Spectral analysis of solar radiation for the determination of the air constituents and pollutants

F.V. Topalis, E.K. Triantafillopoulou, A.A. Kanellias, I.F. Gonos,

V.D. Petrova, H.D. Kambezidis

Abstract

The paper presents the basic principles and the possible remote sensing applications of a passive pyrheliometric scanner with automatic sun tracking to record spectrally the solar radiation in the UV, Visible and NIR wavelength ranges (180-1000 nm with a resolution of 0.5 nm). The construction of this system and the development of the appropriate software facilitates the qualitative and quantitative determination of various atmospheric constituents and pollutants. The computed results, based on the measurement of the solar spectrum, which are presented in the paper, seem to be in a quite good agreement with the measured values of the atmospheric pollutants that were determined by means of instruments.

1. Introduction

The research topics in the atmosphere are numerous. Among them research related with the transmission absorption and scattering of the solar rays due to the various constituents of the atmosphere has been attracted since long ago. The study of the transmission of solar radiation within the whole atmosphere thickness is very important since it enters many applications. Some of them refer to the estimation of solar radiation at the earth's surface through algorithms, the distribution of sunlight over the sky hemisphere and to atmospheric optics also related to space applications regarding the transmission of images from satellites through the atmosphere.

PAssive Pyrheliometric SCAnner (PAPYSCA) is a system (Fig. 1) designed and developed for the recording of the solar radiation spectrally in the UltraViolet (UV), VISible (VIS) and Near InfraRed (NIR) wavelength. It is obvious by its name (Passive) that the system requires no energy source for recording solar energy, other than the sun [1-6].

Fig. 1. PAPYSCA apparatus.

2. Description of the system.

The system has two major parts, the first one is the hardware and the other one is the software [5, 6].

The hardware (Fig. 2) is consisted of the following units:

a computer controlled sun-tracker,

a system for spectral recording of the solar radiation which includes two concentric lenses, two optical fibers to guide solar radiation, two diffraction gratings, a CCD sensor for measuring the solar radiation and finally an A/D Converter to convert the spectral values from

analog to digital form, a PC for storing and processing the spectral data, along with carrying the appropriate software to drive the sun-tracker and perform the measurements, and a VHF link for transmitting the spectral data to the base station.
The software part of the system is developed except for, as already mentioned, driving the sun-tracker, the main unit and the corresponding for the VHF communication protocol, it can also determine, qualitatively and quantitatively, the atmospheric consistuents and aerosols, from the spectral data, at the location of the measurement.

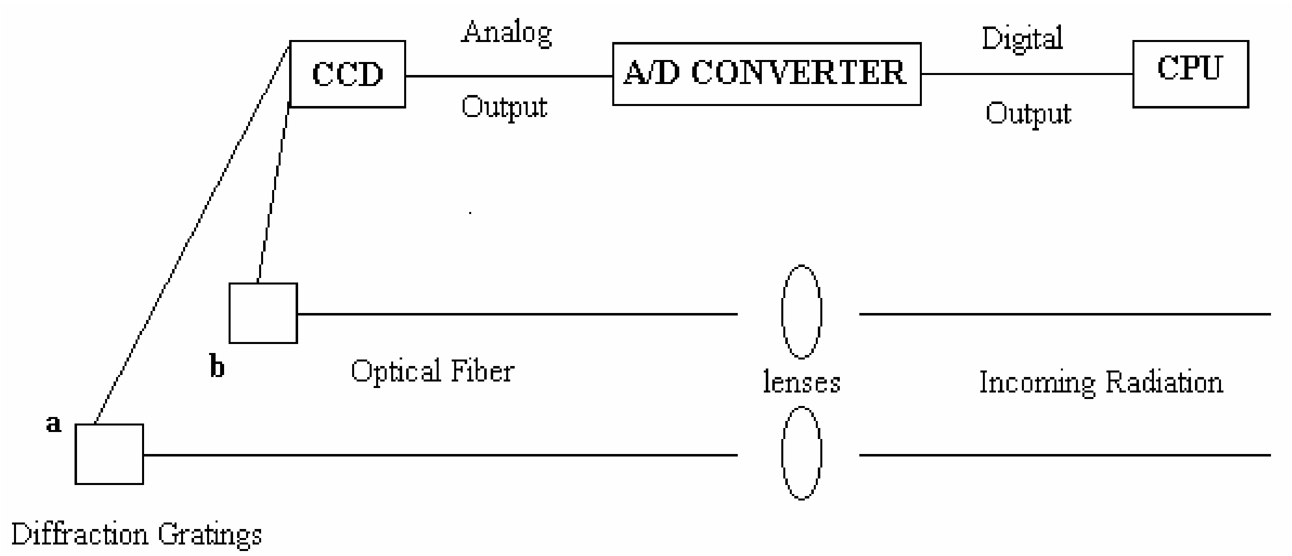

Fig. 2. PAPYSCA hardware layout.

The spectral range that is covered by the system is 200-1000 nm with a resolution of 0.5 nm and this has been achieved by the use of two diffraction gratings, one (a) for wavelengths from 180 nm to 575 nm (UV & VIS regions) and one (b) for wavelengths from 500 nm to 1000 nm (VIS & NIR regions).

3. Methodology

After installing the movable apparatus at the selected site, the twin lenses are oriented towards the desired direction for the type of measurement required (solar or sky radiation). This is obtained by a sun-tracker which is driven by a PC via the software that has been developed for this procedure.
Solar radiation enters through the lenses and is guided by the fiber optics to the diffraction gratings. The two different spectral regions are being merged by the CCD sensor into a single series of spectral solar irradiance which afterwards is being converted to digital form by the A/D Converter. At the central processing unit the digital signal can either been stored or it can be processed for the estimation of the atmospheric consistuents.
Total spectral transmission of the atmosphere (in the sun-sensor direction), considering single scattering, are deetermined by the following function [4, 7]:

$$P(\lambda, z) = I(\lambda, z)/I_0(\lambda)D$$

where I(λ,z) is the measured irradiance in Wm^{-2} (a function of wavelength λ and zenith angle z), $I_o(\lambda)$ is the spectral extraterrestrial radiation [7] and D is a correction factor for the earth-sun distance [4].
Total spectral transmission function (towards zenith), P', is given by the following equation [4, 7]:

$$P'(\lambda, z) = \exp[-t'(\lambda, z)]$$

where τ’(λ,z) is the spectral optical thickness (towards zenith) and is given from the equation [4, 7, 8]:

$$t'(l,z) = 1/m \ln[1/P(l,z)]$$

where m is the atmospheric optical mass.

4. Masurements

As shown in Fig. 3 (using the one diffraction grading for wavelengths from 180 nm to 575 nm) and Fig. 4 (using the other one for wavelengths from 500 nm to 1000 nm) measurements during two individual days in Athens, a relatively clear one (curve a) and a rather polluted one (curve b) many useful conclusions can be derived concerning atmospheric consistuents and aerosols related to air pollution.

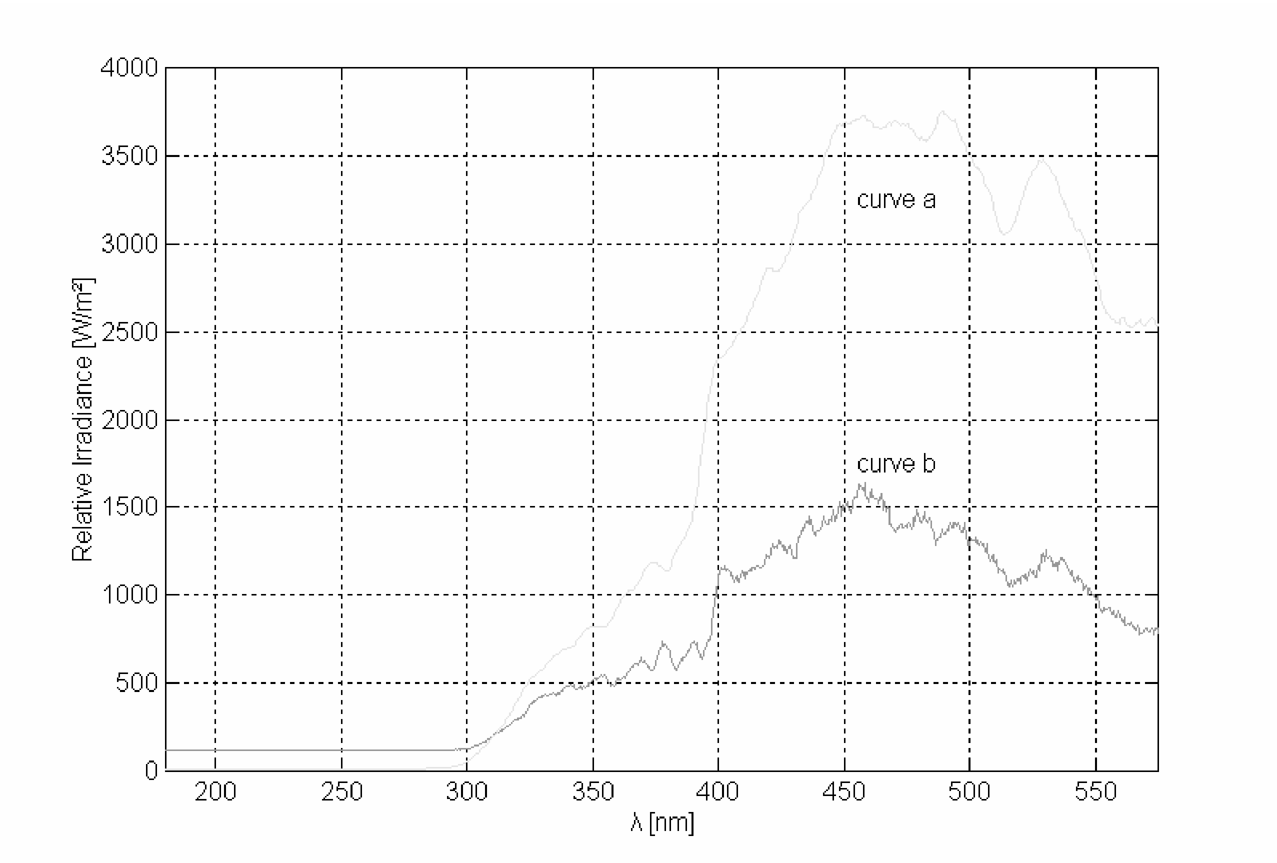

Fig. 3. Spectral scanning of direct solar radiation in Athens on a clear day (a) and a polluted one (b).

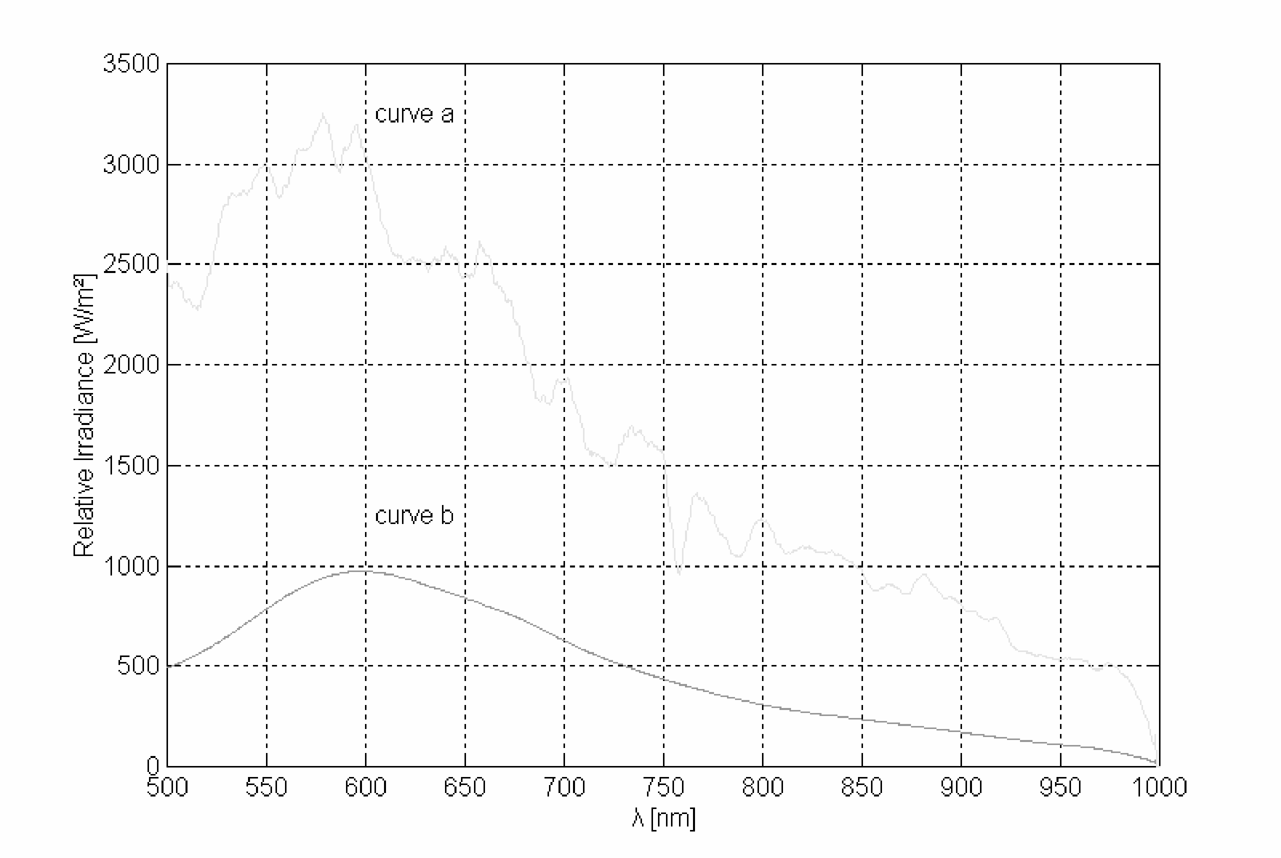

Fig. 4. Spectral scanning of direct solar radiation in Athens on a clear day (a) and a polluted one (b).

A comparison to the two above curves shows that radiance is considerably lower during the highly polluted day due to an aerosol scattering increase so we come to the conclusion that the polluted atmosphere influences the received solar radiation. Another fact that is clear from the two curves is that someone can easily identify some of the absorption lines such as oxygen absorption at 760 nm, water vapour absorption at 720 nm and carbon dioxide absorption at 780 nm.

5. Applications of PAPYSCA

The study of the transmission of solar radiation within earth's atmosphere is an important subject with applications to :

the spectral distribution of solar radiation at the earth's surface,

the distribution of radiation and luminance over the sky dome,

atmospheric optics,

the estimation of atmospheric consistuents and aerosols related to climatic changes and air pollution,

correction of satellite images due to atmospheric influences and many more.

Those applications influence various scientific and experimental fields. For example measurements of solar radiation and sky luminance may give the distribution of the measured parameters under various conditions which might help in the design of appropriate systems aiming at the exploitation of solar energy, as well as helping modern building architecture to find efficient ways of energy saving.

Another application is meteorological satellite images that can be corrected from the PAPYSCA measurements. This can be achieved in the case of simultaneous satellite and ground based PAPYSCA measurements by isolating the atmospheric effect, due to atmospheric transmission can be derived from the ground based measurements.

Last but not least, knowledge of real atmospheric consistuents, which vary at their distribution, size and concentration due to rapid and great urbanisation that results to an increase in air pollution, is required for many applications in atmospheric chemistry studies, air pollution, as well as climatic change research and remote sensing features.

6. Conclusions

It is obvious, from all the above, that PAPYSCA is a versatile tool for atmospheric physics measuring the direct solar radiation after its passage through the atmosphere of the earth. Compared to similar systems priced one order of magnitude higher, it has the same capabilities, it is much more compact, lightweight, easier to operate and lacks the use of external energy supply other than the sun.

Of course, though it has been developed to overcome the calculated problems faced by the scientific community when try to measure sun and sky radiation, further improvement and development of the system is possible and it is the intention of the research group, so that it will comply with future needs.

7. References

A.D. Adamopoulos, H.D. Kambezidis, D. Zevgolis, F.V. Topalis, V. Djepa: "*Aerosol Optical Thickness Through Modified Langley-plots in the Atmosphere of Athens*". 2nd ISES-Europe Solar Congress, Portoroz, Slovenia, September 14-17, 1998

[1] A.D. Adamopoulos, H.D. Kambezidis, D. Zevgolis, F.V. Topalis, V. Djepa: "*Variability of Total Optical Thickness in the Atmosphere of Athens*". 2nd ISES-Europe Solar Congress, Portoroz, Slovenia, September 14-17, 1998

[2] A.D. Adamopoulos, H.D. Kambezidis, D. Zevgolis, F.V. Topalis, V. Djepa: "*Aerosol Optical Thickness Through Modified Langley-plots in the Atmosphere of Athens*". 2nd ISES-Europe Solar Congress, Portoroz, Slovenia, September 14-17, 1998

[3] H.D. Kampezidis, A.D. Adamopoulos, V. Djepa, D.Zevgolis, F.V. Topalis: "*A radiative model based on multispectral direct solar radiation measurements*", Development and application of computer techniques to environmental studies, 1998, pp.89-98.

[4] H.D. Kampezidis, V.D. Petrova, A.D. Adamopoulos. "*Radiative transfer I. Atmospheric transmission monitoring with modeling and ground-based multispectral measurements*", Applied Optics, 36, 1997, pp. 6976-6982.

[5] H.D. Kampezidis, N.K. Sakelariou, F.V. Topalis, A.A. Kanellias, V.D. Petrova: "*Air pollution monitoring with a passive pyrheliometric scanner*", Fresenious Environmental Bulletin 5, 1996, pp. 631-636.

[6] H.D. Kampezidis, N.K. Sakellariou, F.V. Topalis, A.A. Kanellias, V.D. Petrova: *"Passive Pyrheliometric Scanner Space Applications"*. Earth Observation and Monitoring Systems, Proceedings of the 1st Workshop with the support of European Commission, DG XII, Hellenic Committee for Space Research and Technology, Athens, January 1995, pp 517-523.

[7] C. Gueymard: "*A simple model of the atmosperic radiative transfer of sunshine*",Rep. FSEC-PF-270-95,Florida Solar Energy Center, USA, 1995.

[8] V.E.. Cachorro, J.L Casanova A.M. de Frutos: "*The influence of Angstrom parameters on calculated direct solar spectral irradiances at high turbidity*", Solar Energy Center, 39, pp.399-407, 1987.

Data of the authors

F.V. Topalis[1], E.K. Triantafillopoulou[1],
, A.A. Kanellias[1], I.F. Gonos[1]
[1]National Technical University of Athens
9, Heroon Politehniou St., Zografou
GR 157 80 Athens, Greece
Department of Electrical and Computer Engineering,
[1]Laboratory of Photometry
Tel. (+30-1)7723627, 7723506, 7723539, Fax 7723628
e-mail: topalis@softlab.ntua.gr, igonos@softlab.ntua.gr

V.D. Petrova[2], H.D. Kambezidis[2]
[2] National Observatory of Athens

COMPARISON OF THE NEW EN FOR STREET LIGHTING WITH THE FORMER STANDARDS

M. Eckert

СРАВНЕНИЕ НА НОВИТЕ ЕВРОПЕЙСКИ НОРМИ ЗА УЛИЧНО ОСВЕТЛЕНИЕ С ПРЕДХОДНИТЕ СТАНДАРТИ

М. Екерт

ENERGY EFFECTIVE LUMINAIRES WITH FLUORESCENT LAMPS

B. Sai, Ukraine

НОВИ ЕНЕРГОИКОНОМИЧНИ ПРОМИШЛЕНИ ОСВЕТИТЕЛИ И ПРОЖЕКТОРИ

Б. Сай, Украйна.