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Calculation and measurements of infrared radiation at the surface

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RESUMEN

Datos de radiación infrarroja en superficie para el periodo de 1980 a 1987, obtenidos por el Observatorio de Radiación Solar del Instituto de Geofísica de la Universidad Nacional Autónoma de México, se analizan con la ayuda de modelos empíricos y teórico para la transferencia de radiación de onda larga. Los resultados del modelo teórico y las medidas concuerdan para los años de 1980-1982. Para los años posteriores existen diferencias entre los cálculos y los datos que se incrementan año con año. Estos resultados indican que las medidas no son confiables de mediados de 1982 en adelante ya que no existen causas físicas para un crecimiento monótono de la radiación infrarroja a partir de 1982.

Usando los datos confiables hemos ajustado la fórmula de Swinbank para diferentes estaciones (ciudad de México), utilizando diferentes constantes. Esto permite una mejor determinación de los flujos en superficie.

Con estas fórmulas empíricas y teóricas hemos corregido los datos para todo el periodo. La anomalía de 1982, 1983 (año de El Chichón y El Niño) se hace patente.

ABSTRACT

Infrared radiation data for the period 1980-1987 obtained at the Solar Radiation Observatory of the Institute of Geophysics of the National University of Mexico, is analyzed with the help of empirical and theoretical models for the transfer of long wave radiation. Model results and measurements agree for the years of 1980-1982. For later years there are differences between calculations and data, increasing year after year. These results indicate that measurements are not reliable from mid-1982 and on, the reason being that there are no physical causes for a monotonous increase in infrared radiation starting in 1982.

Using the good data we have adjusted Swinbank's formula to different seasons (Mexico City), by using different constants. This allows a better determination of the surface fluxes.

With these empirical and theoretical formulas we have corrected the data, for the whole period. The anomaly of 1982, 1983 (year of El Chichon and El Niño) becomes apparent.

1. Introduction

Long wave radiation has been generally studied from the analysis of night time data and consequently, empirical formulas for its prediction are based on measurements made at night. For day-time conditions it is assumed that these formulae are valid. However at night there is a tendency for occurring thermal inversions, emphasizing low atmospheric temperatures close to the surface. Therefore using daytime temperatures may result in the overestimation of the infrared radiation at the surface.

The accuracy of Swinbank's formula

$$F = 5.31 \times 10^{-14}\ T^{6} mWcm^{-2} \tag{1}$$

is remarkable for night time hours but in the early afternoon overestimates the fluxes for the reasons mentioned above.

Measurements of long wave radiation have been made in Mexico on a regular basis since 1980, at the Solar Radiation Observatory of the Geophysics Institute of the National University of Mexico (ORS-UNAM), with an Eppley precision infrared radiometer (PIR). The record data extends to our days and it is complete except for an important interruption from October, 1983 to June, 1984. For the missing data we used the monthly averages of the 7 other years, so that the trend of the whole record is preserved. To our knowledge no previous use of these data has been made, except for the attempt present here. Some sporadic measurements of long wave radiation were carried out by Chavez (1980) with the purpose of checking the accuracy of empirical formulas for infrared fluxes at the surface. Those measurements where carried out at two mexican locations in 1976 and although a correction of the coefficients of the formulas was made, the results indicated just a limited success.

In the present study we review the record data from 1980 to 1987. The original idea was to look for evidence of the presence of two very important phenomena that occurred in that period, namely: the eruption of El Chichon volcano, and El Niño. We thought both events would have atmospheric repercussions. In the first case the injection of volcanic materials in the atmosphere would cause an important change in its aerosol load, which in turn would modify the conditions for both the scattering of solar radiation, and possibly, the absorption and emission of long wave radiation. The increase of scattered radiation (diffuse radiation) has already been reported by Gay *et al.* (1985, 1989), and the modification to the emission of atmospheric radiation is to be discussed presently.

In the case of the El Niño, its presence would possibly be detected by a slight change in the long wave radiation measured at the surface, produced by the temperature increase that accompanied the strong drought of 1982 and 1983 over the Mexican plateau. This effect of El Niño is opposed to the results of theoretical models that, based on the presence of El Chichon cloud in the stratosphere, expect decreases in surface temperature and H_2O concentration and a corresponding decrease in long wave radiation (Vupputuri, 1984).

Again the presence of the El Niño was apparent in the solar global radiation data analyzed by Gay and Conde (1989) in that there was a significant increase in the values of this radiation parameter during the relevant (1982-1983) period of time.

In this paper we were able to accomplish two things. We modified (1) so that we would get a better agreement with our data, obtaining different coefficients for different seasons, which we defined as warm dry, humid, and cold dry. On the other hand, we corrected the long wave radiation data for an apparent linear bias (increasing), probably produced by deterioration of the instrument. From the corrected data some inferences can be drawn regarding our original purpose.

2. Model comparisons

Comparisons of the data with empirical and theoretical models of infrared radiation at the surface were carried out in order to get an idea of their behavior. In the first place we used the solution for the downward flux of the radiative transfer equation in which (Cerni, 1984) broad band models for the transmission of water vapor and carbon dioxide were used. This approach depends on the temperature profile and concentration profiles of the radiatively active gases: water vapor and CO_2. The water vapor and temperature were obtained at standard meteorological levels from vertical soundings at 6 am and 6 pm local time (SARH, 1980-1985); surface values of these parameters came from the ORS-UNAM (private communication). The atmospheric CO_2 was considered to have a constant mixing ratio equal to 4.56×10^{-4} (Manabe and Moller, 1961) corresponding to 320 ppm. The contribution of clouds to long wave radiation at the surface has been analyzed previously by the authors (Conde and Gay, 1986; Conde, 1988) as suggested by Ramanathan (1976) or using the empirical formula proposed by Paltridge and Platt (1976). We used their emissivities, cloud cover and type of clouds, and those given by London (1957), considering seasonal and latitudinal values. In this work we will refer to this contribution only when it might obscure our conclusions related to El Chichon effect.

As a second check we used (1), for it only depends on screen temperature, a rather simple parameter to obtain and because its limitations are rather well known, for example, its tendency to overestimate radiation in the afternoon, the uncertainties in the data corresponding to dawn hours due to dew formation on the instrument's dome (Paltridge, 1970), and variations due to the season of the year.

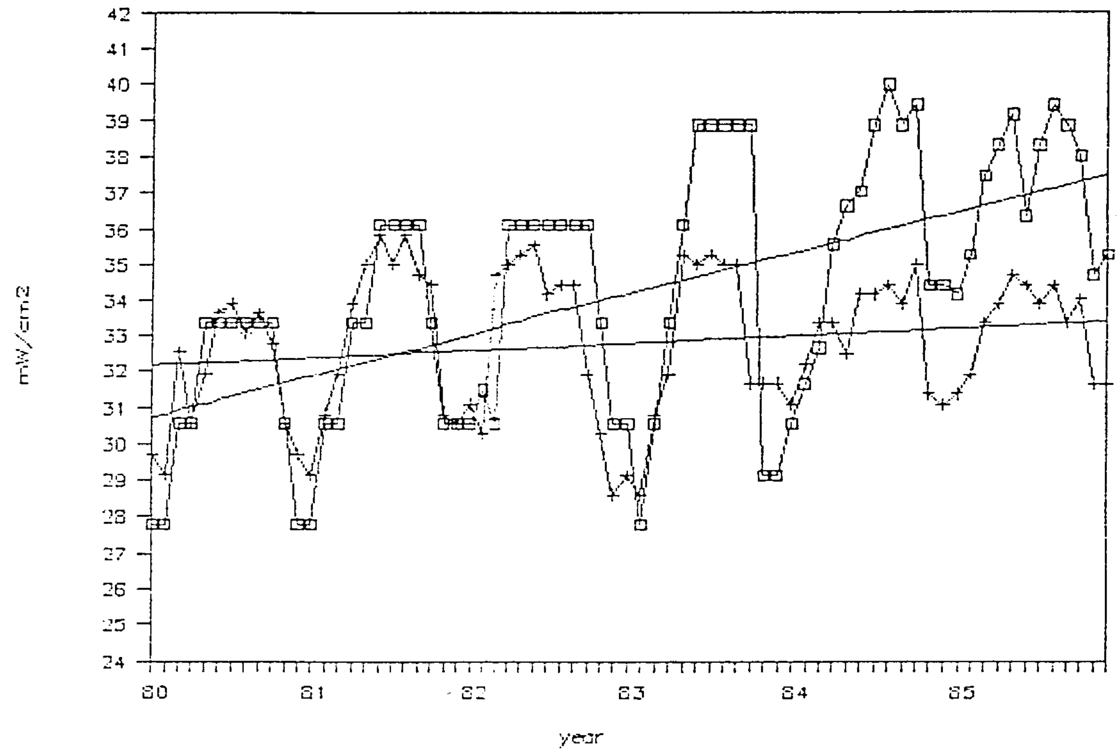

Fig. 1. PIR's data (□) compared with the results for downward long wave radiation at the surface (+) calculated with Cerni's emissivities. The figure shows the different tendencies.

The first comparisons we made were between monthly averages of measured long wave radiation and the results obtained from the theoretical model with Cerni's broad band absorption. In this instance we also used average profiles for temperature, water vapor and the constant mixing ratio already mentioned for CO_2.

Figure 1 shows the monthly averages of the infrared radiation as well as the theoretical results. It is clear that the agreement between the two is very good for the first 2 and a half years becoming worse and worse for later ones. The fact that 1983 shows an apparent increase in the values of the long wave radiation can be expected from the discussion above; but the further increase in the measured values for 1984 and 1985 does not have a physical explanation. This is also shown in the figure by the discrepancy with the theoretical calculations that, although show some increase for 1983, for later years they do not (at least in the same proportion). It can be argued that since our theoretical model includes relevant information (temperature, water vapor, carbon dioxide profiles) but not all, i.e., aerosols, then the differences can be explained by the presence of these which can contribute to the infrared radiation but are not taken into account by the model. This argument might hold for 1983 but does not for 1984 and 1985. The evidence provided by measurements of diffuse radiation indicate that for 1984 and 1985 the amount of scatterers had decreased from the high 1983 values to normal ones (Gay and Conde, 1989). Figure 1 also shows the tendencies of both the calculated values and the unreal one of the measurements. The possibility of the contribution of clouds to the differences in 1983 has been discarded considering

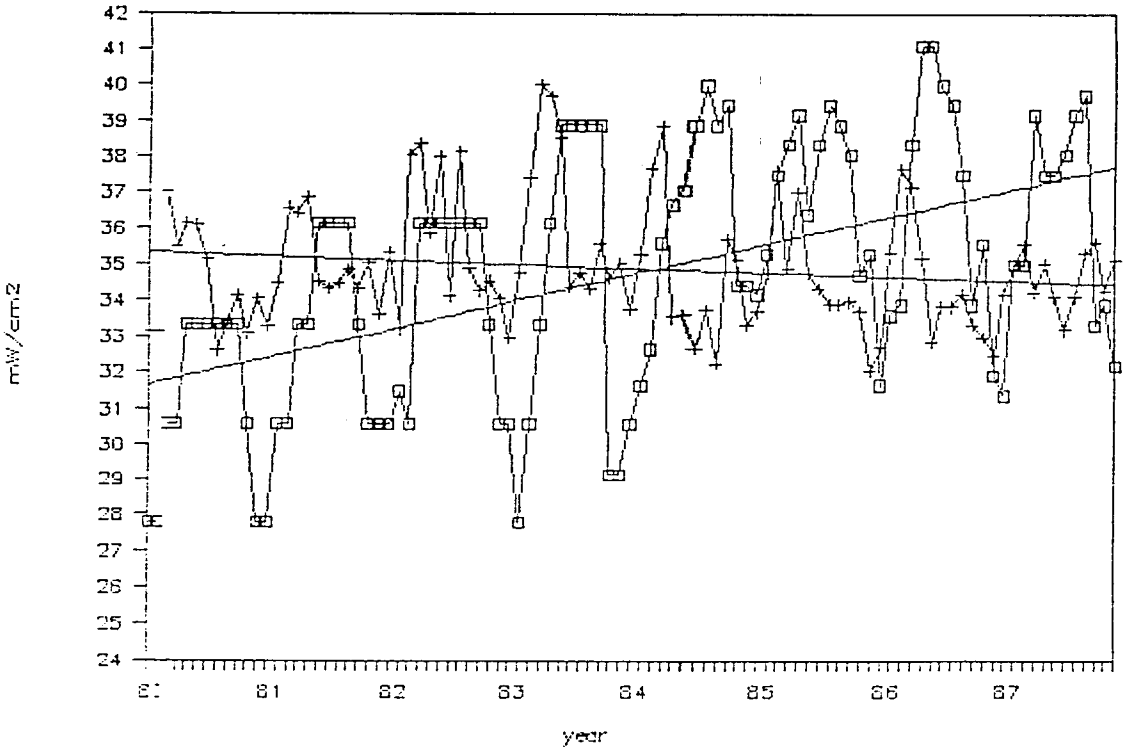

Fig. 2. PIR's data (□) compared to the results using Swinbank's formula (+), with their respective trends. The values of the empirical formula overestimates the data from 1980 to the beginning of 1983. This tendency is inverted for the rest of the record.

the prevailing dry conditions we mentioned before and the very low precipitation for that year (Gay *et al.,* 1985); nevertheless we considered that any cloud contribution must have been lower or equal than $0.05 mW cm^{-2}$ for that year (Conde, 1988). For the other years we have established a possible maximum of $0.12 mW cm^{-2}$, that cannot explain the differences shown in Figure 1.

In order to gain a better understanding of the behavior of the data we made a further comparison. This time we compared the measurements with the infrared fluxes calculated by (1) using monthly averages of surface temperatures. The results are plotted in Fig. 2. Calculated values represent overestimations of measured ones for 1980 to 1983 and undervaluations for the following years. A more careful analysis of the data reveals that although Swinbank's values are larger than the measured, still they fall within the standard deviation of the data for 1980 to 1982. For the following years the situation reverses, having smaller calculated values still within the standard deviation for 1984 and out of this interval for the following years. This last result is very difficult to believe due to the characteristic behavior of (1). The obvious conclusion then is that the data shows an increasing bias that is wrong. The probable reason for this is the constant deterioration of the instrument and the lack of periodic calibration and quality control of the data. We will return later to this point, and propose a correction for the instrument's values.

3. Swinbank's formula

The relative good agreement between data and calculations (both empirical and theoretical) for the first two years of the record provides a convincing argument in favor of the validity of the measurements of long wave radiation taken during this period. It should be emphasize that these comparisons were made using data corresponding to 6 am and 6 pm . This limitation was imposed by the times at which vertical soundings of the atmosphere are taken and provides the input data for the theoretical model.

Due to the practical importance of (1) and the fact that, although within the standard deviation of the measurements, it overestimates more those that correspond to dry months we decided to try an adjustment in order to get a better agreement between data and empirical predictions.

Some time ago Paltridge (1970) assesing the quality of radiation data obtained in Aspendale, Australia, suggested ways for correcting the predictions given by Swinbank's formula. He realized that the discrepancies were different for different seasons and whether they corresponded to daytime or nighttime. Therefore his recommendations were made in the sense of addin and subtracting certain numbers to Swinbank's and using the temperature either at the surface or at around 2 km altitude depending on the season and time of day (Paltridge and Platt, 1976).

In this section we propose instead, the use of the same formula but with different coefficients corresponding to either nighttime or daytime and season (cold and dry, warm and dry, and humid). Figures 3 and 4 show the seasonal averages for surface temperature and humidity for 1980 to 1987, which gave the criterion for the proposed coefficients. The simple method we developed was to obtain the average ratio between the data and the results of (1) for the different seasons and hours mentioned above. As we expected, these constants turn out to be lower than unity in all cases, except for the 6 am humid season. With these results we constructed the new coefficients (Table I) for the adjusted Swinbank's formula. Daytime values for the coefficients were calculated from the measurements corresponding to 6 pm while nighttime values are associated with coefficients

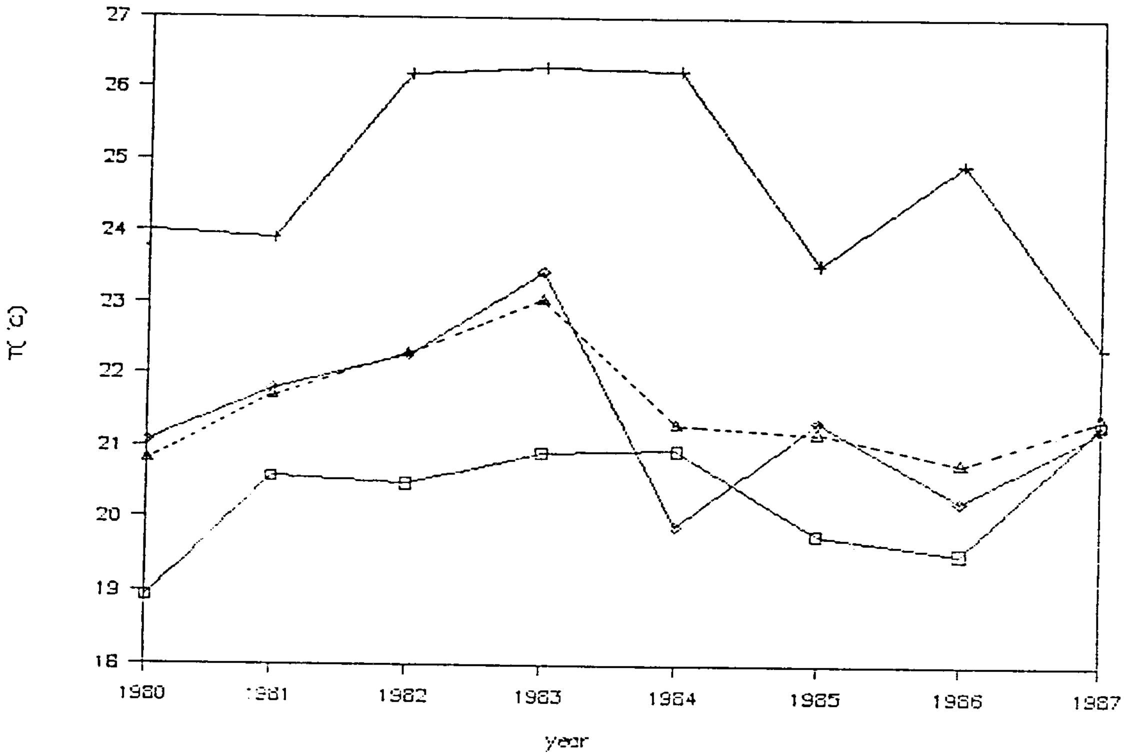

Fig. 3. Annual average of surface temperature (dashed line) for 1980 to 1987. The figure also shows the averages of the proposed seasons: cold dry (□), warm dry (+) and humid (◇).

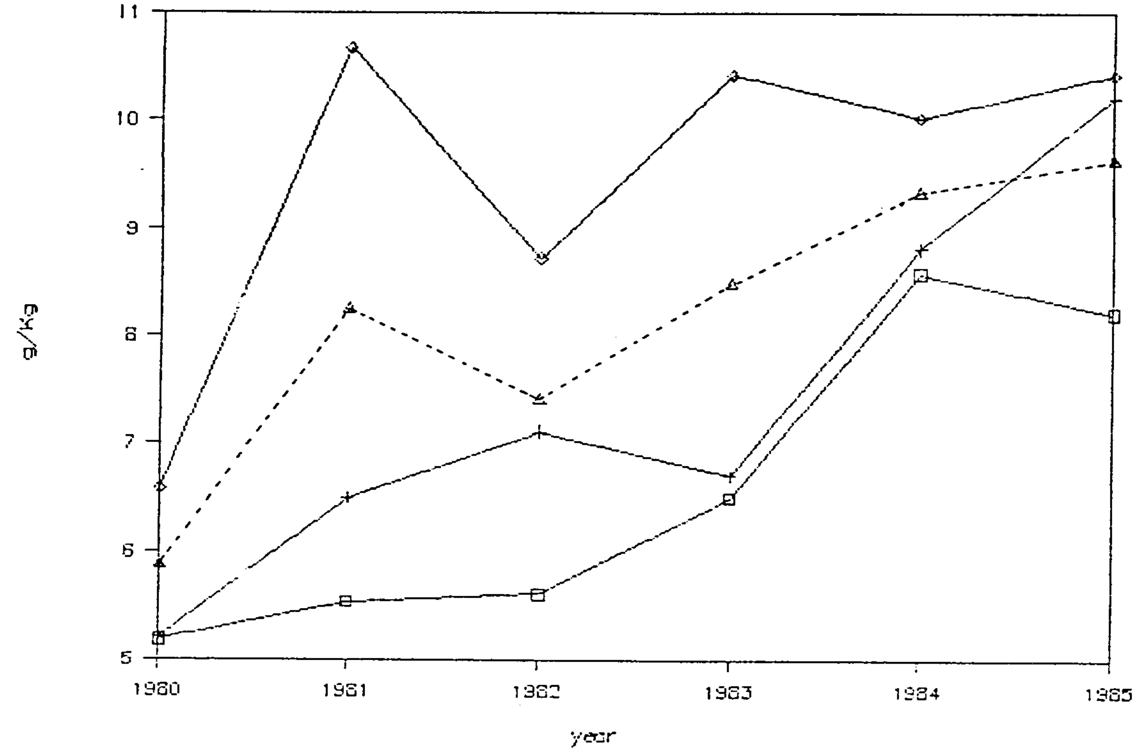

Fig. 4. Annual averaged mixing ratio at the surface for 1980 to 1987 (dashed line). Also shown the same averages for the seasons: cold dry (□), warm dry (+) and humid (◇).

TABLE I. SEASONAL CONSTANTS
($\times 10^{-14}$)

	COLD DRY (Jan, Feb, Nov, Dec)	WARM DRY (Mar, Apr)	HUMID (Jun-Oct)
Swinbank	5.31	5.31	5.31
Adjusted Swinbank 6 pm	(A1) 4.63	(B1) 4.55	(C1) 5.20
Adjusted Swinbank 6 am	(A2) 5.30	(B2) 5.03	(C2) 5.59

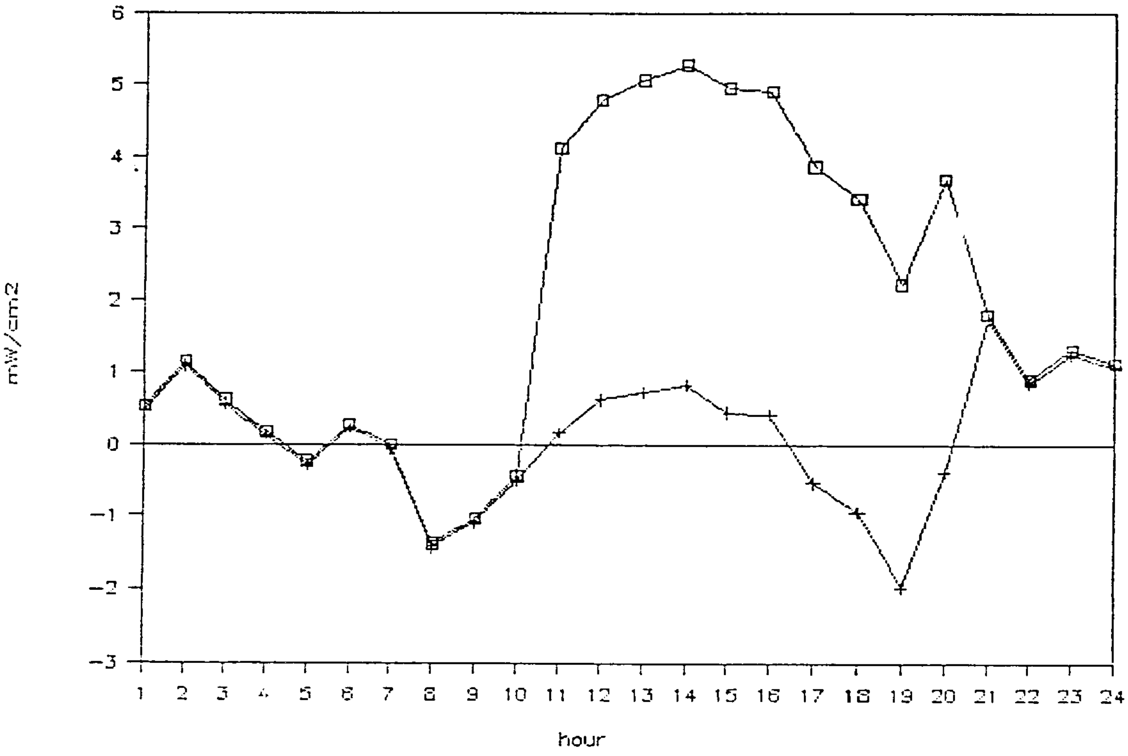

Fig. 5. Differences between Swinbank results and data (□) and our Adjustment minus data (+) for the averaged hourly values in the cold and dry season.

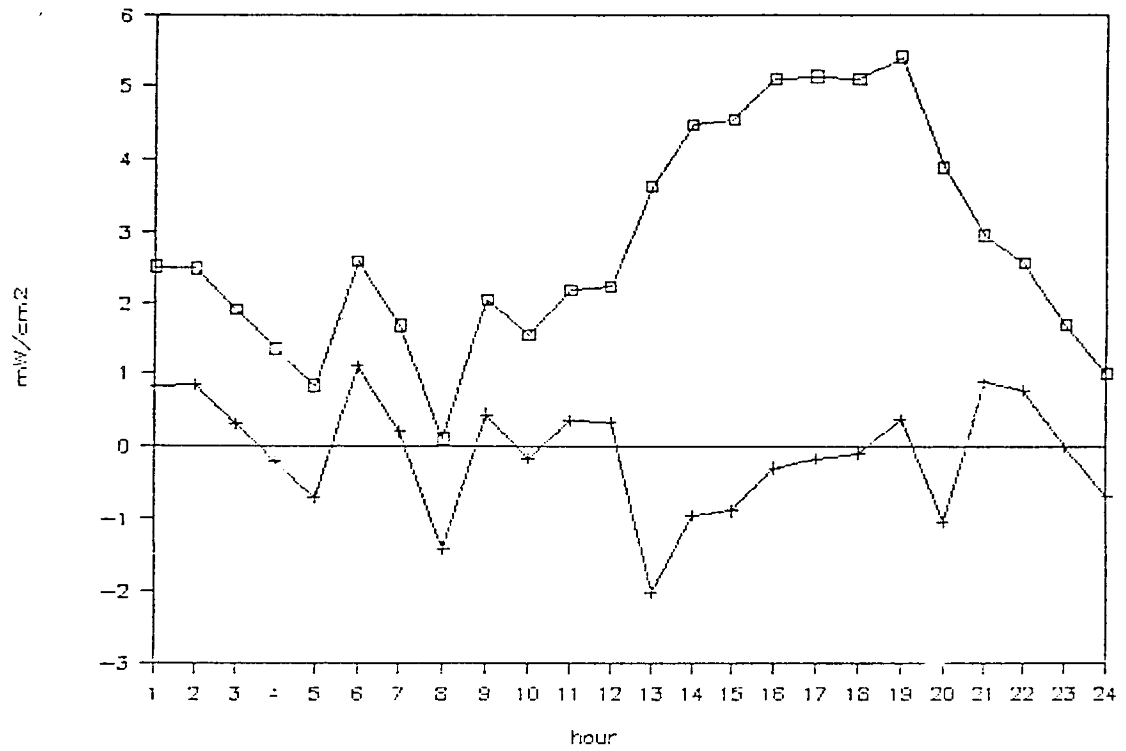

Fig. 6. Same as in Figure 5, but for the warm and dry season.

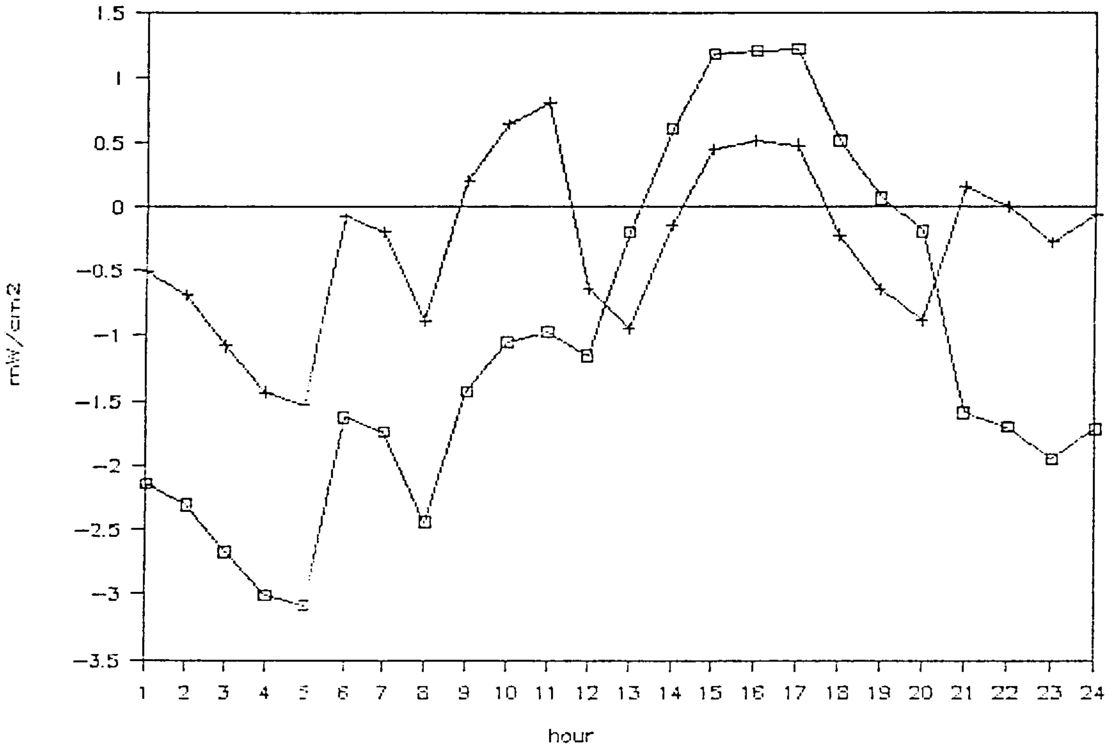

Fig. 7. Same as before, but for the humid season.

calculated from the measurements obtained at 6 am. This is carried out for each season. Figures 5, 6 and 7 show the hourly averaged values for 1980 and 1981 of the differences between the measurements and the results of the calculations obtained using Swinbank's original coefficient and our adjusted ones, in the cases of cold dry, warm dry and humid seasons, respectively. The improvement in the accuracy of the calculations when using the latter coefficients is very clear, especially for daytime data.

4. Proposed correction of the data

Using our theoretical model with the necessary profiles, and Swinbank's adjusted formula with monthly averages of surface temperatures corresponding to 6 pm, we reproduce the monthly values of the infrared fluxes at the surface for the entire period 1980 to 1985. In Fig. 8 we show the results of the calculations. We can see that there is good agreement in general between the two methods although they present different trends. This fact may be explained in terms of their different sensitivities to different parameters; for example, Swinbank's formula dependence on temperature has to be very strong (T^6).

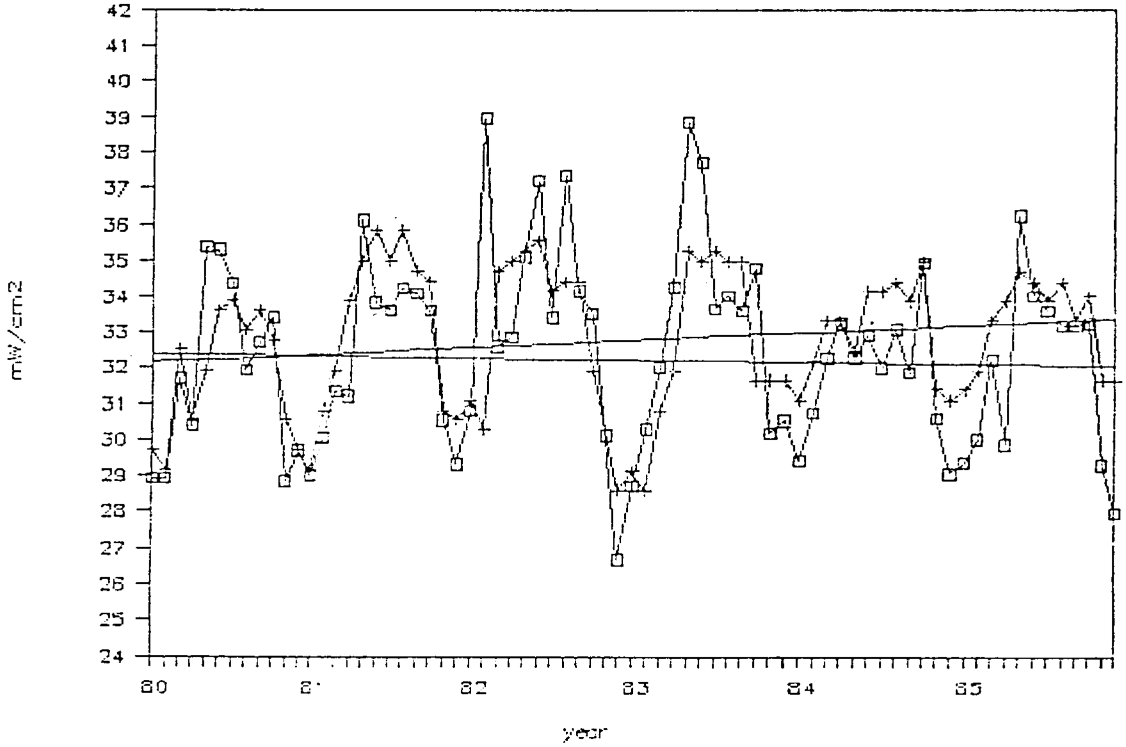

Fig. 8. Comparison of the results for long wave radiation calculated with our adjusted constants for Swinbank's formula (□) and those obtained with Cerni's method (+). The figure also shows the different tendencies.

If the bias present in the radiation data (Fig.1) is linear then we can correct it. Considering that the slope for the data from 1980 to 1987 was $0.064mWcm^{-2}$ per month while, for example, Swinbank's formula (1) predicts a negative slope of $-0.009mWcm^{-2}$, then we can bring data to have Swinbank's slope. To make the correction we have two possibilities, either the correction is made according to the theoretical or to the empirical linear trends. We proceeded in both ways. The results are shown in Figs. 9 and 10 where we plot the corrected instrument's values according to Cerni's and its predicted values and the correction of the experimental values according to the empirical formula's trend and its predictions, respectively. In these figures we show only the calculated values for 1984 since the observational data are either incomplete or unreliable due to their inconsistent behavior as compared with the calculated results. As it could be expected the agreement between the corrected values and the predictions (calculated) becomes much better.

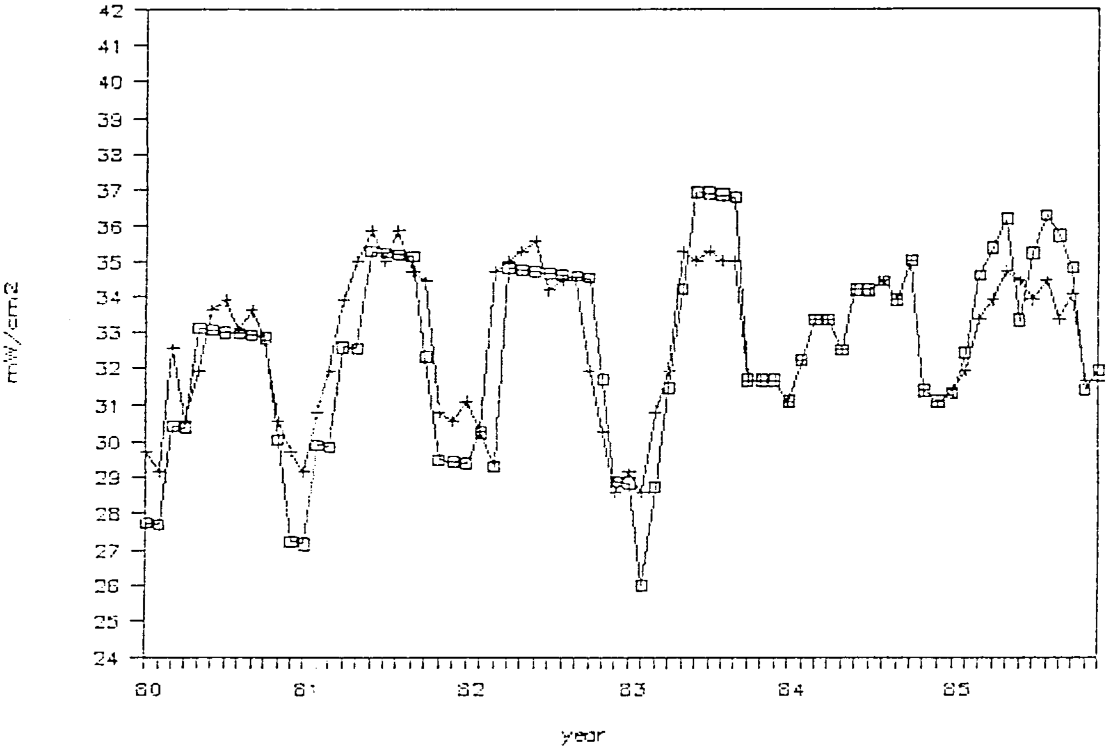

Fig. 9. Instrument's data corrected for the tendency showed by the Cerni's results (□) and compared with those same results (+). (The missing or unreliable data of 1984 are substituted by Cerni's results).

The observation of the corrected data reveals features that were hidden in the original. For one thing, the expected increase in the long wave radiation during the period of El Chichon and El Niño (1982, 1983) appears in the new data with an apparent maximum during 1983. On the other hand, the differences between the calculated values and the data give us some information about the phenomena. For example, the calculated values for 1983 according to Cerni's model underestimate the data. This tells us that the ingredients (water vapor, temperature, carbon dioxide) in the model are not sufficient to explain the measurements. This result is a possible indication of the existence of other radiators in the atmosphere whose contribution would make the difference already mentioned. The most probable candidate being the aerosols of volcanic origin deposited into the atmosphere by the El Chichon.

The differences between predicted values through the adjusted Swinbank's formula and data differ in the opposite way, that is, predicted values overestimate the radiation for 1983. The

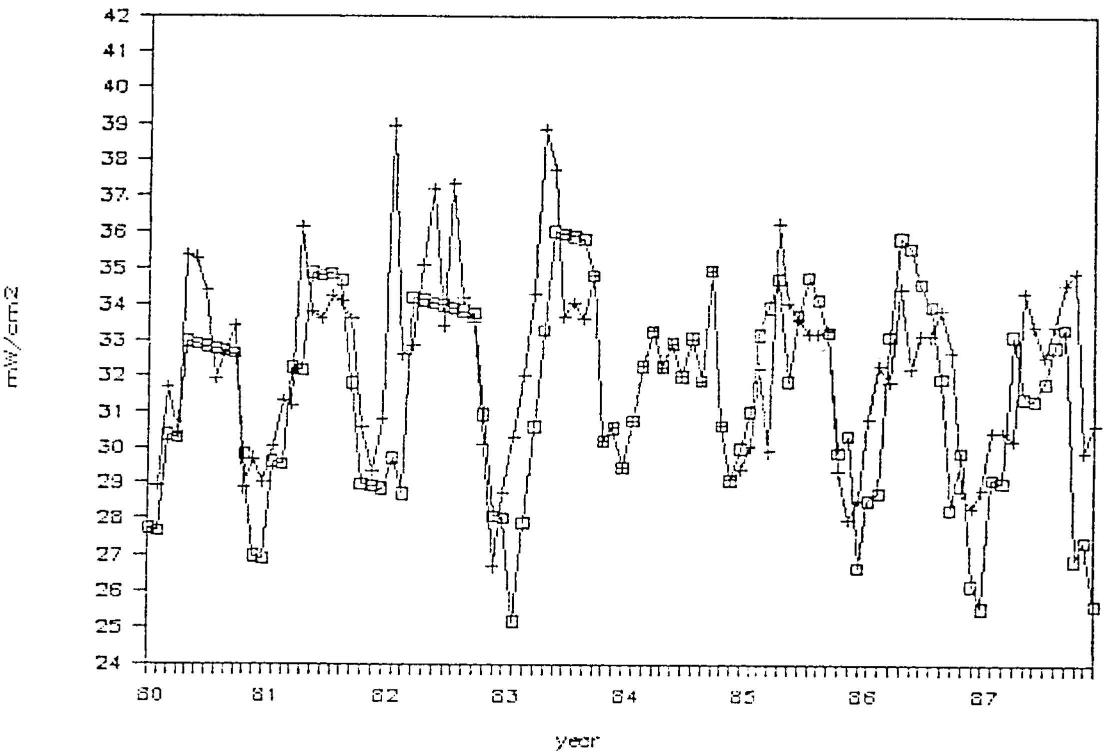

Fig. 10. Data corrected with the tendency showed by our Adjusted Swinbank's formula results (□) and compared with the same results (+). (The missing or unreliable data of 1984 are substituted by our Adjusted values).

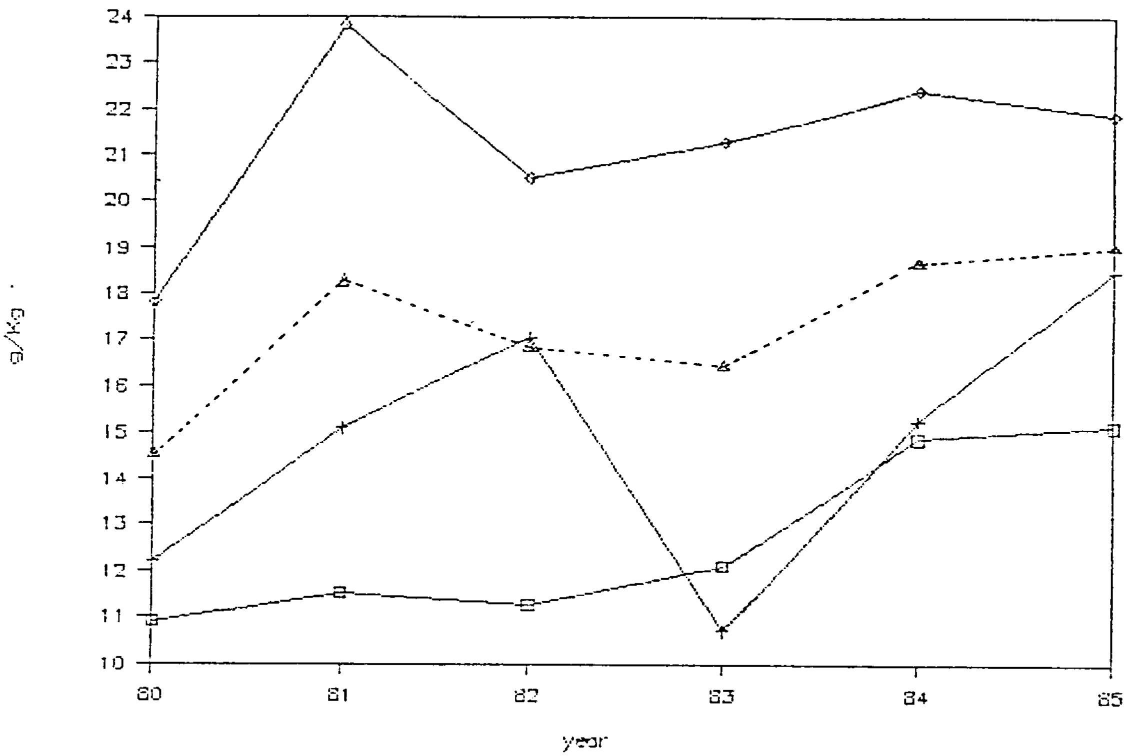

Fig. 11. Sum of the mixing ratios used for Cerni's model. Dashed line indicates the annual average, (□) refers to cold dry season, (+) is for warm dry and (◇) for humid season.

reason resides in the fact that the empirical formula is much more sensitive to temperature alone than the instrument, and in that year (because of El Niño) the surface temperature is the highest of all the record. Also, our Swinbank's adjustment expects "normal" conditions for water vapor concentrations, and in 1983 in the Mexican plateau there was a drought caused, again, by El Niño; this is shown in Fig. 11, where we have the sum of the mixing ratio from the surface to 300 mb, the profile used in Cerni's model. These are also the reasons why in the series predicted by this formula the enhanced radiation during 1983 is more conspicuous.

With the purpose of checking the validity of our empirical formulas we use the temperature and mixing ratio profiles reported by Paltridge (1970) obtained near Aspendale, Australia, and found that our constant for dry and cold (in winter) and dry and warm (in summer) are in better agreement with the theoretical results of Cerni's model (Table II). The criterion for choosing these constants is based on the values of surface temperature (Table II) and of mixing ratio at the surface (6.2 g/kg for summer and 5.0 g/kg for winter), compared with the normal values in Mexico City (Figs. 3 and 4).

TABLE II. PALTRIDGE' S DATA
($mWcm^{-2}$)

	SUMMER (WARM DRY)		WINTER (COLD DRY)	
	MIDDAY	MIDNIGHT	MIDDAY	MIDNIGHT
T(°C)	30.20	17.50	12.50	8.50
Cerni	34.03	30.38	26.96	25.91
Swinbank	41.39	32.02	28.85	26.51
Swinbank Adjustment (Coefficients Table I)	35.46 (B1)	29.19 (B2)	25.16 (A1)	25.36 (A2)

5. Conclusions

Since the data we used were monthly averages (6 am, 6 pm) and no attempt was made to select specific days, this means that the coefficients we propose for use with Swinbank's formula contain information the sky (clouds) than the original formula does not. This is probably reflected in that our values for the 6 pm coefficients are slightly smaller. Therefore our predictions, will be more accurate in an average sense. The differences in the values of the coefficients corresponding to different seasons reflect effects of humidity, more evident between humid and dry than the difference between warm-dry and cold-dry periods. The differences between the 6 pm and 6am coefficients can be interpreted also in terms of the water vapor content of the atmosphere, afternoons are dryer than mornings and therefore the coefficients of the second are greater than the first. Keeping in mind the simple form of (1) we propose to use different coefficients for different conditions the more obvious correspond to humid or dry seasons. For daytime hours we recommend to use the 6 pm constant(s) and during the night the 6 am ones.

Regarding the series of observational data we were able to correct the obvious bias presumably due to the instrument deterioration and detect the changes in the long wave radiation produced during the occurrence of El Chichon and El Niño. From the comparisons of the data with empirical and theoretical models we can infer an increase in the temperature, as reflected by the results according to Swinbank's adjusted formula (more sensitive to temperature) and the presence of radiatively active aerosols of volcanic origin manifested by the difference between the calculations made with the theoretical model and the data corrected with the same model.

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