THERMAL AND RADIATIONAL ASPECTS OF THE CHRISTMAS EVE 1977 AIR POLLUTION EPISODE IN MEXICO CITY

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RESUMEN

Durante la noche del 24 de diciembre de 1977, miles de llantas fueron quemadas en las calles de la Ciudad de México. La carga adicional en la troposfera de partículas y materia gaseosa aunada a condiciones meteorológicas de estabilidad atmosférica, generaron un episodio de contaminación severa del aire afectando el balance térmico. El día 25 de diciembre entre las 0700 y las 1400 horas TSV (tiempo solar verdadero), la visibilidad horizontal se redujo a menos de 1 km, alcanzando su mínimo de <0.1 km entre las 1200 y las 1400 horas TSV. La altura matutina de la capa de mezcla fue de 90 m con velocidad media del viento de 1 m seg^{-1}. Los efectos térmicos de la capa atmosférica de aerosoles se manifestaron mediante un calentamiento nocturno de 2-3° C (efecto de invernadero); durante el día, hubo por el contrario un enfriamiento de 1.5° C. La duración de insolación se redujo 1 hora. La turbiedad atmosférica alcanzó valores muy altos. La radiación total incidente en la superficie disminuyó en 26.8%. La razón radiación difusa/directa se invirtió, indicando que gran parte de la radiación entrante fue dispersada en la capa de aerosoles. La acción combinada de los procesos de absorción y retrodispersión en la capa adicional de aerosoles parece ser la responsable del enfriamiento diurno del aire en superificie.

Se analizan por separado los efectos sobre el balance térmico de la absorción y la retrodispersión en la capa. La retrodispersión (reflexión) es similar a la producida por una capa de nubes. Utilizando el modelo de Yamamoto y Tanaka, se estima que el albedo global se pudo incrementar de 0.15 a 0.30. Los efectos radiativos descritos pueden ser los responsables del enfriamiento diurno observado.

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ABSTRACT

During the night of Dec. 24, 1977, thousands of rubber tires were burned in the streets of Mexico City. The additional tropospheric load of particulate and gaseous matter together with meteorological conditions of stability produced a severe episode of air pollution perturbing the heat balance. On Dec. 25 between 0700 and 1400 hours True Solar Time (TST), horizontal visibility was reduced to less that 1 km, reaching its minimum < 0.1 km between 1200-1400 hours TST. Morning mixing height was 90 m with average wind velocity of 1 m sec^{-1}. The thermal effects of the atmospheric aerosol layer produced warming at night of 2-3°C (greenhouse effect). During the day, on the contrary it was cooler by 1.5°C. Duration of sunshine was reduced 1 hour. Atmospheric turbidity reached very high values. Total downward radiation was diminished by 26.8%. The ratio diffuse/direct radiation was inverted indicating that much of the incoming radiation was diffused in the aerosol layer. The combined action of the absorption and backscattering processes of the additional aerosol layer seems to be the responsible of the diurnal air cooling at the surface. Both effects are separately analyse on the thermal balance. Backscattering is similar to the one produced from a cloud layer. Using the Yamamoto and Tanaka model, one estimates that global albedo may be increased from 0.15 to 0.30. The above described radiative effects may be responsible for the observed diurnal cooling.

1. The air pollution problem of metropolitan areas is a very complex one which solution demands a global understanding of the situation.

Mexico City with 10×10^6 inhabitants leaving in a basin with reduced air drainage due to the presence of high mountain chains located in the opposite side of the dominant wind flow together with a very high annual frequency (35:7%) of calm wind, offers the necessary conditions for the development of a critical air pollution problem. On the other hand, the location of the city in a latitude (19°N) and altitude of 2 268 m a.s.l., produces a regime of insolation enough for the creation of photochemical smog in particular, if one considers the presence of 1.5×10^6 registered mobile sources (automobiles, omnibuses, trucks, etc.) circulating every day in the whole city and thousands of large, medium and, small industries diseminated widely in the whole Valley, last but not least, the presence of a huge denudated surface which belonged to the dessicated Texcoco Lake at the oriental outskirts of the city, produces, with other minor "natural" sources an important contribution to the environmental problem with natural dust which in enormous amounts blows persistently (al least during the dry season, namely, October to April) over the city.

The major global effects from air pollutants produced under the above circumstances are: greenhouse effect, owing to CO_2 ; the effect of particulates on the earth-atmosphere heat balance, and the effect of climate change from man's massive use and dissipation of energy.

Many reports have published that substantiate the above mentioned effects (Galindo, 1965, 1977; Galindo and Muhlia, 1970; Jáuregui, 1969, 1971, 1974).

The dry season begins in the middle of fall, holds back the whole winter and ends during spring time. In winter the high frequency of low thermal inversion layers with calm wind produce conditions of high atmospheric stability ending sometimes in atmospheric stagnation. Under these conditions, it has been the custom of many people to burn used tires in the streets of Mexico City during Christmas Holidays and New Year's Eve. Although, city authorities have restrained any attempts to repeat this practice, we shall present in this report, a severe episode of air pollution occurred during the night of Dec. 24, 1977 where thousands (the news estimated about 5×10^4) of rubber tires were burned in the streets of different parts of Mexico City.

2. The additional atmospheric load of particulate and gaseous matter together with meteorological stability gave as a result severe air pollution episode.

What follows, in an analysis under the above circumstances of the profound –but transitory– perturbation of the meteorological elements including the radiation field. Much of the data were measured at the Central Meteorological Observatory of Tacubaya (19°24' N, 2 308 m a.s.l.) from which we acknowledge the assistance of Mr. S. Aguilar Anguiano, General Director. The data of solar radiation and atmospheric turbidity are from our records at the University City (19°20' N, 2 268 m a.s.l.). All the actinometric measurements are performed on the installations of the Central Observatory of Atmospheric Radiation located in the south part of the city. All the data are expressed in True Solar Time (TST).

During December, the nights are cool and clear with dry and weak winds accompanied by strong radiational cooling. Frequently, a surface temperature inversion is observed in 0600 soundings. In fact, the radiosondes of Dec. 24 and 25 showed a low thermal inversion. The Richardson number for the bottom layer (780-700 mb), of the soundings of Dec. 24, 25 and 26 was always greater than one. The highest value was reached in the morning of Dec. 25, $R_i = 48 \times 10^3$, i.e., turbulent movements were practically absent and stagnation was severe. In general, the synoptic situation remain the same for the three days.

Under these meteorological conditions, the combustion process of thousands of small fires burned in streets all over the city added to the lower atmosphere many different sorts of particulate and gaseous matter, both directly and throughout subsequent reactions in the atmosphere. Fine mineral residues such as ashes, unburned bits of carbon and soot were seen as they precipitated next morning.

Horizontal visibility gradually decreased during the night of Dec. 24, from 5 km at midnight to < 1 km between 0700 and 1400 hours on Dec. 25; minimum values of less than 0.1 km were reached from 1200 to 1400 hours. However, between 1400 to 1500 hours, visibility improved markedly up to 6 km (see Fig. 1). This maximum of visibility coincided with the maximum recorded values of surface air temperature and wind speed (5 knots); atmospheric transparency also improved. The maxima of the above parameters is an indication that turbulence breaked the stagnation conditions. At this time also appeared on the sky 0.1 Sc cloud.

The behavior of the temperature field is also remarkable; night temperatures of Dec. 24 are greater by 2-3°C than the ones corresponding to Dec. 23 and 25. The first radiosonde of Dec. 25 showed a vertical increase of temperature at all levels from surface (780 mb) up to 690 mb of about 1.5°C; this heating produced and enhancement of the depth of the smog layer which had a height of

1 050 m from the surface. The morning mixing height (Holzworth, 1967) was 90 m with average wind velocity of 1 m sec^{-1}. On the contrary, during the day, after 0900 hours surface air temperature is lower by 1.5°C with respect to Dec. 24 and 26 at the same time. This cooling persisted until 1400 hours. The evening radiosonde gave a mixing height of 1500 m and average wind velocity of 4 m sec^{-1}.

The particles in the atmosphere interact with water vapor, the interface thus formed is called aerosol. The most optically active aerosols are particles with radii between 0.1 and 1μ. Besides the reduction on the visibility, aerosols attenuate the direct incident solar beam and increase the diffuse light from the hemisphere of sky over the observer.

Therefore, one can estimate the impact of an increase of the abundance of aerosols performing measurements of the radiation field.

The measurement of the spectral direct solar component gives information, in relative terms of the particulate load of the atmosphere by means of the Angström's turbidity coefficient at least for particles sizes between 0.1 and 1.0μ and a Junge's particle size distribution (Massachussets Institute of Technology, 1971).

The computed values of the Ångström's daily average turbidity coefficient are quite large:

Date	$\bar{\beta}$	$(\Delta\bar{\beta}/\bar{\beta}_{20})\%$
Dec. 24, 1977	.243	+ 38
Dec. 25, 1977	.473	+ 68
Dec. 26. 1977	.355	+ 58

Here $\bar{\beta}_{20}$=.150 is the average value of the atmospheric turbidity coefficient obtained from measurements performed in the last 20 years assuming that the wavelength exponent $\alpha=1.3$.

On Dec. 24, in spite that the atmospheric turbidity coefficient retained a value higher than the average, the diurnal variation of atmospheric turbidity showed the normal observed pattern. However, the next day, atmospheric turbidity started at 1100 hours to increase continuously reaching a turbidity coefficient β_{max}=0,879 at 1530 and then decreasing rapidly. On Dec. 26, this peculiar behavior repeated but with reduced turbidity values of about 25% with respect to the day before. The maximum value reached at the same time of Dec. 24. It should be noted that the highest recorded value is an upper boundary for our numerical computation (Galindo and Muhlia, 1970) i.e. in reality could be even higher. In any case, the above facts indicate that the atmospheric transparency was reduced even before the night of Dec. 24. But the burned tires added an enormous amount of particulate matter enhancing the quasi permanent anthropogenic aerosol layer over the city (see fig. 2).

Duration of sunshine records from a Campbell-Stokes recorder show that the burning of the paper strips were from 0650 to 1620 and 0650 to 1610 for Dec. 24 and 26 respectively, while on Dec. 25 burning started at 0750 and finished at 1610; that is, in spite of the fact that total and sky radiation records had started at 0640, the paper strip started to burn on Dec. 25 one hour later (sunrise occurred at 0630 and sunset at 1730). In general, the observed effects of a dense haze on sunshine are normally of narrowing of the burning trace. On Dec. 25, however, the incident energy flux did not reach the burning threshold and the main result was one hour of sunshine reduction.

Figures 3, 4 and 5 show the daily records of total downward global radiation R_G and scattered radiation R_d. Direct radiation is computed as the difference $R_G-R_d=R_D$. From these figures a whole-day diminution of total incident flux (global, scattered and direct radiation) for Dec. 25 is observed with respect to the days before and after. The reduction being more important in the afternoon just after the maximum value is reached. Between 1400 to 1500 hours the presence of the Sc cloud is also recorded. The scattered radiation predominates in the afternoon coinciding with the maximum of temperature and coincides with the diurnal variation of atmospheric turbidity.

Table 1 shows daily totals of the radiation components and its percental distribution with respect to the 20 year average value for

December of global radiation and the ratios of each component. There is a reduction of 26.8% in the total radiation on Dec. 25, for the other days the departures from the mean are not significant since they are within the ±5% of instrumental errors.

The diffuse/direct ratio is very significant, for Dec. 24 is 0.87 but for the next two days increase to 1.39 and 1.07, i.e., for cloudless days normally there is more direct than diffuse radiation, this relationship has been inverted during the episode under discussion.

Since the synoptical situation was, in general, the same for the three days under study and the advective movements were almost absent, one could consider that the observed relative cooling at the surface of the morning of Dec. 25 was due to radiative effects. Unfortunately, our data can not give information on the relative contribution of the processes of absorption and backscattering. Let us assume that the extra-aerosol layer was the main responsible of the 26.8% of reduction of the total downward flux through a combined action of absorption and backscattering. Althoug both effects are simultaneous, in what follows, we analyse their influence separately on the thermal balance:

Let us assume that the 26.8% of the total incoming flux is completely absorbed by the extra-aerosol layer, one could think that the increased atmospheric thermal emission from the overheated aerosol layer was not enough to compensate the cooling of the air at the surface due to the reduction of the incoming solar radiation, therefore, the net effect is the relative cooling.

On the other hand, if one assumes that the 26.8% of the reduced total radiation has been reflected back to space, then one may consider that the perturbation of the atmospheric thermal emission was not considerable with respect to the normal values of this time of the year therefore, the relative cooling of the air at the surface was due simply to the reduction of the incident solar radiation. In this case, the cooling is larger than on the conditions of absorption being also present. Here it is important to note that 26% of backscattering would correspond approximately to the reflection produced from a cloud layer. Furthermore, if one introduces the measured values of the atmospheric turbidity coefficient into the calculations of Yamamoto and Tanaka (1972), the changes of average global albedo are from 0.15 to 0.30. This means that the increase in particle load increases the global albedo. The augmented backscattering and albedo may be an explanation for the observed cooling during Dec. 25.

3. The facts here presented show that the combustion process involved in the burning of the rubber tires produced a profound transitory perturbation of the atmospheric elements. The main effects observed are due to the overload of the particulate and gaseous matter of the atmosphere.

During the night of Dec. 24, perhaps the increase of CO_2 as final combustion product resulted in a greenhouse effect with an increase of air temperature of 2°C.

During the day hours, the particles increased the tropospheric aerosol layer perturbing all the components of the radiation field. The reduction on the visibility and the increase of the atmospheric turbidity coefficient are indicators of the enhancement of the aerosol layer. The total downward radiation was diminished by 26.8% and the ratio diffuse/direct radiation was also inverted as an indication of a very dense aerosol layer. It seems that the combined action of absorption and backscattering processes was responsible of the relative cooling by 1.5°C.

It is urgent that measures should be taken in order to reduce the actual levels of air pollution and without doubt the practice of burning rubber tires should be absolutely refrained.

TABLE 1. Alterations of the anthropogenic aerosol layer on solar radiation.

	R_G (ly day^{-1})	$R_G/\bar{R}_{G_{20}}$** (%)	R_d (ly day^{-1})	R_D (ly day^{-1})
Dec. 24	387	- 2.0	180	207
Dec. 25	289	-26.8	168	121
	300*	-23.8*	168*	132*
Dec. 26	376	- 4.8	194	182

* without cloud

** $\bar{R}_{G_{20}}$ = 395 ly day^{-1}

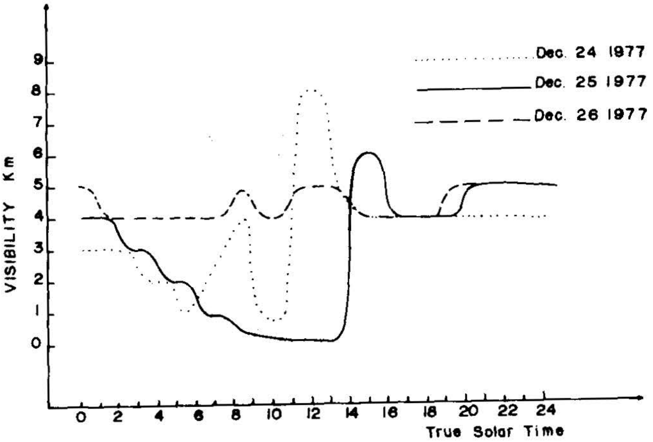

Fig. 1 Horizontal visibility during the stagnation period.

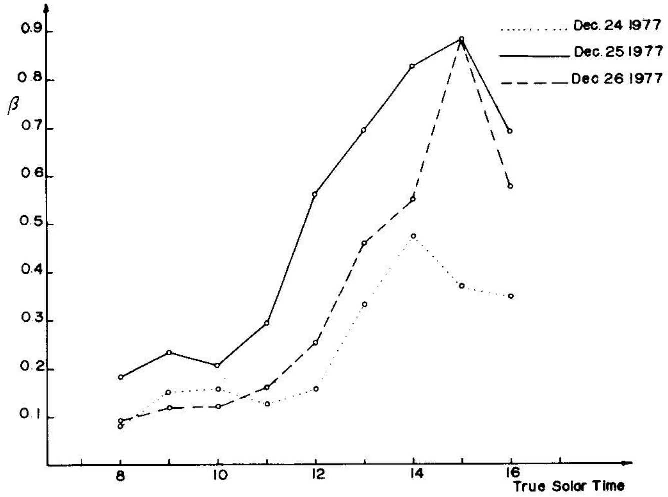

Fig. 2 Diurnal variation of atmospheric turbidity computed from measurements of solar radiation made at the University City campus.

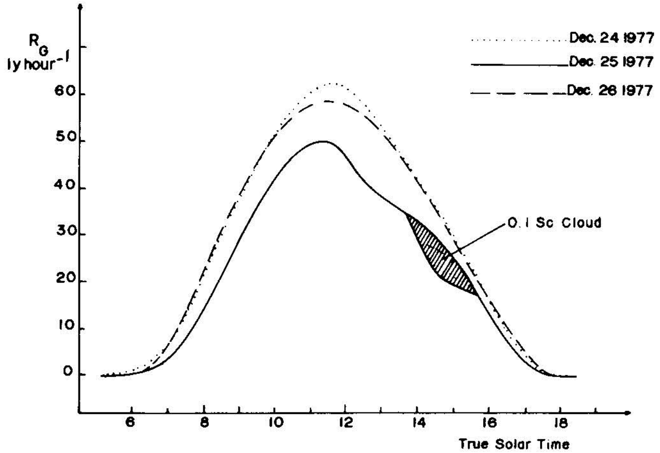

Fig. 3 Measured total downward solar radiation at the University City campus with calibrated Kipp & Zonen pyranometers.

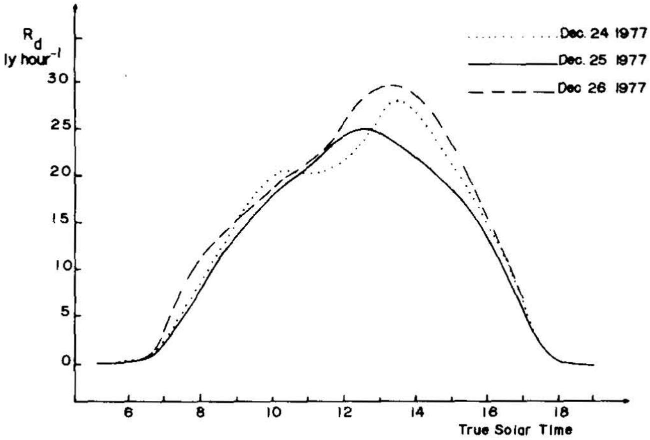

Fig. 4 Measured diffuse radiation at the University City campus with calibrated Kipp & Zonen pyranometer with shading ring.

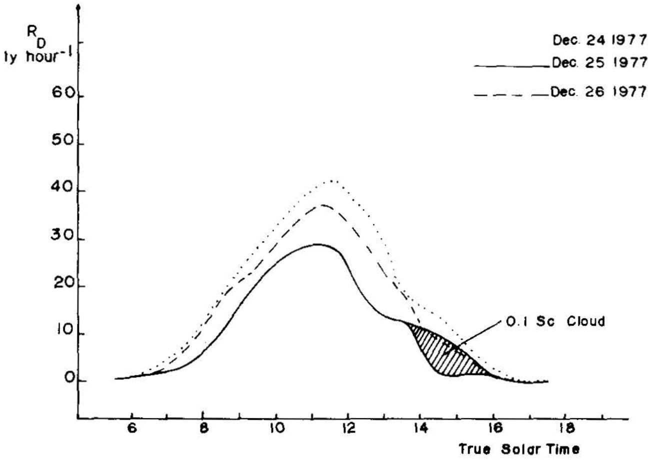

Fig. 5 Computed direct solar radiation from the data of Figures 3 and 4.

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