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Temperature trends at Camaguey, Cuba, after some volcanic eruptions

JUAN CARLOS ANTUÑA, ISMAEL POMARES and RENE ESTEVAN

Estación LIDAR, Centro Meteorológico de Camagüey, Apartado # 134, Camagüey 70100, Cuba

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RESUMEN

Se estudian las tendencias de la temperatura en el curso de los tres años siguientes a las erupciones volcánicas del Agung, El Chichón y Pinatubo, empleando datos de temperatura media mensual de cuatro estaciones meteorológicas del Polígono Meteorológico de Camagüey (PMC). Se encontró una tendencia decreciente para la temperatura media mensual después de estas erupciones. En general las tendencias en los tres años posteriores a cada una de ellas presentan diferencias estadísticamente significativas a un nivel del 99,5% respecto a las tendencias para todo el período, revelando el efecto de enfriamiento que ocasionaron tales erupciones. También en los casos de Agung y El Chichón las tendencias fueron significativamente diferentes, a un nivel del 90%, respecto a la tendencia nula. Las diferencias en el enfriamiento ocasionado por el Pinatubo con respecto a los ocasionados por El Chichón y Agung se explican por las particularidades del movimiento de la nube estratosférica del primero, que tuvo lugar en una época del año diferente a los otros dos. La evaluación de las anomalías de temperatura registradas en el PMC en el año siguiente a la erupción muestran un enfriamiento más intenso que el que se registró en el Hemisferio Norte como un todo, reforzando la hipótesis de una respuesta particularmente acentuada del PMC, y probablemente para una isla como Cuba, ante el apantallamiento de la radiación solar por aerosoles estratosféricos, que resulta del particular aislamiento térmico debido a la notable diferencia entre las capacidades caloríficas de la superficie terrestre y del mar.

ABSTRACT

Temperature trends in the three years following the volcanic eruptions of Agung, El Chichón and Pinatubo are studied, employing monthly mean temperature data from four meteorological stations of the Meteorological Poligon of Camagüey (PMC). A descendent tendency was found for monthly mean temperature following those eruptions. In general the trends in the three years following the eruptions are different, at a significative level of 99.5%, from the trends of the entire data periods, revealing the cooling effects of those eruptions. Also in the Agung and El Chichón case the trends were significatively different at a 90% level, from the null trends. Different cooling effects between Pinatubo eruption and Agung and El Chichón eruptions are explained by the particularities of the movement of the stratospheric aerosols plume of the first, occasioned by the different epochs of the year in wich Pinatubo erupted respect to Agung and El Chichón. The evaluation of the temperature anomalies registered in the PMC in the year following the eruptions show a most intense cooling than in the Northern Hemisphere as a whole, reinforcing the hypothesis of the particular acentuate response of the PMC and probably for an island as Cuba to the shadowing of solar radiation by stratospheric aerosols, as result of its particular thermal insulation occasioned by the notable difference between the thermal capacities of the land and sea.

1. Introduction

In the context of the actual efforts to understand the forcing mechanisms of climate at different time and scale levels, the studies of volcanic aerosols effects play an important role. Althought it had been recognized, the main efforts have been taken place in long term global scale and only few and scarce studies in finner time-space scale. One of the reasons for that situation may be the difficulty mean identify volcanic effects at those levels due to other competing climate variations (Robock, 1991). In the author's opinion, the particular thermal insulation features of islands and its limited areal extent could permit to study the volcanic impact in finner scales.

A previous article reported local effects over the monthly mean temperature and sunshine in the Meteorological Poligon of Camagüey (PMC), an area of 14 000 Km^2, with four meteorological stations, located in the east region of Cuba island. The temperature anomaly was in the order of - 1.0 °C and for the sunshine was - 1.7 hours, for may 1982, a month after the El Chichón eruption, at the arrival time of the stratospheric cloud over the Caribbean. No other possible causes of those anomalies, than the suddenly reduction of the incoming solar radiation, was found (Antuña *et al.*, 1994).

An hypotesis was enuntiated to explain such pronounced anomalies. It was sustained in the notable difference between the thermal capacities of the land and sea. That phenomenon occasioned a critical thermal insulation for islands, that is not present in similar areas embedded in continental regions. Those reasons permited to explain the different facts that presented mexican stations during May 1982 (Galindo *et al.*, 1984) although they are located in the same latitude band of the Cuban stations analyzed (Antuña *et al.*, 1994). In the present paper new evidences are shown reinforcing such hypothesis.

One of the statistical procedures used for solving the problem of climate change detection in the last years is the linear trend detection (Sneyers, 1992). Here we report the effects found in the trends of the monthly mean temperatures for the same region than the previous paper, for the three years following the volcanic eruptions of Agung (March, 1963), El Chichón (April, 1982) and Mt. Pinatubo (June, 1991).

2. Materials and methods

Monthly mean temperature data series from four meteorological stations of the PMC were completed as large as data were available. The station record periods are listed in Table 1, showing practically a quasinormal period for all of them. Five observations in the course of the day were available: 12:00, 15:00, 18:00, 21:00 and 00:00 UT.

Table 1. Station record data.

Station	Begin	End	Years	Latitude	Longitude
Camagüey	1/1963	6/1994	31	21° 24' N	77° 51' E
Nuevitas	1/1964	6/1994	30	21° 34' N	77° 15' E
Florida	1/1967	6/1994	27	21° 30' N	78° 15' E
Esmeralda	1/1967	6/1994	27	21° 51' N	78° 03' E

In order to select the volcanic eruptions, the Dust Veil Index (DVI) (Lamb, 1970; Robock and Mao, 1992) was examined for tropical eruptions in the period of available data. As a result three eruptions with DVI > 500 were selected: Agung (8 °S), El Chichón (17 °N) and Pinatubo (15 °N).

Quality of monthly mean temperature series was evaluated. For every station at every hour, monthly averages and standard deviations were calculated for the entire record period. Values of the monthly mean temperature out of the range of two standard deviation, for the corresponding month, were recalculated from the original daily data and the erroneous ones corrected. Finally homogenity of every data serie was tested, employing the Runs Test. All the series were homogeneous with no less than 97.5% level of significance.

A three years period (36 months) following the month of the eruption was selected as temporal analysis unit, because for a composite of three eruptions including Mt. Agung and El Chichón was found a substantial cooling (0.33 °C), during the 3 years after the composite event (Mass and Portman, 1989).

At each station, for every hour the least squares fit was done for the subseries of monthly mean temperature from the 3 years values (36 months) after every one eruption and for the entire series, including the former subseries. For Agung it was possible to do it only in the case of Camagüey station. The hypotesis of the differences between the slope of every subserie and the null slope were tested, using the t-Student test, at the significant level of 90%. The hypotesis of the equality of the slopes of the 3 years periods following the eruptions and the general trends for every station and hour were tested too, with the same test, at the 99.5% significance level.

3. Results and Discussion

Table 2 shows the slopes of the complete series of monthly mean temperature for the four stations at the five hours, which will be called hereafter "general trends". It will be used for comparison purposes. Note the general warming tendency, that will be discussed in details in a forthcoming paper (Antuña and Rivero, 1995). In the next Tables 3, 4 and 5, slopes of the 36 months monthly mean temperature subseries, following eruptions of Agung, El Chichón and Pinatubo are shown. The cases in wich the null hypotesis for the slopes, at the 90% significance, was rejected, are marked with an asterisc (*).

Table 2. Slopes (°C/month) from the least squares fit to the mean monthly temperatures for the complete series, for every station and hour. Slopes signed with an asterisc (*) are significative different (at 90% level) from the null slope.

Hour (UT)	Camaguey	Nuevitas	Florida	Esmeralda
12:00	0.0025 *	0.0022 *	0.0044 *	0.0025 *
15:00	- 0.0003	0.0038 *	0.0006	0.0011
18:00	- 0.0005	0.0062 *	0.0012	0.0005
21:00	0.0002	0.0059 *	0.0018 *	0.0009
00:00	0.0026 *	0.0027 *	0.0031 *	0.0019 *

Table 3 shows a negative trend of monthly mean temperature for all the hours for Camagüey station, the only one available for the time of occurrence of Agung eruption. It is possible to appreciate that in general the slopes are significatively different from zero, with the exception of the hour 00:00 UT. If we compare with the general trends for the same station, Table 2, it is evident the changes of the signs of the slopes except at 15:00 and 18:00 UT, but yet in these cases, the decreasing tendencies are reinforced. Other important feature is that the absolute

values of the slopes for the post Agung period are at least one order of magnitude bigger than the absolute values of the slopes for the general trends. Moreover, there is a difference between the slopes of the monthly mean temperature subseries for Agung and the slopes of the monthly mean temperature general trends, significative at 99.5% at least, for all the hours.

Table 3. Slopes (°C/month) from the least squares fit to the mean monthly temperatures for the 36 months following the Agung eruption, for every station and hour. Slopes signed with an asterisc (*) are significative different (at 90% level) from the null slope.

Hour (UT)	Camaguey
12:00	- 0.0618 *
15:00	- 0.0511 *
18:00	- 0.0492 *
21:00	- 0.0421 *
00:00	- 0.0277

Similar features may be observed for the post El Chichón monthly mean temperature trends, Table 4. It is shown that all the slopes, for all the stations at every hours, are different from zero with a 90% of significance. Also the slopes behavior, show descendent tendencies for monthly mean temperature, with absolute values one order of magnitude bigger, at least, than the corresponding slopes for the general trend. The slopes of the 36 months monthly mean temperature subseries following El Chichón are all different from the monthly mean temperature general trends at the 99.5% of significance.

Table 4. Slopes (°C/month) from the least squares fit to the mean monthly temperatures for the 36 months following the El Chichón eruption, for every station and hour. Slopes signed with an asterisc (*) are significative different (at 90% level) from the null slope.

Hour (UT)	Camaguey	Nuevitas	Florida	Esmeralda
12:00	- 0.0754 *	- 0.0566 *	- 0.0783 *	- 0.0993 *
15:00	- 0.0682 *	- 0.0643 *	- 0.0537 *	- 0.0564 *
18:00	- 0.0626 *	- 0.0628 *	- 0.0464 *	- 0.0713 *
21:00	- 0.0568 *	- 0.0555 *	- 0.0360 *	- 0.0661 *
00:00	- 0.0589 *	- 0.0558 *	- 0.0493 *	- 0.0792 *

The common observed behavior for Agung and El Chichón cases, in the significant differences between the slopes of the monthly mean temperatures for the post eruptions periods and the general trends as such as between the first and the null slope is a relevant fact. If in the Agung case the availability of only one station monthly mean temperature data set limitates the possible inferences about the effects in more than one point on the study region, in El Chichón case, the presence of effects over the monthly mean temperature in the 3 years following the eruption at scale of PMC, at least, is evident. The general warming tendency in a period quasinormal (27

to 31 years), was reverted to a heavier homogeneous cooling trend in the period of three years following El Chichón in the area of the PMC and in the case of Agung at least in one point of it. Such cooling trend is at least one order of magnitude bigger (in absolute values) than the general trends.

The Pinatubo case shows particularities with respect to the formers. The monthly mean temperature tendency is not totally homogeneous. Table 5 shows, with exception of the slopes for Florida and Camagüey stations at 21:00 UT, descendent trends of the monthly mean temperatures, in the same order of magnitude than for post Agung and El Chichón periods, but with lesser absolutes values. It is notable the fact of not significative differences between the slopes for post Pinatubo period and the null slopes, at the 90% significance level, for all the cases.

Table 5. Slopes (°C/month) from the least squares fit to the mean monthly temperatures for the 36 months following the Pinatubo eruption, for every station and hour. Any slope is significatively different from the null slope at 90% significance level.

Hour (UT)	Camagüey	Nuevitas	Florida	Esmeralda
12:00	- 0.0334	- 0.0266	- 0.0325	- 0.0362
15:00	- 0.0328	- 0.0106	- 0.0248	- 0.0254
18:00	- 0.0103	- 0.0165	- 0.0099	- 0.0144
21:00	0.0027	- 0.0182	0.0131	- 0.0016
00:00	- 0.0141	- 0.0108	- 0.0116	- 0.0121

The results of the test of the hypothesis for the differences between the slopes for post Pinatubo period and the general trends show a significative difference for all the cases, with the exception of Esmeralda at 21:00 UT, as was found for post Agung and El Chichón periods, showing again the cooling effect.

For ilustrative purposes Figures 1, 2 and 3 show the courses and trends of the monthly mean temperatures for Camagüey station, corresponding to the 36 months following Agung, El Chichón and Pinatubo eruptions respectively for two selected hours (12:00 and 18:00 UT). In all of them are clearly shown the descendent tendency of the trends, but in particular Pinatubo lower trends are evident as was discussed before.

So far, the cooling effects are evident in the three cases studied if we consider the significative statistical differences between the slopes of the monthly mean temperatures in the post eruption periods and the general trend as such as the changes in the sign of the trends. It is reasonable to attribute such phenomena to the reduction of the incoming solar radiation by the stratospheric aerosol clouds from those eruptions, that have been documented by many authors (DeLuisi *et al.*, 1977; De Luisi *et al.*, 1983; CDN, 1992).

The low cooling effect of Pinatubo contradicts the fact that this eruption injected around three times the amount of SO_2 in the stratosphere than El Chichón and consequently atributed a DVI of 1 000, while the DVI values for El Chichón and for Agung were 800 (Robock and Mao, 1992). We can try to explain such contradictory fact as result of a most intense reduction of the incoming solar radiation of Agung and El Chichón than Pinatubo over the north-tropical latitude band wich includes the island of Cuba. In that sense the first two take place in a different epoch of the year than Pinatubo, and consequently there are many differences in the movement

and dispersion of stratospheric aerosols plume. El Chichón plume was confined to the north tropical zone between 10 and 30 °N, with very little latitudinal motion (Robock and Matson, 1983). The Mt. Pinatubo plume straddled to the equator, between 10 °S and 20 °N (Bluth *et al*, 1992). Such different motion of the Pinatubo plume, with respect to Agung and El Chichón plumes, have been explained as a result of the different phases of the Quasi-Bienal Oscillation QBO), between the month of the Pinatubo eruption and the months of both El Chichón and Agung eruptions.

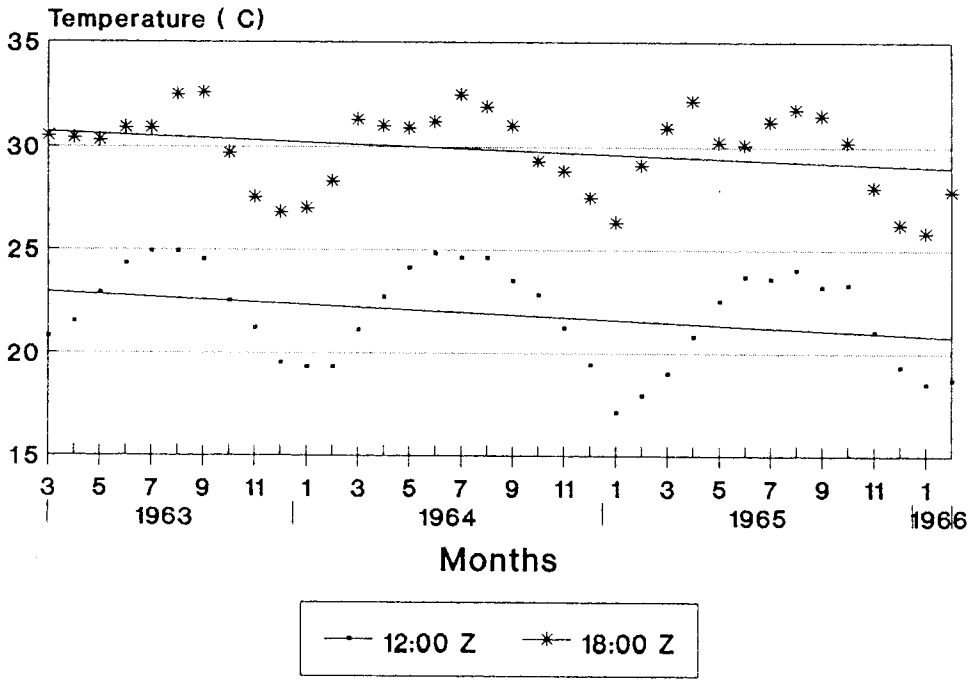

Fig. 1. Monthly mean temperatures course in the 36 months following the Mt. Agung eruption, at 12:00 and 18:00 UT. Trends line for every hour is shown.

Measurements taken during the NASA airborne mission to the Caribbean, in July 1991, reveal that the Pinatubo plume in the tropical zone was highly variable both in structure and in strength. Peak scattering ratios of 3 were found north of 20 °N in lidar profiles, at the time that south to 15 °N peak scattering ratios were typically greater than 10 (Winker and Osborn, 1992). In the same mission spectral optical depths maximun values were observed around 10 °N, south of the Pinatubo, indicating the initial stratospheric trajectory of the volcanic plume (Valero and Pilewskie, 1992).

Other important elements to understand the lesser effects of Pinatubo eruption than those of El Chichón over the PMC are Mauna Loa Observatory measurements (19.53 °N - 155.58 °W). Lidar station reported integrated backscatter values of $4 \cdot 10^{-3}$ sr^{-1} for the first months of the Pinatubo cloud and $5 \cdot 10^{-3}$ sr^{-1} for the same period of El Chichón. Also the Pinatubo plume was generally below 26 or 27 km and El Chichón plume observed in mid 1982 was as high as 30 km for the upper part of the plume (DeFoor *et al.*, 1992). Measurements of atmospheric transmission of direct solar radiation for Pinatubo reaches maximun values of around 0.77 and for El Chichón, 0.82 (CDN, 1992).

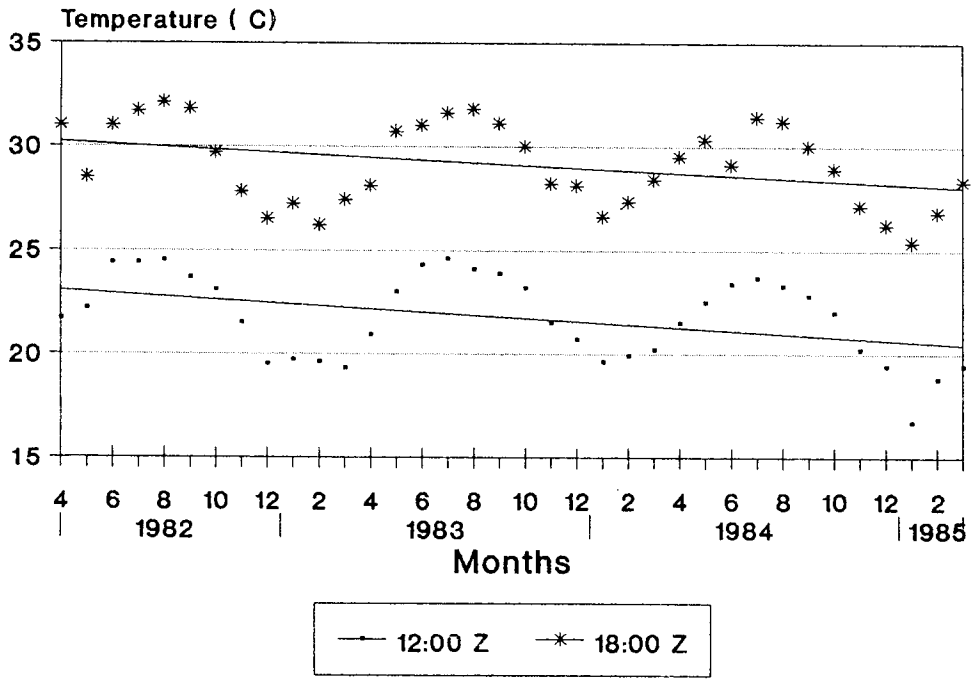

Fig. 2. Monthly mean temperatures course in the 36 months following the El Chichón eruption, at 12:00 and 18:00 UT. Trends line for every hour is shown.

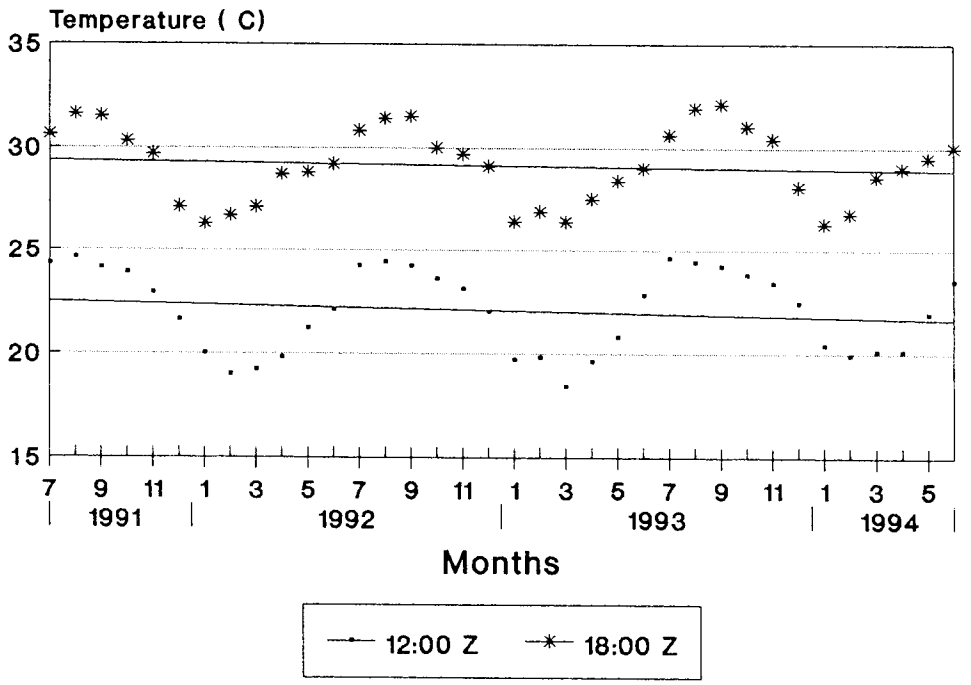

Fig. 3. Monthly mean temperatures course in the 36 months following the Mt. Pinatubo eruption, at 12:00 and 18:00 UT. Trends line for every hour is shown.

The Pinatubo plume facts shown in the mentioned measurements, taken in the tropical zone, permit to explain the little effect of such plume in comparison with El Chichón and Agung. In the latitudinal band in which Cuba is located, the Pinatubo plume was weaker than El Chichón and consequently its effects on solar radiation reaching the surface were weaker too, as the atmospheric transmission measurements reveal at Mauna Loa, located in the above mentioned latitudinal band.

For comparisons with effects reported in literature, an estimation of the effects of every eruption over the monthly mean temperature, at the end of the first year following the eruption date was obtained. As it was expected effects from Agung and El Chichón are close, with cooling of - 0.6 °C and - 0.7 °C respectively. In the Pinatubo case the cooling was - 0.2 °C. In both the first cases, the values are around two orders of magnitude larger than the values reported by Self and colaborators. They employed the set of the eight largest volcanic eruptions in the period 1800 to 1977, including Agung eruption. Yearly mean surface temperature deviations for more than 1500 Northern Hemisphere stations were composed and show a Northern Hemisphere drop of 0.25 to 0.27 °C for the first year following the eruptions (Self *et al.*, 1981).

Self and colaborators reported too, in the mentioned paper, the yearly mean surface temperature deviation for the year following Agung eruption in the entire Northern Hemisphere. It resulted in a drop of - 0.2 °C, three orders of magnitude lesser than the value reported in the present paper. Those comparisons give us important elements to reinforce our hypotesys of the particular acentuate response of the PMC region to stratospheric aerosols attenuation of solar radiation that authors consider may be extrapolated to the island of Cuba as a whole (Antuña *et al.*, 1994).

The fact that the cooling following the eruptions resulted significant statistically different from the general warming trends for the last 30 years period in the PMC, reveals the potentiality of the greatest volcanic eruptions to force the climate in the region studied (and potentially in our island) in opposite direction to greenhouse gases, at least in the three years following eruptions.

The interrelation between the magnitude of the cooling and the particularities of the portion of the stratospheric plume in the latitudinal band in which Cuba is located, permit to reinforce the solar radiation shadowing as the main influence mechanism of stratospheric aerosols on the monthly mean temperature in the PMC in particular, and to extrapolate it to Cuba in general.

New studies are in course using monthly mean temperature data from meteorological stations located along Cuba, that will permit to validate the hypothesis of the representativeness of PMC with respect to the island as a whole.

4. Conclusions

Cooling effects of the three biggest tropical volcanic eruptions of the last three decades are established for an oriental portion of the island of Cuba. It has been established the potentiality of the biggest volcanic eruptions to force the climate in the PMC in opposite direction to greenhouse gases at least in the three years following eruptions. New evidences have been found to reinforce the hypothesis of particular island responses to solar radiation shadowing and about the high magnitude of it.

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REFERENCES

Antuña, J. C., I. Pérez y D. Marín, 1994. Efecto de los aerosoles estratosféricos de la erupción de El Chichón sobre la temperatura en superficie para el PMC. *Atmósfera*, Vol.**7**, No. 4, pp. 241 - 247 .

Antuña, J. C. and R. Rivero, 1995. Warming trend observed in Camagüey, Cuba. (In preparation.)

Bluth, G. J. S., S. D. Doiron, C. C. Schnetzler, A. J. Krueger and L. S. Walter, 1992. Global tracking of the SO_2 clouds from June, 1991 Mount Pinatubo eruptions. *Geophys. Res. Lett.*, Vol. **9**, No. 2, pp. 151-154.

CDN, 1992. Climate Diagnostics Bulletin. US National Meteorological Center. NOAA, Climate Analysis Center, No. 92/9, 71 pp.

DeFoor, T., E. Robinson and S. Ryan, 1992. Early lidar observations of the June 1991 Pinatubo eruption plume at Mauna Loa Observatory, Hawaii. *Geophys. Res. Lett.*, **19**, 187-190.

DeLuisi, J. J., and B. M. Herman, 1977. Estimation of solar radiation absorption by volcanic stratospheric aerosols from Agung using surface based stations. *J. Geophys. Res.*, **82**, 3477-3480.

DeLuisi, J. J., E. G. Dutton, K. L. Coulson, T. E. DeFoor and B. G. Mendonca, 1983. On some radiatives features of the El Chichón volcanic stratospheric dust cloud and cloud of unknown origin observed at Mauna Loa. *J. Geophys. Res.*, **88**, 6769-6772.

Galindo I., J. A. Otaola and G. Centeno, 1984. Atmospheric impact of the volcanic eruptions of El Chichón over Mexico. *Geofís. Int.*, **23**, 373 - 383.

Lamb, H. H., 1970. Volcanic dust in the atmosphere; with a chronology and assesment of its meteorological significance. *Phil. Trans. Roy. Soc.*, London, **A266**, 424 - 533.

Mass C. F. and D. A. Portman, 1989. Major volcanic eruptions and climate: A critical evaluation. *J. of Climate*, Vol. **2** No. 6, 566-593

Robock, A. and M. Matson, 1983. Circunglobal transport of the El Chichón volcanic dust cloud. *Science*, Vol. **221**, 195-197.

Robock, A., 1991. The volcanic contribution to climate change in the past 100 years. In "Greenhouse Gas-Induced Climate Change: A Critical Appraisal of Simulation and Observations.", M. E. Schlesinger Ed.) Elsevier, Amsterdam, pp. 429 - 443.

Robock, A. and J. Mao, 1992. Winter warming for large volcanic eruptions. *Geophys. Res. Lett.*, Vol. **19**, pp. 2405 - 2408.

Self, S., M. R. Rampino and J. J. Barbera, 1981. The possible effects of large 19th and 20th century volcanic eruptions on zonal and hemispheric surface temperatures. *J. Volcanol. Geotherm. Res.*, **11**, 41-60.

Sneyers, R., 1992. Use and missuse of statistical methods for the detection of climate change. Rep. on the Informal Meeting on Statistical Procedures for Climate Change Detection, Annex 3, 6 pp.

Valero, F. and P. Pilewskie, 1992. Latitudinal survey of spectral optical depths of the Pinatubo volcanic cloud-derived particle sizes, columnar mass loading and effects of planetary albedo. *Geophys. Res. Lett.*, **19**, 163-166.

Winker, D. M. and M. T. Osborn, 1992. Airborne lidar observations of the Pinatubo volcanic plume. *Geophys. Res. Lett.*, **19**:167-170.