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

P.Nithish, S.S.Prijith, Lima.C.B, D.S.Chandra, M.V.Ramana M.V.R. Seshasai

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 onboard 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

Revised Manuscript Received on April 15, 2019.

P.Nithish, Geo Informatics, Civil Engineering, KL Deemed to be University, Andhra Pradesh, Vijayawada, India.

S.S.Prijith, Earth and Climate Science Area, National Remote Sensing Centre, ISRO, Hyderabad, Telangana, India.

Lima.C.B, Earth and Climate Science Area, National Remote Sensing Centre, ISRO, Hyderabad, Telangana, India.

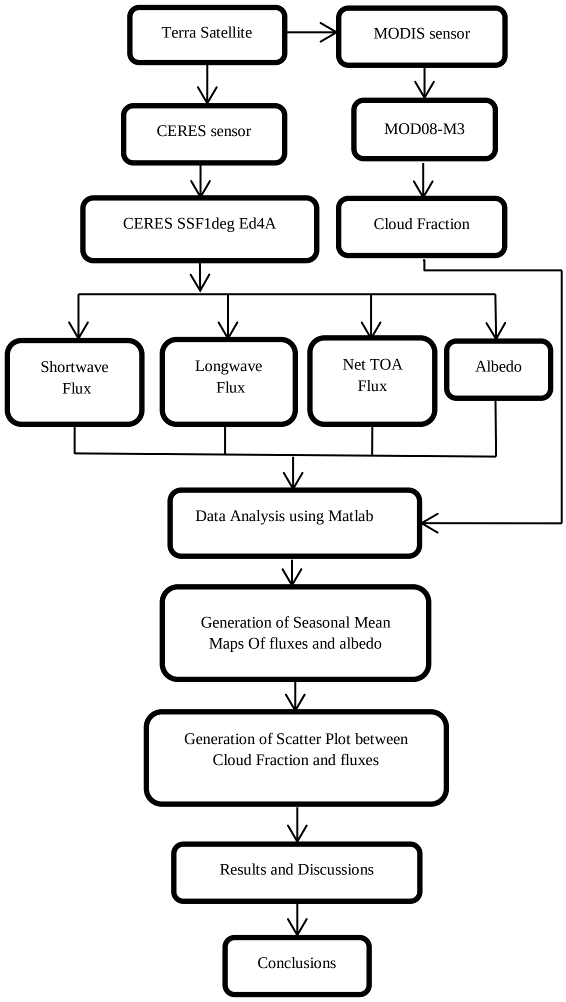
D. Satish Chandra, Civil Engineering, KL Deemed to be University, Vijayawada, India.

M.V.Ramana, Earth and Climate Science Area, National Remote Sensing Centre, ISRO, Hyderabad, Telangana, India.

M.V.R.Seshasai, Earth and Climate Science Area, National Remote Sensing Centre, ISRO, Hyderabad, Telangana, India.

(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 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 north-west.

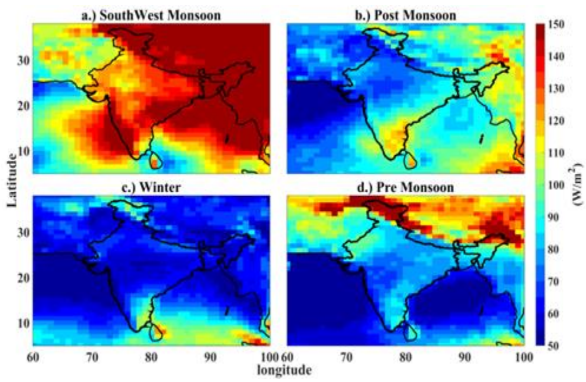


Figure 1: 18-year mean TOA shortwave flux over India.

Spatial variations of longwave flux at top of the atmosphere (F_{LW_TOA}) over the Indian region, in different seasons, have been examined. F_{LW_TOA} is the radiation

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

leaving out to space at top of the atmosphere in the wave length range 3 to 100µm. Figure 2 depicts spatial variation of F_{LW_TOA}, under all sky conditions, over Indian land mass and surrounding oceanic regions in all the four seasons. Under all sky conditions, F_{LW_TOA} is observed to be highest in pre-monsoon over most of the land regions. High values of F_{LW_TOA} are seen over north-west India in post monsoon and southwest monsoon also. F_{LW_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 F_{LW_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.

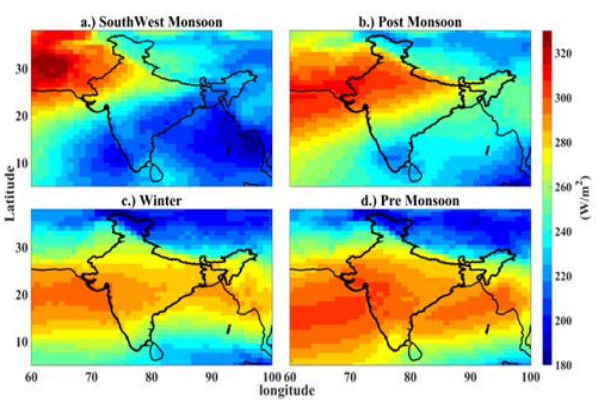


Figure 2: 18-year mean TOA Longwave flux over India.

Figure 3 is same as figures 1 and 2, but for the net flux at top of the atmosphere (F_{NET_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, F_{LW_TOA} is low over the land mass, compared to that over the neighboring oceanic regions. In winter season, a meridional gradient in F_{LW_TOA} is observed with high positive values at southern latitudes and negative values over northern regions. Thus a gradual increase in F_{LW_TOA} is observed in winter over the Indian region, as moving towards north.

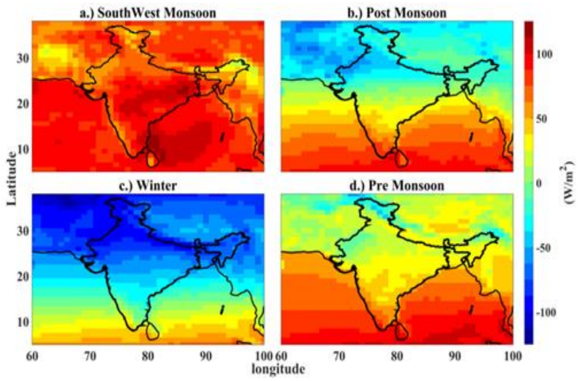


Figure 3: 18-year mean TOA Net flux over India.

Figure 4 depicts seasonal variation of TOA albedo at top of the atmosphere, over the Indian land mass and surrounding oceanic regions, under all sky conditions, in all the four seasons. Albedo is the measure of the diffuse reflection of solar radiation out of the total solar radiation received (Ref). Spatial and seasonal variations of albedo are observed to be similar to that of F_{SW_TOA}, which is shown in figure1. Albedo is observed to be high over most of the regions, during southwest monsoon, mainly because of the large cloud cover persists during this season. In post-monsoon, higher values are observed north-east India, eastern coast and most of the regions of BoB, whereas in winter albedo values greater than 0.25 is observed mainly over north-west India and southern parts of BoB. Significant difference in TOA albedo over land and ocean can be observed in winter mainly because of the low frequency of occurrence of clouds in the season. Compared to other regions, high values of TOA albedo can be observed over the desert regions in north-west India and snow covered regions of Himalayas.

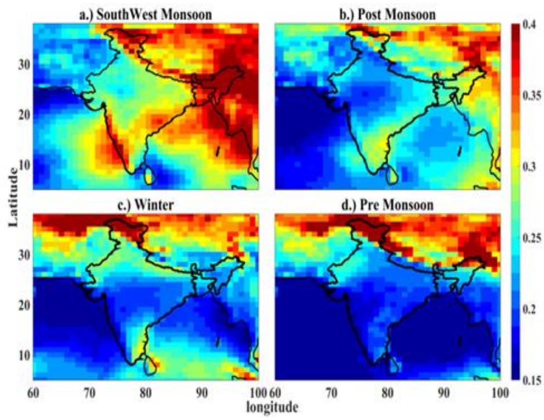


Figure 4: 18-year mean TOA Albedo over India.

Clouds play a major role in governing top of the atmosphere shortwave flux, long wave flux and albedo. Clouds enhance F_{SW_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 F_{SW_TOA} and TOA albedo, during cloud free conditions. Clouds lead to reduction of F_{LW_TOA}, by preventing

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

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.

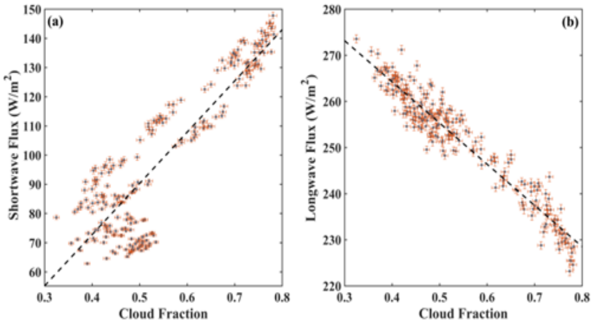


Figure 5: Scatter plot between (a) cloud fraction and reflected short wave flux and (b) cloud fraction and emitted long wave flux at top of the atmosphere.

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.

ACKNOWLEDGMENT

We would like to thank Mr. Shiva Sai Krishna, Mr.Anoop Kumar, Mr. Rounaq Goenka, Mr. Srinivasarao Karri and Ms. Shivali Verma for their constant support and valuable suggestions in this work. The CERES and MODIS data used in this study is obtained from CERES website at https://ceres.larc.nasa.gov/ and LAADS DAAC website at https://ladsweb.modaps.eosdis.nasa.gov/ respectively. This work was supported by National Remote Sensing Centre (NRSC, ISRO) and Koneru Lakshmaiah Education Foundation (Deemed to be University), Andhra Pradesh.

REFERENCES

1. K. E. Trenberth, J. T. Fasullo, and J. Kiehl, "EARTH'S GLOBAL ENERGY BUDGET,"Vol.90, no.3, 2008,pp. 311-324.
2. N. G. Loeb, John M. Lyman, "Observed changes in top-of-the-atmosphere radiation and upper-ocean heating consistent within uncertainty," Nat. Geosci., Vol. 5, no. 2, 2012, pp. 110–113.
3. N. G. Loe, Bruce A. Weilicki, "Toward optimal closure of the Earth's top-of-atmosphere radiation budget," *J. Clim.*, Vol. 22, no. 3, 2009, pp. 748–766.
4. N. G. Loeb, Bruce A. Weilicki, "Multi-instrument comparison of top-of-atmosphere reflected solar radiation," *J. Clim.*, Vol. 20, no. 3, 2007, pp. 575–591.
5. N. G. Loeb, B. A. Wielicki, F. G. Rose, and D. R. Doelling, "Variability in global top-of-atmosphere shortwave radiation between 2000 and 2005," *Geophys. Res. Lett.*, Vol. 34, no. 3, 2007 pp. 1–5.
6. N. G. Loeb, Seiji Kato,., "Advances in Understanding Top-of-Atmosphere Radiation Variability from Satellite Observations," *Surv. Geophys.*, Vol. 33, no. 3–4, 2012, pp. 359–385.
7. J. O. F. Climate and A. Sciences, "Trends in the CERES Dataset , 2000 – 13 : The Effects of Sea Ice and Jet Shifts and Comparison to Climate Models," , Vol. 27, no.6, 2013,pp. 2444–2456.
8. K. E. Trenberth, J. T. Fasullo, K. von Schuckmann, and L. Cheng, "Insights into Earth's energy imbalance from multiple sources," *J. Clim.*, Vol. 29, no. 20, 2016, pp. 7495–7505.
9. S. Park and U. Kingdom, "Earth ' s Energy Imbalance," ,Vol. 308,no. 5727, 2014, pp. 3129–3144.
10. P. Gupta, J. Joiner, A. Vasilkov, and P. K. Bhartia, "Top-of-the-atmosphere shortwave flux estimation from satellite observations : an empirical neural network approach applied with data from the A-train constellation," Vol. 9, no. 7, 2016,pp. 2813–2826.
11. N. Hatzianastassiou A.Fotaidi,C.Matuskos, "Long-term global distribution of earth's shortwave radiation budget at the top of atmosphere," *Atmos. Chem. Phys. Discuss.*, Vol. 4, no. 3, 2004, pp. 2671–2726.
12. G. L. Stephens and T. L'Ecuyer, "The Earth's energy balance," *Atmos. Res.*, Vol. 166, 2015, pp. 195–203.
13. T. L. Ecuyer, P. W. S. Jr, M. Lebsock, and T. Andrews, "latest global observations," *Nat. Geosci.*, Vol. 5, no. 10, 2012, pp. 691–696.
14. S. Dewitte and N. Clerbaux, "Measurement of the Earth Radiation budget at the top of the atmosphere-a review," *Remote Sens.*, vol. 9, no. 11, 2017.
15. K. A. Facts, "Key Aqua Facts," *Delta*, pp. 73–93, 2002.

AUTHORS PROFILE

P.Nithish, Project student at National Remote Sensing Centre, ISRO and Post-graduate Student, Geo Informatics, Department of Civil Engineering, KLEF Deemed to be University, Andhra Pradesh, India.

S.S.Prijith, Scientist 'SE', M&CS division, Earth and Climate Science Area, National Remote Sensing Centre, ISRO

Lima.C.B, SRF, M&CS division, Earth and Climate Science Area, National Remote Sensing Centre, ISRO

D.S.Chandra, Associate Professor, Department of Civil Engineering, KLEF Deemed to be University, Andhra Pradesh, India.

M.V.Ramana, Scientist 'SG', Head, M&CS division, Earth and Climate Science Area, National Remote Sensing Centre, ISRO

M.V.R.Seshasai, Deputy Director, Earth and Climate Science Area, National Remote Sensing Centre, ISRO

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication