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Albedo variations in relation with solar altitude and transmission factor over Arabian Sea at different weather conditions

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Albedo variations with respect to different weather conditions with the observed shortwave radiation data over Arabian Sea using Pyranometer, during June to August 2002, and March -June 2003. The hourly albedo variations are analysed and presented in relation with solar altitude (SinH) and transmission factor (TF). TF classified into three groups: under clear sky (TF > 0.65), partly cloudy (0.4 < TF < 0.65) and overcast condition (TF < 0.4). As per classification, the mean albedo (TF) values are 0.07 (0.71), 0.06 (0.59) and 0.07 (0.30), respectively. The study period includes different weather conditions such as clear sky to overcast conditions and different wind conditions. During the lower wind speeds, albedo is varying between 0.01 and 0.17 and TF varied between 0.16 and 0.73. However, during higher winds (> 12 m/s), there is no significant changes observed in albedo. Variations in TF and albedo during the overcast conditions are significant, however wind also dominating.

[**Keywords**: Albedo, Cloud, Shortwave radiation, Sin H, Transmission factor, Wind]

Introduction

The energy exchange between atmosphere and ocean strongly regulates sea surface temperature variations and controls the rate of global climate change. Thus, the radiation measurements at the ocean surface and their variation are important to understand the ocean-atmosphere coupling influence on climate change. To understand the coupled ocean-atmosphere system it is essential to estimate the surface fluxes either by direct measurements or empirical formulae or by the assimilation of a variety of data into atmosphere and ocean models. Warming of ocean surface happens due to the net short-wave flux, longwave flux, latent and sensible heat fluxes, typically loss of heat is from the ocean to the atmosphere. The exchange of heat happens between the ocean and the atmosphere, also with in the upper and deep layers of the ocean, the transport of energy within the ocean controls the sea surface temperature variations. Direct measurements of radiation fluxes at sea are sparse. Radiations over the sea surface generally estimated from latitude and cloud data[1-5], from satellite data[6-9] and from the reanalyses[10,11] of the assimilating models of the major Weather Prediction Centers, like National Centers for Environmental Prediction/ National Center for Atmospheric Research (NCEP/NCAR) and European Centre for Medium Range Weather Forecasts (ECMWF). Comprehensive diagnostic comparison[11] of the surface fluxes derived from the reanalysis models with the Comprehensive Ocean Atmospheric Data Set (COADS)[12] indicates a systematic biases of more than 20 W/m² in absorbed shortwave radiation over the tropical oceans. Therefore, study on the surface radiative fluxes is very essential in understanding the processes between ocean and atmosphere. The radiation fluxes at the ocean-atmosphere interface are largely variable and are the two largest components in the surface fluxes. These studies coerce the importance of *in situ* measurements of the surface fluxes at the ocean surface, in particular to the Indian Ocean.

Surface albedo plays significant and important role in determining the absorption of solar energy at sea and may be expected to affect local climate through the modification of net radiation budget. Payne[13] has studied variations of sea surface albedo by using solar altitude and atmospheric transmittance using the measured shortwave fluxes. Payne's[13] empirical relationships have been widely used in ocean-atmosphere studies. Further, Payne's albedo results were confirmed by Katsaros *et al.*[14] using Global Atmospheric Research Program (GARP), Atlantic Tropical Experiment at 7° N and Joint Air-Sea

Interaction (JASIN) experiment at 60° N. Above mentioned both the experiments were done during the summer, which may not be including all the weather conditions. Present study includes the variation of albedo in different seasons and weather conditions over the Arabian Sea.

Data and method of analysis

Radiation measurements for such a long period over the sea were sparse. As a part of Indian Climate Research Programme (ICRP), Arabian Sea Monsoon Experiment (ARMEX), direct observations of radiative fluxes were obtained over the sea surface and the relationship of albedo with transmittance factor and solar altitude are studied. ARMEX had been conducted in the Arabian Sea during 2002 (June-August) and 2003 (March-June). The cruise details and tracks are given in Figure 1. During this field experiment, the incoming and reflected shortwave radiation over the sea surface measurements had been made by using Albedometer (Kipp and Zonen, Delft-The Netherlands) onboard ORV Sagar Kanya. Albedometer was mounted on a boom which, extend in front of the bow about 5 m horizontally[15,16]. Continuous data (5 minutes interval) of the two radiative fluxes namely, the shortwave incoming (SWin) and reflected or outgoing (SWout) had been measured over the Arabian Sea[17]. Using the continuous raw data, hourly values are computed and utilized for this analysis. Marine meteorological data such as wind, temperature, cloud etc. are also been observed along with the radiation measurements during the cruise periods.

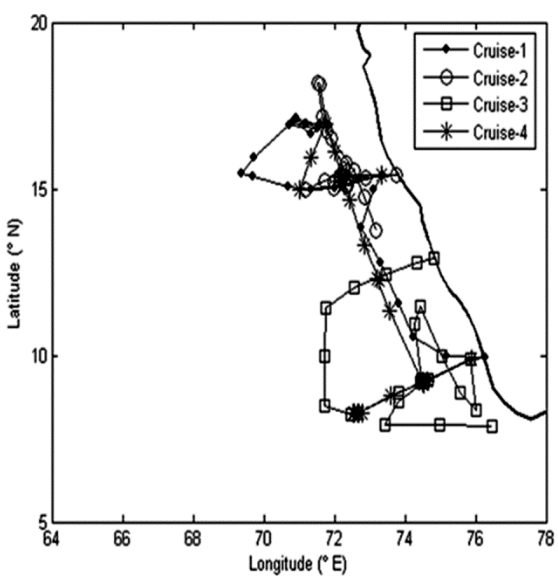

Fig. 1 — Area of study and data collected during the cruises with tracks

Calculation of Albedo and Transmission factor

Albedo was calculated from the measured shortwave radiative fluxes, and transmission factor was calculated using as following:

$$\text{Albedo}\left(\frac{\text{SWout}}{\text{SWin}}\right) \quad \ldots(1)$$

$$\text{Transmission factor (T.F.)}\left(\frac{\text{SWin}}{Q_T}\right) \quad \ldots(2)$$

Where SWin- incoming shortwave radiation measured at the sea surface

SWout- reflected shortwave radiation measured at the sea surface

and Q_T - shortwave radiation incoming at the top of atmosphere

Following Gopala Reddy[4], Dobson & Smith[5], the solar radiation at the top of the atmosphere was calculated as follows:

$$Q_T = (\bar{d}/d)^2 \times S_0 \times \sin H \quad \ldots(3)$$

Where $(d/d)^2$ - distance correction for revolution of the earth

S_0 - Solar constant (W/m²) and

Sin H - sine of the solar altitude, calculated with date, time and location

Results

Mean hourly variations, classification of albedo with Transmission factor (TF) and the variations in different weather conditions are presented in the following sections.

Mean hourly variations

The mean hourly variation during the study period of incoming shortwave radiations (SWin), outgoing shortwave radiation (SWout), albedo along with wind and cloud are presented in the Figure 2. Observations covered the pre-monsoon period and monsoon period covering different weather from cloudy to clear sky and calm to heavy wind condition. The SWin varied between 1.0 W/m² and 1059 W/m², the mean SWin of 391 W/m² during the study period. However, during the monsoon time (active period of the monsoon or heavy rainfall condition) lowest noon time SWin observed (190 W/m² in 2002 and 100 W/m² in 2003, at the time of monsoon onset). The SWout varied with a mean of 21 W/m². The albedo varied between

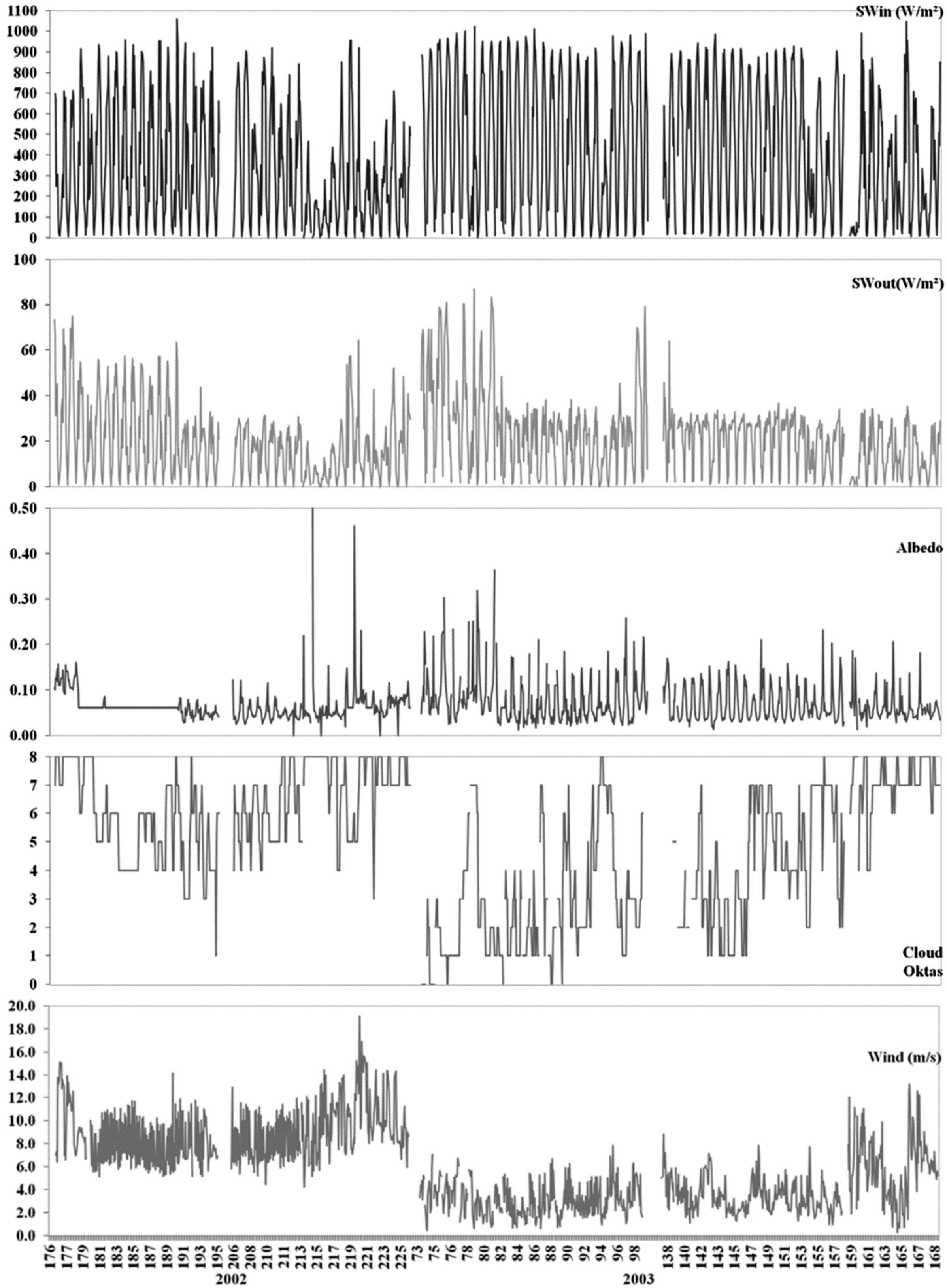

Fig. 2 — Hourly variation of shortwave radiation (incoming and outgoing), albedo, cloud and wind observed over Arabian Sea during the study period (inclusive of all the cruises data given as Julian days)

0.01 and 0.46 with a mean of 0.08 and cloud amount is ranging from clear sky to cloudy conditions. Wind speed varied between 0 m/s and 19 m/s. During noon when SinH is high, albedo value is at a minimum (0.04). When SinH is low during morning and evening, albedo value is at its maximum (0.10).

The estimated values of albedo categorised into 9 groups based on the corresponding values of Sin H are presented in Table 1. Higher albedo is found when solar altitudes low and vice versa. This inverse relationship can be seen between albedo and Sin H.

Relationship of Albedo with transmission factor:

Transmission factor calculated using Equation 2. Mean TF and standard deviation (SD) found to be 0.43 and 0.22 respectively during the study period. Following Payne[13] classification, with the state of the sky, three groups are classified based on mean and SD values of TF.

The groups are as follows:

1. Overcast (TF < mean-SD)
2. Partly cloudy (mean-SD < TF < mean+SD) and
3. Clear (TF > mean+SD)

The mean albedo in each of the three states of the sky calculated from study period data presented in Table 2. The mean albedo is 0.09 in overcast conditions with TF 0.13, when it is partly cloudy the mean albedo reduces to 0.07 with increase in TF to 0.40. In the clear sky condition, TF increases to 0.68 and albedo reduces to 0.05. This indicates when the mean albedo reduces with the increase in TF and vice versa. Payne's classification values are also given in the table in the study area and study period. The Payne’s classification in clear sky condition is almost similar to the present classification. However, other two classifications are indicating little different. In the overcast condition Payne's classification have TF and albedo are 0.06 and 0.12 respectively, which is higher than the present classification.

Table 1 — Variation of Albedo variations with Sin of the solar altitude (SinH)

	Sin of Solar altitude								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
No. of Obs.	137	70	114	51	136	57	144	131	399
SWin	14.3	75.9	127.7	193.8	287.1	351.6	471.0	514.3	667.0
SWout	1.5	7.1	13.1	15.1	20.2	23.5	25.6	26.7	30.3
Albedo	0.12	0.10	0.10	0.09	0.09	0.08	0.07	0.06	0.05

Table 2 — Variation of Albedo variations with Transmission Factor (T.F)

	(Mean + SD) classification (for Present Study)			
	Cloud type	No. of Points	Mean TF	Mean Albedo
TF < 0.4	Overcast	181	0.13	0.09
0.4 < TF < 0.65	Partly cloud	557	0.40	0.07
TF > 0.65	Clear sky	365	0.68	0.05
	Payne Classification			
TF < 0.1	Overcast	45	0.06	0.12
0.1 < TF < 0.65	Partly cloud	788	0.38	0.09
TF > 0.65	Clear sky	270	0.70	0.05

Variation of albedo during different weather conditions

Variation of albedo with wind variations

The variations of shortwave radiation (SWin and SWout) and albedo with solar altitude in different wind speed conditions from the observations are verified and presented. Variations due to higher wind prevails over the study period are illustrated in the Figures 3 and 4. Figure 3 indicates the variations during the selected day when the higher wind prevail (> 8 m/s) and check the variations on other parameters. SWin increases up to noon, then suddenly decrease when the wind speed decreases from 14.6 m/s to 10 m/s. The same feature can be observed in

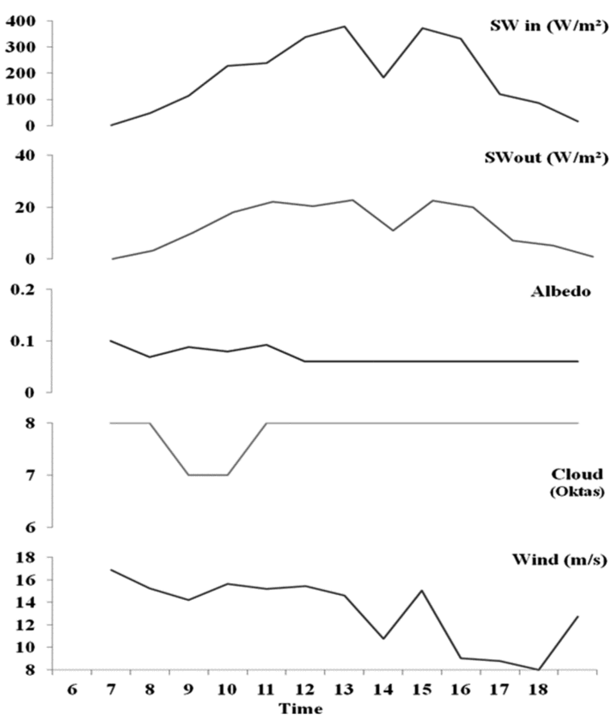

Fig. 3 — Variation of Shortwave radiation, albedo, cloud and wind during the specific day in the study period when higher wind prevails (> 8 m/s).

SWout. The TF has decreased to lower values (0.14) at 1300 hours, where the lower shortwave radiation observed and even there is an overcast condition. Figure 4 illustrates the variation of parameters with respect to SinH. When the SinH is 1.0 the maximum SWin can be observed. However, in this case due to overcast condition, the maximum SWin observed is 339 W/m² with wind speed 15.4 m/s.

Shortwave radiation (SWin and SWout) and Albedo with sin H with calm wind condition (wind speed < 2 m/s) is given in Figure 5. During the study period there is no day with less than 2 m/s wind speed throughout the day, compare the parameters variations with respect to Sin H. There is a gradual increase in SWin. Due to the variations in the wind speed, small waves will form at the sea surface leading to fluctuations in the SWout.

Variation of albedo with the cloud amount

Figures 6 and 7 indicate the variations of SWin, SWout and Albedo during a day and with respect to Sin H during almost cloud free condition and overcast conditions. During the clear sky or cloud free condition, the SWin attains to its maximum (970 W/m²), due to variations in the wind speed, there are

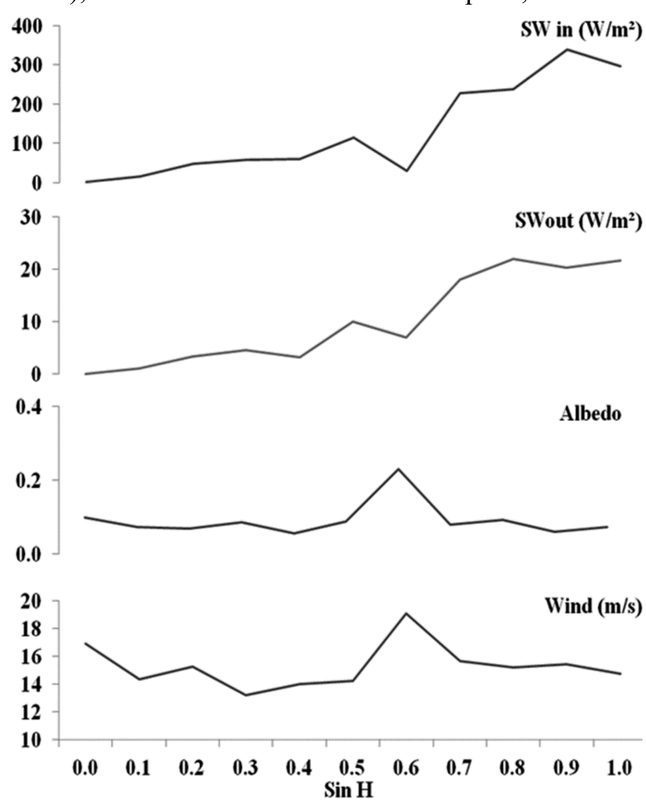

Fig. 4 — Variation of Shortwave radiation, albedo, cloud and wind during the specific day in the study period when higher wind prevails (> 8 m/s) with respect to Sin H

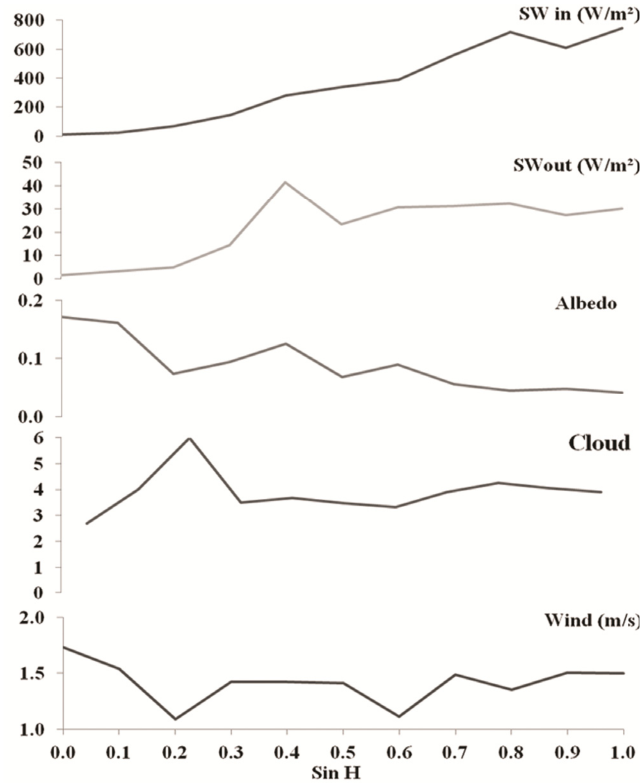

Fig. 5 — Variation of Shortwave radiation, albedo, cloud and wind during the specific day in the study period when calm condition (< 2 m/s) with respect to Sin H

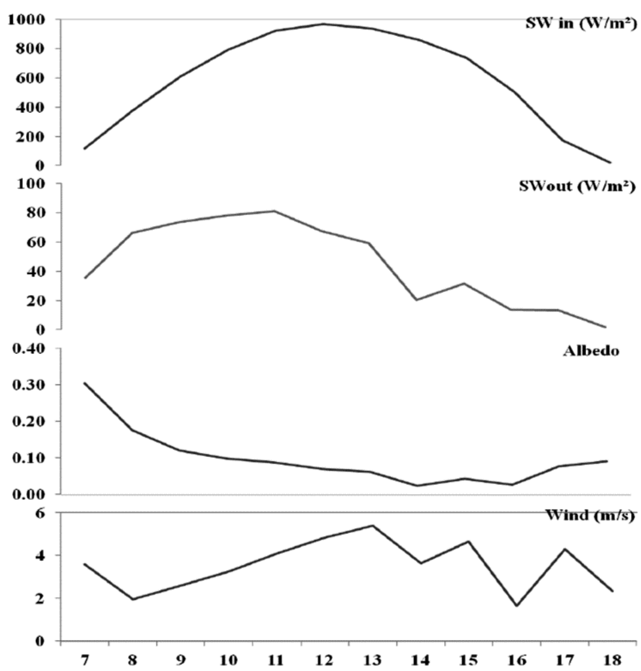

Fig. 6 — Variation of Shortwave radiation, albedo, cloud and wind during the specific day in the study period during Clear sky or cloud free condition

variations in SWout and albedo.

The albedo varied with respect to incoming radiation and it varied between 0.02 and 0.18. The Albedo of 0.02 was observed when the SinH was 0.89 with wind speed of 3.7 m/s and cloud amount was 1 Oktas and TF was 0.7. TF ranged from 0.12 to 0.72 during the cloud free condition. The same features can be observed with SinH (Figure 7).

Variations of parameters during the overcast conditions are given in the Figures 8 and 9. When there is an overcast condition, the SWin reduced to its maximum of 300 W/m², which can be observed in the Figure 8. SWout is following SWin; however, albedo variations are different due to variations in the wind. When there is a lower SWin observed during the afternoon, the TF is 0.22. Variations with respect to SinH are given in Figure 9. Maximum SWin of 340 W/m² can be observed when SinH is 0.8 and TF of 0.32. Albedo varying between 0.05 and 0.12 with wind speed varying between 8.2 m/s and 10.5 m/s.

Higher albedo during noontime

Higher albedo values occur when a cloud passes over the measuring area. Dense low level cloud block the direct incoming solar radiation, during which the Pyranometer measuring the upward flux still sees a strong sun glint from the water surface. This relation is demonstrated in Figure 10, where, albedo of 0.25 is obtained under such cloud conditions. Figure 10 demonstrates the variation of shortwave radiation and albedo with respect to TF. During the noon time the TF is changing between 0.03 and 0.21. However, the SWin reduced to 36 W/m² and albedo attained its maximum of 0.25. The high albedo value was obtained during 1150 hrs (IST). During that time the solar altitude was 0.95, TF was 0.03, the SWin reduced to 36 W/m², wind speed was 6.2 m/s and cloud amount was 6 Oktas. Higher albedo may be the combined effect of the conditions stated above and wind Speed. Such high albedo values of instantaneous observations were presented in Table 3.

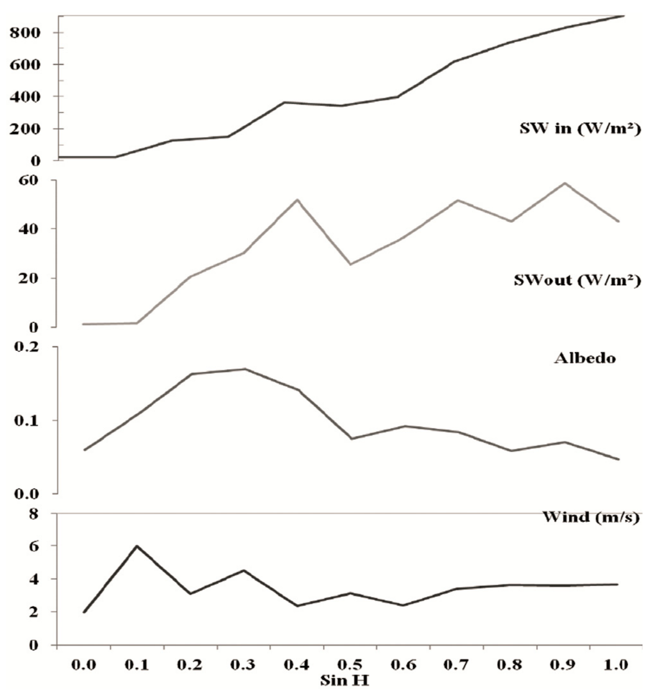

Fig. 7 — Variation of Shortwave radiation, albedo, cloud and wind during the specific day in the study period during clear sky or cloud free condition

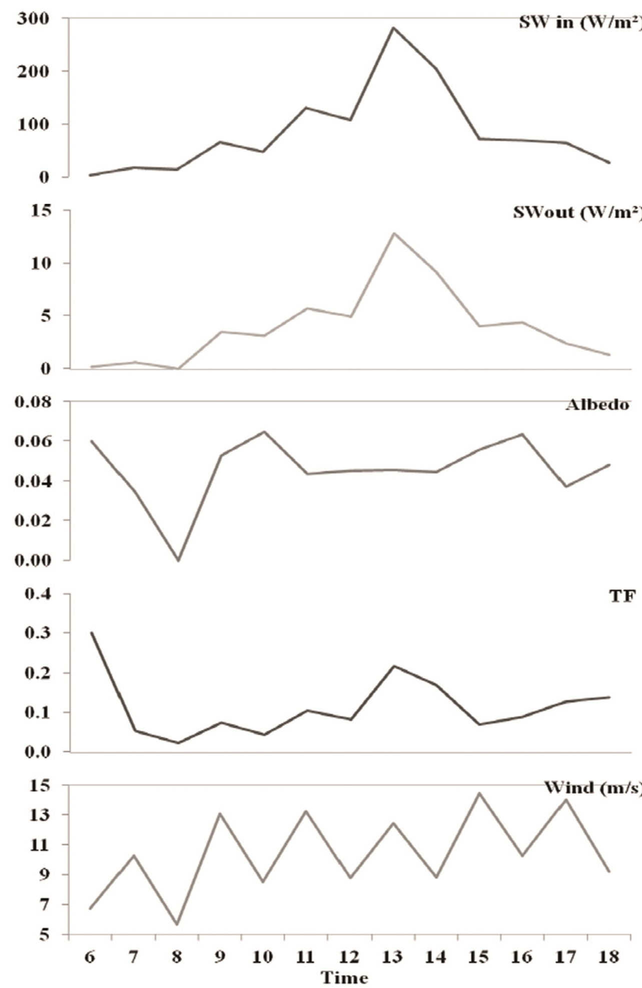

Fig. 8 — Variation of Shortwave radiation, albedo, cloud and wind during the specific day in the study period during overcast condition

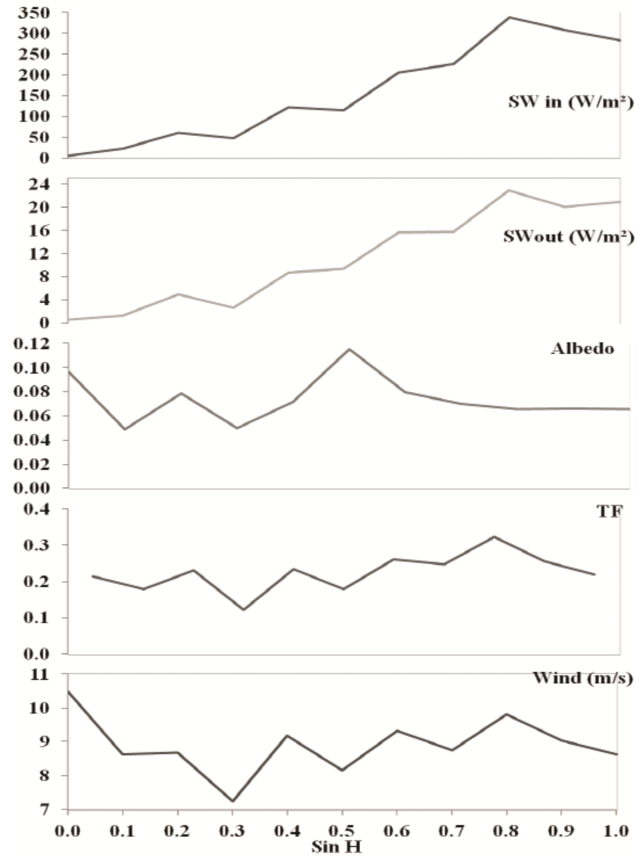

Fig. 9 — Variation of Shortwave radiation, albedo, cloud and wind during the specific day in the study period during overcast condition

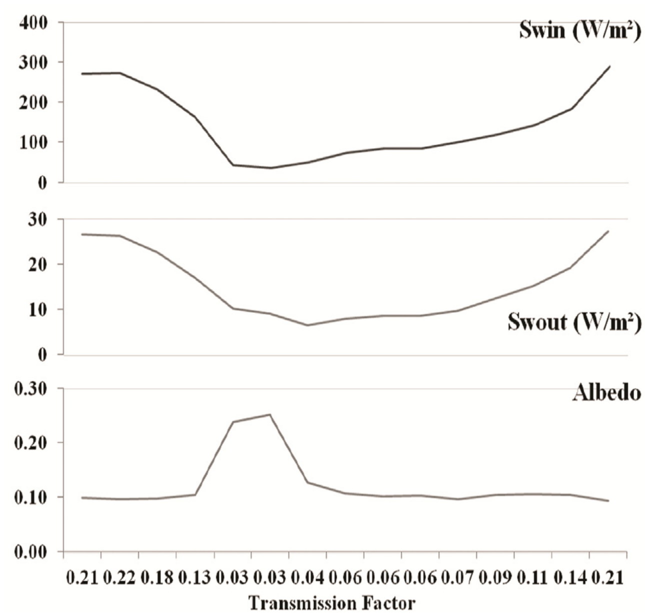

Fig. 10 — variation of SWin, SWout, Albedo with transmission factor when high albedo prevails during the noon time

Table 3 — Summary of sea surface albedo high during noontime

Date	Time	SWin	Albedo	Sin H	TF	Wind Speed	Cloud
20.03.	1105	270.6	0.10	0.92	0.21	6	
2003	1110	273.6	0.10	0.92	0.22	6	
	1115	230.8	0.10	0.93	0.18	5.3	
	1120	163	0.10	0.94	0.13	5	6
	1125	42.9	0.24	0.94	0.03	4.8	
	1130	35.9	0.25	0.95	0.03	5	
	1135	50.6	0.13	0.96	0.04	7	
	1140	73.7	0.11	0.96	0.06	2.6	
	1145	84.9	0.10	0.97	0.06	1.6	
	1150	83.6	0.10	0.97	0.06	2.2	
	1155	100.2	0.10	0.97	0.07	3	
	1200	119.2	0.10	0.98	0.09	5	

Discussion

In this article, we analysed the variations of albedo, by using the shortwave radiation measurements made by the instruments over the Arabian Sea. Albedo over the sea determines the energy balance. The albedo at the sea surface is a function of SinH and TF[13,18]. Albedo is showing a clear inverse relationship with SinH. Previous studies mentioned by Simpson and Paulson[19] that with an increase in TF, albedo also increase, the same feature was observed from this study. The clear sky ocean albedo varies greatly with SinH, but this variation depends on cloud[20]. The new classification which follows the Payne's classification indicated lower values of albedo than that of Payne's classification during overcast and partly cloudy condition. However, during clear sky or cloud free condition, present classification is satisfying the Payne's classification.

Theoretical relationships between wind speed and albedo at clear skies were presented by Payne[13]. Saunders[21] theory reveals the expected changes in albedo with water roughness for clear sky conditions and solar altitudes greater than 30°. Observational data indicates an increasing trend of albedo when transmittance decreasing. The observed data indicates that the albedo increased slightly from 0.05 to 0.17 and transmittance decreased from 0.68 to 0.20. The effect of wind speed on albedo is found to be with clear sky and SinH. At higher SinH, albedo is not affected by wind speed (sea state) up to 12 m/s[14]. The present study also indicated the same i.e. during the higher wind speeds and higher SinH, albedo variations are not prominent. During higher wind speeds, white capping, foam, bubbles, and spray must be considered for calculating Albedo. The effects of

SWout and sea roughness on albedo are of small quantity, since both reduce albedo at lower SinH. Since albedo measurements are difficult to observe over the sea, the attributed errors due to the different observing platforms[14]. Ship data experience height changes from sea conditions, only views the sunlit or shadowed portion of the swell. The effect of pitching is not linear, making measurements at low solar altitudes difficult. The dependence of albedo on sea state has not been determined for higher wind speeds when waves breaking. Foam, and bubbles as well as airborne spray may have significant effects.

For clear sky case, the albedo depends only on Sin H. Albedo hourly values were obtained from Payne[13] and by Simpson and Paulson[22] indicating that diurnal variations in the albedo at the sea surface contribute little to the thermal boundary condition because the albedo is higher for low SinH when the SWin is near to zero. In the noon time, the albedo approaches an asymptotic value of 0.05. The impact of clouds on albedo is complex, since the sea surface fluxes get affected not only by the fraction of total cloud but also the vertical distribution of cloud and their dependence on cloud bulk and microphysical parameters[23]. Solar transmission parameterization is also directly affecting the albedo, which varies with fraction of cloud cover and sun angle[14]. Loeb *et al.*[24] also suggests that albedo variations in the tropics are highly correlated with cloud cover. Because clouds are generated by dynamic processes and the albedo of the earth or energy input to the earth largely depends on the cloud cover, this implies that the interannual variability of cloud cover is small. Albedo variability does not drive temperature anomalies in the atmosphere directly and decay in the atmosphere exponentially with time[24]. The surface radiation budget recognized as fundamental factor to understand the climate system and the albedo is an important issue for obtaining the accurate surface radiation budget[25]. So, further observational studies of radiation and albedo are required to understand the climate changes over sea surface and also in ocean-atmosphere exchanges.

Conclusions

Albedo is having a clear inverse relation with SinH. During the study period, the mean and standard deviation of TF are found 0.43 and 0.22 respectively. The present classification is following the Pyne's classification. However, in the overcast and partly cloudy conditions the present classification indicates lower albedo. During lower winds, albedo is varying between 0.01 and 0.17 and TF varied between 0.16 and 0.73. In the overcast condition, albedo varied between 0.05 and 0.18 and TF varied between 0.04 and 0.30. Albedo measurements over the regional seas and Oceans are necessary for the better understanding air-sea interaction.

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Conflict of Interest

The author declare that there is no conflict of interest.

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