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Research Article

Statistical Analysis and Inter-Comparison of Albedo for Athalassa and Larnaca, Cyprus

Pashiardis S[1], Kalogirou SA[1]* and Pelengaris A[2]

[1]Department of Mechanical Engineering and Materials Science and Engineering, Cyprus University of Technology, Cyprus

[2]Department of Cyprus Public Works, Ministry of Transport Communications and Works, Cyprus

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***Corresponding author**

Kalogirou SA, Department of Mechanical Engineering and Materials Science and Engineering, Cyprus University of Technology, Limassol, Cyprus, Tel: +357-2500-2621; Fax: +357-2500-2637; Email: soteris.kalogirou@cut.ac.cy

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Abstract

A statistical analysis and inter-comparison of the reflected radiation at two sites in Cyprus representing two different climate regimes of the island (Athalassa-inland plain *vs* Larnaca-coastal location) covering the period January 2013-December 2015 is presented. Mean annual and mean monthly daily totals of the reflected radiation and ground albedo as well as their frequency distribution are computed and discussed. The monthly means of reflected irradiance range from 50 to 120 W m^{-2} at Athalassa, while at Larnaca they range between 50 and 140 W m^{-2}. The mean annual albedo for Athalassa is 0.202 which coincides with the most common value given in the literature, while for Larnaca it is higher (0.221). The higher value at Larnaca is attributed to its alluvial (silty sandy) soil which has higher reflectivity compared to the calcarenite (calcium carbonate) soil at Athalassa. The lowest values of albedo at Athalassa, are observed around noon and the higher values in the morning and afternoon. The highest values are obtained in January and February and the lowest in May and June when global solar irradiance have its higher values. On the other hand, we observe an increasing trend from the morning towards the afternoon hours at Larnaca throughout the year. The maximum of daily reflected irradiation is about 6.5 MJ m^{-2} at Athalassa and about 7.5 MJ m^{-2} at Larnaca. The monthly mean daily values of albedo at Athalassa range between 0.175 to 0.224, while at Larnaca they are higher ranging from 0.198 to 0.239. As a result of the differences of the global and reflected radiation of the two sites, the net shortwave irradiation at Larnaca is slightly higher than that at Athalassa, almost throughout the year.

Introduction

The ground albedo or ground reflectance is defined as the ratio of the reflected from ground radiation component to the incoming shortwave radiation in the wavelength range 0.3-3.0 μm. This parameter is an important one for the determination of radiation balances. The accurate knowledge of the radiation components incident on tilted surfaces (i.e., direct beam, diffuse and ground reflected) is essential in solar thermal systems, solar photovoltaics, daylighting applications (e.g., architecture and building design) or agronomic and biological processes (e.g. evaporation and photosynthesis) [1]. Therefore, the reflected radiation component from the surrounding area should be taken into consideration and it can be input to various models, either as immediate ground albedo measurements or as an estimate. In the latter case, the estimates can come from relationships obtained from the literature or from remote sensing processes [2-6]. Errors in the albedo directly lead to uncertainties in the computed net radiation and the simulated surface temperature [7].

The term reflectivity of a surface ρ (λ) refers to the fraction of incident solar radiation reflected at a specific wavelength λ and the term reflection coefficient refers to the average reflectivity over a specific waveband, weighted by the distribution of radiation in the solar spectrum. The reflection coefficient of a natural surface is often called 'albedo'. In general, the albedo of the soils depends on their organic matter content, on the water content, particle size and the angle of incidence radiation [2]. The higher the organic matter in the soil, the lower is the albedo. Albedo decreases as the soil gets wetter, mainly because radiation is trapped by internal reflection at air-water interfaces formed by the menisci of soil pores. The reflectivity of the soil is also increased with decreasing particle diameter. On integration over the whole solar radiation spectrum, albedo ranges from about 10% for soils with high organic matter content to about 30% for desert sand [2,8,1]. Tabulated albedo data for several European locations are included in the European Solar radiation Atlas [9]. In the absence of local data, a typical average value of a bare ground, free of snow is 0.2 [10]. The ground reflected radiation may become a significant parameter as it can reach values of the order of 200-250 W m^{-2}.

It is known that the ground reflectance diurnal distribution is asymmetrical around noon and it increases at high zenith angles [11]. It has been also found that morning albedo values are lower than afternoon ones [12]. The asymmetry between the morning and afternoon values of albedo could be explained from the integration over all the frequencies spectrum of the sunlight, which

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is influenced by the increase in airborne particles, gaseous matter, cloudiness and water vapour in the afternoon period. The effect of other meteorological variables, such as wind and dew, has also been reported to cause the diurnal asymmetry of albedo [13].

An assessment of the solar radiation climate of the Cyprus environment was presented by Jacovides et al. [14], Petrakis et al. [15] presented the 'Typical Meteorological Year' for Nicosia whereas Kalogirou [16] presented the TMY-2 for the same location. More recently, Kalogirou et al. [17] presented a statistical analysis and inter-comparison of the solar global radiation at the above two sites in Cyprus using measurements of 21 months at both sites. Furthermore, the current work is a continuation of a number of studies on different radiation components on the frame of activities of a project on the use on solar radiation [18]. The project refers to the following solar radiation components: UV total UVB and UVA, Direct beam and diffuse radiation, Photosynthetic Active Radiation (PAR) and downward and upward longwave radiation, based on radiation data covering the period 2013-2015. The common feature of all the above studies is that they rely mostly on measurements of solar radiation carried out in the actinometric stations of Athalassa and Larnaca.

The purpose of the present study is to provide comprehensive information on reflected solar radiation for two locations in Cyprus representing two different climate regimes of the island (Athalassa-inland *vs* Larnaca-coastal). The monthly averages of daily totals of reflected radiation on horizontal surfaces were analysed and daily and seasonal variations of albedo were discussed. The relationship of reflected radiation and a number of solar radiation variables were investigated and its frequency distribution was calculated. This is essential because of the fact that the atmospheric conditions in the area favor dry summers and cold winters, high air temperatures and low vapour pressure values at midday in summer time which affect the transition of radiation through the atmosphere.

The interest of the paper is that similar data series have not been recorded before and no similar analysis has been done in Cyprus. Additionally, it is the first time that reflected radiation data were undergone quality control processes. Furthermore, the study can be used as a reference for the estimation of albedo of an area, based either on its relationship with various radiation components or through satellite images.

Topography, Climatology, Measurements and Quality Control

Topography and climate characteristics of the two sites

The radiation data on which this study is based are being monitored at two meteorological stations: one located at Athalassa, an inland plain location and the other one at Larnaca Airport which is near the coast (Figure 1). The site parameters of the two stations are listed in Table1.

The climate of both stations is typical Mediterranean with mild winters (mean seasonal air temperature of about 12 °C at Larnaca and 10.5 °C at Athalassa) and warm summers (mean seasonal air temperature of 27.5 °C at Larnaca and 29.5 °C at Athalassa). At Larnaca Airport sea-breeze cells develop in late spring and summer. Although Athalassa is an inland location, a westerly sea-breeze is mainly noticeable during the summer time blowing from the Morphou bay between the mountainous ranges of Pentadactylos and Troodos (Figure 1). The annual rainfall is about 320 mm at Athalassa and about 340 mm at Larnaca. Most of the rainfall occurs between October and March; summer months are mostly dry. The two sites are characterised by relatively high global and horizontal beam radiation intensities. The average annual sunshine duration is 3332 hours for Athalassa and slightly higher at Larnaca (3368 h). All the above climatic averages refer to the 1981-2010 period.

Table 1: Site parameters for the two meteorological stations.

Site	Location	Latitude	Longitude	Altitude (m,m.s.l)
Athalassa	inland	35.141^0 N	33.396^0 E	165
Larnaca	coastal	34.873^0 N	33.631^0 E	1

The annual average daily global radiations exceed 18.5 MJ m^{-2} at the two sites, whereas the horizontal beam radiation is 13.1 MJ m^{-2} for Athalassa and 14.2 MJ m^{-2} for Larnaca, respectively. Consequently, the fraction of the beam component of the global radiation is relatively high at both sites, viz., the annual average daily fraction is >0.600 at the two sites. Comparing the two sites it seems that Larnaca has slightly higher rates of global radiation than Athalassa, since the average yearly cumulative global irradiation is 6835 MJ m^{-2} for Athalassa and 7183 MJ m^{-2} for Larnaca. The monthly average frequency of days according to the classification of the magnitude of the daily clearness index K_T (daily global to daily extraterrestrial radiation), showed that both clear and partially cloudy days exceed 90% annually (K_T>0.35) [18-23].

Regarding the type of the soil, at Athalassa is calcarenite (calcium carbonate) and at Larnaca is alluvial (silty sandy).

Measurements and Quality Control Processes

The period for presenting the data in both stations is January 2013 until December 2015 (i.e., 3 years), when both stations operated simultaneously, so as to allow for comparison of the different variables of solar and terrestrial radiation. Measurements of total solar irradiance on a horizontal surface were taken with Kipp&Zonen CM11 pyranometers whose spectral range is from 285 to 2800 nm. Both stations are also equipped with Kipp&Zonen CM11 broadband albedo meters to measure the reflected radiation. The albedo meters consist of two pyranometers located on horizontal surface: one facing

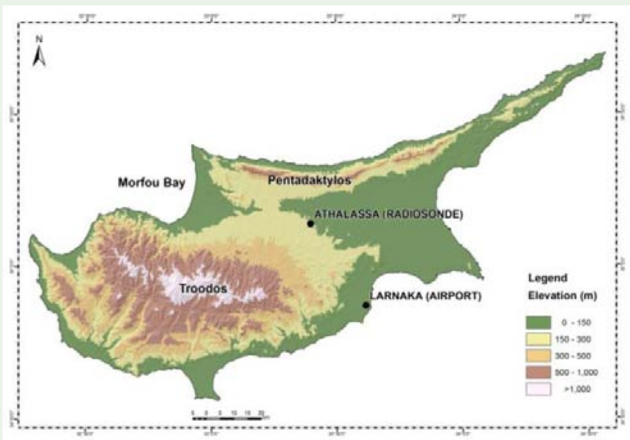

Figure 1: Map of Cyprus showing the location of the two radiometric stations.

the sky and the other facing the ground at the height of 2 m above the ground. All the sensors are factory calibrated, in accordance with the World Radiometric Reference (WRR). Global radiation instruments are calibrated outdoor against standard references at irregular time intervals during the study period. The errors involved in the radiation measurements are found to be no less than ±2% for the normal incidence beam irradiance and ±3% for the global irradiance.

A Campbell Scientific Instruments data-logger, located at each site (Model CR10), monitors and stores the data at 10-min intervals (the meters are scanned every 10-seconds and average, maximum, minimum and instantaneous values at 10-min intervals are calculated and stored). The stored data are downloaded to a desktop computer periodically. The data refer to the Local standard Time (LST=GMT+2). About 5% of the data values are missing because of some problems with the instruments and some defects and maintenance in the data acquisition systems. The validity of the individual measurements was checked in accordance with WMO recommendations [25] and other tests proposed by various authors [23,24,1]. Details about the quality control procedures used in this study for the global irradiance are given by Pashiardis and Kalogirou [25]. All data that do not meet the conditions specified by the suggested tests are not used in the study.

The Baseline Surface Radiation Network (BSRN) has established globally physical possible, extremely rare and climatological limits for the hourly reflected solar irradiance measurements [24]. They have proposed the following physical limits for the shortwave upwards irradiance:

Min: -4 W m^{-2} and Max: $I_{SC} * \varepsilon * 1.2 * (\cos(\theta_z))^{1.2} + 50$ W m^{-2} (1)

where, I_{SC} is the solar constant (1367 W m^{-2}), θ_z is the solar zenith angle, ε is the eccentricity correction given by:

$$\varepsilon = 1 + 0.03344 * \cos(j' - 0.048869) \quad (2)$$

where, j' is the day angle which is a function of the Julian day number of the year, *j*:

$$j' = 2\pi j / 365.25 \quad (3)$$

The solar zenith angle is a function of the latitude (φ), the solar declination angle (δ) and the hour angle (ω):

$$\theta_z = \cos^{-1}(\cos\delta * \cos\varphi * \cos\omega + \sin\delta * \sin\varphi) \quad (4)$$

The solar declination angle is given by:

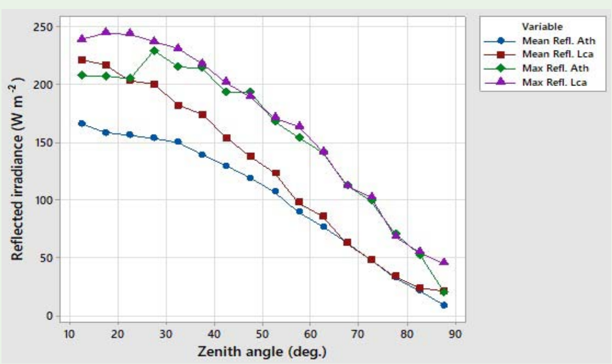

Figure 2: Hourly mean and maximum values of reflected irradiance *vs* Solar Zenith angle at both stations.

$$\delta = 23.45 * \sin(360 \frac{(284 + j)}{365}) \quad (5)$$

The second test refers to the extremely rare limits where the minimum values are higher than -2 W m^{-2} and the maximum limits are given by the following equation:

Min: -2 W m^{-2} and Max: $I_{SC} * \varepsilon * (\cos(\theta_z))^{1.2} + 50$ W m^{-2} (6)

The third test includes climatological limits based on statistics obtained from a number of sites in United States:

Max: $I_{SC} * \varepsilon * 0.95 * (\cos(\theta_z))^{1.2} + 55$ W m^{-2} (2^{nd} level) (7)

Max: $I_{SC} * \varepsilon * 0.87 * (\cos(\theta_z))^{1.2} + 50$ W m^{-2} (1^{st} level) (8)

The limits labelled as '1^{st} level' are the 'smallest' testing limits, while those labelled as '2^{nd} level' are the second lower limits.

Figure 2 shows the plot of reflected irradiance (mean and the maximum hourly values) with respect to different ranges of the zenith angle for both stations. The coincidence of maximum values of both stations for a given mean value of zenith angle is evident from the graph, indicating the upper limits of the reflected irradiance. The following quadratic equations can describe the maximum values of the hourly reflected irradiances (MaxR) for the two sites:

$$MaxR_{Ath} = 188.2 + 2.260 * \theta_z - 0.0482 * \theta_z^2 \quad R^2 = 0.989 \quad (9)$$

$$MaxR_{Lca} = 252.1 + 0.108 * \theta_z - 0.0301 * \theta_z^2 \quad R^2 = 0.990 \quad (10)$$

The respective equations for the mean values of the hourly reflected irradiances (Mean R) for the two sites have the following form:

$$MeanR_{Ath} = 174.4 - 0.329 * \theta_z - 0.0188 * \theta_z^2 \quad R^2 = 0.995 \quad (11)$$

$$MeanR_{Lca} = 261.3 - 2.353 * \theta_z - 0.0065 * \theta_z^2 \quad R^2 = 0.989 \quad (12)$$

The coefficients of determination (R^2) for both cases are very high. Implementing the above testing limits, it was found that the hourly reflected irradiances are within the above limits for both stations (Figure 3).

Figure 3 shows the hourly values of reflected irradiance (blue) and the testing criteria for maximum Physically Possible Limits (PPL) (red), Extremely Rare Limits (ERL) (green), Climatological Limits (cl) of the 1^{st} level (purple) and 2^{nd} level (black) and the Maximum Reflected irradiance estimated by the quadratic equations (9 and 10, respectively) (brown) at a) Athalassa and b) Larnaca.

The time series plots of the hourly values of reflected solar irradiance during the period 2013-2015 for both stations are shown in Figure 4. The figure indicates that the hourly values at Larnaca ranged between 0 and about 240 W m^{-2}, while at Athalassa they ranged mainly between 0 and about 200 W m^{-2}. The highest hourly values are recorded during the summer period and the lowest in the winter.

Results and Discussion

Monthly statistics of reflected irradiance and albedo

Figure 5 shows the boxplots of the reflected irradiance for each month of the year for both stations. The boxplots show the 1^{st} and the 3^{rd} quartiles, the median and the extreme values of the hourly reflected irradiance. A line curve connects the mean values of each month. The graphs show that the variability of the reflected irradiance at Larnaca is higher than that at Athalassa. The monthly mean values of Larnaca are higher than the respective values at Athalassa. The monthly means are increased from winter to summer, with the highest recorded in July at both stations. The monthly means range from 50 to 120 W m^{-2} at Athalassa, while at Larnaca they range between 50 and 140 W m^{-2}. The median values are generally higher than the means during the summer months.

The picture of ground albedo (ρ) is different from the reflected irradiance. All the months show outliers, particularly above the upper whisker portion (Figure 6). The monthly mean values of ρ at Larnaca are increased from 0.20 in January to 0.24 in September and then they are decreased up to 0.21 by the end of the year (Figure 6b). The monthly variation at Athalassa shows different evolution compared to that at Larnaca. During the first 4 months it remains constant (about 0.22) and it decreases in May to 0.18. Afterwards it increases up to September (0.23) and then it drops to 0.18 in December (Figure 6a).

The results of the statistical analysis of hourly albedo values are also shown in Table 2. The Table shows the monthly statistics estimators for each month for both stations. The statistical parameters presented in the Table are:

number of data (*N*), arithmetic mean (*Mean*), standard deviation (*StDev*), coefficient of variation (*CV* in %), minimum (*Min*), first quartile (*Q1*), *median*, third quartile (*Q3*) and maximum (*Max*).

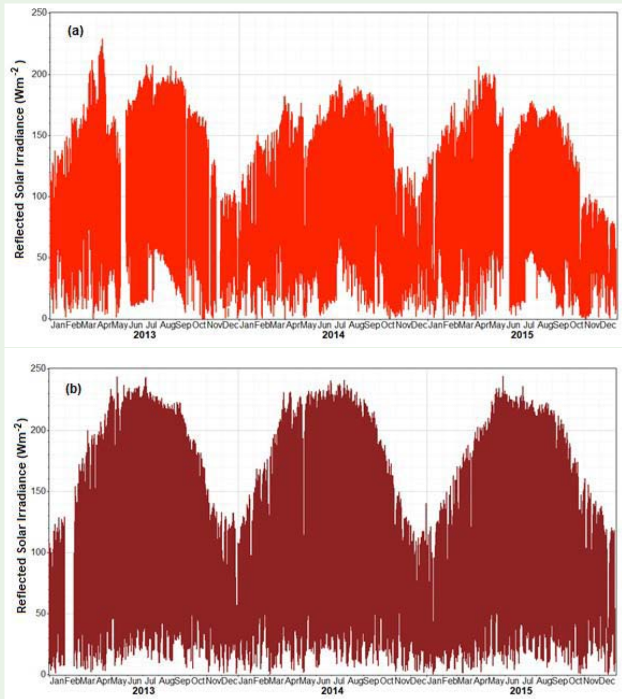

Figure 4: Time series plot of hourly reflected solar irradiance during the period 2013-2015 at a) Athalassa and b) Larnaca.

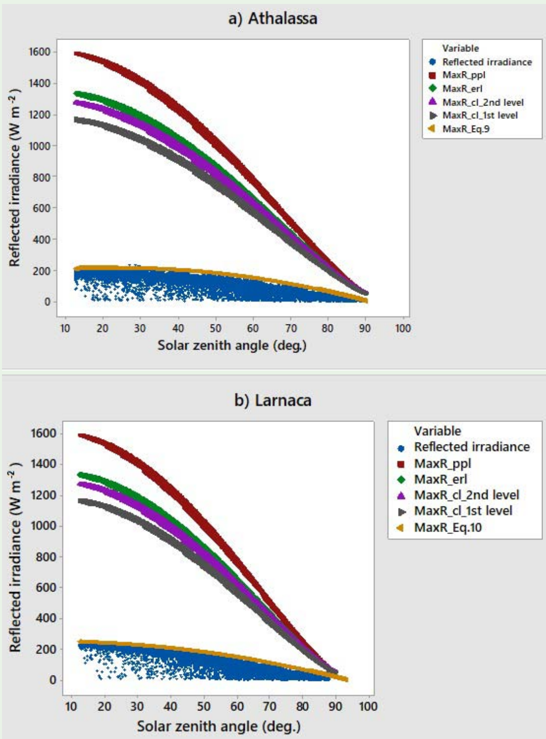

Figure 3: Hourly values of reflected irradiance (blue) and the testing criteria for maximum Physically Possible Limits (ppl) (red), Extremely Rare Limits (erl) (green), Climatological Limits (cl) of the 1st level (purple) and 2nd level (black) and the Maximum Reflected irradiance estimated by the quadratic equations (9 and 10, respectively) (brown) at a) Athalassa and b) Larnaca.

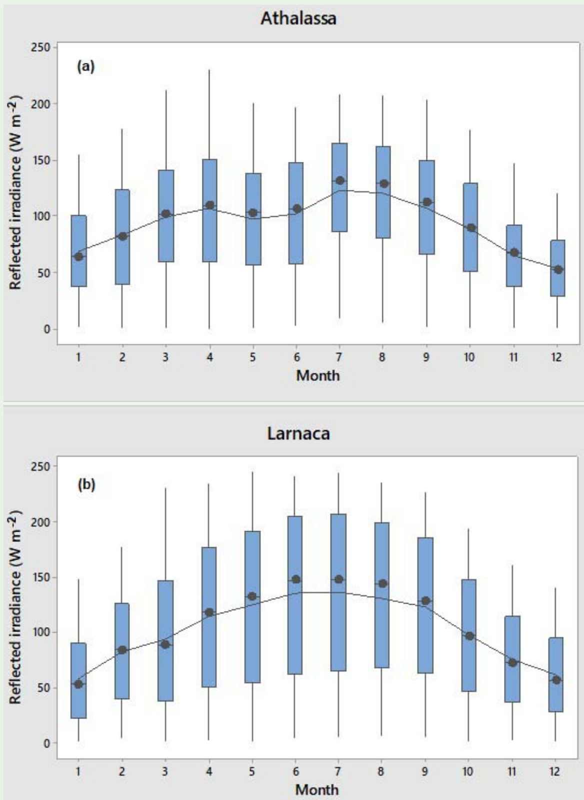

Figure 5: Monthly boxplots of hourly reflected irradiance (W m^{-2}) at a) Athalassa and b) Larnaca.

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Table 2: Monthly statistical estimators of albedo (ρ) for each month of the year for both stations.

a) Athalassa

Month	N	Mean	StDev	CV(%)	Min	Q1	Median	Q3	Max
1	756	0.216	0.027	12.67	0.12	0.199	0.219	0.236	0.309
2	838	0.227	0.027	11.89	0.153	0.208	0.225	0.242	0.33
3	970	0.22	0.03	13.43	0.107	0.199	0.216	0.235	0.343
4	1079	0.217	0.043	19.87	0.098	0.183	0.212	0.244	0.41
5	924	0.181	0.036	19.85	0.074	0.158	0.177	0.201	0.338
6	1139	0.193	0.032	16.8	0.124	0.169	0.188	0.21	0.293
7	1150	0.208	0.029	14.12	0.151	0.187	0.201	0.218	0.309
8	1116	0.219	0.032	14.76	0.166	0.197	0.213	0.23	0.337
9	959	0.228	0.034	15.06	0.129	0.208	0.22	0.236	0.395
10	924	0.209	0.042	20.08	0.082	0.182	0.213	0.23	0.386
11	683	0.186	0.031	16.65	0.073	0.164	0.184	0.206	0.287
12	729	0.177	0.032	18.37	0.079	0.154	0.177	0.197	0.266
Year	11267	0.207	0.037	18.05	0.073	0.183	0.207	0.228	0.41

b) Larnaca

Month	N	Mean	StDev	CV(%)	Min	Q1	Median	Q3	Max
1	753	0.197	0.03	15.4	0.118	0.182	0.198	0.219	0.264
2	666	0.203	0.031	15.47	0.121	0.185	0.206	0.225	0.277
3	971	0.211	0.026	12.31	0.122	0.197	0.21	0.227	0.296
4	1080	0.216	0.026	12.07	0.124	0.2	0.214	0.233	0.319
5	1116	0.225	0.026	11.53	0.118	0.212	0.224	0.241	0.295
6	1236	0.234	0.025	10.63	0.176	0.218	0.23	0.247	0.353
7	1164	0.235	0.025	10.53	0.181	0.218	0.234	0.249	0.336
8	1116	0.235	0.024	10.09	0.182	0.221	0.234	0.249	0.316
9	1014	0.239	0.024	10.19	0.163	0.223	0.241	0.255	0.315
10	930	0.231	0.03	12.8	0.126	0.211	0.231	0.249	0.316
11	774	0.223	0.026	11.66	0.124	0.208	0.224	0.24	0.297
12	742	0.207	0.034	16.24	0.108	0.188	0.209	0.231	0.283
Year	11562	0.223	0.03	13.37	0.108	0.205	0.225	0.242	0.353

The variability of ground albedo is expressed by the coefficient of variation. Table 2 indicates that the variability of albedo is higher at Athalassa than at Larnaca. Furthermore, the weather conditions during the summer season are more stable than the other seasons as it is indicated by the lower values of CV.

Table 3 shows the means and the standard deviations of ground albedo for different classifications of hours based on the clearness index for each season of the year. The hourly clearness index (k_t) is defined as the ratio of global irradiance to the extraterrestrial irradiance both measured on horizontal surfaces ($k_t = G/G_0$). The hours are classified as clear when the clearness index is higher than

Table 3: Means and Standard Deviations (StDev) of ground albedo for different classification of days, for the four seasons of the year at Athalassa and Larnaca.

Athalassa	Clear		Partly cloudy		Cloudy	
SEASON	Mean	StDev	Mean	StDev	Mean	StDev
Winter	0.21	0.03	0.218	0.034	0.183	0.036
Spring	0.2	0.033	0.225	0.044	0.187	0.045
Summer	0.195	0.021	0.231	0.037	0.228	0.052
Autumn	0.206	0.027	0.215	0.037	0.206	0.065
Larnaca	Clear		Partly cloudy		Cloudy	
SEASON	Mean	StDev	Mean	StDev	Mean	StDev
Winter	0.215	0.026	0.2	0.03	0.175	0.031
Spring	0.223	0.022	0.216	0.028	0.195	0.032
Summer	0.236	0.018	0.232	0.036	0.225	0.023
Autumn	0.237	0.019	0.227	0.033	0.21	0.033

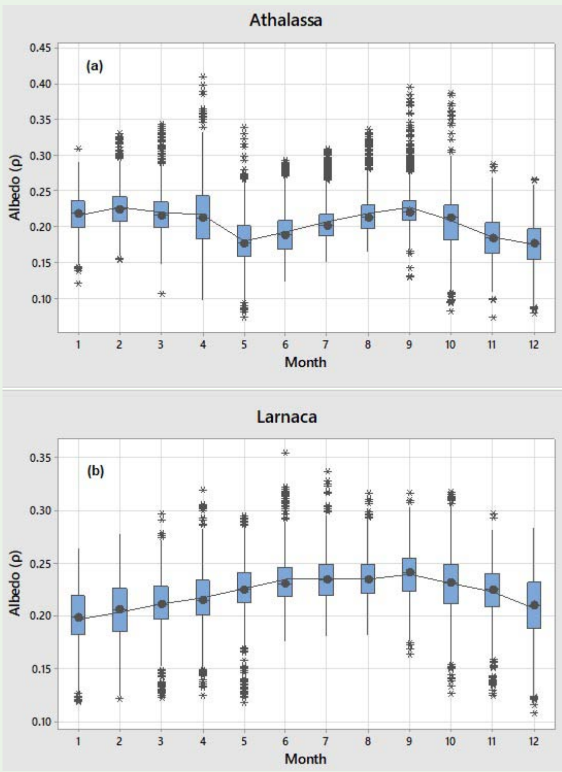

Figure 6: Boxplots of ground albedo (ρ) at α) Athalassa and b) Larnaca.

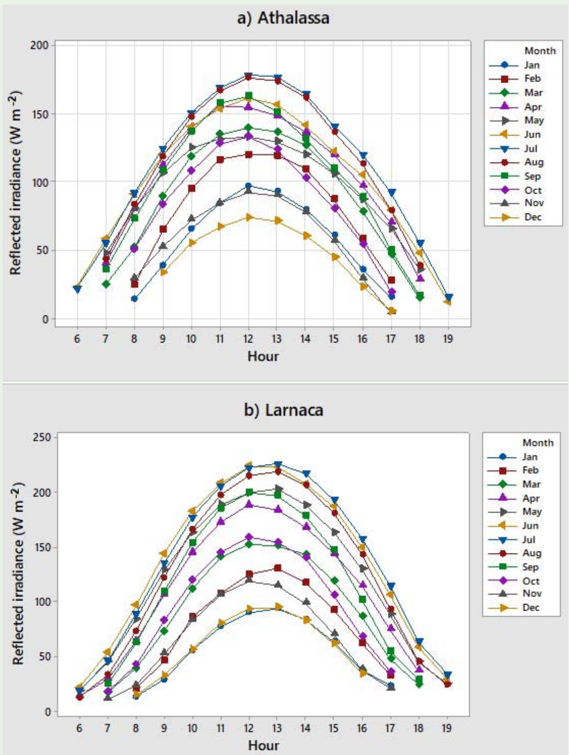

Figure 7: Daily evolution of the monthly mean hourly reflected irradiance (W m^{-2}) for the period 2013-2015 at a) Athalassa and b) Larnaca.

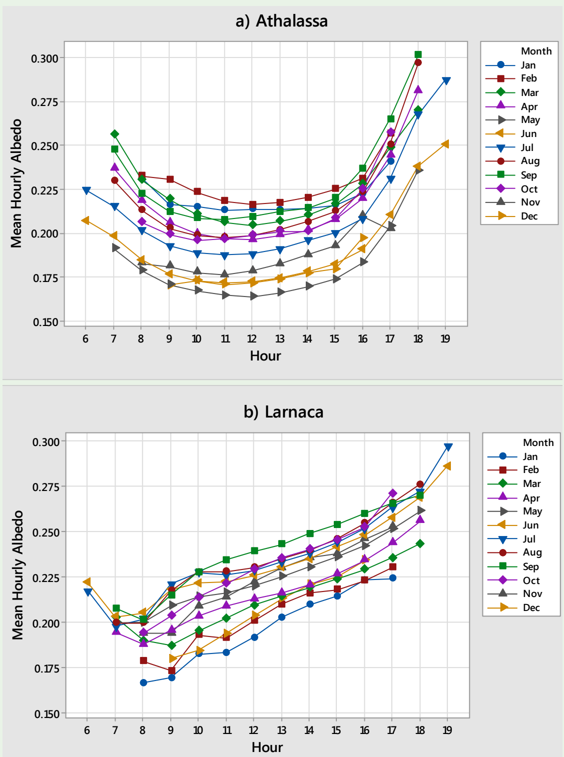

Figure 8: Daily evolution of the monthly mean hourly albedo for the period 2013-2015 at a) Athalassa and b) Larnaca.

0.65 and cloudy when $k_t < 0.35$. For the cases of $0.35 < k_t < 0.65$, the hours are classified as partly cloudy. At Larnaca, on clear days, ρ is higher than the other two classifications. However, at Athalassa, ρ is higher when the prevailing weather conditions are partly cloudy.

Daily variation of reflected irradiance and average ground albedo

The daily variation of the average hourly reflected irradiance (R) is shown in Figure 7. The figure shows that R fluctuates between 74 W m^{-2} in December and 178 W m^{-2} in July at solar noon at Athalassa. The values at Larnaca are higher than in Athalassa and they fluctuate between 95 W m^{-2} in December and 226 W m^{-2} in July at solar noon. A high symmetry is also observed around the months of June or July when the irradiance reaches its maximum, and it decreases in spring and autumn and reaches its minimum in winter months. The results can be explained by taking into account the symmetry relation between the summer and winter solstices.

With respect to the mean hourly albedo a different picture is obtained. As it is indicated in Figure 8a, the lowest values of albedo are observed around noon and the higher values in the morning and afternoon at Athalassa. The highest values are obtained in January and February and the lowest in May and June when global solar irradiance have its higher values. On the other hand, we observe an increasing trend from the morning towards the afternoon hours at Larnaca throughout the year (Figure 8b). The highest values are occurred in September and the lowest in January. The annual mean value of albedo at Athalassa is 0.201, while at Larnaca is 0.221.

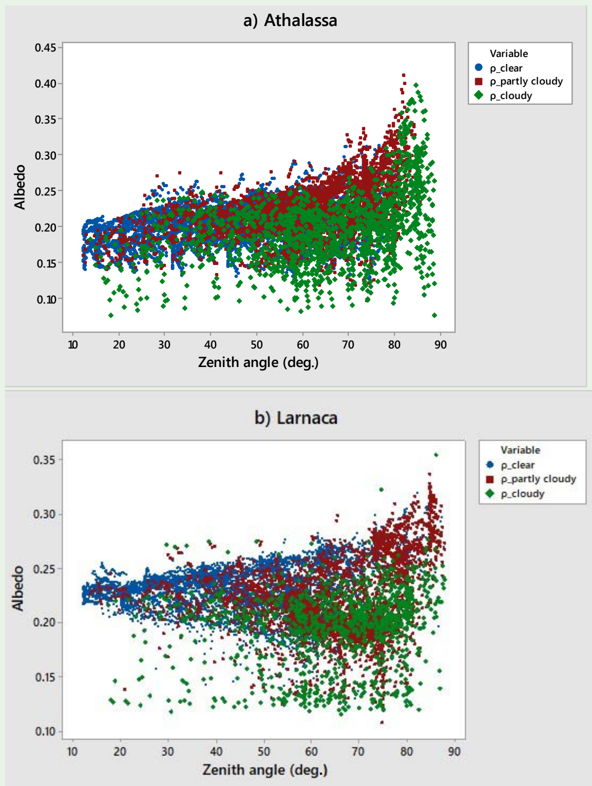

Figure 9: Ground albedo *vs* zenith angle based on the classification of hours as clear, partly cloudy and cloudy at a) Athalassa and b) Larnaca.

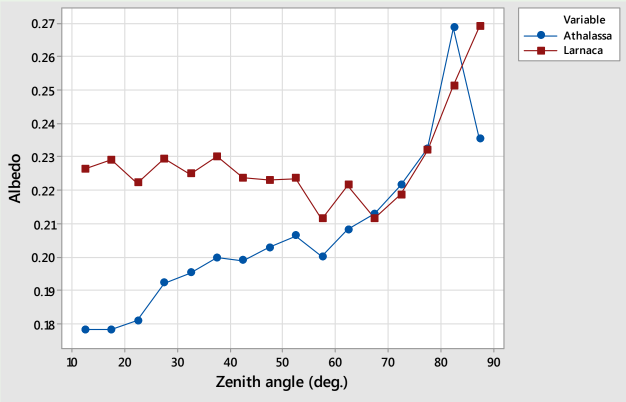

Figure 10: Variation of albedo with zenith angle at Athalassa and Larnaca.

Ground albedo versus zenith angle

Figure 9 shows the relationship between the ground albedo and the zenith angle for different types of weather conditions for both stations. The similarities between the graphs of the two stations are evident. As it is expected, ground albedo is higher when the zenith angle is high. Generally, during cloudy conditions, ground albedo is lower than the respective values of clear and partly cloudy conditions. Furthermore, the mean values of ground albedo were estimated for different ranges of 5 degrees of zenith angles. Figure 10 shows the variation of ground albedo with the zenith angle for both stations for different ranges of zenith angles. Athalassa shows an increasing trend of ground albedo with the zenith angle. In contrast, Larnaca shows a constant value of 0.225 up to $\theta_z = 50^0$, then a slight decrease (0.210-0.220) in the range of θ_z between 50 to 70^0 and finally an increasing value on the same levels of Athalassa.

Frequency distribution of reflected irradiance and hourly albedo

The annual frequency distribution of the hourly reflected and global irradiances of both stations are shown in the marginal plots of Figure 11. There is a linear relationship between the two variables. Regarding the frequency distribution which is estimated from the skewness and kurtosis coefficients [29], the global irradiance has a narrow peak with positive tails and the frequency distribution of reflected irradiance is a bimodal and symmetrical with flat peak for both stations. However, the frequency distribution of the albedo of both stations is approximately normal (Figure 12).

The seasonal Cumulative Density Functions (CDF) of the reflected irradiances for both stations is shown in Figure 13. Generally, higher values are recorded at Larnaca. In Summer, in 60% of the cases, the reflected irradiance is less than 140 W m^{-2} at Athalassa and less than 175 W m^{-2} at Larnaca.

The monthly histograms of albedo of both stations are presented in Figure 14. The seasonal CDF curves of albedo for each station are shown in Figure 15. The data of the monthly histograms are almost normally distributed. The median (50%) value of ρ, in Spring and Summer is 0.2 at Athalassa and about 0.23 at Larnaca.

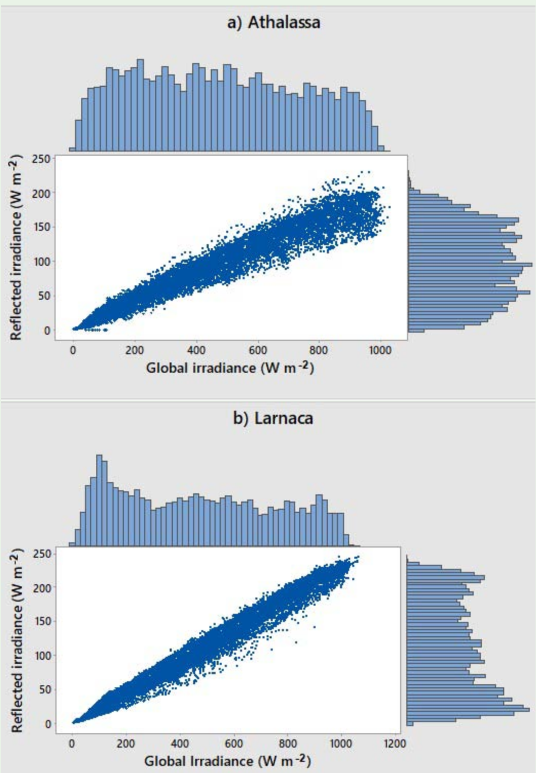

Figure 11: Marginal plot of the hourly reflected and global irradiance with the annual frequency distributions of the two variables at a) Athalassa and b) Larnaca.

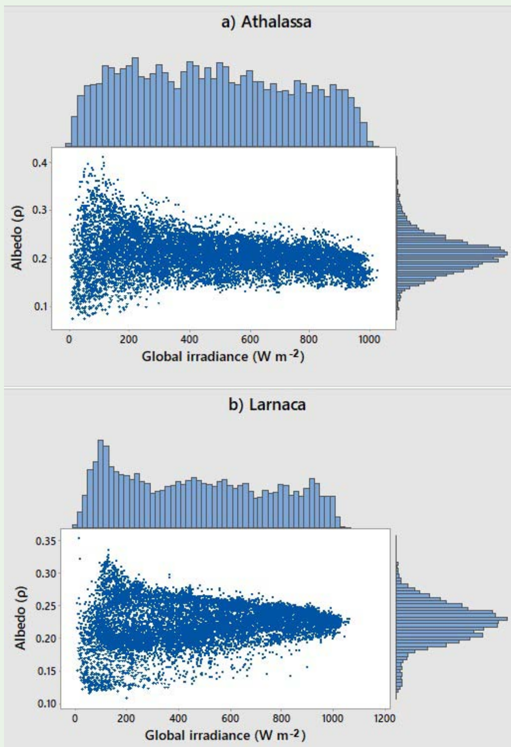

Figure 12: Marginal plot of the hourly global irradiance and albedo with the annual frequency distributions of the two variables at a) Athalassa and b) Larnaca.

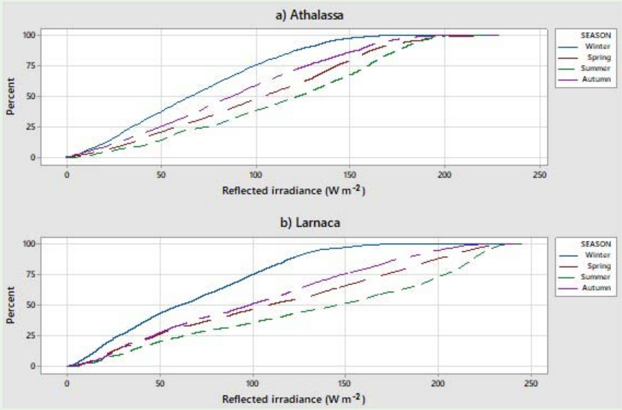

Figure 13: Seasonal cumulative density function (CDF) of reflected irradiance at a) Athalassa and b) Larnaca.

Statistical analysis of daily values of reflected irradiation and albedo

Data variation: Daily global solar radiation and reflected radiation have been analysed and compared in this study. Figure 16 shows the temporal evolution of daily global solar and reflected radiation at both stations. Data reveal a common evolution shape with maxima in summer and minima in winter, mainly due to the daily minimum solar zenith angle and day-length (astronomical factors) variation during the year. Large fluctuations are observed in the spring months

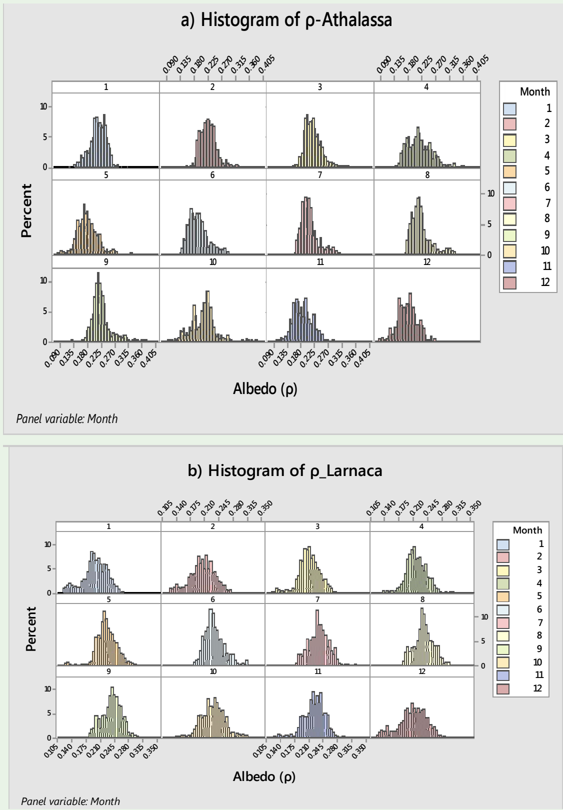

Figure 14: Monthly histograms of hourly albedo values at a) Athalassa and b) Larnaca.

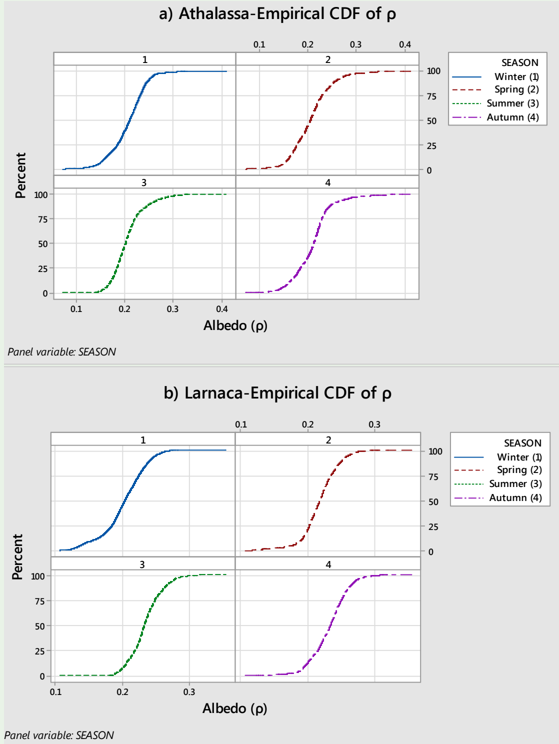

Figure 15: Cumulative density function (CDF) of ground albedo for the four seasons of the year at a) Athalassa and b) Larnaca.

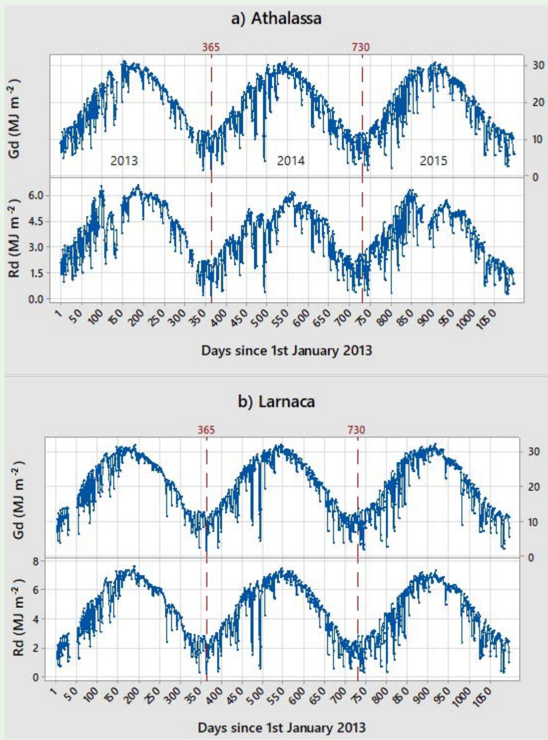

Figure 16: Co-variability of daily measured reflected irradiation (R_d) and daily global horizontal solar radiation (G_d) during the period 2013-2015 at a) Athalassa and b) at Larnaca.

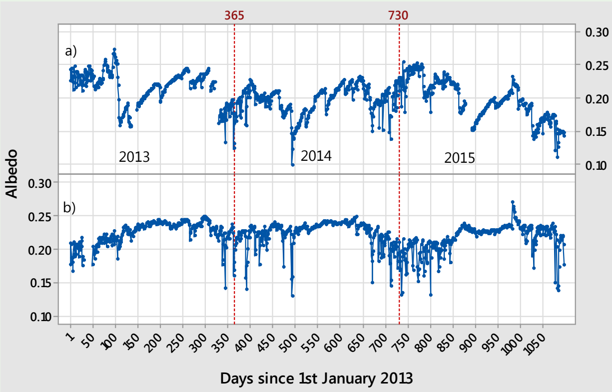

Figure 17: Time series plot of daily albedo during the period 2013-2015 at a) Athalassa and b) at Larnaca.

and November which are mainly due to the unstable meteorological conditions during the transition from cold to warm weather and *vice versa*. The maximum of daily global solar horizontal irradiation is reached in June or July and is around 31 MJ m^{-2} at Athalassa and around 32 MJ m^{-2} at Larnaca. The maximum of daily reflected irradiation is about 6.5 MJ m^{-2} at Athalassa and about 7.5 MJ m^{-2} at Larnaca.

The daily time series plot of ground albedo of both stations is presented in Figure 17. The pattern at Larnaca shows a slight increasing trend from January to September and then the albedo drops up to the end of the year. In contrast, the pattern at Athalassa is not constant throughout the year.

Monthly and seasonal statistics of daily albedo values: Table 4 presents the monthly descriptive statistics of daily albedo for both stations. The daily monthly mean values of albedo at Athalassa range between 0.175 to 0.224, while at Larnaca they are higher ranging from 0.198 to 0.239. The descriptive statistics of daily albedo on a seasonal basis is presented in Table 5. The low values of the coefficient of variation during the summer months indicate that during these months the weather conditions are more stable.

The variability of albedo throughout the year is shown in Figure 18. The variability is higher during the winter season (rainy season) compared to the summer (dry season) when the soil is dry.

Frequency distribution of daily reflected irradiation and albedo: The annual histogram of the Probability of Density Function (PDF) of the daily reflected and global irradiation of both stations is displayed in Figure 19, while the frequency distribution of albedo is shown in Figure 20. As indicated in Figure 19, the type of the annual distribution of the daily reflected irradiation is bimodal for both stations. The *PDF* graphs show similarities with the highest frequencies occurring at around 2 and 5 MJ m^{-2} of reflected irradiation at both stations.

Table 4: Monthly descriptive statistics of daily albedo for both stations.

a) Athalassa

Month	N	Mean	StDev	CV(%)	Min	Q1	Median	Q3	Max
1	93	0.216	0.023	10.61	0.157	0.2	0.221	0.234	0.254
2	84	0.224	0.018	8.12	0.188	0.207	0.224	0.242	0.251
3	93	0.215	0.018	8.36	0.178	0.201	0.215	0.227	0.256
4	90	0.208	0.03	14.17	0.157	0.18	0.215	0.229	0.272
5	77	0.176	0.024	13.68	0.098	0.157	0.179	0.187	0.222
6	82	0.183	0.018	9.94	0.15	0.168	0.181	0.2	0.212
7	92	0.2	0.013	6.69	0.173	0.19	0.201	0.211	0.22
8	93	0.21	0.014	6.85	0.183	0.198	0.212	0.222	0.232
9	84	0.218	0.014	6.47	0.182	0.21	0.219	0.226	0.243
10	93	0.204	0.028	13.68	0.137	0.186	0.214	0.227	0.237
11	78	0.184	0.024	13.17	0.145	0.166	0.179	0.196	0.242
12	91	0.175	0.027	15.38	0.109	0.151	0.172	0.194	0.23
Year	1050	0.202	0.027	13.45	0.098	0.183	0.205	0.222	0.272

b) Larnaca

Month	N	Mean	StDev	CV(%)	Min	Q1	Median	Q3	Max
1	92	0.198	0.021	10.67	0.13	0.186	0.203	0.214	0.226
2	66	0.205	0.021	10.2	0.151	0.194	0.208	0.223	0.234
3	93	0.211	0.017	7.8	0.129	0.206	0.211	0.221	0.24
4	90	0.215	0.014	6.3	0.172	0.208	0.215	0.226	0.237
5	93	0.224	0.016	7.08	0.129	0.222	0.228	0.231	0.238
6	90	0.231	0.005	2.13	0.218	0.227	0.231	0.234	0.239
7	93	0.234	0.006	2.74	0.221	0.226	0.237	0.239	0.243
8	93	0.234	0.004	1.79	0.224	0.232	0.235	0.237	0.241
9	90	0.239	0.008	3.56	0.212	0.234	0.239	0.242	0.269
10	93	0.229	0.014	6.09	0.17	0.225	0.233	0.236	0.249
11	90	0.222	0.015	6.75	0.149	0.219	0.226	0.231	0.245
12	93	0.206	0.025	12.05	0.136	0.198	0.214	0.223	0.237
Year	1076	0.221	0.02	8.88	0.129	0.212	0.226	0.234	0.269

Table 5: Seasonal descriptive statistics of daily albedo for both stations.

a) Athalassa

SEASON	N	Mean	StDev	CV(%)	Min	Q1	Median	Q3	Max
Winter	268	0.204	0.031	15.4	0.109	0.184	0.209	0.23	0.254
Spring	260	0.201	0.029	14.61	0.098	0.18	0.205	0.222	0.272
Summer	267	0.198	0.019	9.56	0.15	0.186	0.2	0.212	0.232
Autumn	255	0.202	0.027	13.21	0.137	0.185	0.21	0.224	0.243
Year	1050	0.202	0.027	13.45	0.098	0.183	0.205	0.222	0.272

b) Larnaca

SEASON	N	Mean	StDev	CV(%)	Min	Q1	Median	Q3	Max
Winter	251	0.203	0.023	11.19	0.13	0.19	0.207	0.22	0.237
Spring	276	0.217	0.016	7.46	0.129	0.209	0.219	0.229	0.24
Summer	276	0.233	0.006	2.36	0.218	0.228	0.234	0.238	0.243
Autumn	273	0.23	0.014	6.29	0.149	0.225	0.233	0.238	0.269
Year	1076	0.221	0.02	8.88	0.129	0.212	0.226	0.234	0.269

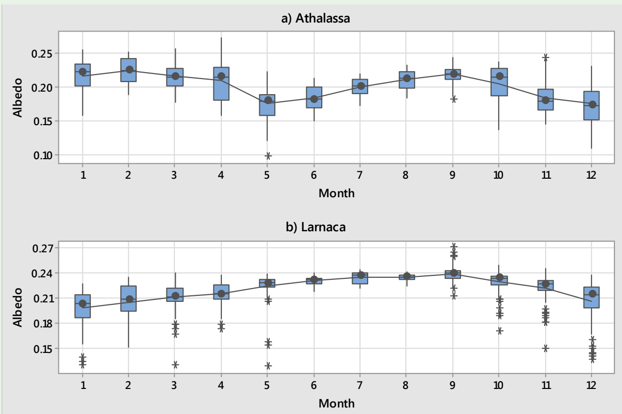

Figure 18: Boxplots of daily albedo values at a) Athalassa and b) Larnaca.

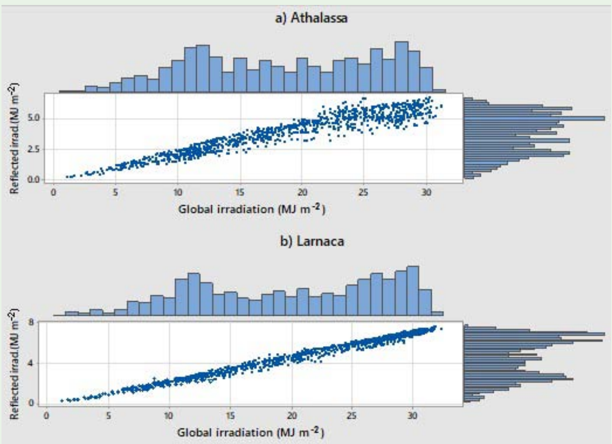

Figure 19: The annual histogram of the frequency distribution (*PDF*) of the daily reflected and global irradiation of both stations.

However, the PDF graph for albedo at Athallassa follows approximately the normal probability curve, while the PDF for albedo at Larnaca has a narrow peak with negative tail (Figure 20). The curve of the normal distribution is also shown on both histograms of albedo.

The PDF curves of albedo of both stations on a monthly and seasonal basis are shown in Figure 21. The characteristic of the PDF graphs is that the frequencies of albedo at Larnaca, are concentrated mainly in the range of 0.2 to 0.25, while at Athalassa we observe wider ranges (0.125-0.250). The Cumulative Density Function (CDF) of albedo on a seasonal basis for both stations is presented in Figure 22. During summer, in 50% of the cases albedo at Athalassa is less than 0.200, while at Larnaca is less than 0.234.

Relationship between reflected radiation and other radiation components

A linear relationship exists between the two variables:

Hourly data (W m^{-2}): $R_{Ath} = 0.198 * G_{Ath}\ R^2 = 0.982$ (13)

$$R_{Lca} = 0.226 * G_{Lca}\ R^2 = 0.993 \quad (14)$$

Daily data (MJ m^{-2}): $R_{Ath} = 0.201 * G_{Ath}\ R^2 = 0.986$ (15)

$$R_{Lca} = 0.227 * G_{Lca}\ R^2 = 0.997 \quad (16)$$

The characteristic of these relationships is that the coefficients of determination are close to 1. Generally, the slopes of the equations of the hourly and daily data of each station are comparable. For Athalassa the slope is close to 0.2 and for Larnaca is 0.226.

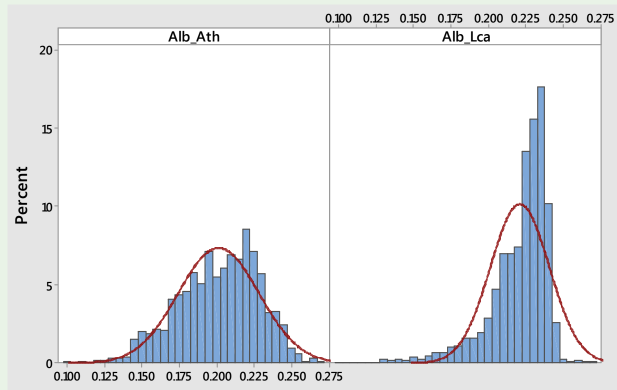

Figure 20: Probability density function (PDF) of albedo at a) Athalassa and b) Larnaca.

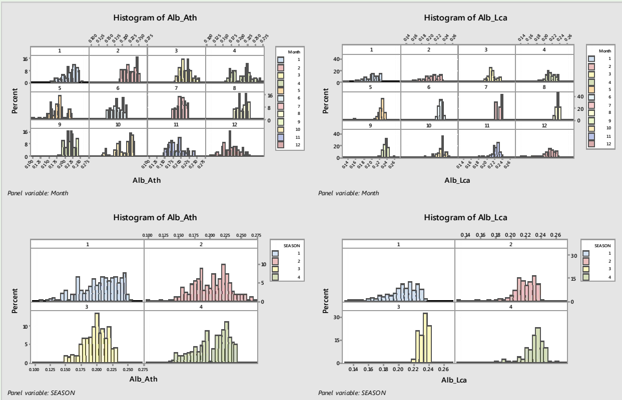

Figure 21: Histograms of albedo on a monthly and seasonal basis for both stations.

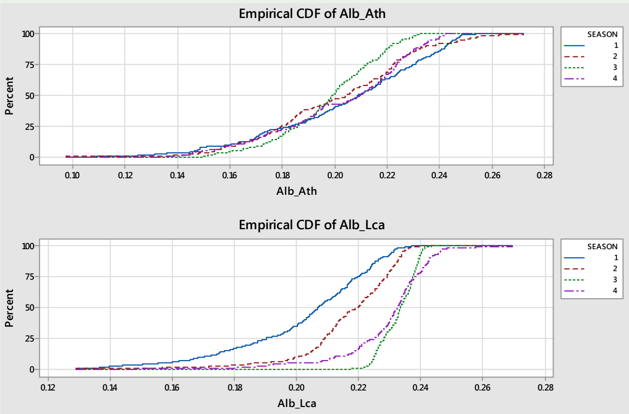

Figure 22: The Cumulative Density Function (CDF) of albedo on a seasonal basis for both stations.

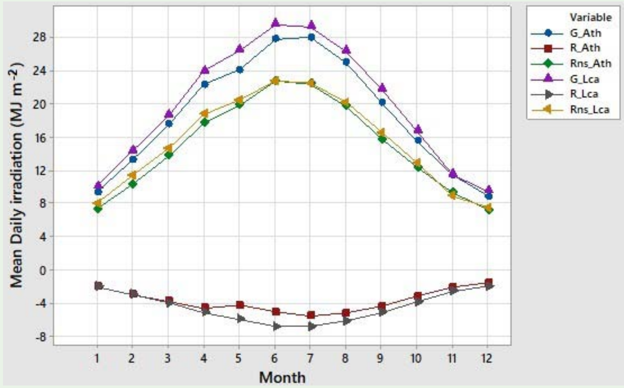

Figure 23: Monthly mean daily values of Global (G), Reflected (R) and net shortwave irradiation (R_{ns}) (MJ m^{-2}) at both stations.

Inter-Comparison of the Two Sites

The inter-comparison of the broad-band solar radiation intensity measurements at both sites are reported in Table 6 for the daily reflected and global radiation as well as for albedo. The solar radiation intensities are reported as monthly average daily values, and the relative attenuations are reported for each variable. The relative attenuation is defined as:

$$RelativeAttenuation(\%) = ((X_{Lca} - X_{Ath}) / X_{Ath})*100 \quad (17)$$

where X refers the type of solar radiation, i.e., either reflected, global, or albedo. The subscripts refer to the two sites.

As indicated in Table 6, the magnitudes of the monthly average daily values of the two types of solar radiation components (reflected and global) are higher at Larnaca than at Athalassa. The only exception is the reflected radiation in January, which is slightly higher at Athalassa. Generally, the percentages of relative attenuation of the reflected radiation are much higher (> 12%) during the period April-

Table 6: Monthly average daily solar global, reflected and average daily albedo at Athalassa and Larnaca and their relative differences.

	Athalassa (MJ m^{-2})			Larnaca (MJ m^{-2})			Relative Attenuation (%)		
Month	Reflected	Global	Albedo	Reflected	Global	Albedo	Reflected	Global	Albedo
1	2.06	9.36	0.216	2.03	10.01	0.198	-1.46	6.99	-8.17
2	2.96	13.27	0.224	2.97	14.35	0.205	0.28	8.13	-8.35
3	3.79	17.54	0.215	3.97	18.57	0.211	4.67	5.92	-1.83
4	4.63	22.27	0.208	5.17	23.92	0.215	11.57	7.4	3.1
5	4.28	24.05	0.176	5.96	26.38	0.224	39.27	9.69	27.19
6	5.09	27.78	0.183	6.81	29.53	0.231	33.85	6.29	26.29
7	5.59	27.96	0.2	6.84	29.26	0.234	22.52	4.65	17.14
8	5.23	24.91	0.21	6.16	26.3	0.234	17.74	5.57	11.51
9	4.39	20.09	0.218	5.17	21.68	0.239	17.79	7.92	9.41
10	3.22	15.51	0.204	3.86	16.72	0.229	19.84	7.81	12.38
11	2.1	11.37	0.184	2.56	11.45	0.222	22.07	0.72	20.88
12	1.57	8.78	0.175	1.99	9.44	0.206	26.83	7.46	17.78
Year	3.75	18.53	0.202	4.49	19.93	0.221	19.96	7.54	9.66

December. The relative attenuation of global radiation is higher at Larnaca than at Athalassa and it ranges between 1 to 10%. The albedo is higher at Larnaca than in Athalassa, in nine months of the year (April-December).

The net shortwave irradiation (R_{ns}) is estimated as the difference between the global solar radiation and the reflected radiation. Figure 23 presents the monthly mean daily irradiation of the global, reflected and net shortwave irradiation for both stations. The net shortwave irradiation at Larnaca is slightly higher than that at Athalassa, almost throughout the year.

Conclusion

The paper gives a review of the results obtained from the statistical analysis of the reflected solar radiation at Athalassa (inland location) and Larnaca (coastal location). A quality control process was implemented for the validation of measured data which is based on the Baseline Surface Radiation Network (BSRN) recommendations with established globally physical possible, extremely rare and climatological limits for the hourly reflected solar irradiance measurements.

The computation of the ground reflected radiation (albedo) plays an important role in the process of estimating solar radiation incident on an inclined surface. In general, the albedo of the soils depends on their organic matter content, on the water content, particle size, the type of the soil and the angle of incidence radiation.

The measured reflected solar radiation data have been analysed and monthly average hourly and daily values were calculated and their frequency distributions have been reported. The monthly means of reflected irradiance range from 50 to 120 W m^{-2} at Athalassa, while at Larnaca they range between 50 and 140 W m^{-2}.

The mean annual albedo for Athalassa is 0.202 which coincides with the most common value given in the literature (0.2), while for Larnaca it is higher (0.221). The higher value at Larnaca is attributed to its silty sandy soil which has higher reflectivity compared to the calcarenite soil of Athalassa. The lowest albedo values occurred in winter (rainy season) and the highest in summer (dry season). The lowest values of albedo at Athalassa, are observed around noon and the higher values in the morning and afternoon. The highest values are obtained in January and February and the lowest in May and June when global solar irradiance have its higher values. On the other hand, we observe an increasing trend from the morning towards the afternoon hours at Larnaca throughout the year. The highest values occurred in September and the lowest in January.

The maximum of daily global solar horizontal irradiation is reached in June or July and is around 31 MJ m^{-2} at Athalassa and around 32 MJ m^{-2} at Larnaca. The maximum of daily reflected irradiation is about 6.5 MJ m^{-2} at Athalassa and about 7.5 MJ m^{-2} at Larnaca. The monthly mean daily values of albedo at Athalassa range between 0.175 to 0.224, while at Larnaca they are higher ranging from 0.198 to 0.239. As a result of the differences of the albedo at the two sites, the net shortwave irradiation at Larnaca is slightly higher than that at Athalassa, almost throughout the year.

At Larnaca, on clear days, albedo is higher than the cases of partly cloudy or cloudy conditions. However, at Athalassa, albedo is higher when the prevailing weather conditions are partly cloudy. The frequency distribution of the albedo of both stations is approximately normal.

Nomenclature

A_s	Skewness coefficient
CDF	Cumulative Density Function
CV	Coefficient of Variation (%)
G	Global solar irradiance [Wm^{-2}]
G_0	Extraterrestrial irradiance [Wm^{-2}]
G_{0d}	Daily extraterrestrial irradiation (ETR) [MJ m^{-2}]
G_d	Daily global irradiation [MJ m^{-2}]
I_{sc}	Solar constant [1367 Wm^{-2}]
j	Julian day number (1..365)
j'	day angle [degrees]
K	Kurtosis
k_t	Hourly clearness index ($k_t = G / G_0$)
K_T	Daily clearness index ($K_T = G_d / G_{0d}$)
Max	Maximum
Min	Minimum
N	Non missing observations
N^*	Missing observations
PDF	Probability density function
Q1	First Quartile
Q3	Third Quartile
R	Reflected irradiance [Wm^{-2}]
R_d	Reflected irradiation [MJ m^{-2}]
R_{ns}	Net shortwave radiation [MJ m^{-2}]
R^2	Coefficient of determination
StDev	Standard deviation

Greek:

δ	Solar declination [degrees]
ε	eccentricity correction
θ_z	Solar Zenith Angle (SZA) [degrees]
ρ	Ground albedo
φ	Latitude [degrees]
ω	Hour angle [degrees]

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