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Spatial and temporal variability of atmospheric surface albedo over the central north region of India for the period of 2004-2016

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ABSTRACT

Thirteen years (2004-2016) of solar radiation data of the surface albedo over eight stations in the central north region of India was estimated and annual, seasonal, and geographical variations were also investigated. The selected sites of the central north region of India encounter a wide range of atmospheric conditions. The average annual surface albedo varies from ~ 0.144 to 0.34, and show high synoptic variability between different places and even at individual sites. The differences between the maximum and minimum surface albedo range from 0.02 to 0.44. The lowest mean was occurred in Nainital (~0.152) whereas, highest was recorded in Jaipur (~0.236). In examining the variations of the estimated albedo values with the altitude, sites were divided into three groups: low (<500 m), middle (500-1000 m), and high altitude (mountain sites) (> 1000 m); the mean albedo values for each category are ~ 0.198, ~ 0.167, and ~ 0.177 respectively. In studying the effects of latitude on albedo values, the sites were also further divided into three groups: low (<25 degree), middle (25-30 degree), and high latitudes (>30 degree), for which the mean monthly albedo values are 0.168, 0.222, and 0.183, respectively.

Key words: Surface and solar albedo, aerosol, solar radiation, solar energy, vegetation.

INTRODUCTION

The radiant solar energy of the sun initiates the various processes and mechanisms of the Earth's system (Siingh et al., 2011; Ban-Weiss et al., 2015; Kumar et al., 2018). The solar radiation data has achieved great importance in the recent past years (Hocaoglu et al., 2017; He et al., 2018). In the last decade, the demand of power in India has increased manifold due to large industrial growth (Hoeve et al., 2012). Hence, it becomes significantly important to know the ground reality of large-scale solar energy based resources (Jaidevi et al., 2011). Many researchers have done extensive research on solar radiation relevant to their country in diversified areas such as computing the coefficients of the correlation connecting global solar radiation to sunshine duration, neural network approach for modeling global solar radiation, techniques for the precise estimation of hourly values of global, diffuse and direct solar radiation etc. (Kumar, 2011; Bakirici, 2017). Although a number of global and regional broadband surface albedo products have been generated from satellite observations, most of them contain albedo over land-surfaces only (Lee and Penner, 2011; Sergio et al., 2016). Scientific investigations through satellite remote sensing data provide an effective means to understand and characterize the effect of atmospheric aerosols on solar radiation temporally and globally (Pandithurai et al., 2008; Kumar, 2013; Qin, 2015). It is to be noted that satellite sensors view the entire Earth and produce global images, thus resolving the spatial patterns resulting from the spatial inhomogeneities (Pant et al., 2008). In the present paper, we have attempted to provide some useful solar radiation information to the agricultural scientists and to the designers of solar energy utilization systems, under the climatic conditions of Central North (CN) region of India, which may also serve as a useful reference for system designers and users in other regions, with similar climatic conditions. An extensive analysis were conducted previously in regard to atmospheric radiative properties through the interaction of atmospheric aerosol particles with solar radiation data, which further affects the Earth's energy balance budget (Siingh et al., 2012).

In the present work, a thorough investigations of solar radiation data on the long term (2004-2016) basis has been attempted over the eight selected most populated places of Central North region of India. The present work was focused on to study the monthly, seasonal, and annual variations of surface albedo, over various major cities in Central North India on a long-term basis of thirteen years (2004-2016). Further, the study on solar radiation was made by dividing the long term into the three different groups of four years. Latitudinal and altitude effects have also been considered on the collected solar radiation data over the eight selected sites of Central North region of India.

As far as we understand, no systematic study of surface albedo has been carried in India till now on a long term basis, specially over the central north region of India. The present work is likely to be helpful to the solar power developers in achieving their target for further growth of solar power utilization, apart from its intrinsic benefits to the agriculture sector.

Table 1. Monthly mean atmospheric surface albedo values of all the stations.

Station	Lat, °N	Long, °E	Alt, m	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Delhi	28.56	77.01	233	0.197	0.193	0.185	0.189	0.194	0.2	0.194	0.187	0.188	0.19	0.192	0.2
Shimla	31.01	77.16	2202	0.24	0.265	0.234	0.204	0.188	0.191	0.189	0.187	0.185	0.181	0.186	0.2
Raipur	21.25	81.68	298	0.17	0.167	0.165	0.163	0.17	0.172	0.17	0.164	0.17	0.173	0.172	0.171
Bhopal	23.28	77.35	523	0.182	0.18	0.174	0.164	0.158	0.162	0.161	0.16	0.161	0.16	0.16	0.168
Chandigarh	30.75	76.88	347	0.192	0.188	0.173	0.174	0.163	0.174	0.184	0.189	0.193	0.188	0.186	0.196
Jaipur	26.81	75.8	390	0.243	0.243	0.242	0.242	0.243	0.241	0.227	0.216	0.216	0.223	0.235	0.24
Kanpur	26.4	80.4	127	0.208	0.203	0.194	0.208	0.22	0.223	0.212	0.198	0.195	0.198	0.203	0.211
Nainital	29.25	79.26	2084	0.153	0.15	0.147	0.148	0.149	0.153	0.155	0.156	0.155	0.148	0.148	0.152

Table 2. Annual Maximum, Minimum and Mean surface albedo values of all the stations.

Station	Maximum	Minimum	Mean	Range
Delhi	0.204	0.181	0.192	0.023
Shimla	0.341	0.178	0.201	0.163
Raipur	0.176	0.161	0.169	0.015
Bhopal	0.187	0.15	0.167	0.037
Chandigarh	0.2	0.165	0.187	0.035
Jaipur	0.247	0.211	0.236	0.036
Kanpur	0.218	0.193	0.208	0.025
Nainital	0.155	0.144	0.152	0.011

METHODOLOGY AND DATA ANALYSIS

The selected sites of central north region of India, are located between latitudes (20°-30° N, 74°-84° E) and elevation ranging between 100 - 2500 m above sea level. Albedometer is an instrument that measures global and reflected solar radiation and the solar albedo (Bakirici, 2017). The albedometer is composed of two pyranometers, the up facing one, measuring the global solar radiation, while the down facing measuring the reflected solar radiation (Pant et al., 2008). The irradiance in W/m^2 in each direction is calculated by dividing the pyranometer output, a small voltage, by the sensitivity (Jaidevi et al., 2011). The albedo is calculated by dividing the reflected short wave radiation by the global short wave radiation (Rathore et al., 2017).

The data utilized in the present study was taken from the standard atlas of solar radiation measurements data reported by the India Meteorological Department (IMD), New Delhi which is the principal government agency of India in matters relating to meteorology. Over forty five ground stations are currently being maintained by IMD in its solar radiation network (Kumar, 2013). Climatically, central north region of India lies mainly in the north temperate zone of the Earth (Qu et al., 2016). In the winter season, the lowest temperature on the plains dips to below ~3 °C, whereas during the summer, the temperature often rises as high as ~52°C in the Thar deserts of Rajasthan (Vincendon et al., 2015). The data collected for the present work include mean monthly values of global solar radiation on the horizontal surface in different seasons for the past thirteen years period of 2004 - 2016. Further, an attempt has also been made to study the impact of a location's altitude and latitude on the estimated albedo values over the central north region of India.

RESULTS AND DISCUSSION

The monthly mean clear-sky surface albedo values for the eight different stations of India, calculated using the method was described in Table 1, whereas the annual maximum, minimum, and mean along with their range values of the surface albedo are presented in Table 2.

Annual variations of surface albedo

The annual mean values were obtained by averaging the monthly values of each station. The lowest mean was occurred in Nainital (~ 0.152), while the highest was recorded in Jaipur (~0.236). Although Jaipur and Nainital

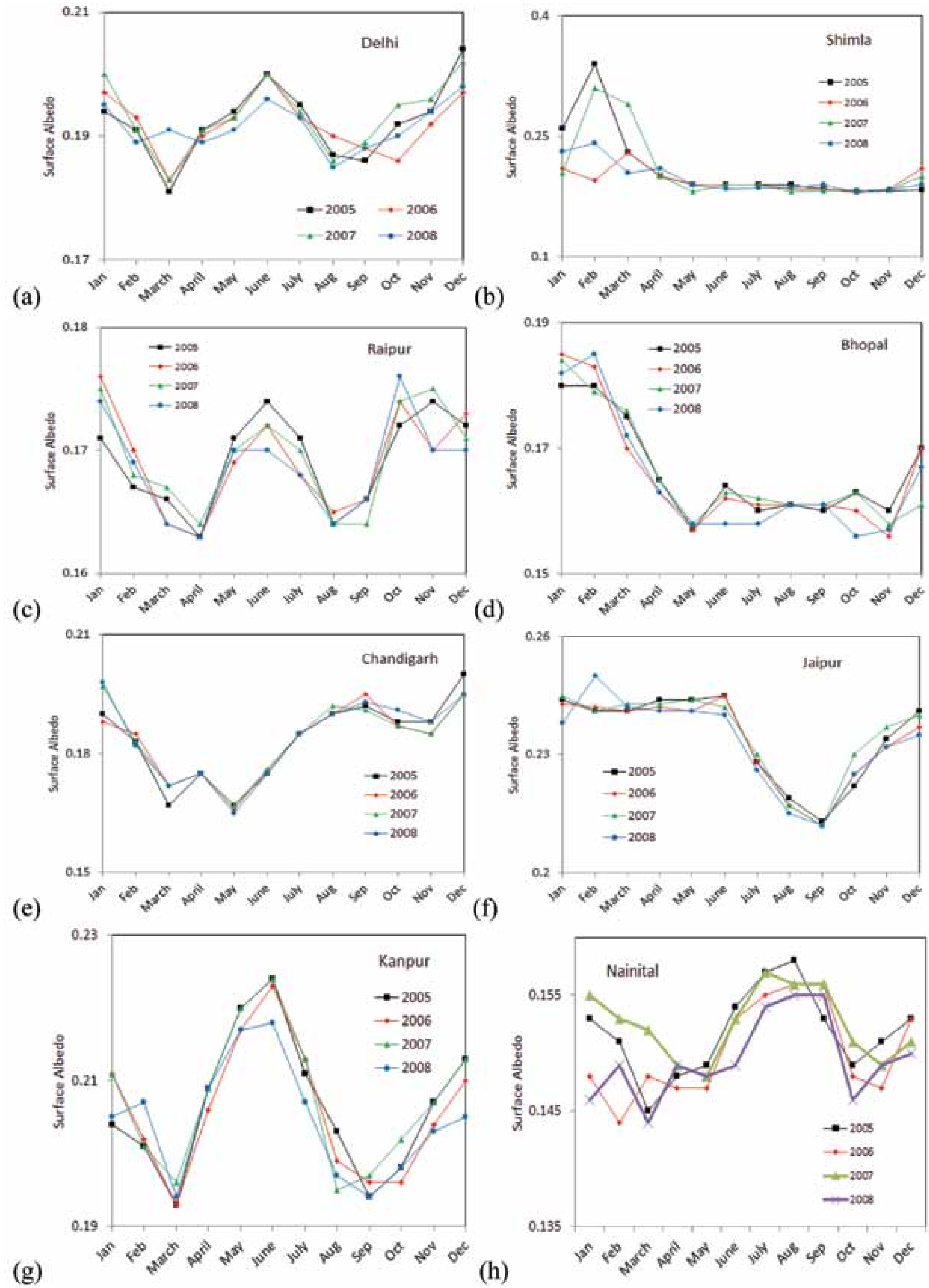

Figure 1(a-h). Monthly mean variation of atmospheric surface albedo over eight selected places of the central north region of India for the four year period of 2005-2008.

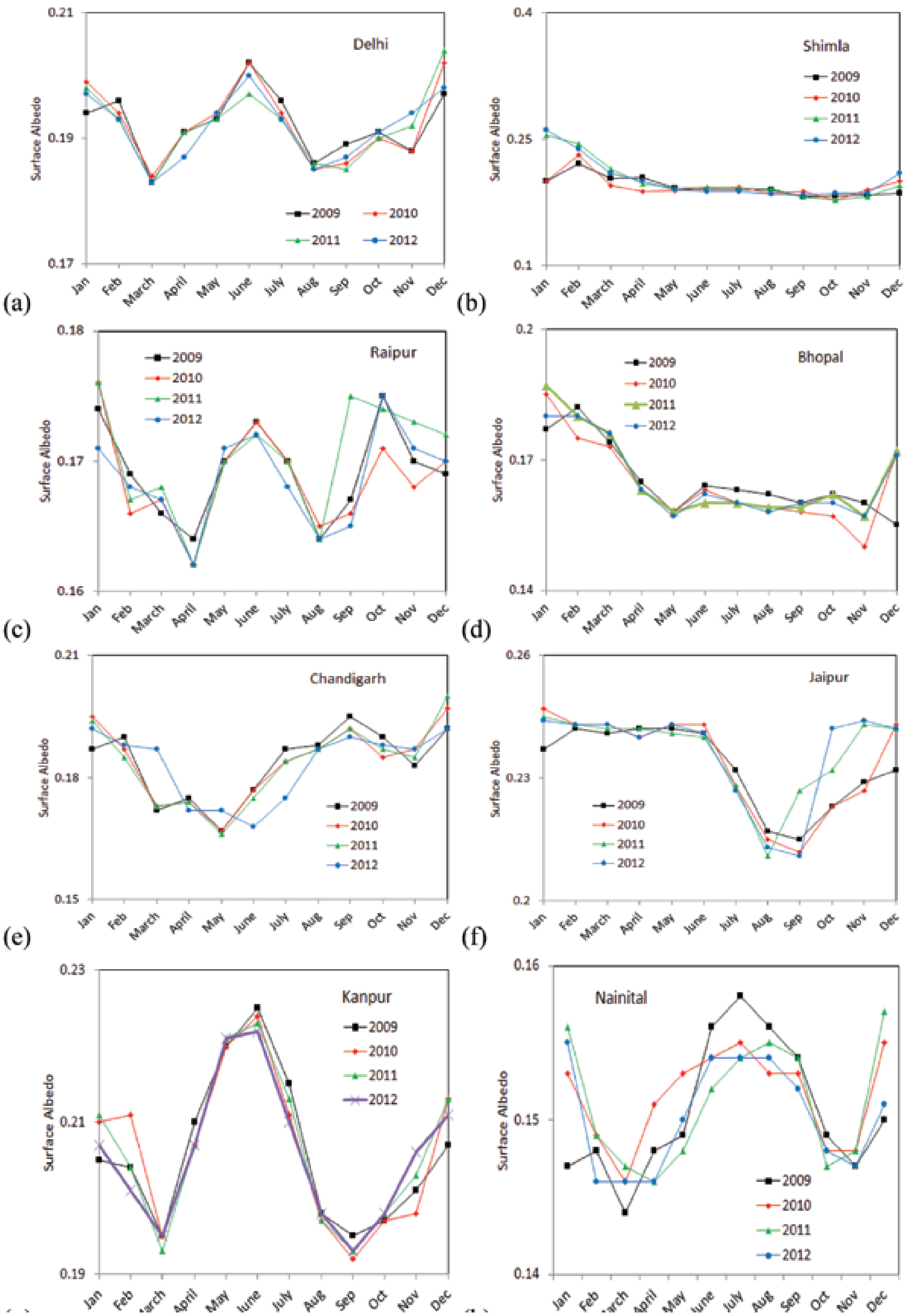

Figure 2(a-h). Monthly mean variation of atmospheric surface albedo over eight selected places of the central north region of India for the four year period of 2009-12.

are not far from the capital Delhi, yet their average albedo values differ from Delhi region by ~0.040 and ~0.042, respectively. These differences may be due to the effects of vegetation in Nainital and low altitude of Jaipur. The mean surface albedo of eight stations of central north region of India falls within the range of ~ 0.011-0.037, while three stations (Kanpur, Jaipur and Shimla) show values ~ 0.201-0.236, and the five stations (Delhi, Raipur, Bhopal, Chandigarh and Nainital) have values ranging from ~0.152 to 0.192. The overall averaged surface albedo (mean average for all stations) in central north regions of India was found to be ~0.152-0.236, which is comparable to the international albedo data values used in energy budget calculations (Bakirici, 2017).

The maximum values range from ~ 0.155 at Nainital to ~ 0.341 at Shimla, while the minimum values also range between Nainital (~ 0.144) and Jaipur (~ 0.211). However, the differences between maximum and minimum albedo values at individual sites were also found to be noteworthy. The lowest difference was 0.011 at the Nainital site, while the highest difference of 0.163 was recorded at Shimla. The average difference between the maximum and the minimum albedo values is ~0.285 for the rest of the stations. The existence of such differences between the highest and lowest albedo values at individual stations may be due to extreme changes in the weather conditions from one season to another. This includes behavior of climate change due to temperature variations and aerosol concentrations in the air (Siingh et al., 2013; Sun et al., 2015; Jahani et al., 2017). However, such broad ranges of values were also reported over Southern Great Plains previously (Yin et al., 2015). Figure (1-3) compares the annual results of different sites of central north region of India by taking years in three groups namely 2005-2008, 2009-2012, and 2013-2016. In the 2005-2008, the maximum and minimum albedo value was found over Shimla (~ 0.34) and Nainital (~ 0.144). These were attributed due to less vegetation effects over these two mountainous locations. The same trend was also found over Shimla (~0.261) and Nainital (~0.144) in 2009-12 and 2013-16 (Figures 4-6).

Seasonal variations of surface albedo

The mean monthly surface albedo values of all the central north stations in India were shown in Figure 4, whereas Figure 5 demonstrates the characteristic seasonal variations of albedo data values, with high values in winter DJF (December, January and February) and low data values in the monsoon months of JJAS (June, July, August and September). The surface albedo values decrease during March and reaches a minimum in July. In August, the albedo starts to increase again, until it reaches its highest value in February. Such a pattern was earlier investigated in the neighboring places of India (Srivastava et al., 2011; Souhail et al., 2015). However, a degree of deviation from this trend is evident at some stations (see Table 1). It was found that some stations show higher albedo values in the month of July than in May. In response to this observed trend, we divided the surface albedo data values into four seasonal groups: DJF (December, January, and February) winter, MAM (March, April, and May) summer, JJAS (June, July, August and September) Monsoon, ON (October and November) Post Monsoon. The average surface albedo values for winter, summer, monsoon and post monsoon were found to be ~ 0.30, 0.25, 0.31, and 0.36, respectively. These values are consistent with the findings of seasonal variations in albedo values in Saudi Arabia (Maghrabi and Al-Mostafa, 2009) as well as global averages (He et al., 2014). An increase of 0.11 in the albedo from summer to winter is noteworthy.

Altitude and latitudinal geographical variations

We, further investigated the impact of a location's altitude and latitude on the estimated albedo values over the central north region of India. For altitude, the surface albedo data values were divided into the following three groups: low altitude, 0–500 m; middle altitude, 500–1000 m; and upper mountain sites at altitudes greater than 1000 m. The mean monthly surface albedo values for these three groups are 0.198, 0.167, and 0.177 respectively. It shows that surface albedo increases as altitude decreases (Siingh et al., 2012). It is to be mentioned here that altitude of Bhopal is 523 m, which is very close low altitude whereas Shimla and Nainital are low pollution sites as compared to sites of altitude less than 500 m, which are more polluted (Singh et al., 2010; Sinnett and Feddersen, 2016). It is to be mentioned here that out of the five sites (Delhi, Raipur, Bhopal, Chandigarh and Nainital) with altitude < 500 m, Delhi is highly polluted. Interestingly, this is opposite to the study by Lee et al., (2011) carried out on three German sites having different altitudes.

However, this trend is not uniform for all of the sites in India (Pant et al., 2008; Pandithurai et al., 2008). The latitudinal variations of surface albedo in central region of India were studied by dividing the sites into three groups: low latitudes (LL), <25° N; middle latitudes (ML), 25–30° N; and high latitudes (HL), greater than 30° N. The average monthly albedo values for these three groups were 0.168, 0.222, and 0.183, respectively. In regard to latitude, the trend is not completely uniform, as some high latitude stations show lower values of albedo than do those at lower latitudes (e.g. Nainital with albedo ~ 0.152). One may note from Figures (3-5) a low surface albedo at Chandigarh during the months of March to June, which may be due to increasing high aerosol concentrations and changing climate pattern at location like Chandigarh which is highly polluted due to industrial growth and increasing vehicular

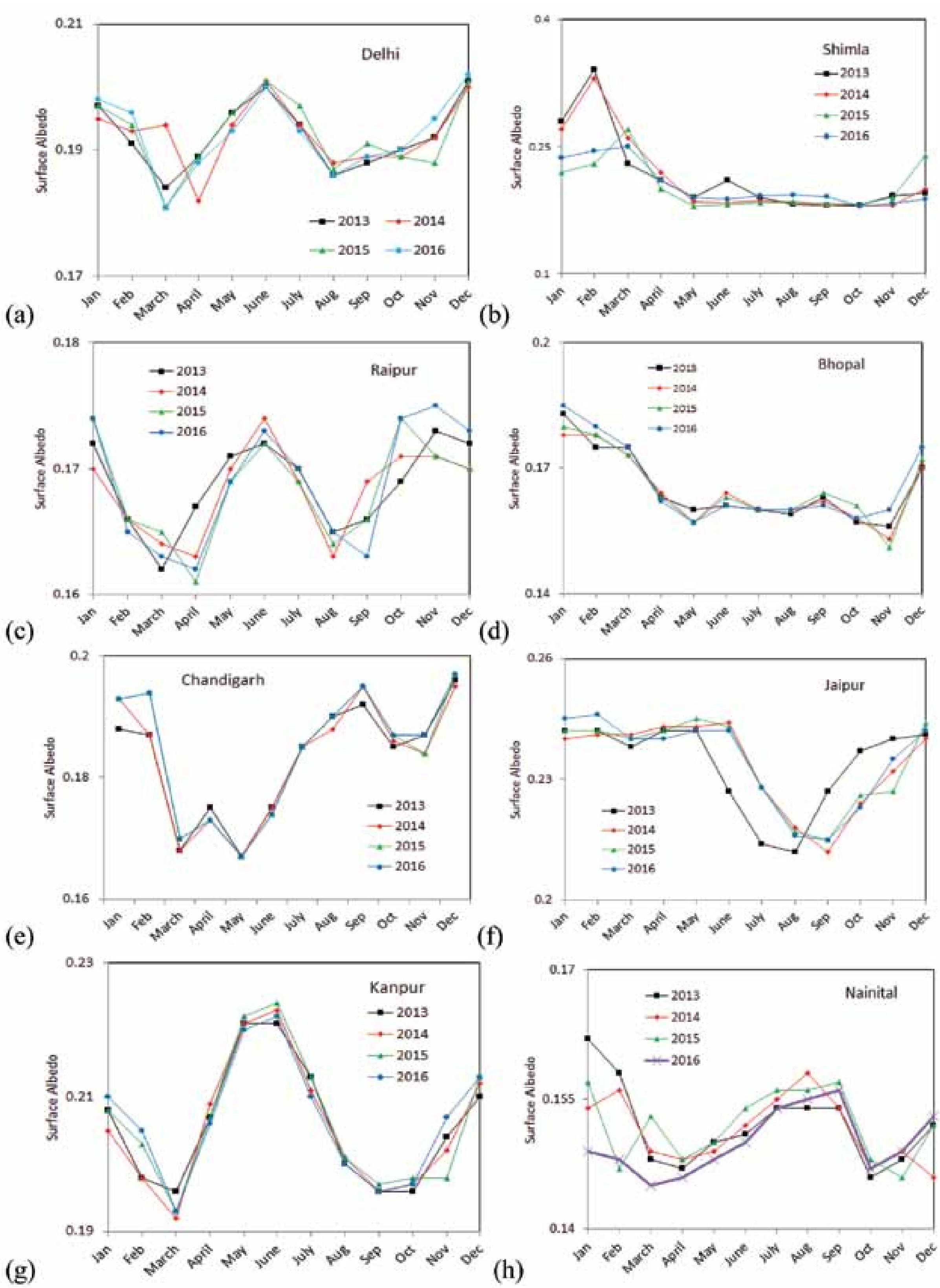

Figure 3(a-h). Monthly mean variation of atmospheric surface albedo over eight selected places of the central north region of India for the four year period 2013-16.

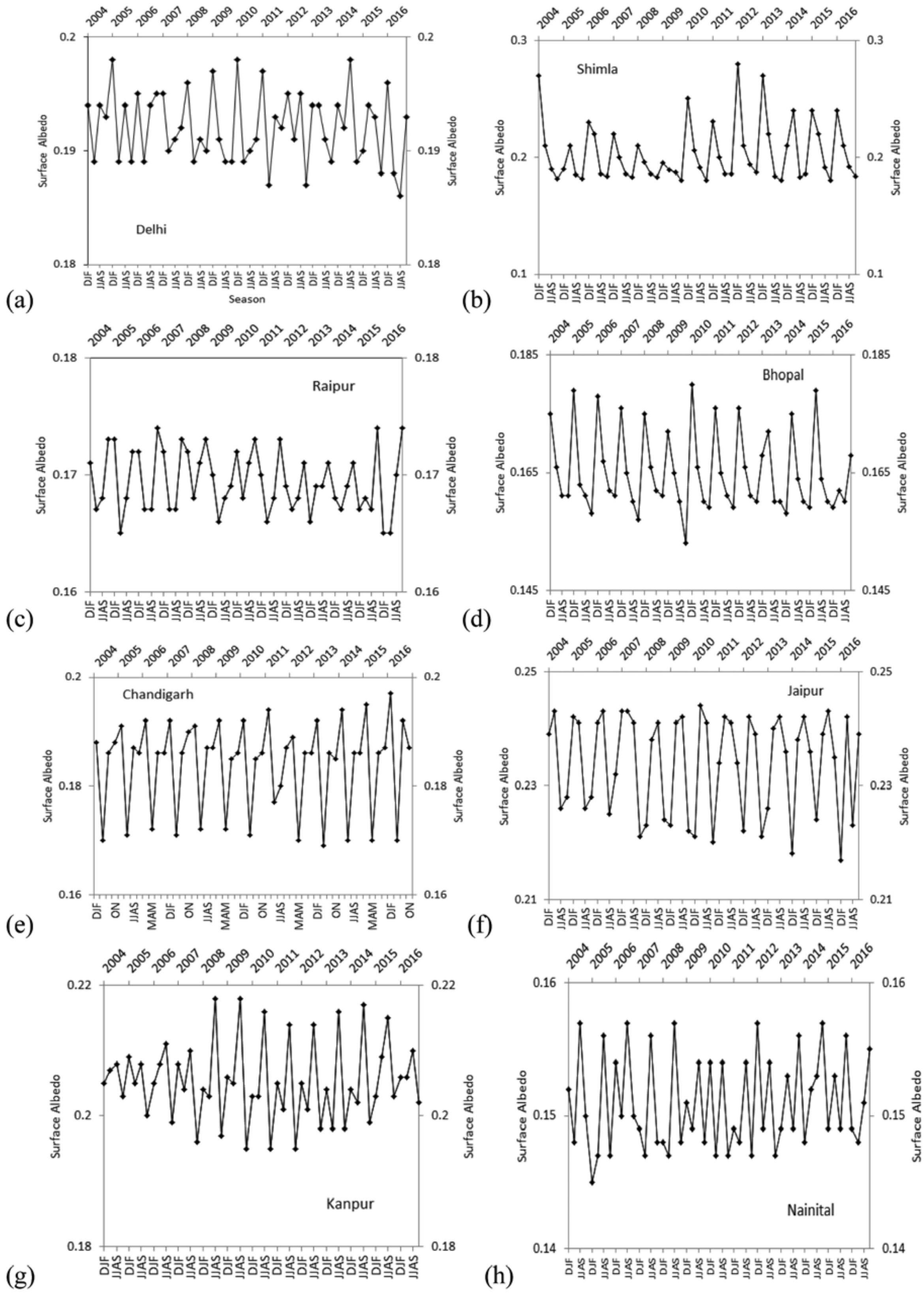

Figure 4(a-h). Seasonal and inter annual mean variation of atmospheric surface albedo over eight selected places of the central north region of India for the period 2004-2016.

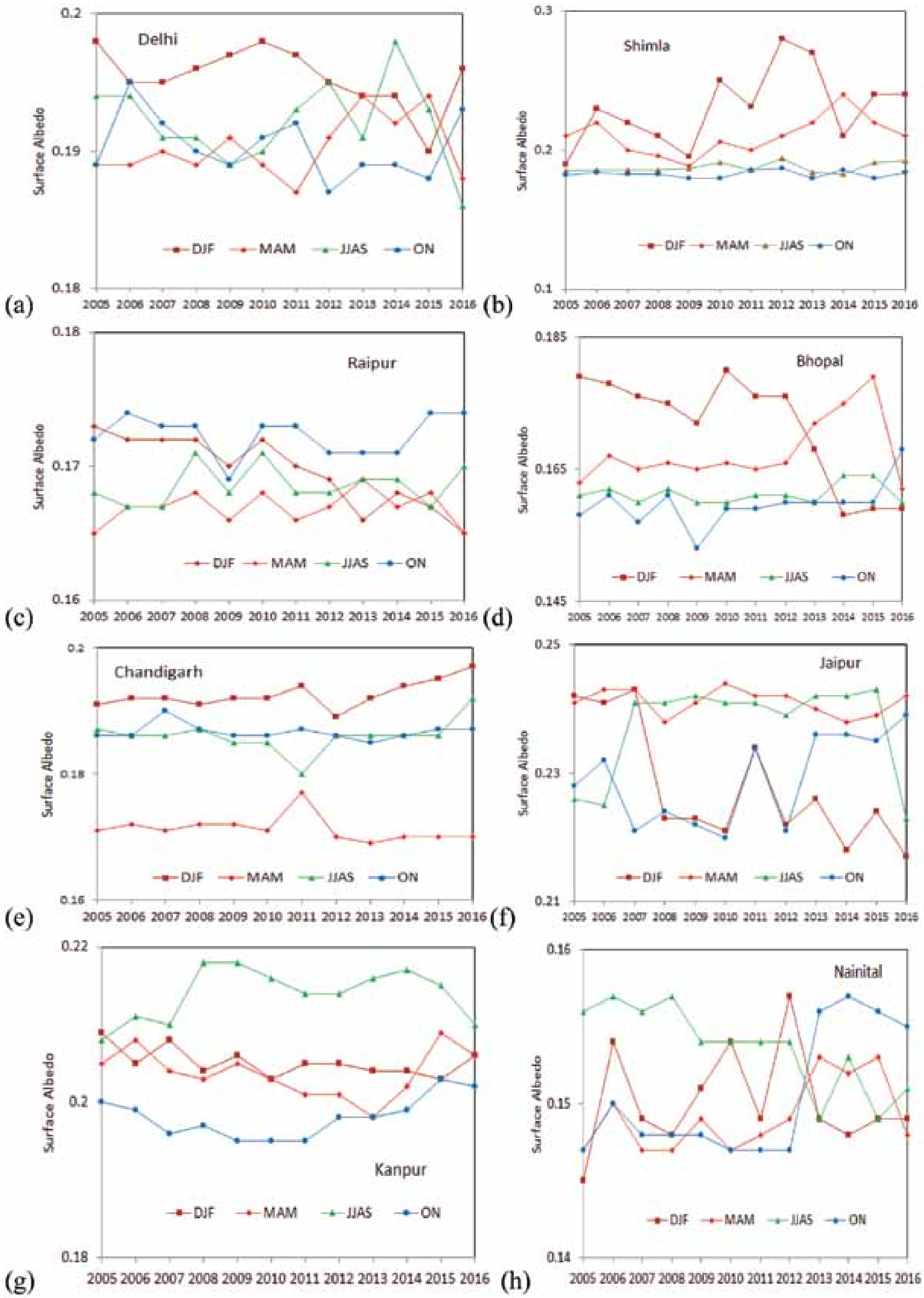

Figure 5(a-h). Mean annual variation of atmospheric surface albedo over eight selected places of the central north region of India for the period 2004-2016.

Table 3. Annual Maximum, Minimum and Mean surface albedo values of all the stations.

Station	2005-08			2009-12			2013-16		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Delhi	0.204	0.181	0.192	0.204	0.183	0.193	0.201	0.181	0.193
Shimla	0.34	0.18	0.197	0.261	0.178	0.195	0.34	0.18	0.261
Raipur	0.174	0.163	0.169	0.176	0.162	0.169	0.175	0.161	0.169
Bhopal	0.185	0.156	0.167	0.187	0.15	0.164	0.178	0.151	0.166
Chandigarh	0.2	0.165	0.184	0.197	0.166	0.184	0.197	0.167	0.185
Jaipur	0.25	0.212	0.234	0.247	0.211	0.236	0.246	0.212	0.234
Kanpur	0.224	0.193	0.206	0.225	0.192	0.207	0.224	0.192	0.207
Nainital	0.158	0.144	0.15	0.158	0.144	0.15	0.162	0.145	0.152

traffic (Rathore et al., 2017), whereas at Jaipur, the surface albedo value was not found to be too low during these months, but it was comparable with other places (Tables 1-3). Since increased pollution leads to increasing particulate concentrations that clouds may contain with increasing pollution and more drops per unit volume, hence it becomes optically thicker and more reflecting (Hoeve at al., 2012).

Furthermore, some stations located at the nearly same latitude (e.g. Kanpur and Jaipur) show different albedo values. This variation in surface albedo is probably due to the differences in ground cover and altitude because Kanpur has an altitude of ~ 127m, whereas Jaipur has an altitude of ~ 390m. Further, it is to be noted that when two locations of central north regions of India have different average solar altitudes, their surface albedo values were also found to differ. Additionally, the surface albedos of two locations that have the same latitude but different sunshine conditions may likewise differ (Joerg et al., 2015).

CONCLUSIONS

Utilizing solar radiation data, the clear-sky surface albedo values at eight sites in central north region of India, were calculated and their synoptic variations investigated over a long duration of thirteen years. The major findings of the present study are given here.

The mean annual surface albedo values were found to be in the range of 0.144 to 0.34.

The surface albedo values showed high variability between different sites and even at individual sites.

Mean surface albedo over the central north region of India was found to be ~0.196 for the thirteen years period of 2004-2016.

The lowest albedo values occurred in the March month of the summer (~0.147) at Nainital, and the highest value in the February month of the winter (~ 0.265) at Shimla. Further, the surface albedo values tend to increase at higher latitudes, and decrease at higher altitudes. Such findings would be of highly advantageous to future energy balance studies and solar energy based applications.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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