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EVIDENCE OF THE EL CHICHON STRATOSPHERIC VOLCANIC CLOUD IN NORTHERN GREECE

C. S. ZEREFOS*

RESUMEN

El borde norte de los residuos del SO_2 volcánico lanzado a la estratósfera por El Chichón fue rastreado en Tesalónica (41^oN) desde principios del verano de 1982. La evidencia se basa en mediciones de rutina del SO_2 columnar, hechas con el espectrofotómetro Brewer Mark II fuera de la ciudad de Tesalónica. Tomando en cuenta la contribución de la contaminación troposférica al SO_2 columnar, se espera que alrededor de 2 m-atm-cm del SO_2 columnar pueda atribuirse a la carga estratosférica de origen volcánico.

ABSTRACT

The northern edge of the remnants of the volcanic SO_2 thrown into the stratosphere by El Chichón was traced at Thessaloniki (41 deg. north) since early summer, 1982. The evidence is based on routine measurements of columnar SO_2 made with the Brewer Mark II spectrophotometer outside the city of Thessaloniki. Allowing for the contribution of tropospheric pollution to the columnar SO_2 it is expected that about 2 m-atm-cm of columnar SO_2 may be attributed to the stratospheric load of volcanic origin.

* *Physics Dept., Univ. of Thessaloniki, Campus Box 149, Thessaloniki, GREECE.*

INTRODUCTION

The giant cloud thrown in the stratosphere by the El Chichón volcanic eruption (17.33°N) in April 1982 has been observed from various places of the northern hemisphere such as over the U. S. and Canada (McCormick, Hofmann and Rosen, this issue, and J. Kerr, AES, Canada, private communication) in Europe (Jäger *et al.*, and Fiocco *el al.*, Lefrère *et al.*, this issue) and Japan (Hirono *et al.*, this issue). Also instrumentation on board Nimbus - 7 provided global information on the spatial distribution and evolution of the stratospheric aerosol and the columnar SO_2 amounts of volcanic origin (McCormick, this issue, Krueger, 1983, Heath *et al.*, 1983). The cloud is a mixture of dust, sulfur gases and sulfuric acid which provided spectacular sun appearances in various places (Brooks and Schaaf, this issue) including Thessaloniki, Greece in early October, 1982.

Droplets of sulfuric acid may remain in the stratosphere for several months cooling the troposphere by reflecting sunlight and warming the stratosphere by absorbing IR radiation from the earth (Quiroz, this issue, Sear and Kelly, 1983).

This study presents independent evidence on the arrival and evolution of the El Chichón SO_2 cloud over Thessaloniki, Greece (41°N) from spectrophotometric UV measurements.

EXPERIMENTAL RESULTS

A programme for monitoring columnar ozone and SO_2 on a routine basis from Thessaloniki airport started in April, 1982. The observatory site is about 10 km south of the city of Thessaloniki (600.000 inhabitants) and measurements are made with a commercial Brewer Mark II spectrophotometer developed by the Atmospheric Environment Service (AES) in Toronto.

The Brewer spectrophotometer measures the intensity of light in the UV absorption spectrum of ozone at five wavelengths with a resolution of 0.6nm: 306.3nm, 310.1nm, 313.5nm, 316.8nm and 320.1nm. In this spectral interval, SO_2 has also strong and variable absorption which is a maximum at the first wavelength and decreases considerably at the other Brewer wavelengths.

The measured intensity of direct sunlight at each of the five wavelengths is also a function of the columnar amounts of O_3 and SO_2 and may be written as:

$$\log I_\lambda = \log I_{o\lambda} - \beta_\lambda m - \delta_\lambda \sec\vartheta - \alpha_\lambda O_3 \mu - \alpha'_\lambda SO_2 \mu' \qquad (1)$$

in which I_λ and $I_{o\lambda}$ the measured UV monochromatic intensities at the instrument and outside the atmosphere, β_λ and δ_λ the Rayleigh and particulate scattering coefficients at λ, α_λ and α'_λ the O_3 and SO_2 absorption coefficients at λ, μ and μ' the corresponding enhancement of the solar path through O_3 and SO_2, m the number of atmospheres along the incident light path and ϑ the solar zenith angle.

The light intensity measurements given in equation (1) may be combined to give suitable algorithms which provide reliable estimates of the columnar ozone and SO_2 (Kerr *et al.*, 1980). These algorithms and intercalibration of the spectrophotometer in comparison with the Brewer prototype were done at AES (March, 1982 and August, 1983).

Having at hand routine measurements of the columnar SO_2 an attempt is made to estimate the columnar SO_2 above the lowest atmospheric layer mixed by turbulence which is usually limited by a temperature inversion. For that purpose, ground-level urban SO_2 was routinely measured near downtown at the University Campus which, together with measurements of the meteorological mixing height (from preliminary radiosonde release) can give estimates of the urban columnar SO_2. If $(SO_2)_z$ is the concentration of SO_2 at height z and h the mixing height, the right hand side of equation (2) gives the columnar SO_2 in the mixing layer:

$$h(SO_2) = \int_0^h (SO_2)_z \, dz \qquad (2)$$

The Brewer spectrophotometer measures the total SO_2 column which is the sum of the tropospheric and stratospheric SO_2 columns. The difference between the total columnar SO_2 and the columnar SO_2 in the mixed layer will give the residual SO_2 column above the mixing height:

$$(SO_2) \text{ above mix. height} = \int_0^\infty (SO_2)_z \, dz - \int_0^h (SO_2)_z \, dz \qquad (3)$$

Although in a given situation SO_2 may be present in the troposphere above a low temperature inversion, we shall consider in the following that the residual SO_2 column above the mixing height is only a function of the stratospheric SO_2 column. This unrealistic assumption is supported by a few measurements of tropospheric SO_2 made with aircraft ascents up to a height of 4 km above sea level. These measurements have shown negligible SO_2 amounts in the free troposphere above about the 2 km height (less than 2 ppb). It should be pointed out here that the SO_2 spectrophotometric measurements are done near local noon at which time the mixing height during the summer season may be as high as 2 km or more.

Figure 1 shows the columnar SO_2 in m-atm-cm above the mixing height from May through November, 1982. Dots are based on daily average urban SO_2 and small circles on simultaneous urban and total SO_2 columnar measurements.

From Figure 1 we can make a tentative estimate of the stratospheric SO_2 column by allowing 1 m-atm-cm to represent the columnar average SO_2 background in the free troposphere. Under this assumption the (assumed of volcanic origin) stratospheric SO_2 column shows peak values during the summer months which range from 1 up to 3 m-atm-cm. The denser part of the SO_2 cloud appears to have passed over Thessaloniki in mid July. In July 1982 the sulfate debris from El Chichón had already reached 75°N at altitudes of 15 and 17 km (Mroz *et al.*, this issue).

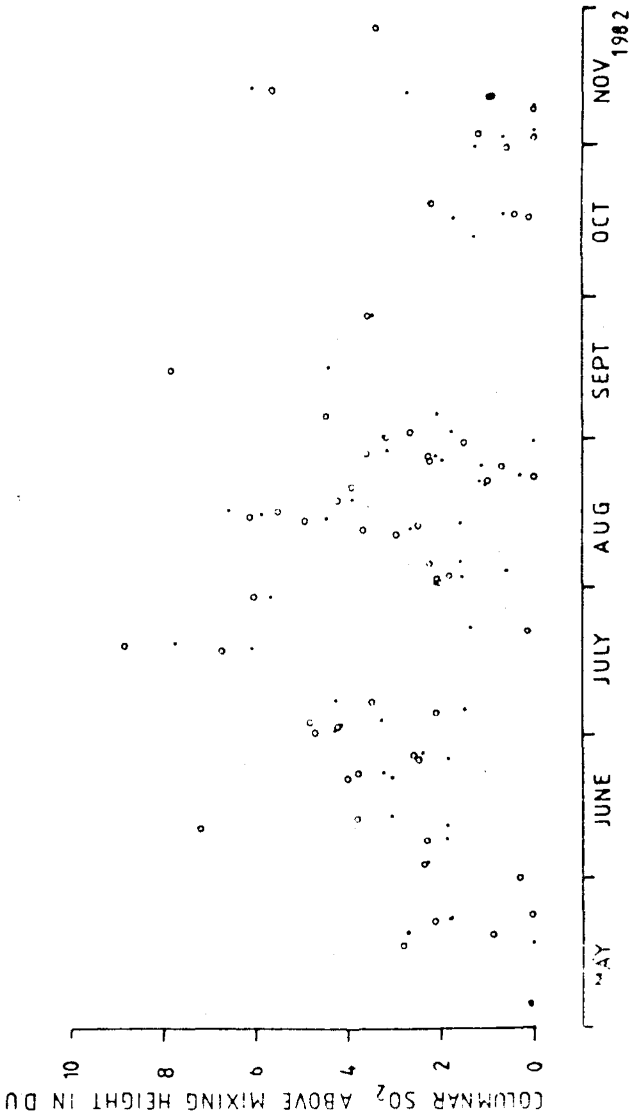

Fig. 1. Estimates of the SO_2 column in m-atm-cm (D.U.) above the mixing height during the period from May through November 1982. The SO_2 column in the mixed layer has been removed from the total amount as daily average (dots) and as simultaneous-same hour measurements (open circles).

DISCUSSION AND CONCLUSIONS

Krueger (1983) showed that stratospheric SO_2 from El Chichón caused a spectral interference with the measurements of the Total Ozone Mapping Spectrometer (TOMS) on board Nimbus. The interference allowed Krueger to tentatively estimate the total stratospheric SO_2 content which, based on the average columnar amount of 42 m-atm-cm and a cloud area of 2.8×10^6 km^2, amounted to 3.3×10^9 kg on April 6, 1982. About one month later the total stratospheric SO_2 content had decayed by a factor of 2 (Heath *et al.*, 1983). This relatively rapid removal was attributed to its catalytic destruction by OH. Assuming that the same rate of removal continued to operate during the next 4 to 5 months (that is a factor of 2 per month) we can tentatively estimate the area covered by the volcanic SO_2 cloud in July. Thus in mid-summer the total stratospheric SO_2 content is expected to have decayed by a factor of about 10 or to be about 3.3×10^8 kg. According to our estimate on the columnar stratospheric SO_2 (2 m-atm-cm or 5.7×10^{-5} kg m^{-2}) the total area covered by the cloud is expected to be 5.8×10^{12} m^2 i.e. about double the area covered by the cloud on April 6, 1982 (Krueger, 1983). Estimates of that type may provide useful information on coupled stratospheric chemical and transport processes provided the evolution of the columnar amount and the area covered by the SO_2 cloud is known.

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