Seasonal and Spatial Variations of Top of the Atmosphere Fluxes and Albedo Over the Indian Region

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Abstract--- Seasonal and spatial variations of reflected short wave, emitted long wave and net flux, along with albedo, at top of the atmosphere over India region have been examined. The analysis has been carried out using long term satellite observations from CERES on-board Terra, for a period of 18 years from March 2000 to February 2018. Reflected shortwave flux, net flux and albedo at the top of the atmospheres are observed to be highest during southwest monsoon (June-September), over most of the regions of Indian landmass and surrounding oceanic regions. Whereas, emitted longwave flux at top of the atmosphere is observed to be highest in pre-monsoon, over most of the land regions, and lowest in southwest monsoon. Seasonal and spatial variations of TOA fluxes and albedo are observed to be affected mainly by the variations in the cloud cover region in different seasons.

Index terms: Short wave flux, Long wave flux, Net flux, Albedo, CERES, MODIS.

I. INTRODUCTION

Earth’s climate is generally determined by the balance of incoming solar radiation by emitted terrestrial and reflected solar radiations [1]. Any alteration in the energy balance of Earth atmosphere system can lead to change in climate [2]. When the energy balance is maintained between the incoming and outgoing radiation, global mean temperature remains unaltered. But, when the energy gain and loss are not in balance [3], global temperature can either be increased or decreased, depending upon the increase or decrease of energy trapped within the earth-atmosphere system[4]. If the amount of outgoing radiation is less (more) than that of incoming, more (less) energy is trapped and hence will lead to warming (cooling) [5].

The earth radiation budget can be altered by external and internal factors, by changing the amount of incoming/outgoing radiations [6]. The external factors include variations in solar activity and Milankovitch cycle, whereas the internal factors include changes in earth surface features and atmospheric constituents. One of the major factors in Earth atmosphere, which can lead to changes in outgoing short wave and long wave radiations, is presence of clouds [7]. Clouds reflect significant fraction of solar radiation back to space and hence lead to higher albedo [8]. In addition, atmospheric constituents such as aerosols and greenhouse gases also affect the net radiation at top of the atmosphere, mainly through scattering and absorption [9]. Aerosols are tiny particles, either in solid or in liquid phase, suspended in the atmosphere and affect the radiation balance through their direct, indirect and semi-direct effects. Depending upon the characteristics, aerosols can lead to either cooling or warming of the atmosphere. Greenhouse gases, including water vapor, CO2, methane, etc., absorb long wave radiation and make the earth atmosphere warmer [10].

Rapid growth of industrialization and urbanization has led to significant increase in emissions of greenhouse gases and aerosols, especially in the past few decades over several regions on the globe [11]. The effects of these anthropogenic contributions in radiation balance of the earth-atmosphere system can be examined by measuring incoming and outgoing solar and terrestrial radiations [12]. Any alteration in radiation balance of earth-atmosphere can be monitored by measuring the net flux, which is the difference between incoming solar radiation and outgoing radiation, which includes reflected solar and emitted terrestrial radiations [13]. Positive values of net flux indicate trapping of more radiation in earth atmosphere system and hence warming, whereas negative values indicate cooling [14]. The present study examines spatial variations of short wave, long wave and net flux, along with albedo, at top of the atmosphere, over Indian land mass and surrounding oceanic regions using long term satellite observations.

II. DATA COLLECTION AND METHODOLOGY

The study region considered is between 5°N & 38°N and 60°E & 100°E, which includes Indian landmass and surrounding oceanic regions.

Satellite based measurements have been used to generated long term data set of reflected solar radiation, outgoing longwave radiation and albedo at top of the atmosphere (TOA), with large spatial coverage over the globe. CERES is a broadband, scanning radiometer, having three channels to measure (i) total radiance (0.3 to >100 μm), shortwave radiance (0.3–5 μm) and radiance in the atmospheric window at 8–12 μm [15]. The CERES instrument is capable of operating in either of the two modes: (i) cross-track or track or
(ii) rotating plane (bi-axial scanning) (Ref). The spaceborne sensor, CERES is currently onboard four satellites, namely Terra (from Dec 1999), Aqua (from May 2002), SNPP (from Oct 2011) and NOAA-20 (from Nov 2017) (Ref). In the present study, seasonal variations of Shortwave Flux, Longwave Flux, Net Flux and Albedo at top of the atmosphere over the Indian region have been examined using the data from Clouds and the Earth’s Radiant Energy System (CERES) on-board Terra, for a period during March 2000 to February 2018. The dataset generated out of CERES measurements is reported to be unprecedented in terms of its consistency and accuracy [2]. The data set used in the present study is level 3, CERES_SSF1deg_Ed4A, monthly mean product at a spatial resolution of 1°×1°. In order to examine the effects of cloudiness on reflected shortwave and emitted long wave fluxes at top of the atmosphere, level 3 monthly mean day time cloud fraction from MODIS onboard Terra has been used in the present study.

The seasons are defined as, Southwest monsoon (June to September), Post monsoon (October and November), winter (December to February) and Pre monsoon/Summer (March to May), for the analysis. These mean maps are generated using MATLAB R2016b. Below Flow chart explains the methodology for this study.

Flow chart: Flow chart showing the methodology

III. Results and Discussion

Figure 1 (a to d) depicts the reflected Shortwave Flux at the top of the atmospheres ($F_{SW, TOA}$) for all sky conditions, for southwest monsoon, post monsoon, winter and pre-monsoon respectively. Shortwave Flux is result of specular and diffuse reflection of incident shortwave radiation by the underlying surface. Significant seasonal and spatial variations in $F_{SW, TOA}$ have been observed over Indian region. Among all the four seasons, $F_{SW, TOA}$ is observed to be highest during southwest monsoon, over most of the regions in land and ocean. In southwest monsoon, $F_{SW, TOA}$ is observed to be highest over north east India and western coast, along with northern and eastern parts of Bay of Bengal (BoB) and eastern Arabian Sea. In post-monsoon, $F_{SW, TOA}$ is observed to be high over eastern parts of Indian peninsula and BoB, but less than the values observed during southwest monsoon. Over North West regions of Indian land mass, including the state of Rajasthan, $F_{SW, TOA}$ is observed to be higher in southwest monsoon followed by that in pre-monsoon. Most of the land regions experience minimum $F_{SW, TOA}$ in winter, whereas it is observed minimum in pre-monsoon over most of the oceanic regions. High values of $F_{SW, TOA}$ observed over most of the regions during JJAS are mainly due to the presence of clouds associated with southwest monsoon. Clouds reflect large amount of solar radiation than that from the underlying surfaces. High $F_{SW, TOA}$ during October-November over eastern part of India and southern peninsular India are also due to presence of clouds, associated with Northeast monsoon, which is the major period of rainfall over the eastern coast consisting of regions of Andhra Pradesh, Rayalaseema and Tamilnadu-Pondicherry. Among all the four seasons, $F_{SW, TOA}$ is observed to be minimum in winter over most of the regions, mainly because of the minimum frequency of occurrence of clouds. $F_{SW, TOA}$ is less over most of the regions in pre-monsoon than that in southwest monsoon; but more than that in winter, especially over the desert regions in northwest.

![Figure 1: 18-year mean TOA shortwave flux over India.](image-url)
leaving out to space at top of the atmosphere in the wave length range 3 to 100µm. Figure 2 depicts spatial variation of FLW_TOA under all sky conditions, over Indian land mass and surrounding oceanic regions in all the four seasons. Under all sky conditions, FLW_TOA is observed to be highest in pre-monsoon over most of the land regions. High values of FLW_TOA are seen over north-west India in post monsoon and southwest monsoon also. FLW_TOA is highest over most of the regions of Arabian Sea and BoB in pre-monsoon, followed by that in winter season. Among all the seasons, minimum FLW_TOA is observed over south-east Arabian Sea, peninsular India, eastern coast and all most entire BoB, during southwest monsoon. This is mainly because of the large cloud cover persists over these regions during southwest monsoon, which prevents large amount of long wave radiation emitted from the underneath surface to reach top of the atmosphere.

Figure 2: 18-year mean TOA Longwave flux over India.

Figure 3 is same as figures 1 and 2, but for the net flux at top of the atmosphere (FNET_TOA) under all sky conditions. All Net flux is defined as the incoming (absorbed solar radiation) minus the outgoing (outgoing Longwave radiation) components of radiation. Net radiation can be positive, negative, or zero. Net radiation is positive when there is more incoming radiation than outgoing long wave radiation. This typically occurs during day time when the sun is out and the air temperature is the warmest (Ref.). Net radiation is negative during night time, as there is no incoming solar radiation and hence the net flux is dominated by outgoing terrestrial longwave radiation. Net radiation is zero when the incoming and outgoing components are in perfect balance, which doesn’t occur too often. Net radiation is observed to be positive and high over most of the regions, including land and ocean, during southwest monsoon. It is observed to be high over the southern latitudes, especially over oceanic regions and low over northern latitudes in pre-monsoon and post monsoon seasons. During pre-monsoon, FLW_TOA is low over the land mass, compared to that over the neighboring oceanic regions. In winter season, a meridional gradient in FLW_TOA is observed with high positive values at southern latitudes and negative values over northern regions. Thus a gradual increase in FLW_TOA is observed in winter over the Indian region, as moving towards north.

Figure 3: 18-year mean TOA Net flux over India.

Clouds play a major role in governing top of the atmosphere shortwave flux, long wave flux and albedo. Clouds enhance FSW_TOA and TOA albedo, by reflecting significant amount of solar radiation back to space. In addition to clouds, highly reflecting surfaces such as snow covered regions and deserts also contribute significantly to FSW_TOA and TOA albedo, during cloud free conditions. Clouds lead to reduction of FLW_TOA by preventing
penetration of long-wave terrestrial radiation into space, by absorbing and reradiating back to earth surface. Since clouds are at higher altitudes and at low temperature, compared to that of underlying surface, amount of long radiation emitted from cloud top will be lesser compared to that from the surface. Figure 5(a) shows scatter plot between cloud fraction and reflected shortwave flux over the Indian region, including surrounding oceanic regions. Figure 5(b) is same as figure 5(a), but between cloud fraction and emitted long wave flux. Each point in the figure is corresponding to average of monthly mean cloud fraction and flux over the entire study region (5°N to 38°N and 60°E to 100°E), whereas the horizontal and vertical error bars represent corresponding standard errors of cloud fraction and fluxes respectively. Increase (decrease) in reflected short wave (emitted long wave) with increase in cloud fraction is clearly seen in figure 5.

![Figure 5](image_url)

**Figure 5:** Scatter plot between (a) cloud fraction and reflected short wave flux and (b) cloud fraction and emitted long wave flux at top of the atmosphere.

### IV. CONCLUSION

Climate on Earth is maintained by balance of incoming and outgoing radiation. Continuous monitoring of net flux at top of the atmosphere makes it possible to examine any alteration in radiation balance of earth atmosphere system, which leads to change in climate. Rapid increase in human activities has led to increase in emissions of greenhouse gases and aerosols, which are major climate forcing agents, over several regions including Indian subcontinent. The present study examines spatial variations of albedo, reflected short wave, emitted long wave and net fluxes at top of the atmosphere over Indian land mass and surrounding oceanic regions in different seasons, Southwest monsoon (June to September), Post monsoon (October and November), winter (December to February) and Pre monsoon/Summer (March to May). Significant seasonal and spatial variations are observed with highest values of reflected shortwave flux, net flux and albedo during southwest monsoon, over most of the regions and highest values of long wave fluxes in pre-monsoon. Seasonal and spatial variations of cloud cover are observed to play a major role in governing the TOA fluxes and albedo over the Indian region. Further analysis is needed to explore long term trends in TOA fluxes and albedo due to changes in surface characteristics and atmospheric constituents.

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