USE OF CLEAR DAY SOLAR RADIATION FOR ESTIMATION OF ANTHROPOGENIC AEROSOLS IN ATMOSPHERE OF TIRANA

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Abstract

Change of irradiative properties of the atmosphere during clear days is an indicator, among others, of existence of atmospheric aerosols and can be used as a method for assessment both air pollution and solar energy potentials, and their variation in time and space. The main objective of this study is to estimating the optical depth (AOD) of atmosphere in Tirana in a clear sky and its time evolution using measurement of solar energy falling in an horizontal surface. Radiance measurements were carried by a meteorological station situated at the height of 20 m over the ground. We estimated AOD by measurement of solar energy falling on a horizontal surface globally on a daily time scale, during first two hours after the sunrise, during the last two hours before the sunset, also globally before and after noon time. We estimated change on solar insolation from one day to the other and within a day from morning hours to evening hours. Measurements were carried during long periods with clear sky. Careful measures were made to estimate inference of air humidity and wind speed on modification of solar insolation data. Day one was considered the first clear sky day after heavy rain day. We have found that solar energy falling on a horizontal surface decreases with increasing days from last rain and from morning hours to evening hours. The decreasing rate of insolation is described by a power function $I = I_0\, d^{-\alpha}$ W/m^2 where α varies from 0.006 to 0.03, depending on the season. Correlation coefficients, considering uncertainties due to multiple factors influencing the results, are really good, more than 0,9. Periodical daily change of solar energy during clear days is a strong indication of their anthropogenic origin.

Key words: *anthropogenic aerosols, solar insolation, time dependence of aerosols, clear day radiation*

Introduction

Atmospheric aerosols play an important role in global climate forcing through their direct and indirect effects. They also have significant regional impacts on both climate and air quality. Information on aerosol type is crucial for improving our understanding and assessment of anthropogenic influences of aerosols on climate. [1]

Atmospheric aerosols are suspensions of solid and/or liquid particles in air. Aerosols are ubiquitous in air and are often observable as dust, smoke, and haze. Both natural and human processes contribute to aerosols concentrations. On a global basis, aerosols mass derives predominantly from natural sources, mainly sea salt and dust. However, anthropogenic (manmade) aerosols, arising primarily from a variety of combustion sources, can dominate, in and downwind of highly populated and industrialized regions, and in areas of intense agricultural.

The term “atmospheric aerosols” encompasses a wide range of particles types having different compositions, sizes, shapes, and optical properties. Aerosols loading, or amount in the atmosphere, are usually quantified by mass concentration or by an optical measure, aerosols optical depth (AOD). AOD is the vertical integral through the entire height of the atmosphere of fraction of incident light either scattered or absorbed by airborne particles. [2]

The spatial and temporal distribution of aerosol microphysical and optical properties is heterogeneous in nature and is caused by the wide variety of aerosol sources and have relatively short atmospheric lifetime. In urban regions, aerosols originate most commonly from industrial and domestic emissions, biomass burning, local transportation, and local wind-driven dust. [3] Aerosols vary in time and space, and increasing aerosol amounts generally lower the downward surface solar radiation. Small aerosols in the submicron sizes are usually associated with black carbon, organic aerosol, sulfate, nitrate, etc., and these small particles are mostly anthropogenic. Carbon rich anthropogenic aerosols have higher efficiency in reducing the surface solar radiation. Therefore, if aerosol amount changes over time, it would be very important to partition the change between anthropogenic and natural ones. [4]

Aerosol direct irradiative effect denotes the change in irradiative flux at top of the atmosphere or at the Earth’s surface due to the presence of aerosols. Present measurement capabilities permit determination of the global annual average cloud-free aerosol for solar radiation. Deriving the aerosol direct effect over land from flux measurements is complicated by a large and highly heterogeneous surface reflection. During recent years, different inversion methods have been proposed to retrieve aerosol microphysical properties using sun and sky radiance measurements in the horizontal or principal plane configurations Applying such methods to sky radiance and sun-photometric measurements many authors have presented results of columnar aerosol optical and microphysical properties sky radiance measurements in the horizontal plane have received less attention due to the difficulties in data quality assurance. One of the major difficulties in retrieving aerosol properties from sky radiance is the screening of partially cloud-contaminated data. The sky radiance measurements allow us to obtain columnar optical and microphysical aerosol properties throughout the day.[5]

The main objective of this study is to quantify the aerosol irradiative effect at the surface in Tirana and on temporal scales in clear sky condition, estimating temporal evolution, both in daily and hour scale.

Estimation method and measuring system

As the solar radiation passes through the earth’s atmosphere it is modified due to the following reasons: Absorption by different gases in the atmosphere, molecular (or Rayleigh) scattering by the permanent gases and aerosol scattering due to particulates.

Absorption by atmospheric molecules is a selective process that converts incoming energy to heat, and is mainly due to water, oxygen, ozone, and carbon dioxide. A number of other gases absorb radiation but their effects are relatively minor and for most practical purposes can be ignored. [6]

Atmospheric scattering can be either due to molecules of atmospheric gases or due to smoke, haze, and fumes. [7]

As the primary constituents of the atmosphere and the thickness of the atmosphere remain essentially constant under clear-sky conditions, molecular scattering can be considered constant for a particular wavelength. [8] The effects of the atmosphere in absorbing and scattering solar radiation are variable with time as atmospheric conditions changes due to frequent changes in concentration of two main components: aerosols and humidity. The result is change of atmospheric transmittance and the daily solar energy falling on the ground. The transmittance values vary with location and elevation between 0 and 1. It is important for any evaluation of influence of aerosols concentration on air transmittance to define a standard atmosphere “clear” sky and calculate the hourly and daily radiation that would be received on a horizontal surface under these standard conditions. We agreed to use the transmittance of the air after a heavy rain period as a reference zero day clear sky transmittance. Following days were counted as days after the clear sky day zero.

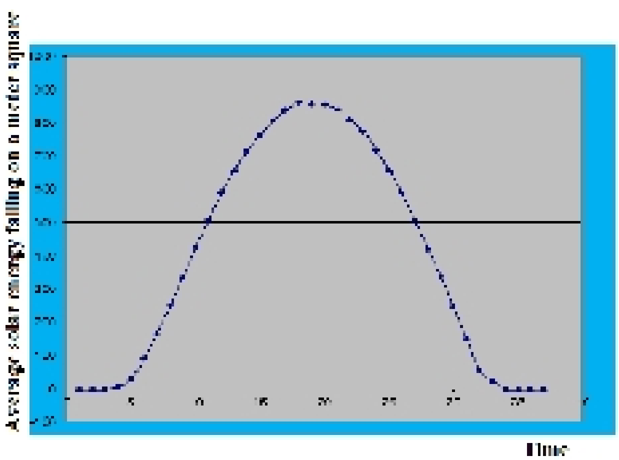

Figure 1 A typical clear sky daily distribution of solar energy for the month of June. Every point of the curve corresponds to the average solar energy falling on a square meter of horizontal surface during half an hour

The solar insolation on a horizontal plane was estimated for all the day (from sunrise to sunset), for half of the day (from sunrise to noon end from noon to sunset) and also for first two hours in the morning and last two hours in the evening. The reason was to estimate influence of anthropogenic daily activities on changes of concentration of aerosols in atmosphere.

Our preliminary observation showed that solar energy arriving on the ground was very sensitive to small fluctuations of cloud coverage of the sky during the day which strongly affects the results of measurement. To minimize disturbances due to above mention effects we carefully checked the sky through all the day and dismissed the data of measurement made during days with variable coverage of the sky. Also, in all cases, we carefully compared the half an hour distribution of measured solar energy with a standard clear sky distribution for the given period of the year to check if some occasional cloud had escaped our investigations. In Figure 1 is shown a typical clear sky daily distribution of solar energy for the month of June. Every point of the curve corresponds to the average solar energy falling on a square meter of horizontal surface during half an hour.

Air humidity and wind speed are to other factors that cause a disturbance of estimation of evolution of concentration of aerosols even in clear sky and, also there were impossible to control. In order to minimize the disturbance caused by above factors we determined the correlation functions between falling solar energy and mean relative humidity of the air and mean speed of the wind, respectively. Measurement data of solar energy were then corrected for the contribution effect of relative humidity and speed of the wind.
Meteorological parameters interesting our study, it is solar radiation, air relative humidity wind speed and rain rate, were measured using a Davis Vantage Pro2 weather station situated at the height of 20 m over the ground on top of the Main Building of Polytechnic University of Tirana. The above parameters were estimate in a time scale of half an hour and the respective means of parameters during the corresponding time were recorded.

Results and discussion

a) Corrections due to air humidity and wind speed.

Air humidity and wind speed are two factors that cause effects similar to the effects caused by dust and aerosols in the atmosphere in clear sky. To consider and minimize modifications caused on estimation of evolution of concentration of aerosols by air humidity and wind, factors that is not possible to control, we studied the correlation between daily, morning hours and afternoon hours solar energy with air humidity and mean wind speed. In figure 2 is show a typical correlation between daily solar energy falling in unite horizontal area and daily mean air humidity. Data corresponds to thirteen consecutive clear sky days after day zero with intensive rains. Three of the days were not considered due to cloud developments. The linear approximation regression equation is Y =-0.2164X +8.5574 and correlation coefficient R^2 = 0.2126, which means that only 21% of changes on daily mean solar energy is related to changes on mean daily air humidity. However the correlation coefficient changes from one case to the other.
Wind is the second factor that modifies average solar energy falling on the ground, but any increase on mean wind speed causes increase of mean falling solar energy. In figure 3 is shown a typical correlation between daily solar energy falling in unite horizontal area and mean before noon and after noon and corresponding mean wind speed. Black line corresponds to linear approximation of dependence between mean wind speed and solar energy falling in a horizontal surface from sunrise to noon, while

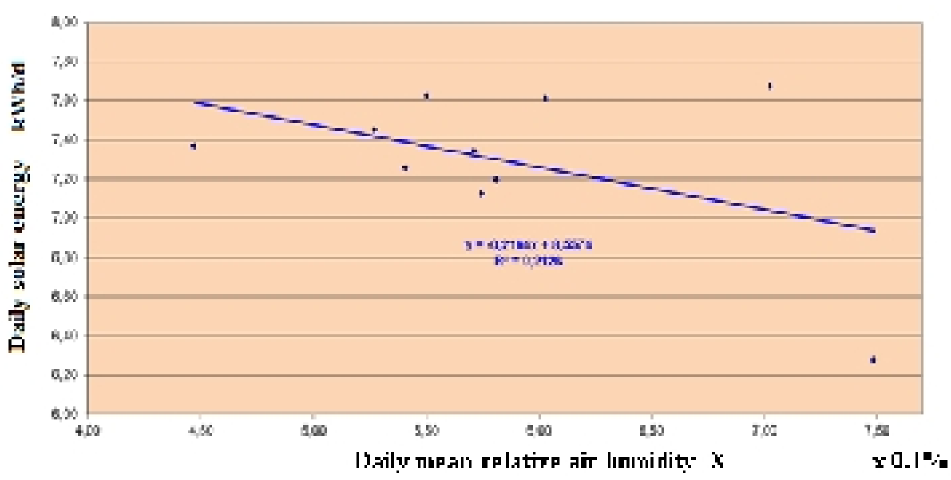

Figure 2. Dependences between daily mean relative humidity of the air and daily total solar energy falling in a horizontal surface. Data corresponds to thirteen consecutive clear sky days after day zero with intensive rains. Three of the days were not considered due to cloud developments. Regression equation is Y =-0.2164X +8.5574 and correlation coefficient R^2 = 0.2126

red line corresponds to linear approximation of dependence between mean wind speed and solar energy falling in a horizontal surface from noon to sunset. Data corresponds to thirteen consecutive clear sky days after day zero with intensive rains. Three of the days were not considered due to cloud developments. Regression equation for morning hours is Y = 0.0716X +4.236, correlation coefficient R^2 = 0.651, and for afternoon hours is Y = 0.038X +4.0227, correlation coefficient R^2 = 0.3869. Correlations between mean air humidity and total solar energy falling in unite horizontal area is negative; it is increase of air humidity cause decrease of falling solar energy. On the contrary, correlations between mean wind speed and total solar energy falling in unite horizontal area is positive; it is increase of mean wind speed cause increase of falling solar energy.

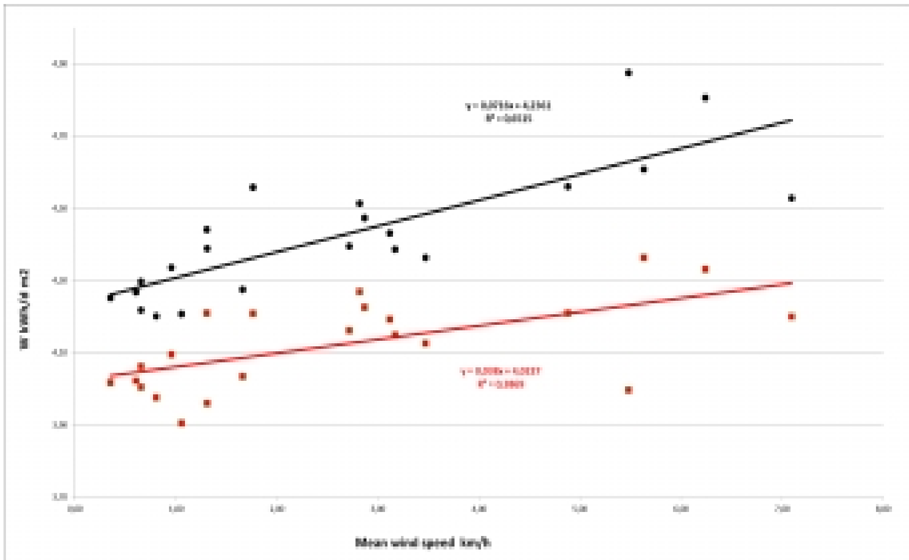

Figure 3. Dependence between wind mean speed and total solar energy falling on a horizontal surface. Black line is for data from sunrise to noon, while red line is for data from noon to sunset. Data corresponds to thirteen consecutive clear sky days after day zero with intensive rains. Three of the days were not considered due to cloud developments. Regression equation for morning hours is Y = 0.0716X +4.236, correlation coefficient R^2 = 0.651, and for afternoon hours is Y = 0.038X +4.0227, correlation coefficient R^2 = 0.3869

Then above dependaces show that wind and relative air humidity act in opposite directions, and corrections needed to be made to the experimental data to convert in standard condition data, in some cases, can compensate each other.

b) Dependence of falling mean solar energy on time past from last rainy day

The main objective of the study was finding a time dependence relationship between mean solar energy falling in a horizontal surface and time past from last rainy day. We supposed that most of aerosols go to the ground during a heavy rainy day and the atmosphere can be considered as “clean”. Any future change to amount of solar energy falling to a horizontal surface is supposed to be caused by change of amount of aerosols in the atmosphere. Data were properly converted to “standard atmosphere” data, it is data corrected for air humidity and wind speed. In figure 4 are shown two typical graphs of evolution of total solar energy falling during a clear sky day on a horizontal surface with number of days passed from last rainy day. Data corresponds to thirteen consecutive clear sky days after day zero with intensive rains. Three of the days were not considered due to cloud developments. Blue line and markers corresponds to measured uncorrected data.

Approximation line best fitting the data was a power function of the form: $Y = 7.7634\ X^{-0.033}$, where Y is total solar energy falling during a clear sky day on a horizontal surface of are 1 m^2 and X is for number of days passed from last heavy rainy day. Correlation coefficient $R^2 = 0.8068$. Black line and markers are for real data corrected for air relative humidity and speed of the wind. Approximation line best fitting the data was a power function of the form $Y = 7.7634\ X^{-0.045}$ and correlation coefficient $R^2 = 0.9685$. Increase of correlation coefficient for corrected data can be considered as a probable demonstration of our suggestion that main factors causing fluctuation of energy data in apparently identical sky conditions are air humidity and speed of the wind. Aerosols are important to the climate system because they affect the radiative balance of the planet. They scatter and absorb solar radiation, and therefore contribute to atmospheric solar heating and surface cooling. Urban/industrial pollution and smoke from vegetation burning are mostly anthropogenic, while dust and marine aerosols are mostly natural. There is also uncertainty in distinguishing natural from anthropogenic aerosols. The reason is that natural and anthropogenic aerosols have different proportions of fine and coarse aerosols. However one of main charasteristics of anthropogenic aerosols is their time dependance, it is their dependance on the human activity which is the source of aerosols. Urban aerosols originate from daily activity of inhabitants, mainly trnsport. Having this in mind we expect to find some periodical change during the day and night on concetration of aerosols, which will be an indicator of anthropogenic origin of aerosols. During the night, when the urban activity is diminished, the amount of anthrogenic aerosols is expected be less than in afternoon. We compared solar energy falling in unit area during morning hours (from sunrise to the noon) with solar energy falling in unit area during morning hours (from noon to sunset). In figure 5 is shown difference between solar energy falling in a clear sky day on a square meter of horizontal surface during morning hours (from sunrise to noon) with solar energy in a clear sky day on a horizontal surface during afternoons hours (from noon to sunset) with number of days passed from last rainy day.

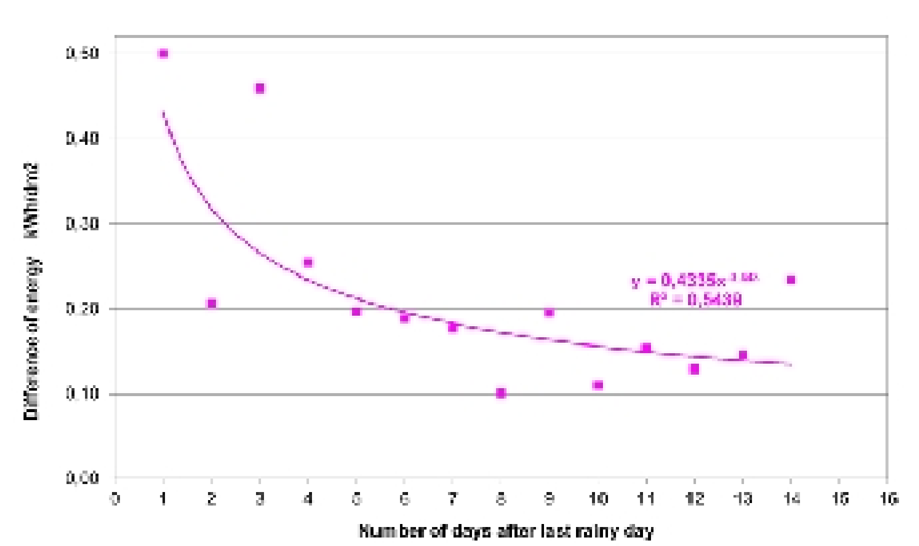

Figure 4. Evolution of total solar energy falling during a clear sky day on a horizontal surface with number of days passed from last rainy day. Blue line and markers are for real uncorrected data. Approximation function best fitting the data is $Y = 7.7634\ X^{-0.033}$ and correlation coefficient $R^2 = 0.8068$. Black line and markers are for real data corrected for air relative humidity and speed of the wind. Approximation function best fitting the data is $Y = 7.7634\ X^{-0.045}$ and correlation coefficient $R^2 = 0.9685$

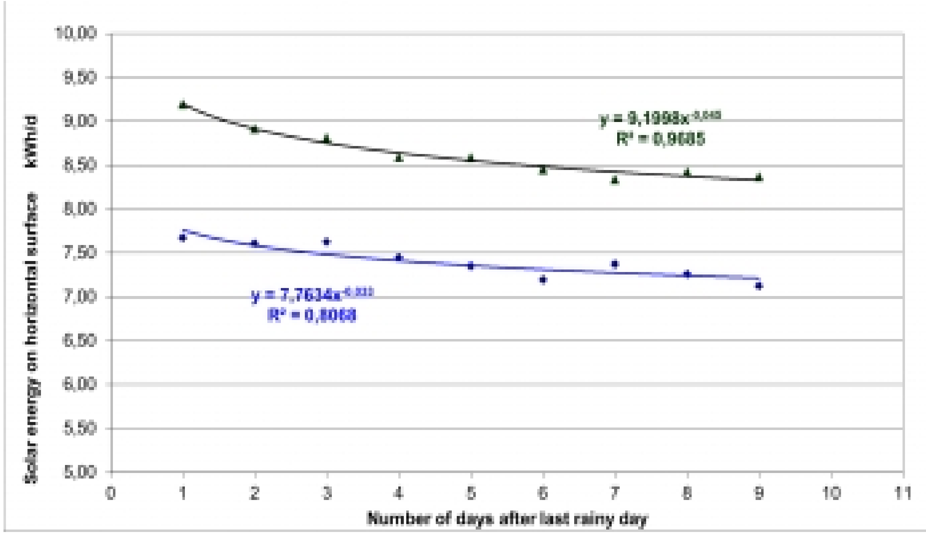

Figure 5. Difference between solar energy falling in a clear sky day on a square meter of horizontal surface during morning hours (from sunrise to noon) with solar energy in a clear sky day on a horizontal surface during afternoons hours (from noon to sunset) with number of days passed from last rainy day.

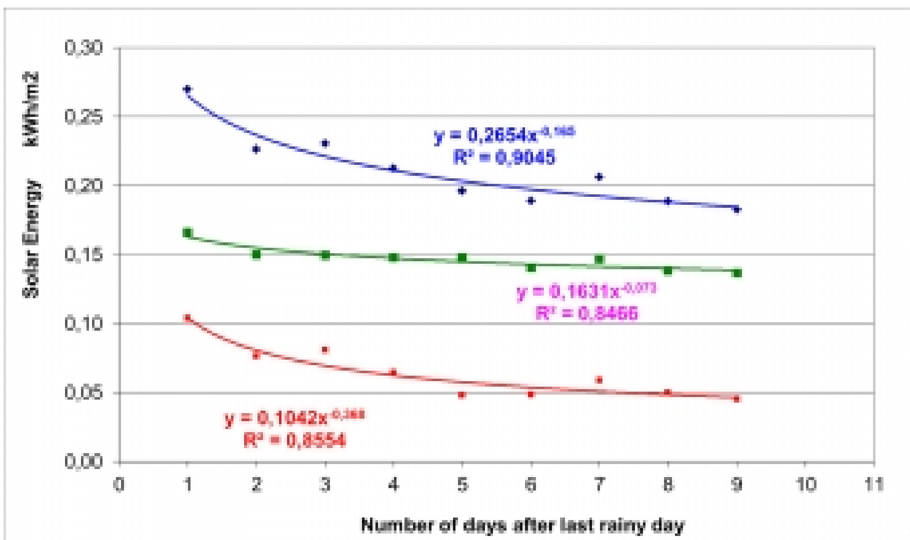

Figure 6. Solar energy falling in a clear sky day on a horizontal surface during first two hours of the day after sunrise (blue line and marks), solar energy falling in a clear sky day on a horizontal surface during last two hours of the day before sunset (green line and marks) and the difference between the two firsts with number of days passed from last rainy day.

Data corresponds to thirteen consecutive clear sky days after day zero with intensive rains. Three of the days were not considered due to cloud developments. Approximation line best fitting the data was a power function of the form: $Y = 7.7634\ X^{-0.443}$ where Y is difference between solar energy falling in a clear sky day on a square meter of horizontal surface during morning hours (from sunrise to noon) with solar energy in a clear sky day on a horizontal surface during afternoons hours (from noon to sunset) and X is for number of days passed from last heavy rainy day. Correlation coefficient $R^2 = 0.5439$. Data are corrected for relative air humidity and wind speed. It is interesting to note that difference between morning and afternoon solar energy is consistent, which shows that its origin is related with anthropogenic activities during the day. Fast decreasing of the difference with days passed from the last rainy day shows a trend toward a dynamic equilibrium between decantation process of aerosols

during the night and their generation during the day.
In figure 5 the data used are total energy falling in a horizontal surface during morning hours and afternoon hours, which cause a smoothing effect on differences between energies. In order to have a more accurate evidence of anthropogenic nature of periodic change of aerosol concentration we compared solar falling in a clear sky day on a horizontal surface during first two hours of the day after sunrise (Figure 6 blue line and marks), solar energy falling in a clear sky day on a horizontal surface during last two hours of the day before sunset (green line and marks) and the difference between the two firsts with number of days passed from last rainy day. Data corresponds to thirteen consecutive clear sky days after day zero with intensive rains. Three of the days were not considered due to cloud developments. Approximation power equation for data measured during first two hours of the day is $Y = 0.2654\ X^{-0.165}$ and correlation coefficient $R^2 = 0.9045$. Data are corrected for relative air humidity and wind speed. Approximation power equation for data measured during last two hours of the day is $Y = 0.1631\ X^{-0.073}$ and correlation coefficient $R^2 = 0.8466$. Also, approximation power equation for differences between two sets of data is $Y = 0.1042\ X^{-0.368}$ and correlation coefficient $R^2 = 0.8561$. The last result and much higher correlation coefficient (0.86 compared with 0.54) better confirm the result shown in Figure 5 (the difference between morning and afternoon solar energy is consistent). This is again evidence supporting our suggestion that, with good probability, aerosols that cause changes in absorption of solar radiation is related with anthropogenic activities during the day. Also, fast decreasing of the difference with days passed from the last rainy day again shows a trend toward a dynamic equilibrium between decantation process of aerosols during the night and their production during the day.

Conclusions

Use of solar radiation on a horizontal surface during clear sky day can be a useful method to monitor changes in aerosols density in near atmosphere. The correlation coefficients are as high as more than 0.95. We applied this method for the first time to monitor the atmosphere in Tirana. First preliminary results evidenced some very interesting phenomenon. Aerosol concentration in atmosphere of Tirana is very dynamic. It changes from one day to the other and from morning to afternoon. Concentration of aerosols increase with increasing number of days passed from last rainy day. The approximation function best describing the change is a power function. It is interesting to note that difference between morning and afternoon solar energy is consistent, which shows that change in concentration of aerosols is mainly related to anthropogenic activities during the day. However, the difference tends to decrease with increasing of number of days passed from the last rainy day, which is an evidence of a trend toward a dynamic equilibrium between decantation process of aerosols during the night and their generation during the day.

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