Annual and Seasonal Trends of Solar Radiation in Athens, Greece

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Abstract: This study deals with the solar radiation levels recorded at the Actinometric Station of the National Observatory of Athens, focusing on the trends of the global and diffuse horizontal irradiances in the period of 1992-2017 (26 years). The analysis shows that the annual global radiation time series over Athens in the above period presents a positive trend (+0.40%/decade and +2.38%/decade for all and clear skies, respectively), while its diffuse counterpart shows negative trend (-5.19%/decade and -6.77%/decade for the same sky conditions, respectively) during the same period. Also, the seasonal trends of both solar radiation components are examined. The global horizontal radiation shows positive trends in summer (+1.85%/decade and +2.10%/decade under all and clear skies, respectively), while a negative trend is calculated in the winter season (-2.46%/decade and -1.99%/decade for the same sky conditions, respectively). In the case of the diffuse solar radiation there are found negative trends in both seasons and both sky conditions. These findings confirm a recovery in the solar radiation levels over Athens in the recent 26 years.

Keywords: Solar radiation, Global horizontal irradiance, Diffuse horizontal irradiance, trends, Athens, Greece.

1. INTRODUCTION

Solar radiation reaching the surface of the Earth is the primary source for life as it controls various fields [1-3]. The exploitation of solar energy for various applications started almost twenty years ago mainly for PV installations [4]. Fluctuations of solar radiation are caused by changes in atmospheric constituents (*e.g.*, [5]), by variations in cloud cover (*e.g.*, [6]), as well as by changes in the Sun-Earth geometry (Milankovitch theory).

In view of the above, solar radiation undergoes variations at scales as short as seasons and as long as decades (*e.g.*, [7]). The short-term variations are mainly attributed to the rotation of the Earth around the Sun, and the long-term ones to changes in atmospheric composition. In this context, the so-called “global dimming/brightening effect” refers to a decrease/-increase in the solar radiation levels [7] that has serious implications in the Earth’s climate (*e.g.*, [8]).

There are various studies in the international literature that refer to the solar radiation variations at different sites worldwide and differing periods. A decline in the solar radiation intensity over North America and Europe has been found in the period of 1960-1980, and a recovery afterwards of ~+1.50 Wm^{-2}/decade to +2.40 Wm^{-2}/decade in 1990-2000 [9, 10]. However, solar dimming continues to exist over India and Southeast Asia [11-13] estimated a decline in global solar radiation of -2.30 Wm^{-2}/decade over China (an average value from 459 stations in the period 1961-2000). Very few studies, though, cover several years beyond 2000s (*e.g.*, [14]). On the other hand, the Mediterranean area, as a crossroad of atmospheric aerosols, has been investigated only by [15] in the period 1979-2012.

A recent study by Kazadzis *et al.* [16] examined the variation of the global horizontal radiation levels over Athens and found a trend of +0.80%/decade in the period 1983-2012 or a +0.40%/decade in 1900-2012. Kambezidis [17, 18] repeated calculations of the global solar irradiance trend and found a contradictory result (+0.41%/decade in 1992-2017); he attributed this discrepancy to the different periods examined in the studies.

The present work analyses global horizontal and diffuse horizontal irradiance data for Athens in the period of the last 26 years (1992-2017). The structure of the paper is as follows. Section 2 presents the data used in the study (*i.e.*, the data collection in Sub-section 2.1, the data processing in Sub-section 2.2, the methodology in Sub-section 2.3). Section 3 presents the results of the study (*i.e.*, the trend in the global radiation in Sub-section 3.1, the trend in the diffuse solar radiation in Sub-section 3.2). Section 4 presents the main conclusions of the study. Acknowledgments and References follow.

2. MATERIALS AND METHODS

2.1. Data Collection

The Actinometric Station of the National Observatory of Athens (ASNOA) is a unique organized

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solar radiation platform in Greece (37.97° N, 22.72° E, 107 m amsl) in terms of long-term records and completeness in the measuring solar components. It is situated on the Hill of Pnyx, very close to the Acropolis of Athens. It started its operation in 1953 by measuring global horizontal radiation. In the progress of time, ASNOA was enriched with other radiometric equipment for measuring additional solar radiation components, *e.g.*, diffuse horizontal radiation. The parameters analysed in this work are the global horizontal irradiance (H_g in Wm^{-2}), and the diffuse one (H_d in Wm^{-2}). Both parameters are recorded at ASNOA by a data logger, which performs measurements every 20 s. The logger calculates 1-min averages from three 20-s samples and stores them. The 1-min values are further processed off-line following a quality-control test (QCT) shown in Table **1**, where H_b is the direct horizontal irradiance ($H_b = H_g - H_d$, in Wm^{-2}); $H_{g,ex}$ is the extra-terrestrial global solar horizontal irradiance given by [19]:

$$H_{g,ex} = S \cdot H_{g,o} \cdot sin\gamma, \quad (1a)$$

where the solar constant ($H_{g,o}$) is 1360.8 Wm^{-2} (the latest value according to [20], and γ the solar altitude; a precise expression for S is given by [21]:

$$S = 1.00011 + 0.034211 \cdot cos\,\tau + 0.00128 \cdot sin\,\tau + 0.000719 \cdot cos(2\tau) + 0.000077 \cdot sin(2\tau) \quad (1b)$$

$$\tau = 2\pi \cdot (J-1)/365, \quad (1c)$$

where J is the day number of the year (J = 1 for 1 January, J = 365 for 31 December, and J = 366 for 31 December on leap years).

1-min values of the H_g and H_d components were used in this study from the ASNOA records, covering the period of 1992-2017 (26 years).

Table 1: QCTs for the 1-min Average Values of the Irradiance Parameters at ASNOA [22]. Those Solar Radiation Values not Obeying any of the Criteria were Rejected

$H_d < 1.1\ H_g$
$H_g < 1.2\ H_{g,ex}$
$H_d < 0.8\ H_{g,ex}$
$H_b < H_{g,ex}$
$H_g \geq 10\ Wm^{-2}$ (lower detection limit of pyranometers)
$\gamma \geq 5^{o}$ (avoiding the pyranometer's cosine effect)

Both H_g and H_d are recorded at ASNOA with Eppley PSP pyranometers since 1987; these pyranometers are regularly calibrated against a prototype Eppley PSP one that is calibrated from time to time at PMOD/WRC, Davos, Switzerland. The diffuse horizontal irradiance is measured with the aid of an Eppley shadow-band device; its measurements are corrected offline for the shadow-band effect by using the Littlefair (1989) methodology.

2.2. Data Processing

The first step in the data processing was the quality control of the data time series of both solar radiation components at the 1-min level. After that, the 1-min radiation values were converted into hourly averages and then into monthly means. The 312 monthly values (26 years x 12 months) of each radiation parameter were tested for inhomogeneity, but no important findings came up. Seasonality was also extracted from the monthly time series of each parameter as solar radiation is subject to an annual cycle. The methodology for removing seasonality in a time series can be found in Wikipedia (https://en.wikipedia.org/-wiki/Seasonality, accessed on 31 May 2018). After that, deseasonalised monthly values for both H_g and H_d data series were derived. From these monthly values, deseasonalised seasonal and annual values were estimated. In this study, the seasons of winter (December, January, February) and summer (June, July, August) were considered as being associated with low and high radiation levels, respectively.

2.3. Methodology

The data processing described in Sub-section 2.2 was applied to the H_g, H_d data under all-sky conditions. In order to isolate the H_g and H_d values under clear-sky conditions, such cases were derived upon the criterion of $H_{b,n} \geq 120\ Wm^{-2}$, where $H_{b,n}$ is the direct-normal solar radiation:

$$H_{b,n} = \frac{H_g - H_d}{sin\gamma} \quad (2)$$

The above equation was applied to all remained 1-min H_g and H_d values after passing through QCT (Table **1**); therefore, a separate data base with the two solar parameters for the clear-sky cases was formed. The all-sky H_g and H_d values were those that remained after the application of the QCT without any additional criterion imposed on the measurements. Therefore, two different data bases were created, one for the all-sky case and another for the clear-sky one. The homogeneity test was applied to both solar radiation components in the two data bases, which did not show important findings. Seasonal and annual averages were then calculated from both data bases and both solar radiation components.

3. RESULTS AND DISCUSSION

3.1. Trends in H_g

Figure **1** shows the annual H_g averages under all- and clear-sky conditions. The linear fits to both plots show the annual trends of H_g under the mentioned cloudiness. These fits have relations given by the equations:

$$H_{g,a} = 30.45 + 0.17\ year \tag{3a}$$

$$H_{g,c} = -1633.15 + 1.01\ year \tag{3b}$$

where the subscripts a, c refer to all- and clear-sky conditions, respectively. The parameter *year* refers to any year of the period 1992-2017.

Considering the decade 1992-2001, and applying its end years to Eq. (3a), taking the difference $H_{g,a2001}$ - $H_{g,a1992}$, and dividing it by the 1992-2017 mean = 370.12 Wm^{-2}, it is found that H_g has a trend of +0.40%/decade or +0.04%/year over the studied period. These percentages are related to trends of +1.53 Wm^{-2}/decade or +0.15 Wm^{-2}/year, respectively. For the case of clear skies, the trends become +2.38%/decade (≈+0.24%/year) and +9.09 Wm^{-2}/decade (≈+0.91 Wm^{-2}/year), if the average = 382.21 Wm^{-2} is taken into account.

Table **2** presents a comparison of the H_g trend between this study and that from other similar works. One may observe the different periods examined in the studies mentioned as well as the discrepancies in the trends themselves. The latter may be attributed to two reasons: (i) the different periods over which the trends are estimated, and (ii) the spatial average of H_g in some cases in contrast to the point averages considered in the present study and in Kambezidis (2018b).

Figure **2** shows the trend of the H_g time series for winter and summer under all-sky conditions over Athens during the period of the study. The linear fits to both plots show the seasonal trends of H_g under the mentioned cloudiness. These fits have relations given by the equations:

$$H_{g,a,w} = 1875.20 - 0.79\ year \tag{4a}$$

$$H_{g,a,s} = -1596.65 + 1.04\ year \tag{4b}$$

The subscripts w, s refer to winter/summer, respectively. Again, considering the decade 1992-2001, applying the end years to Eq. (4a), taking the difference $H_{g,a,w2001}$ - $H_{g,a,w1992}$, and dividing it by the mean = 288.77 Wm^{-2}, it is found that H_g has a winter trend over the studied period of -2.46%/decade or -0.25%/year. These percentages correspond to trends of -7.11 Wm^{-2}/decade or -0.71 Wm^{-2}/year, respectively. By repeating the above calculations for the summer season in Eq. (4b), it is found that the H_g time series

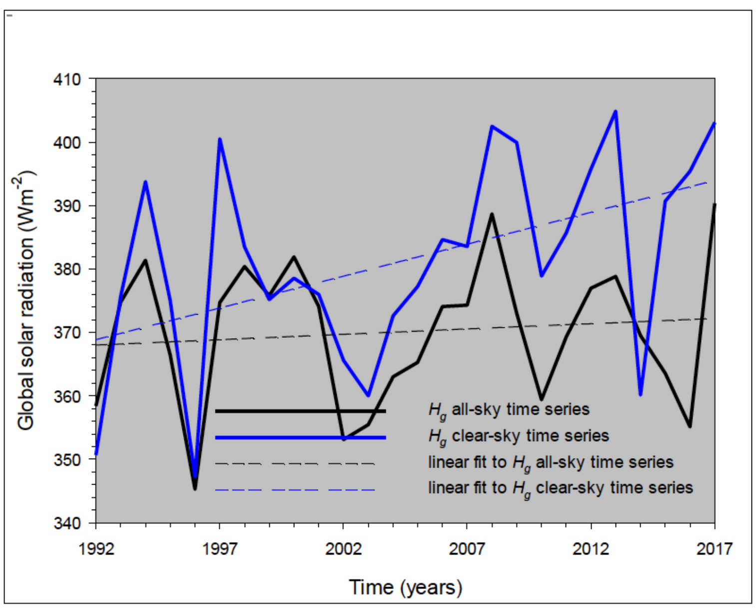

Figure 1: Variation of the annual mean H_g values under all- and clear-sky conditions in Athens over the period 1992-2017. The linear best-fit expressions are given by Eqs. (**3a**) and (**3b**) for all- and clear-skies, respectively.

Table 2: Trends in the Annual H_g Mean Values under all- and Clear-Sky Conditions for Various Sites in Europe/Asia and Periods. A Question mark (?) Implies an Unmeasured Value

Cloudiness Conditions	Trend in H_g %/decade (Wm^{-2}/decade)	Reference	Period (region)
all skies	+0.40 (+1.53)	present work	1992-2017 (Athens, Greece)
clear skies	+2.38 (+9.09)		
all skies	+0.41 (+1.50)	[17,18]	
clear skies	+2.36 (+9.09)		
all skies	+0.80 (?)	[16]	1983-2012 (Athens, Greece)
all skies	+0.40 (?)		1900-2012 (Athens, Greece)
all skies	+3.30 (?)	[23]	1993-2011 (Thessaloniki, Greece)
all skies	? (+1.81)	[24]	1966-2015 (The Netherlands)
all skies	? (+3.70) ? (+2.50) ? (+3.50) ? (+3.90) ? (+2.30)	[14]	1986-2012 (C. Europe) 1986-2012 (N. Europe) 1986-2012 (E. Europe) 1986-2012 (S. Europe) 1986-2012 (NW. Europe)
all skies	? (-1.00) ? (+4.70) ? (+2.80) ? (+3.50)	[25]	1994-2010 (Balearic Ils., Spain) 1985-2010 (Mallorca, Spain) 1983-2010 (W. Europe) 1983-2010 (C. Europe)
all skies	? (+0.60)	[15]	1979-2012 (Mediterranean)
all skies	? (+2.10)	[26]	? (E. Mediterranean)
all skies	? (+1.10)	[9]	1987-2002 (Europe)
all skies	+3.20 (?)	[27]	1980-2007 (Europe)
all skies	? (+7.70) ? (+6.00)	[28]	1983-2013 (N. Italy) 1983-2013 (S. Italy)
clear skies	? (+7.60 to +7.90)		1986-2013 (from N. Italy to S. Italy)
all skies	+2.50 (?)	[29]	1990-2016 (NW. Italy)
all skies	(?) (+1.90 to +3.70)	[30]	1992-2015 (Europe, excluding Balkans)
all skies	+2.4 (+3.0) +1.9 (+2.9) +1.6 (+1.7) +2.7 (+5.0) +2.4 (+2.6) +2.0 (+2.6) +2.2 (+3.3) +2.7 (+2.8) +3.0 (+5.7) +1.8 (+2.0)	[31]	1983-2015 (CE. Europe) 1983-2015 (CW. Europe) 1983-2015 (NW. Europe) 1983-2015 (S. Europe) 1983-2015 (N. Europe) 1992-2015 (CE. Europe) 1992-2015 (CW. Europe) 1992-2015 (NW. Europe) 1992-2015 (S. Europe) 1992-2015 (N. Europe)
all skies	? (+4.20) ? (+7.10) ? (+4.50)	[32]	1989-2004 (Mediterranean) 1985-2000 (E. Europe) 1985-2001 (Europe)
all skies	? (-2.30)	[13]	1961-2000 (China, average of 459 stations)
all skies	? (-5.40)	[12]	after 2000 (S. Asia)

C. = Central, E. = Eastern, N. = Northern, S. = Southern, NW. = Northwestern, CE. = Central Eastern, CW. = Central Western

has a trend of +1.85%/decade (≈+0.19%/year) or +9.36 Wm^{-2}/decade (≈+0.94 Wm^{-2}/year), taking into account that = 488.95 Wm^{-2}.

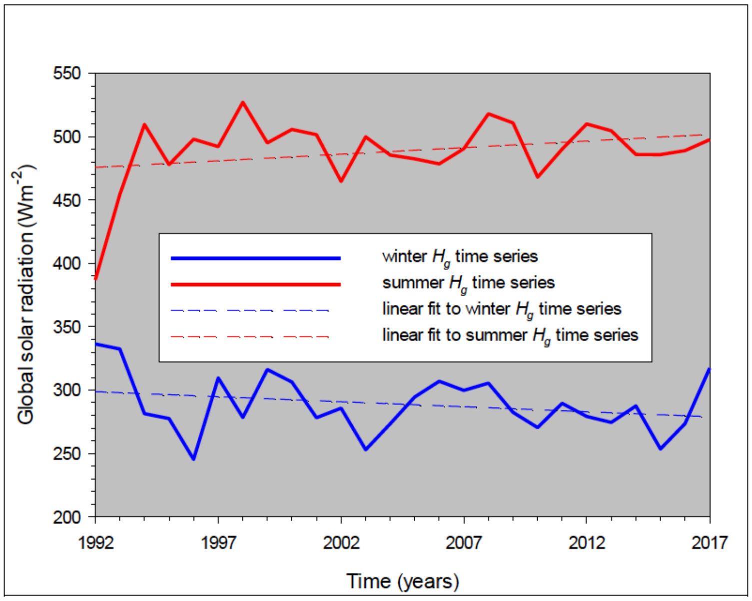

Figure 2: Variation of the winter/summer mean H_g values under all-sky conditions in Athens over the period 1992-2017. The linear best-fit expressions are given by Eqs. (**4a**) and (**4b**) for winter and summer, respectively.

For the clear-sky cases, Figure **3** shows the trend of the H_g time series for the winter and summer seasons over Athens. The linear fits to both plots show the seasonal trends of H_g under the mentioned cloudiness. These fits have relations given by the equations:

$$H_{g,c,w} = 1614.49 - 0.66\ year \quad (5a)$$

$$H_{g,c,s} = -1859.62 + 1.18\ year \quad (5b)$$

Again, considering the decade 1992-2001, applying the end years to Eq. (5a), taking the difference $H_{g,c,w2001}$ - $H_{g,c,w1992}$, and dividing it by the mean = 297.88 Wm^{-2}, it is found that H_g has a winter trend over the studied period of -1.99%/decade or ≈ -0.20%/year. These percentages correspond to trends of -5.94 Wm^{-2}/decade or ≈ -0.59 Wm^{-2}/year, respectively. By repeating the above calculations for the summer season in Eq. (5b), it is found that the H_g time series has a trend of +2.10%/decade (+0.21%/year) or +10.62 Wm^{-2}/decade (≈+1.06 Wm^{-2}/year). Note that = 505.17 Wm^{-2}.

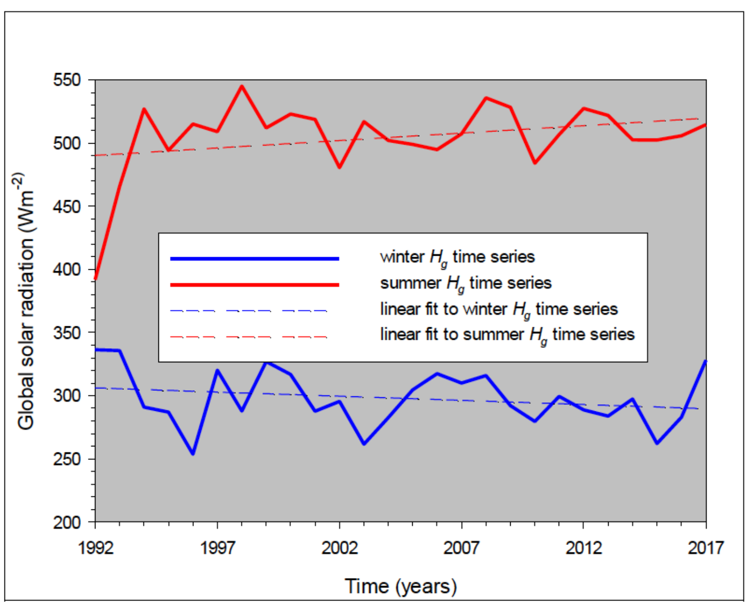

Figure 3: Variation of the winter/summer mean H_g values under clear-sky conditions in Athens over the period 1992-2017. The linear best-fit expressions are given by Eqs. (**5a**) and (**5b**) for all- and clear-skies, respectively.

Table **3** gives a summary of the winter/summer trends in the H_g time series and comparison with available results from similar studies.

The discrepancy between the present seasonal trend results and those in Kambezidis [17, 18] referring to the same period, venue and H_g time series may be attributed to the different way of calculating the trend. In the present study, the linear regression to the data series was preferred; in Kambezidis [17, 18] the ITA (Innovative Trend Analysis; [33, 34]) methodology was applied. The ITA method is a qualitative process and, therefore, the two sets of results cannot really be compared quantitatively.

3.2. Trends in H_d

Figure **4** shows the annual H_d averages under all- and clear-sky conditions. The linear fits to both plots show the trends of H_d under the mentioned cloudiness. These fits have relations given by the equations:

$$H_{d,a} = 1682.07 - 0.77\ year \quad (6a)$$

$$H_{d,c} = 2210.76 - 1.03\ year \quad (6b)$$

Table 3: Trends in the Winter/Summer H_g Mean Values under All- and Clear-Sky Conditions from Available Studies

Season (Cloudiness Conditions)	Trend in H_g %/decade (Wm^{-2}/decade)	Reference	Period (region)
winter (all skies)	-2.46 (-7.11)	present work	1992-2017 (Athens, Greece)
summer (all skies)	+1.91 (+9.36)		
winter (clear skies)	-1.99 (-5.94)		
summer (clear skies)	+2.10 (+10.62)		
winter (all skies)	practically no trend	[17, 18]	
summer (all skies)	practically no trend		
winter (clear skies)	practically no trend		
summer (clear skies)	practically no trend		
winter (all skies)	? (?) ? (?) ? (?) ? (?) ? (+1.40)	[14]	1986-2012 (C. Europe) 1986-2012 (N. Europe) 1986-2012 (E. Europe) 1986-2012 (S. Europe) 1986-2012 (NW. Europe)
summer (all skies)	? (+4.80) ? (?) ? (?) ? (+5.80) ? (?)		1986-2012 (C. Europe) 1986-2012 (N. Europe) 1986-2012 (E. Europe) 1986-2012 (S. Europe) 1986-2012 (NW. Europe)
winter (all skies)	? (-1.30)	[25]	1983-2010 & 1994-2010 (CE. Europe)
summer (all skies)	? (+0.40) ? (+2.10) ? (+4.30)		1994-2010 (CE. Europe) 1983-2010 (CE. Europe) 1983-2010 (Europe, excl. UK, France)

C. = Central, E. = Eastern, N. = Northern, S. = Southern, NW. = Northwestern, CE. = Central Eastern

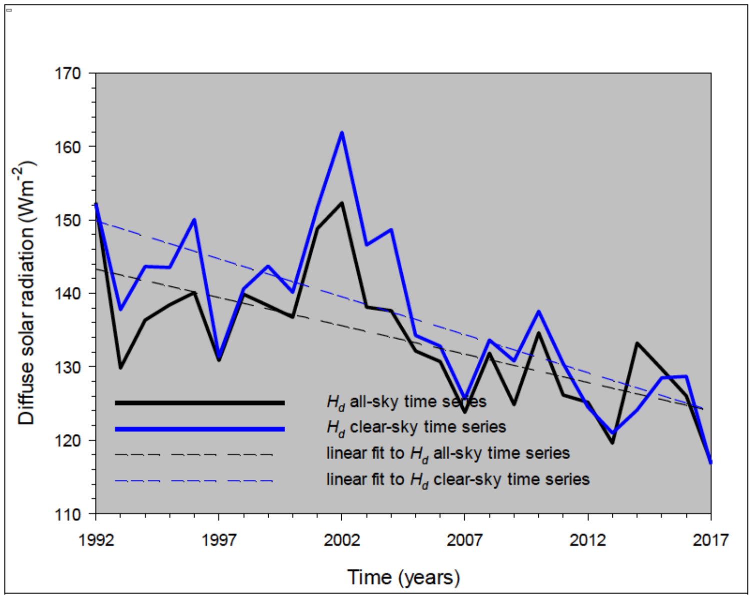

Figure 4: Variation of the annual mean H_d values under all- and clear-sky conditions in Athens over the period 1992-2017. The linear best-fit expressions are given by Eqs. (6a) and (6b) for all- and clear-skies, respectively.

In the same way, considering the decade 1992-2001, applying the end years to Eq. (6a), taking the difference $H_{d,a2001}$ - $H_{d,a1992}$, and dividing it by the mean = 133.64 Wm^{-2}, it is found that H_d has a trend over the studied period of -5.19%/decade or ≈ -0.52%/year. These percentages correspond to trends of -6.93 Wm^{-2}/decade or ≈ -0.69 Wm^{-2}/year, respectively, if the average = 133.64 Wm^{-2} is taken into account. For the case of clear skies, the trends become -6.77%/decade (≈-0.68%/year) and -9.27 Wm^{-2}/decade (≈-0.93 Wm^{-2}/year), if it is taken into account that = 136.94 Wm^{-2}. This decline in H_d under clear skies in the Athens area after 1992 may be attributed to a decline in the cloud optical depth (COD) over the Eastern Mediterranean (especially for low-level clouds [15]). Moreover, Floutsi *et al*. [35] found a decline of -1.30% in the precipitation amount over the Mediterranean during 2002-2014, "indicating a possible decline in convection and low-level cloudiness". In addition, Founda *et al*. [36] found a +3.00% increase in the annual sunshine duration values in the period 1983-2011 in the Athens area, a finding that supports the decline in COD.

A straightforward comparison of the all- and clear-sky trend results in H_d of this work cannot be made as similar studies do not almost exist in the literature apart from the work of Kambezidis [17, 18] who found same results. This gap in knowledge is probably due to a worldwide scarcity of H_d measurements because of expensive purchase and maintenance of solar platforms.

Figure **5** shows the seasonal (winter/summer) trend of H_d under all-sky conditions over Athens during the period of the study. The linear fits to both plots show the seasonal trends of H_d under the mentioned cloudiness. These fits are given by the expressions:

$$H_{d,a,w} = 1087.83 - 0.48\, year \quad (7a)$$

$$H_{d,a,s} = 2405.12 - 1.13\, year \quad (7b)$$

By applying the mentioned H_g calculations to H_d, it is found that the winter trend in H_d is -3.18%/decade (≈-0.32%/year), or -4.25 Wm^{-2}/decade (≈-0.43 Wm^{-2}/year), if the mean = 133.61 Wm^{-2} is taken into account in the calculations. For summer, the above results become -7.60%/decade (-0.76%/year), and -10.17 Wm^{-2}/decade (≈-1.02 Wm^{-2}/year), respectively. Note that = 133.86 Wm^{-2}.

Figure **6** shows the seasonal (winter/summer) trend of H_d under clear-sky conditions over Athens in the period 1992-2017. The linear fits to both plots show the seasonal trends in H_d under the mentioned cloudiness. These best fits are given by the equations:

$$H_{d,c,w} = 1305.32 - 0.58\, year \quad (8a)$$

$$H_{d,c,s} = 2471.72 - 1.16\, year \quad (8b)$$

By repeating the known calculations as for H_d clear skies, it is found that the winter trend in H_d is -3.83%/decade (-0.38%/year), or -5.22 Wm^{-2}/decade (-0.52 Wm^{-2}/year), if the mean = 136.22 Wm^{-2} is taken

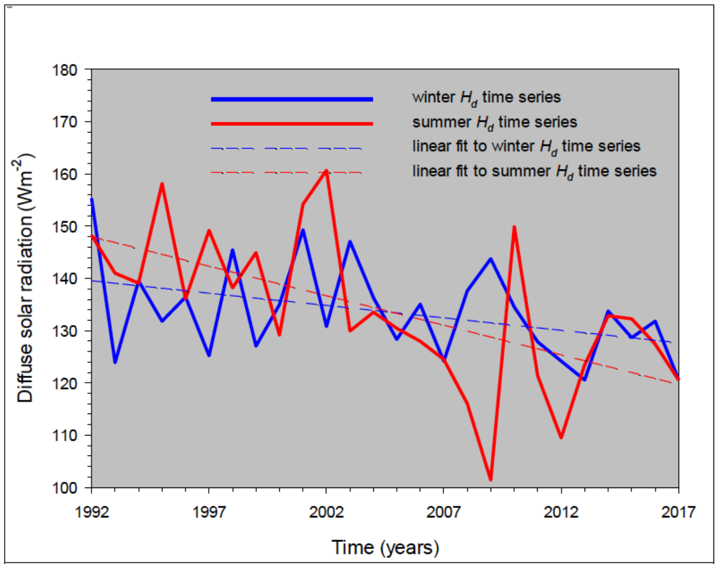

Figure 5: Variation of the seasonal mean H_d values under all-sky conditions in Athens over the period 1992-2017. The linear best-fit expressions are given by Eqs. (7a) and (7b) for winter and summer, respectively.

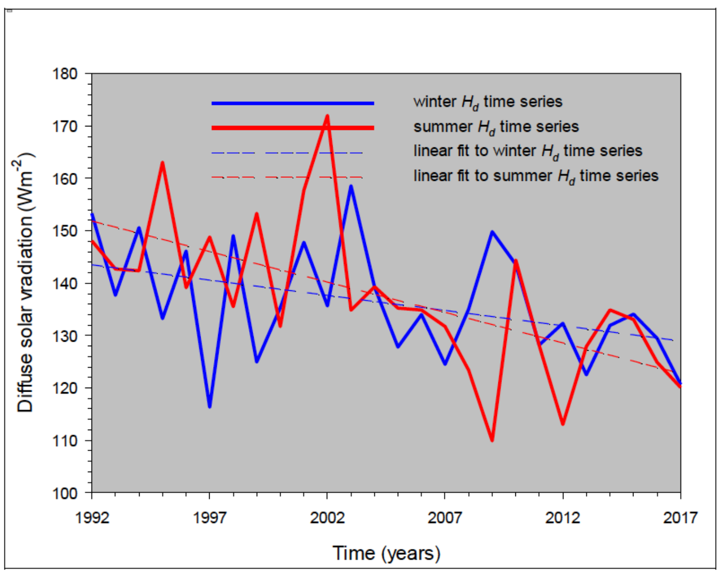

Figure 6: Variation of the seasonal mean H_d values under clear-sky conditions in Athens over the period 1992-2017. The linear best-fit expressions are given by Eqs. (8a) and (8b) for winter and summer, respectively.

into account in the calculations. The summer calculations lead to a trend of -7.60%/decade (-.76%/year), and -10.44 Wm^{-2}/decade (-1.04 Wm^{-2}/year), respectively. Note that = 137.30 Wm^{-2}.

Comparison of the seasonal trends in the diffuse solar irradiance with other from similar studies do not really exist in the international literature, as it is known up to now. The only attempt was made by Kambezidis [17, 18]. Table **4**, therefore, gives the comparison between the present study and that by Kambezidis [17, 18].

From the above Table it is seen that the qualitative results of Kambezidis [17, 18] are in a better agreement with those of the present work for H_d than for H_g (see Table **3**)

4. CONCLUSIONS

The present study investigated the variations and trends in two solar radiation components (global, diffuse) on horizontal surface over Athens in the period 1992-2017. The main conclusions of this work can be summarised in the following.

Table 4: Trends in the Winter/Summer H_d Mean Values under All- and Clear-Sky Conditions from Available Studies

Season (Cloudiness Conditions)	Trend in H_d %/Decade (Wm^{-2}/Decade)	Reference	Period (Region)
winter (all skies)	-3.18 (-4.25)	present work	1992-2017 (Athens, Greece)
summer (all skies)	-7.60 (-10.17)		
winter (clear skies)	-3.83 (-5.22)		
summer (clear skies)	-7.60 (-10.44)		
winter (all skies)	slight negative trend	[17, 18]	
summer (all skies)	very significant negative trend		
winter (clear skies)	significant negative trend		
summer (clear skies)	very significant negative trend		

To examine the annual solar radiation trends, application of a linear regression to the deseasonalised annual mean global/diffuse radiation values was made. In any type of skies, the analysis gave a positive trend of +0.40%/decade (+1.53 Wm^{-2}/decade) for H_g and a negative trend of -5.19%/decade (-6.93 Wm^{-2}/decade) for H_d.

Repetition of the above methodology for the seasonal trends to the two solar radiation components was made; for all-sky conditions, the analysis showed a winter trend for H_g of -2.46%/decade (-7.11 Wm^{-2}/decade) and a summer one of +1.85%/decade (+9.36 Wm^{-2}/decade). For clear skies, the winter trend became -1.99%/decade (-5.94 Wm^{-2}/decade) and the summer one +2.10%/decade (+10.62 Wm^{-2}/decade). The corresponding values for the diffuse solar component were as follows. All skies: winter trend of -3.18%/decade (-4.25 Wm^{-2}/decade), summer trend of -7.60% (-10.17 Wm^{-2}/decade). Clear skies: winter trend of -3.83%/decade (-5.22 Wm^{-2}/decade), summer trend of -7.60% (-10.44 Wm^{-2}/decade).

The above trend values show that these are all negative for H_d in both seasons, while for H_g it is negative in winter and positive in summer. These results clearly indicate a recovery in solar radiation levels over Athens in the period 1992-2017 (brightening effect) after a reduction in prior years [7, 37, 39]. Especially in the case of H_d, this negative trend may be attributed to a decline in COD over the Eastern Mediterranean [15].

A recent study on the reconstruction of AOD values over Romania in the period 1961-2015 [38] confirms the results of the present work. Particularly, these researchers state, “These reconstructed AOD time series reveal an upward trend in AOD until mid-1980s, followed by a downward trend until the present”. Indeed, the decrease in AOD in the period 1992-2017 over the Balkans can be related to an increase in clear-sky solar radiation. As a matter of fact, the brightening effect over the Mediterranean, the Balkans and Southern/Eastern Europe has been verified by many relevant studies [2, 9, 14-16, 23, 26-28, 31].

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