Boucher et al. 2013; Twomey 1977; Albrecht 1989; Pincus and Baker 1994; Loeb and Schuster 2008; Su et al. 2010; Stevens and Feingold 2009; Storer et al. 2013; Klein and Hartmann 1993; Matsui et al. 2004, 2006; Chen et al. 2014; Koshiro and Shiotani 2014; Randall et al. 2003; Hartmann et al. 1992; Bréon et al. 2002; Keil and Haywood 2003; Labonne et al. 2007; Costantino and Bréon 2013; Meyer et al. 2013; Painemal et al. 2014). Further, aerosols and cloud properties tend to co-vary with meteorological variables; such as relative humidity (RH), temperature profiles due to aerosol swelling in humid environments (e.g. Su et al. 2010; Haywoodetal. 1997; Charlsonetal. 2007; Myhreetal. 2007; Myhreetal. 2007; Jonesetal. 2009; Krishna Kumar et al. 2019). Hence, aerosol loadings and its properties present a strong variability in atmosphere dynamics not only directly by perturbing the radiation and fluxes and varying convection processes but also indirectly by modulating the cloud properties and inducing changes in meteorological parameters.

The goal of this study is to analyze aerosol impact especially on atmosphere thermodynamics by observing covariability in meteorological parameters as well as fluxes in different aerosol loadings. The motivation of this work is analysis of sensitivity of atmospheric radiative and thermodynamic interaction to aerosol loading and lower-tropospheric static stability (LTSS) (Matsui et al. 2004; Stevens and Feingold 2009), defined as the potential temperature difference between the surface and the 700 (mb) pressure level (Klein and Hartmann 1993). Andersen and Cermak 2015; Stolz et al. 2015, Matsui et al. 2006; Dagan et al. 2016; Feofilov et al. 2015; Chen et al. 2017; Li et al. 2017; Wu et al. 2017 have reported various thermodynamical perturbations due to aerosol loading which also have motivated this attempt.

This paper examines the sensitivity of the aerosol effect on the meteorological parameters, their profiles as well as radiation fluxes. This work is carried out on a local scale, over Delhi, India which has shown significant variation in the aerosol loading in last years. Besides, India, being a tropical region is hardly cloud free (Satapathy et al. 2014). Therefore, the study of atmospheric thermodynamics during aerosol loading, this particular case becomes vital. Four years (2014-2017) satellite products of MODIS and radiation flux information from CERES have been used for this study. This work provides a glimpse at seasonal covariability of aerosol and atmospheric dynamics at a local scale with the help of satellite remote sensing.

2. DATA AND METHODOLOGY

Aerosol Optical Depth products from CERES as well as MODIS, for 4 years (2014-2017) over Delhi are considered in this study. Further, these data are segregated into 3 seasons (DJF, MAM and JJAS) and seasonal analysis has been carried out to understand the impact of aerosol on the thermodynamics state of the atmosphere. These are daily data products. Every 10 alternative day data has been chosen in these study.

The Clouds and the Earth's Radiant Energy System (CERES) is part of NASA's Earth Observing System (EOS), provides radiative flux data both about insolation and IR short and long wave fluxes at the top-of-the-atmosphere (TOA) and at the earth surface as well (Wielicki et al. 1998). CERES has been very useful towards Earth Radiation Budget Experiment (ERBE) these products have been the part of this study. CERES also provides cloud are aerosol products, collocated with flux data products, thus proving extremely useful in the understanding of cloud-radiation interactions, especially the cloud feedback effects on the earth's energy balance. Therefore, these radiative flux products are also used in this study to strengthen the understanding of atmosphere dynamics in presence of aerosol loadings.
MODIS is also one of the leading sensors in providing high resolution data products such as aerosol, cloud properties, atmospheric thermodynamic and meteorological parameter on the same platform, therefore very useful in delineating the covariability effects of atmosphere states with its processes (Borbas et al. 2015). AOD, Stability Indices, thermodynamic parameters are particularly used from MODIS data products in this study.

3. RESULT AND DISCUSSION

3.1 Evolution of Radiative properties from CERES
CERES provides the radiation flux products for long wave (LW) as well as short wave (SW) at the top of the atmosphere (TOA) which is very advantageous to understand the atmospheric conditions instantaneously. Besides, the irradiance of the same channels from the surface of the earth is also available in CERES products. These data are used for further analysis of the atmosphere dynamics and thermodynamics in presence of aerosol from radiative point of view. Long wave flux at top of the atmosphere (LWTOA) and short song wave flux at top of the atmosphere (SWTOA) with AOD and aerosol concentration achieved from CERES are plotted in figure 1 and 2 respectively. The two plots in each figure include the seasonal anomaly and the 2D probability distribution of these products. These are plotted for 3 seasons separately.

Fig. 1: Time series anomaly and 2D PDF plot of SW Flux in the TOA in 3 seasons from CERES
From figure 1 it can be seen that, the seasonal anomaly of SWTOA correlated with seasonal AOD anomaly i.e. for positive AOD anomaly, SWTOA anomaly has negative values in all the seasons though of different magnitudes. The magnitude is due to the seasonal variation in the atmospheric processes, such as occurrence of clouds and presence of aerosol. It’s quite clear that aerosol obstructs the SW flux to go to the top of the atmosphere, thus showing a negative anomaly. Higher is the aerosol concentration, lesser is the SW flux at TOA, as observed in DJF which is of higher aerosol content compared to other seasons. Similarly, the 2D probability distributions of year wise AODs versus year wise SW fluxes are plotted. This results also conform a negative correlation between AODs and SWTOA. The higher AODs suppress the SW, thus a lower of SWTOA is high in amount irrespective of seasonal differences and type of AODs as well. As AODs show an increase in 2017, the low value of SWTOA is high in 2017 compared to other years. Inferences from figure 2 with the case of LWTOA is rather complicated. Similar inference as that of SW can be made here but there are significant traces of positive anomaly of LWTOA with positive AOD anomaly, especially as seen in JJAS. This explains the complicated coupling with cloud. LW are also absorbed by aerosol thus reducing the flux at TOA, but LW is hugely affected by the presence of clouds. The presence of aerosol might influence the cloud process, their microphysics and dynamics, and thereby increasing the LWTOA implicitly. The similar observation can be made in case of 2D probability distribution plots. The rise in LWTOA with high aerosol can be attributed to the complex coupling between aerosol and cloud, and thus modulating the cloud radiative properties. The perturbation in SWTOA and LWTOA, however small maybe, is not insignificant in altering the energy balance of the earth and its atmosphere.
3.2 Impact in Meteorological Parameters from MODIS

Nevertheless, the stability indices available from MODIS L2 product are also plotted with AOD in figure 3 to understand the role of aerosol in the local atmospheric thermodynamics. Lifted index (LI) and K-index (KI) products, available from MODIS imply the atmospheric stability conditions. From the figure 3, apparently the positive anomalies in AOD are also strongly correlated with LI and KI which suggests the advent of atmospheric stability in presence of aerosols. The positive values of LI in presence of AOD suggest that the convective processes have hindered, leading to decrease in the updraft which might influence the cloud dynamics. It can also be concluded that the lapse rate, and other thermodynamic parameters of atmosphere are perturbed by the presence of aerosols.

![Fig. 3: Time series plot Lifted Index and K-index from MODIS with AOD](image)

4. CONCLUSION

Four years (2014-2017) of long wave and shortwave flux from CERES and atmospheric thermodynamic products from MODIS have been used to understand the influence of presence of aerosol in atmospheric dynamics. This analysis has been carried over a regional area, Delhi, India by characterizing the seasonal variability of the above mentioned parameters. This work is an attempt to relate the change in regional atmospheric thermodynamics to the aerosol forcing and thus accounting the role of aerosol in modifying the earth’s radiation budget from remotely sensed observations of space-borne sensors. The correlated variations observed in the results emphasizes that aerosols play a significant role in incurring modification in a regional atmosphere as well as the useful role of satellite remote sensing in understanding such paramount atmospheric and climatic environmental conditions.

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