Effect of Tropospheric Nitrogen Dioxide on Incoming Solar Radiation

H.D. Kambezidis[1,*], L.D. Melas[2], D.H. Kampezidou[3] and B.E. Psiloglou[1]

[1]*Research Director, National Observatory of Athens, Greece*

[2]*Research Engineer, Centre for Research and Technology, Thessaloniki, Greece*

[3]*Postgraduate Student, Umeå University, Umeå, Sweden*

Abstract: Incoming **s**olar radiation is known to undergo an interaction with the constituents of the Earth's atmosphere. This interaction is expressed by means of the mechanisms of absorption, scattering and reflection. The occurrence of each such mechanism depends on the size of the molecules in relation with the wavelength of the incoming radiation. The study of the interaction of solar radiation with atmospheric constituents, including aerosols, has long attracted scientific interest; such an interaction is related to climate-change issues. Among the atmospheric constituents, interest has been given to the anthropogenically-derived nitrogen dioxide (NO_2) in the troposphere, since there has been found that anthropogenic aerosols have been playing an important role in their interaction with the incoming solar radiation. That is the reason for the recent discovery of the global dimming phenomenon. Mean daily solar radiation values from the Actinometric Station of the National Observatory of Athens (ASNOA) are compared with simultaneous ones of NO_2 measured by the network of the Greek Ministry of Environment within the Athens basin. The period considered in this study covers the years 1990 - 2004. The study examines clear-sky conditions in order to show the influence of NO_2 alone on solar radiation. The results show that increasing levels of NO_2 cause smaller/greater scattering of solar radiation (global/diffuse components) at different rates, thus resulting in an attenuation of solar radiation; this attenuation rate is greater in the global component than in the diffuse one, in absolute terms.

Keywords: Nitrogen dioxide, solar radiation, aerosols, athens, greece.

1. INTRODUCTION

It is well-known that the incoming solar radiation is affected by the various constituents of the Earth's atmosphere, such as gases and aerosols (e.g. [1]). The solar-radiation attenuators are of natural or of anthropogenic origin. Nitrogen dioxide (NO_2) from combustion units (industry, vehicles) has been of major concern for the Athens air quality during the '80s and '90s (e.g. [2-4]), since the air-pollution problem in that period was mainly *smog*.

The National Observatory of Athens (NOA) was the first institution to start air-quality measurements in the Athens basin by deploying six semi-automatic stations monitoring sulphur dioxide (SO_2) and black smoke (BS). The network was operated in the period 1969 - 1984. After 1984, the Greek Ministry of Environment started deploying a network of automatic stations in the same area as part of Greece's obligations to EU for monitoring and reporting about the air quality in the city and its surroundings, including NO_2.

The levels of NO_2 have steadily been declining since mid-90s at most of the stations of the Athens network because of the various measures taken by the State to mitigate the photochemical air pollution in the Greater Athens Area. Furthermore, the new EU directive commanded Member States to monitor particulate matter (PM) with diameters of 10 μm and 2.5 μm (PM_{10} and $PM_{2.5}$, respectively). This EU regulation has been adopted by Greece, too. The evolution of the mean annual NO_2 concentration levels as well as those of GHI is shown in Figure **1**.

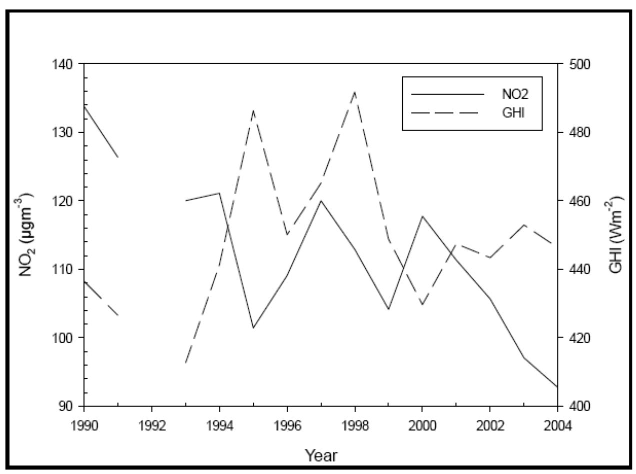

Figure 1: Mean annual levels of NO_2 (solid line, Patission station) and GHI (dashed line, ASNOA station) in the period 1990 - 2004. An almost anti-correlation between the two curves seems to exist. Clear days have only been considered in the plot. Most of the 1992 NO_2 data are missing.

The present study examines the attenuation caused by anthropogenic NO_2 on the incoming solar radiation

*Address correspondence to this author at the National Observatory of Athens, hops Nymphon, GR-11810 Athens, Greece; Tel: +30-210-3490119; Fax: +30-210-3490140; E-mail: harry@noa.gr

E-ISSN: 2410-2199/15

(both global and diffuse components) in a 15-year period (1990 - 2004). The values of the solar radiation components have been taken from the Actinometric Station of NOA (ASNOA).

2. DATA AND METHODOLOGY

The data base for the present study consists of mean daily values of global horizontal solar radiation – GHI (Wm^{-2}), diffuse horizontal solar radiation – DHI (Wm^{-2}), cloud cover (octas), and 24-h averages of NO_2 concentration (μgm^{-3}). The first three parameters have been taken from the measurements of ASNOA; the latter from the air-pollution monitoring network of the Greek Ministry of Environment. All parameters cover the period 1990 - 2004, as diffuse solar radiation measurements began at ASNOA in 1990.

From the daily values, mean annual ones have been calculated. In order to examine the influence of NO_2 on solar radiation, without the effect of clouds, clear-sky days have only been considered. The criterion for the selection has been that the cloud cover be equal or less than 1.7 octas. Therefore, all values of the other parameters (GHI, DHI, NO_2) not corresponding to this criterion have been rejected and have not been considered in the subsequent analysis.

Care has also been taken for the DHI values not to exceed those of GHI by 5% (10% is the usual limit, e.g. [5-7]). Also, any negative or missing values in all parameters of the data base have been excluded from the analysis. In summary, 5483 daily values constituted the initial data base of the study; after the quality-control criteria, 1892 daily values have been left for analysis.

3. RESULTS

A first step in the study is to present a graph of GHI versus NO_2 concentration for the period 1990 - 2004. Figure **2** shows the mean monthly values for both parameters. The prediction limits refer to the region of the GHI uncertainties in predicting the response for a single additional NO_2 observation in the range of 0 – 180 μgm^{-3}. The confidence limits refer to the region of the uncertainties in the predicted GHI values for NO_2 being in the range of 0 – 180 μgm^{-3}.

Since clear days have been considered for the analysis, the graph verifies the influence of tropospheric NO_2 (found within the planetary boundary layer – PBL, mostly) on solar radiation. For higher concentrations of NO_2, lower levels of solar radiation are recorded as a higher attenuation of solar radiation by the NO_2 molecules occurs.

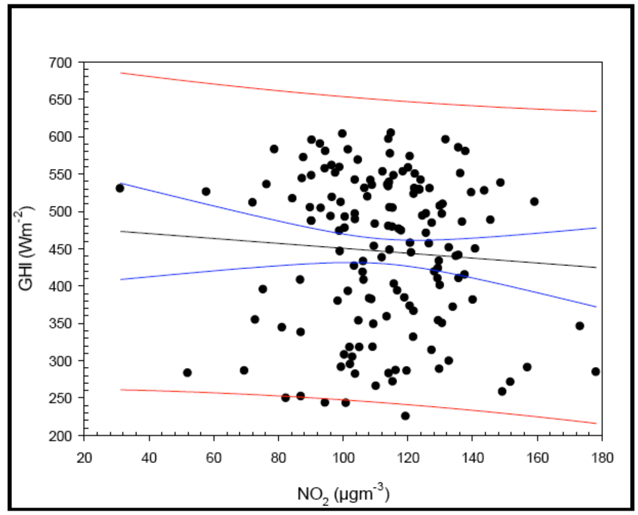

Figure 2: Co-variation of mean monthly values of GHI with NO_2 concentration for Athens in the period 1990 - 2004 under clear skies. The best fit to the measurements is GHI = -0.33NO_2+483.44, R^2 = 0.05. The red band shows the prediction limits and the blue one the 95% confidence limits.

In a second step, a similar graph is derived for DHI and NO_2 concentration for the same period of time. Clear-sky conditions are also chosen in order to avoid the influence of clouds on solar radiation. The same procedure was followed in the case of GHI, as mentioned in Section 2. The diffuse part of the solar radiation is mostly related to the scattering effect of solar light due to the presence of various scatterers in the atmosphere (molecules, aerosols).

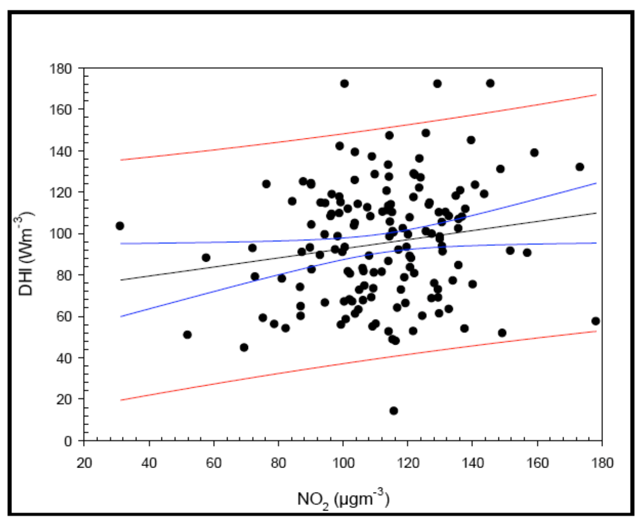

Figure 3: As in Figure **2**, but for the co-variation of DHI with NO_2 concentration. The equation of the best-fit straight line is DHI = 0.22NO_2+70.64, R^2 = 0.03.

As one might expect, increasing values of diffuse radiation occur with increasing values of NO_2 concentration; this implies greater scattering effect of diffuse solar radiation in the presence of higher amounts of NO_2 in the lower atmosphere (troposphere). The explanation is that NO_2 molecules seem to mostly scatter than absorb solar light; this is an integrated effect between NO_2 molecules and incoming solar radiation considered in the wavelength band of 0.300 – 3000 nm as a whole. Therefore, a greater concentration of scatterers in the atmosphere (such as NO_2) results in an enhancement of scattering entities in the atmosphere, thus producing greater diffuse light; this effect is shown in Figure **3** with higher DHI values as NO_2 gets higher concentration values. The opposite has been concluded in the presence of BS particles [8].

An interesting issue in this respect is to examine the rate of simultaneous attenuation of GHI and DHI. One should remember that GHI consists of DHI and direct solar light. This can be accomplished by investigating the behaviour of the ratio DHI/GHI versus NO_2; this behaviour is shown in Figure **4**. As the coefficient in the GHI is higher in absolute terms (see Figure **2**) than that of DHI (see Figure **3**), the best-fit curve to the data present an increasing trend as the NO_2 values increase.

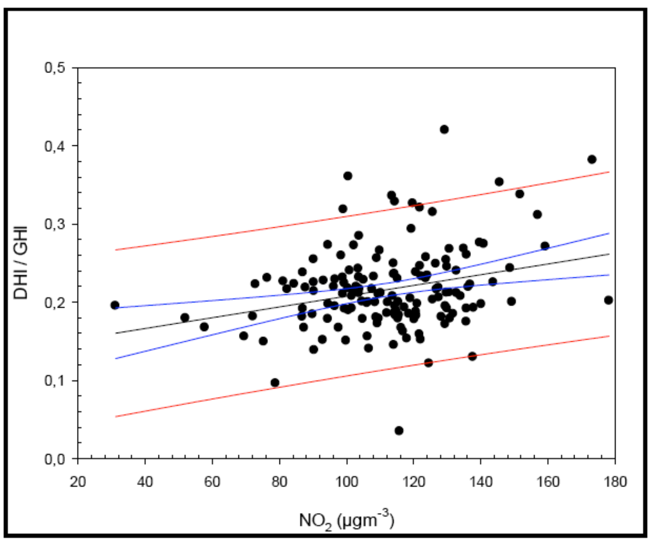

Figure 4: As in Figure **2**, but for the co-variation of the ratio of DHI/GHI with NO_2 concentration. The best-fit straight line has equation DHI/GHI = $0.0007NO_2+0.14$, $R^2 = 0.08$.

To see the effect of NO_2 on solar radiation in an urban environment, such as that of Athens, let us consider two cases of NO_2 concentrations; those of 100 and 200 μgm^{-3} (the latter is the EU limit for taking extra measures by the State). In the first case the value of DHI/GHI is 0.21 and in the second 0.28, from the Equation provided in Figure 4. For a global radiation level of, say, 300 Wm^{-2} for both cases, the DHI is found to be 63 and 84 Wm^{-2}, respectively, i.e. a 21-Wm^{-2} difference between the two values. In this example there is a reduction of 25% in the diffuse radiation. Conversely, considering a diffuse radiation level of 150 Wm^{-2}, the above ratios lead to corresponding GHI values of 714.29 and 535.71 Wm^{-2}. In this case, the reduction in GHI is also 25%. These results agree well with those from an older study in the Thessaloniki area [9], which showed a reduction of about 10% due to a combined water-vapour and dust effect on solar radiation. Similar attenuation values have been found by Solomon *et al*. [10].

4. CONCLUSIONS

The study has revealed an impact of the NO_2 particles on the solar radiation levels in the Athens area for the period 1990 - 2004. This impact is related to producing stronger scattering to the solar rays by the NO_2 particles as their concentration becomes higher. The main conclusion of the study is the different impact of NO_2 on GHI and DHI components. One unit of increase in the NO_2 concentration reduces GHI by almost 0.33 units and increases DHI by 0.22 units. Therefore, the anthropogenically-derived NO_2 within the PBL drastically influences the incoming solar radiation under clear skies. It has to be mentioned here that unavoidably columnar parameters (such as GHI and DHI) are correlated with point Measurements (such as NO_2).

REFERENCES

[1] Iqbal M. An introduction to solar radiation. Academic Press 1983.

[2] Kambezidis HD, Kassomenos P, Kiriaki E. Concentration levels in a monitoring network in Athens, Greece. Atmos Environ 1986; 20: 601-4. http://dx.doi.org/10.1016/0004-6981(86)90104-6

[3] Kambezidis HD, Paliatsos AG. A note on smoke concentration prediction in Athens, Greece. Meteorol Atmos Phys 1991; 45: 181-6. http://dx.doi.org/10.1007/BF01029653

[4] Adamopoulos AD, Kambezidis HD, Zevgolis D. Case studies of atmospheric NO_2 column in the atmosphere of Athens, Greece: comparison between summer and winter. Fres Environ Bull 2002; 11: 480-3.

[5] Kambezidis HD, Psiloglou BE, Gueymard C. Measurements and models for total solar irradiance on inclined surface in Athens, Greece. Solar Energy 1994; 53: 177-85. http://dx.doi.org/10.1016/0038-092X(94)90479-0

[6] Kambezidis HD, Psiloglou BE, Synodinou BM.) Comparison between measurements and models for daily solar irradiation on tilted surfaces in Athens, Greece. Rene Energy 1997; 10: 505-18. http://dx.doi.org/10.1016/S0960-1481(96)00045-6

[7] Psiloglou BE, Santamouris M, Asimakopoulos DN. Atmospheric broadband model for computation of solar

radiation at the Earth's surface. Application to Mediterranean climate. Pure Appl Geophys 2000; 157: 829-60. http://dx.doi.org/10.1007/PL00001120

[8] Kambezidis HD, Melas L. Interaction of black smoke and solar radiation. Proc. 12th Intern. Conf. on Meteorology-Climatology-Atmospheric Physics (COMECAP 2014). Heraklion, Crete, Greece; 2014 May 28-31.

[9] Sahsamanoglou HS, Bloutsos AA. Solar radiation reduction by water and dust in the area of Thessaloniki. Solar Energy 1989; 43: 301-4. http://dx.doi.org/10.1016/0038-092X(89)90118-7

[10] Solomon S, Portmann RW, Sanders RW, Daniel JS, Madsen W, Bartram B, Dutton EG. On the role of nitrogen dioxide in the absorption of solar radiation. J Geophys Res 1999; 104: 12047-58. http://dx.doi.org/10.1029/1999JD900035

Received on 18-11-2014 Accepted on 29-11-2014 Published on 15-04-2015

DOI: http://dx.doi.org/10.15377/2410-2199.2015.02.01.3