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Attenuation of the Atmospheric Aerosol Transmissivity due to Air Pollution

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Abstract

Relationship between atmospheric aerosol transmissivity and air pollution was analyzed using observed data in a large industrial city, Pusan, Korea. The atmospheric aerosol transmissivity predicted by method of present study in Pusan was assessed by the method of Yamamoto *et al.*(1968) in order to set up an empirical model to predict the transmissivity using the various meteorological parameters and air pollution. As a result, good correlation between these two method are observed. Thus, it is possible to conclude that the parameterization of air pollution suggested by this study is another method to give reliable estimate of atmospheric aerosol transmissivity and direct solar irradiance in Pusan.

Key words : Atmospheric aerosol transmissivity, Pollutants, Solar energy

1. INTRODUCTION

The variation of atmospheric aerosol transmissivity is closely related with changes of air pollution and aerosol concentrations. Atmospheric aerosol may greatly affect the global and regional climate through radiation-dynamic processes (Cho, 1980). When solar radiation enters the atmosphere, a part of the incident energy is removed by scattering and absorption of light by air molecules and aerosols. The atmospheric aerosol transmissivity can be determined by measuring the intensity of the direct irradiance. Flowers *et al.*(1969) studied the turbidity over the U.S. during 1961~1966; Peterson *et al.*(1981) used data obtained from July 1969 to July 1975 to study the turbidity over central North Carolina; Liu and Feng (1990) analyzed the atmospheric turbidity over Taiwan during the period from July 1982 to June 1987. Kim *et al.*(1992) divided cloud type into high, middle and low clouds and cloud amount into five groups, and studied the variation of the atmospheric transmissivity by topographic condition and cloud amount.

In this study, the variation of the atmospheric aerosol transmissivity is calculated using air pollution and meteorological data. A simple empirical model is constructed to evaluate the attenuation of atmospheric aerosol transmissivity as a function of the air pollution. Its feasibility is studied by examining the direct solar irradiance predicted by the model based on an assumption that the air pollution is a major parameter affecting solar radiation over industrial cities.

2. DATA AND MODELS

In this paper, we use hourly direct solar irradiance and meteorological data observed at Pusan meteorological station in 1992 under cloudless sky conditions to investigate the effects of air pollution on the atmospheric aerosol transmissivity. To classify the air mass, surface weather charts (00UTC, 12UTC) and skew T-log P diagrams (Osan, Kwangju) are used. Hourly air pollution data (TSP, SO_2, NO_2 and

O_3) from Gwangbokdong air pollution monitoring site, which is located in commercial and seaside area near the Pusan meteorological station were used. The precipitable water vapor is estimated by using the equation proposed by Kondo *et al.*(1983). A method of estimating the atmospheric turbidity coefficient from direct solar spectral irradiance measured using a set of filters was developed by ngström (1961). However, the method formulated by Yamamoto *et al.*(1968) which uses broadband irradiance data is used in this study.

The direct solar irradiance at ground level varies due to the scattering and absorption by various atmospheric constituents. Many solar irradiance models are designed in a manner that permits the atmospheric parameters such as ozone layer thickness, precipitable water vapor, turbidity and ground albedo to be varied independently. From Bird and Hulstrom (1981), and Iqbal (1983) the direct solar irradiance, I is given by

$$I=0.9751\,I_o\tau_r\tau_a\tau_o\tau_w\tau_g, \qquad (1)$$

where I_o is solar constant, τ_r is the transmittance due to Rayleigh scattering, τ_a is the transmittance due to atmospheric aerosol, τ_a is the transmittance due to ozone absorption, τ_w is the transmittance due to water vapor, and τ_g is the transmittance due to the uniformly-mixed gases. The factor 0.9751 is included in Eq (1) because the spectral interval considered by SOLTRAN (Bird and Hulstrom, 1981) is 0.3~3.0 μm.

Atmospheric aerosol transmissivity can be determined as a function of visibility and optical air mass (Iqbal, 1983).

$$\tau_a=[0.97-1.265\,(VIS)^{(-0.66)}]^{(m_a)^{0.99}},$$
$$5<VIS<180\ \text{km} \qquad (2)$$

where VIS is visibility and m_a is optical air mass. Since visibility is closely related with the concentration of the pollutants, a model for the attenuation of the atmospheric aerosol transmissivity is constructed by using the correlation between visibility and concentration of the pollutants. The correlation is calculated by multiple regression analysis based on the observed data of visibility, TSP, SO_2, NO_2 and relative humidity.

3. RESULTS AND DISCUSSIONS

3.1 The transmissivity changes due to the meteorological parameters

Fig. 1 shows the monthly variation of atmospheric aerosol transmissivity calculated using the method of Yamamoto *et al.*(1968). Generally, the atmospheric aerosol transmissivity is higher in the cold season than in the warm season, which is related to the synoptic weather pattern occurring around Korea. Similar results were noted by Chung (1983).

Figs. 2, 3, and 4 show the variations of the transmissivity due to wind, precipitable water vapor, visibility, stability, and the dependence of the air masses, respectively. In general, the northwesterly wind is accompanied by the high transmissivity; while the southeasterly or southwesterly wind causes the low transmissivity

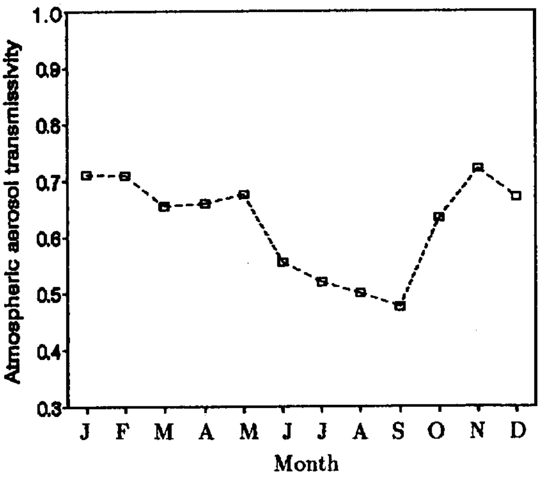

Fig. 1. Monthly variation of the atmospheric aerosol transmissivity at Pusan in 1992.

(Fig. 2a). These phenomena may be related to the synoptic situation such as a high pressure system of northwestern Korea and the Pacific high being at the eastern side of Korea or migratory high pressure in autumn and spring. Fig. 2b shows that there is little correlation between the atmospheric aerosol transmissivity and wind speed. This is in contrast with the results of Chung (1983) and Liu and Feng (1990) who showed the transmissivity was low when the surface wind speed was lesser than or equal to 2 m/sec suggesting that the transmissivity inferred from the direct solar irradiance measurement reflects the aerosols generated and accumulated locally. The higher the precipitable water vapor, the lower the transmissivity (Fig. 2c). It is associated with the synoptic weather pattern, since different origins of air mass would bring in different amounts of water vapor in the vertical column (Chung, 1983). Transmissivity and visibility show the positive correlation (Fig. 2d).

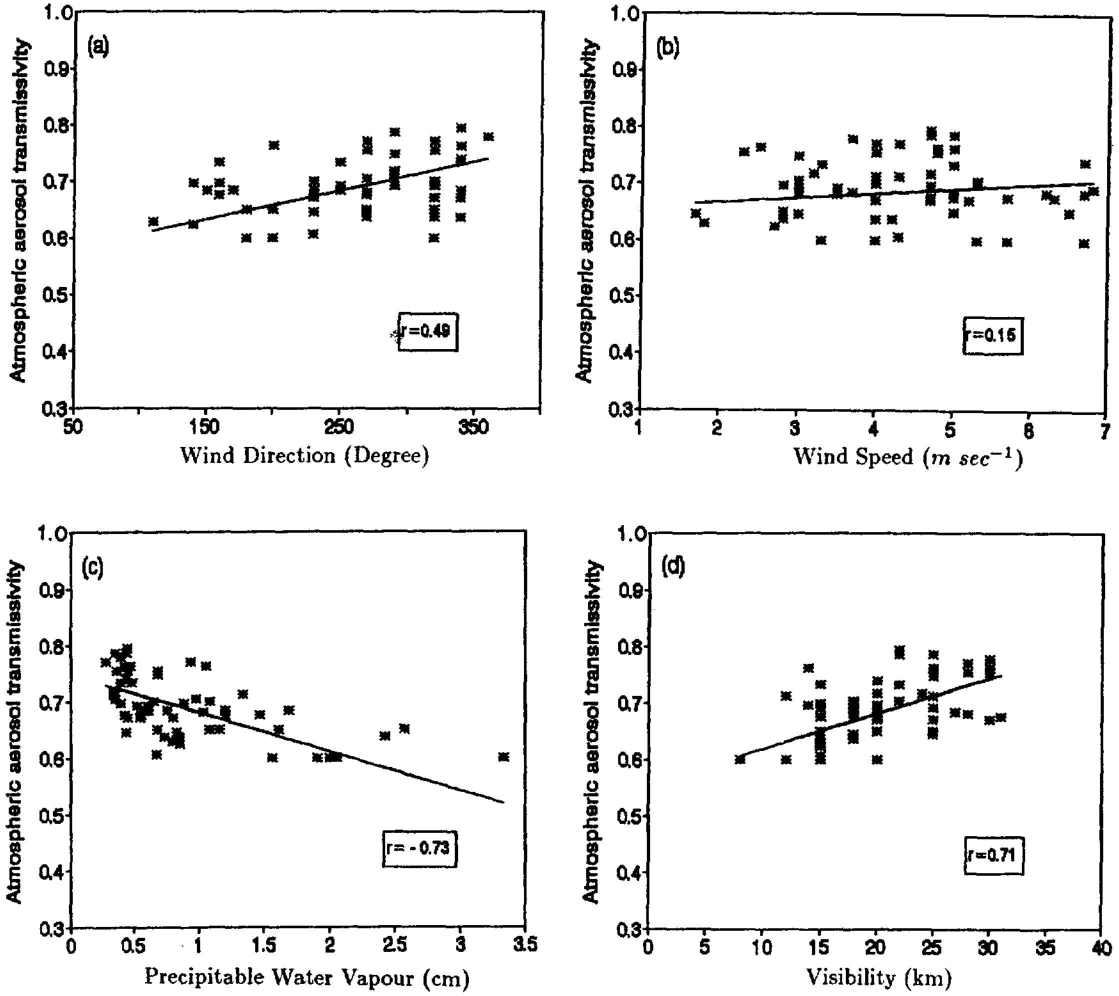

Fig. 2. Scattered diagram showing the relation between the atmospheric aerosol transmissivity and (a) wind direction, (b) wind speed, (c) precipitable water vapor, and (d) visibility.

On a clear day, the degradation of visibility comes from the increase of aerosols in the low atmospheric level. Fig. 3 shows the relationship between the transmissivity and the stability (Turner, 1969). The transmissivity decreases as stability changes from the neutral state toward the extremely unstable state.

The transmissivity was found to be dependent of the prevailing air masses. It is highest under the polar continental air mass in winter (Devel. cP), then is followed by the stagnating polar continental air mass (Stag. cP). Frequent stagnant airflow occurring in fall and spring favors the occurrence of the low transmissivity, while the strong northwesterly monsoon in winter dilutes aerosols efficiently (Fig. 4).

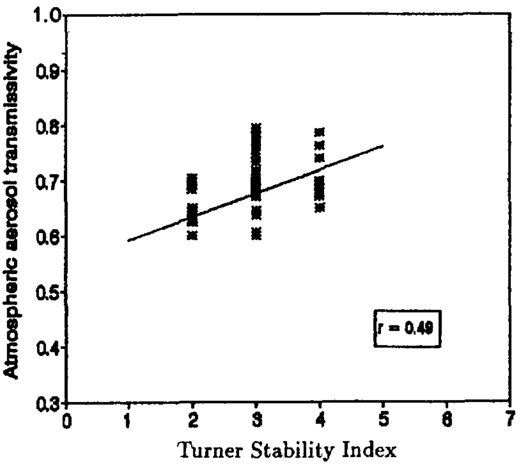

Fig. 3. Same as Fig. 2. except for stability index.

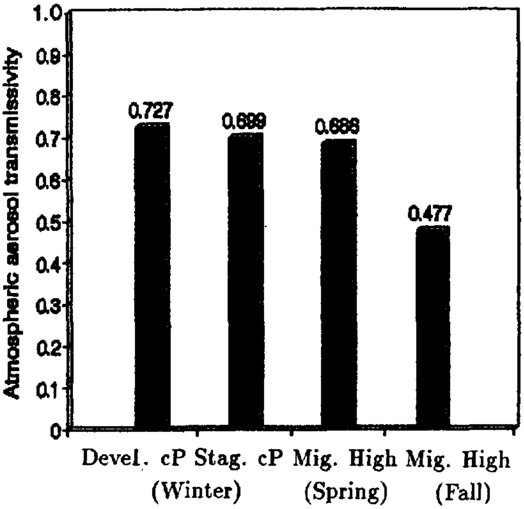

Fig. 4. Mean atmospheric aerosol transmissivity depending on air masses at Pusan in 1992.

3.2 The transmissivity changes due to the air pollutants

Using the data under the same meteorological conditions as used in the previous sections, we carried out multiple regression analysis to investigate the air pollution effects on variation of visibility.

$$[\mathrm{Vis,\ km}] = a - b[\mathrm{TSP},\ (\mu g/m^3)] - c[\mathrm{SO_2},\ (ppb)] - d[\mathrm{NO_2},\ (ppb)] - e[\mathrm{R.H},\ \%],\ \text{for Pusan.} \qquad (3)$$

Results are summarized in Table 1.

Table 1. Regression coefficients between the visibility and the air pollution.

Station	a	b	c	d	e	R^2
Pusan	35.7	0.052	0.076	0.147	0.152	64.4

No. = 523

Error may be caused by the in elevation difference between the Pusan meteorological station and the air pollution monitoring site and by observational error of visibility.

The atmospheric pollution index was defined and evaluated in order to analyze the effect of air pollution on the attenuation of the transmissivity. It was based on the atmospheric concentration levels of three major pollutants; particulates, sulphur dioxide and nitrogen dioxide. The air pollution is classified into five classes based on the EPA's pollutant standard index (PSI) (Table 2).

Class 3 represents average concentrations (TSP, 70($\mu g/m^3$); SO_2, 40(ppb); NO_2, 40(ppb)) at Kwangbokdong in 1992. It is close to PSI

Table 2. Classification of air pollution level.

Class	TSP($\mu g/m^3$)	SO_2(ppb)	NO_2(ppb)
Poll. 1	110	80	80
Poll. 2	90	60	60
Poll. 3 (Standard)	70	40	40
Poll. 4	50	20	20
Poll. 5	30	0	0

value 50 which well describes the air quality descriptor is good.

Using the equation (3) and (2) the effect of the air pollutants on atmospheric aerosol transmissivity is calculated and plotted in Fig. 5(a). The transmissivity decreases as solar zenith angle increases especially in the region greater than 60°. When the air pollution increases from class 5 to 1, the transmissivity difference becomes 0.29, 0.31 and 0.39 at zenith angle 0°, 30° and 60°, respectively.

For a typical atmospheric condition ($O_3=0.30$ cm (NTP), $W=2$ cm), the effect of the air pollution on direct solar irradiance at different optical air mass is calculated using equation (1) and plotted in Fig. 5(b). As the optical air mass increases, the direct solar irradiance decreases. As the air pollution increases from class 5 to class 1, the direct solar irradiance decreases 35, 38.9 and 55.3 percent at the solar zenith angle 0°, 30° and 60°, respectively.

3.3 Comparison

The attenuation effect of the air pollution on the transmissivity and direct solar irradiance was studied using the an empirical relationship obtained in this study. The transmissivity estimated by the method developed in this study and the method of Yamamoto *et al.*(1968) were in good agreement. Comparing the calculated results with measured data at hour angle 0° and 45° (mean atmospheric aerosol transmissivity=0.667, 0.660), root mean square errors of the present study are 0.023 and 0.057, respectively. These root mean square errors of

Table 3. Comparison of results of two methods determining atmospheric aerosol transmissivity.

Date	Yamamoto method *et al.*	TSP (μg/m³)	SO_2 (ppb)	NO_2 (ppb)	Present study
92. 1.27.12	0.637	78	49	26	0.698
92. 3.08.12	0.683	40	13	15	0.782
92. 9.30.09	0.600	43	23	28	0.711
92.12.30.12	0.677	56	31	43	0.687
Average ('92)	0.688	·	·	·	0.663

RMSE : 0.023 (For hour angle 0°)
RMSE : 0.057 (For hour angle 45°)
No. = 74

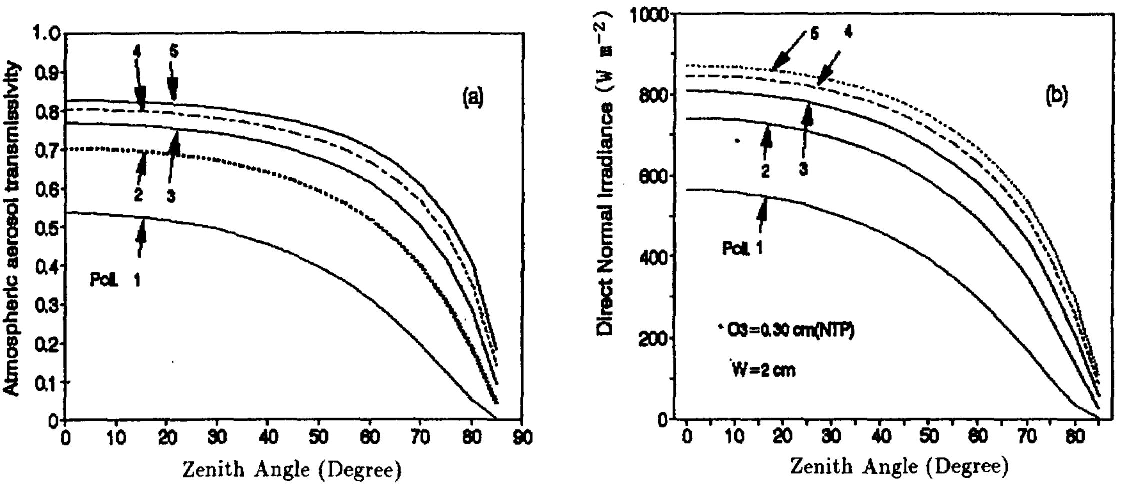

Fig. 5. The attenuation of the atmospheric aerosol transmissivity (a) and direct normal irradiance (b) due to air pollution.

the transmissivity increase with increasing hour angle. Table 3 shows the comparison between atmospheric aerosol transmissivity by Yamamoto *et al.*(1968) method and the ones predicted by the method of present study.

The variation of the transmissivity causes changes in direct solar irradiance over Pusan (Table 4).

Table 4. Comparison between measured and calculated direct solar irradiance.

Date	Measured Value (W/m^2)	TSP (μg/m^3)	SO$_2$ (*ppb*)	NO$_2$ (*ppb*)	Calculated Value (W/m^2)
92. 1.27.12	636	78	49	26	583
92. 3.08.12	659	40	13	15	737
92. 9.30.09	550	43	23	28	590
92.12.30.12	589	56	31	43	582
Average('92)	636	·	·	·	588

RMSE : 49 W/m^2 (For hour angle 0°)
RMSE : 90 W/m^2 (For hour angle 45°)

Comparing against the pyrheliometer data measured at hour angle 0° and 45° (mean total direct irradiances=667, 597 W/m^2), the root mean square errors for the present study are 49 and 90 W/m^2.

The present study produces similar results of Justus and Paris (1985) which were 64 and 73 W/m^2.

4. CONCLUSIONS

The atmospheric aerosol transmissivity was calculated by the method of Yamamoto *et al.* (1968), using direct solar irradiance and precipitable water vapor measurements at Pusan in 1992. The variations of the atmospheric aerosol transmissivity with wind, visibility, precipitable water vapor and stability were discussed. Dependence of the atmospheric aerosol transmissivity on the air masses was also studied.

The results of the study are as follows:

1) Mean atmospheric aerosol transmissivity at Pusan in 1992 is about 0.688. Monthly variation of the atmospheric aerosol transmissivity is characterized by high in cold season and low in warm season.
2) High positive correlation between the atmospheric aerosol transmissivity and visibility is obtained while negative correlation is found between atmospheric aerosol transmissivity and precipitable water vapor. The atmospheric aerosol transmissivity is greater in the wind direction of NW than SE-SW.
   There is little correlation between the atmospheric aerosol transmissivity and wind speed. The atmospheric aerosol transmissivity tends to be dependent of the stability of the PBL and prevailing air masses.
3) When air pollutant concentrations increase from class 5 (TSP, 30 (μg/m^3); SO$_2$, 0 (*ppb*); NO$_2$, 0 (*ppb*)) to class 1 (TSP, 110 (μg/m^3); SO$_2$, 80 (*ppb*); NO$_2$, 80 (*ppb*), the atmospheric aerosol transmissivity difference becomes 0.29, 0.31 and 0.39 at the zenith angle 0°, 30° and 60°, respectively, and direct irradiance decreases by 35, 38.9 and 55.3 percent at the zenith angles 0°, 30° and 60°, respectively.
4) Atmospheric aerosol transmissivity by Yamamoto *et al.*(1968) method and the ones predicted by the method of present study showed good correlation.
5) Measured and calculated direct solar irradiance showed good agreement.

Thus, it showed the possibility of estimating the attenuation of the atmospheric aerosol transmissivity and direct solar irradiance using an empirical relationship based on air pollution and meteorological data.

However it might have some problems applying for the regions of heavy pollution. However, it has been proved that the model developed in this study can be used to estimate the atmospheric transmissivity from the air pollution data.

REFERENCES

Ångström, A. (1961) Techniques of determining the turbidity of the atmosphere, Tellus, 134, 214-223.

Bird, R.E. and R.L. Hulstrom (1981) A simplified clear sky model for direct and diffuse insolation on horizontal surfaces, Sol. Energy Research Institute, Golden, Colorado, SERI/TR 642-761.

Cho, H.G. (1980) On the size distribution of atmospheric aerosol particles from spectral photometric measurement in Seoul. J. of Kor. Met. Soc., 16, 1-9.

------, T.Y. Lee, K.T. Lee and B.Y. Lee (1988) A model for the direct spectral irradiance at the earth's surface on clear days. J. of Kor. Met. Soc., 24, 58-71.

Chung, H.S. (1983) The variation of atmospheric turbidity according to air mass trajectory, M. Sc. Thesis, Yonsei University, Korea.

Flowers E.C., R.A. McCormick, and K. R. Kurfis (1969) Atmospheric turbidity over the United States, J. Appl. Meteor., 8, 955-962.

Iqbal, M. (1983) An introduction to solar radiation, Academic Press, 390pp.

Justus, C.G. and M.V. Paris (1985) A model for solar spectral irradiance at the bottom and top of a cloudless atmosphere, J. Climate and Appl. Meteor., 24, 193-205.

Kim, Y.K., E.S. Jang, B.H. Jin (1992) Variation of the atmospheric transmissivity by cloud amount and topographic condition, J. of Kor. Ear. Sci. Soc., 13, 342-354.

Kondo, J. and A. Miura (1983) Empirical formula of the solar radiation at the ground level and a simple method to examine an inaccurate pyranometer, Tenki, 30, 45-51.

Liu, C.M. and T.S. Feng (1990) Atmospheric turbidity over taiwan, Atmos. Environ., 24A, 1303-1312.

Mächler, M. (1983) Parameterization of solar irradiation under clear skies, M.A. Sc. Thesis, University of British Columbia, Canada.

Peterson, J.T., E.C. Flowers, G. Berri, C.L. Reynolds, and J.H. Rudisill (1981) Atmospheric turbidity over central North Carolina, J. Appl. Meteor., 20, 229-241.

Turner, D.B. (1969) Workbook of atmospheric dispersion estimates, U.S. Dep. of Health, Education and Welfare.

Yamamoto G., M. Tanaka, and K. Arao (1968) Hemispherical distribution of turbidity coefficient as estimated from direct solar radiation measurements, J. Meteor. Soc. Japan, 46, 287-298.

대기오염에 의한 대기투과도 감쇠에 대한 연구

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김유근, 이화운, 이용섭

초 록

산업 도시 부산에서 관측된 기상자료와 대기오염 자료를 이용해 대기오염과 대기투과도의 상호 관계를 연구하였다. 부산에서 대기오염에 의한 대기투과도를 예측하는데 경험적인 모델을 구축하기 위해 여러 기상 요소와 대기오염을 사용하였고, 이 결과를 Yamamoto *et al.*(1968)에 의한 대기투과도 계산 방법과 비교하였다. 그 결과, 두 방법에 의한 결과는 좋은 상관을 나타내었다. 따라서 본 연구에 의해 제시된 대기오염의 모수화는 부산에서 대기투과도와 직달일사량을 신뢰성 있게 예측하는 하나의 방법이라 생각된다.