*Geophysics of Continental Rifts*, B. Ramberg and E. R. Neumann, Eds. (Reidel, Dordrecht, Netherlands, 1978), p. 401.
16. M. H. P. Bott, *Tectonophysics* **73**, 1 (1981).
17. R. W. Girdler, *ibid.* **94**, 241 (1983).
18. C. A. Wood, *ibid.*, p. 529.
19. L. A. J. Williams, in *Continental and Oceanic Rifts, Geodynamics Series*, G. Palmason, Ed. (American Geophysical Union, Washington, D.C., 1982), vol. 8, p. 193.
20. S. C. Solomon and J. W. Head, *Lunar Planet. Sci.* **15**, 806 (1984).
21. T. Spohn and G. Schubert, *Tectonophysics* **94**, 67 (1983).
22. F. L. Scarf and C. T. Russell, *Geophys. Res. Lett.* **10**, 1192 (1983); L. W. Esposito, *Science* **223**, 1072 (1984).
23. C. A. Wood, *NASA Tech. Memo TM-80339* (1979), p. 244; J. W. Head and L. Wilson, *Lunar Planet. Sci.* **13**, 312 (1982); J. B. Garvin *et al.*, *Icarus* **52**, 354 (1982).
24. G. G. Schaber, *Geophys. Res. Lett.* **9**, 499 (1982).
25. The 2-km resolution is defined in terms of the ambiguity function of the radar system (5). Line pair resolution would be approximately 4 km.
26. We thank the staff of the Arecibo Observatory for assistance in data collection; the National Astronomy and Ionosphere Center is operated by Cornell University under contract with NSF and with support from NASA. Supported in part by NASA grant NGR-40-002-088 to J.W.H.

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## Increased Stratospheric Hydrogen Chloride in the El Chichón Cloud

Abstract. *Spectroscopic observations of the total column amount of hydrogen chloride above an altitude of 12 kilometers in the latitude range 20° to 40°N have been made both before and 3 to 6 months after the eruptions of El Chichón Volcano in March and April 1982. In the region of the cloud of volcanic aerosols, the hydrogen chloride total column after the eruptions increased by approximately 40 percent, even after allowance is made for the global secular increase in hydrogen chloride of 5 percent per year. The column amounts of hydrogen fluoride show no such increase.*

The family of odd-chlorine species, that is, Cl, ClO, HCl, HOCl, and $ClONO_2$, is important in stratospheric chemistry because of the potential of Cl and ClO to catalyze the removal of $O_3$ (*1*). Hydrogen chloride serves both as a temporary reservoir for chlorine, from which Cl can be released by reaction with OH, and as the ultimate sink for stratospheric chlorine by diffusion to the troposphere and rainout. It is believed that the principal source of stratospheric chlorine is diffusion of chlorofluoromethanes from the troposphere (*2*); the discovery of additional natural sources of chlorine in the stratosphere could modify our understanding of the chemistry of the $O_3$ layer.

Recently Mankin and Coffey (*3*) reported spectroscopic measurements of the total column amount of HCl and HF above their 12-km observation height as a function of latitude and time. Data in mid-latitudes, covering 5 years, indicate a rate of increase of stratospheric HCl of about 5 percent per year.

In March and April 1982, there were major eruptions of El Chichón Volcano (17°N, 93°W) in Mexico. The volcano injected large amounts of gas and particles into the lower stratosphere (*4*). A coherent cloud was soon established in a zonal band circling the earth (*5*). There have been numerous reports of ensuing changes in the stratospheric sulfur chemistry (*6*), the aerosol burden (*7*), and the visible and infrared optical depths of the stratosphere (*8*), as well as changes in stratospheric chlorine (*9*) and $NO_2$ (*10*).

In July through October 1982, we observed the infrared transmission spectrum of the stratosphere near the northern edge of the cloud of debris from El Chichón. We flew a high-resolution Fourier-transform spectrometer aboard the National Center for Atmospheric Research Sabreliner jet aircraft to measure the spectrum of sunlight that has passed through the upper atmosphere. Analysis of the absorption spectra allows quantitative determination of the total amount of numerous trace species in the atmosphere above the aircraft. Spectra were recorded from 2.5 to 13 μm with an apodized spectral resolution of 0.06 $cm^{-1}$. The instrumentation and technique are discussed in detail elsewhere (*11*).

By September 1982, the cloud of gas and particles from the volcano had spread zonally around the globe and extended in latitude from 10°S to 35°N, as shown in lidar and satellite observations (*12*). We made two flights in early July 1982 and seven more between 15 September and 1 October 1982. The flights were made along a constant-pressure surface of 198 mbar (~11.9 km altitude) along the paths shown in Fig. 1.

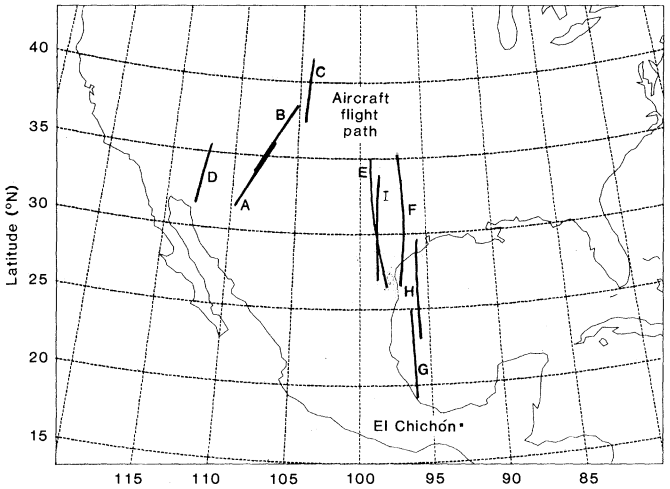


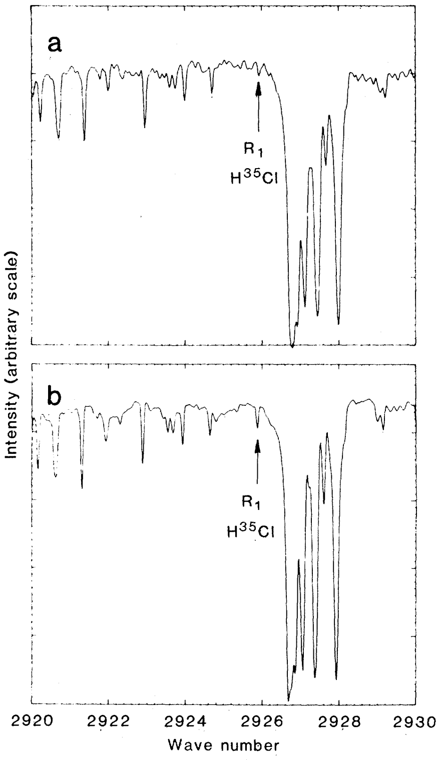
Fig. 1. Map showing the paths of flights made in July through October 1982. Dates for individual flights are given in Table 1. The letter plotted beside each flight path indicates the corresponding entry in Table 1.

Individual spectra were recorded in 6 seconds; spectra were averaged in groups of five or ten to improve the signal-to-noise ratio before analysis. A small portion of one of the averaged spectra is shown in Fig. 2b; a similar spectrum recorded in 1978, before the El Chichón eruptions, is shown in Fig. 2a. The small differences in the spectra are attributable to noise and to a slow wandering of the background level caused by aircraft vibration. The difference in absorption in the HCl line between the two spectra is dramatic. We analyzed the spectra for HCl by comparing the observed spectra with synthetic spectra calculated from the line parameters in the Air Force Geophysics Laboratory compilations (*13*), using the $R_1$ and $R_2$ lines of the $H^{35}Cl$ fundamental band. Other species used in the synthetic spectra include water vapor, $O_3$, and $CH_4$; sulfur gases such as $SO_2$, which might be enhanced in the cloud, do not absorb in this spectral region. The depth of the line in the observed spectrum was compared with the depth of the same line in the calculated spectrum for various amounts of HCl in the calculation. The greatest uncertainty is in the subjective determination of the background level from which to measure the depth. The analysis procedure and the line parameters used were the same as in our earlier work (*3*). The column amounts from different groups of spectra were averaged for an entire flight to improve the accuracy. The uncertainty in the mean was determined from the statistics of the amounts from the different groups. Generally, the statistical uncertainty was smaller than our estimate of the absolute accuracy (about 25 percent) or the relative precision (about 10 percent) of the results because systematic errors are dominant; a further discussion of errors is given in (*3*).

The results from all the 1982 flights are given in Table 1, along with the corresponding results from flights in the same latitude range made before the eruptions. The results are plotted in Fig. 3. There is a marked increase in the HCl column amount between 22°N, our southernmost observation, and 35°N, coincident with optical measurements of the northern limit of the volcanic plume. A measurement near 40°N is in good agreement with the mean column amount at that latitude from earlier years. Measurements made at higher latitudes in July 1982 were also consistent with earlier values. Within the volcanic cloud, there was an HCl increase of 40 percent above the level that would be expected from an extrapolation of the results of earlier measurements to the present epoch. This increase is consistent with the increases between 21 and 27 km observed by Gandrud and Lazrus, who used in situ sampling (*9*). If we assume a uniform increase of 40 percent from 10°S to 35°N, the extent of the cloud as delineated optically (*12*), the total calculated increase in HCl is approximately $0.04 \times 10^6$ metric tons, about 9 percent of the global stratospheric HCl burden. Analysis of the spectra for stratospheric HF showed no significant change, an indication that the HCl increase is due to natural causes and not to chlorofluoromethanes.

Injection of chlorine into the stratosphere by the volcano will increase the stratospheric HCl; on the other hand, the HCl could be changed by modifications of the chemistry in the cloud. If the conversion of $SO_2$ to $H_2SO_4$ aerosol particles consumes OH, the conversion rate of HCl to Cl would be reduced and a larger fraction of the total chlorine would be in the form of HCl. Model calculations, however, indicate that the fraction of the odd chlorine that is in the form of Cl and ClO is not large enough to account for the increase in HCl (*14*). Furthermore, modeling of the sulfur chemistry indicates that, under the conditions of the El Chichón cloud, OH should not be substantially reduced (*15*), although there are uncertainties in the calculations. Therefore, it is likely that the increase is due to the injection of chlorine in some form, gaseous or possibly aerosols, directly into the stratosphere by the volcano.

The enhanced catalytic destruction of $O_3$ by chlorine injected into the stratosphere by El Chichón should reduce the $O_3$ concentration. This reduction may be detected in the tropics by satellite obser-



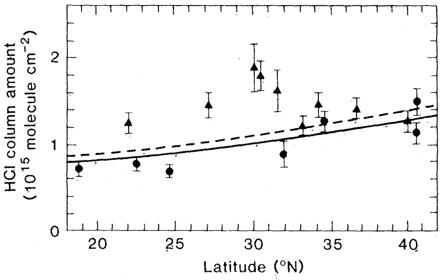


Fig. 2 (left). Comparison of spectra recorded before and after the 1982 eruptions, under similar conditions. (a) Spectrum recorded on 3 July 1978 at an average solar elevation of 9.8° and a latitude of 29.1°N; (b) spectrum recorded on 1 October 1982 at an average elevation of 9.7° and a latitude of 28.4°N. Most of the strong lines are due to absorption by $CH_4$; they are of similar depth in the two spectra. The lines of $H^{35}Cl$ marked $R_1$ show a dramatic increase in absorption. The $R_1$ lines of $H^{37}Cl$ at 2923.73 cm$^{-1}$ are much weaker and are substantially obscured by $CH_4$ absorption. Fig. 3 (right). Comparison of the observed column amount of HCl above 12 km before and after the eruptions of El Chichón in March and April 1982. Circles represent data taken before El Chichón eruptions; triangles, data taken after the eruptions. The solid curve is a fit of data taken at all latitudes before the eruptions. The dashed curve is the result of increasing the values of the solid curve by 10 percent to allow for the increase in HCl from anthropogenic sources in the 2 years between the data sets. The error bars indicate the uncertainty in the mean.

Table 1. Pre- and posteruption data giving the average HCl column for an entire flight. All data recorded since 1978 in the latitude range 18°N to 42°N are reported; the preeruption data are from Mankin and Coffey (*3*); *n* is the number of individual spectra used in the analysis (they were averaged into groups of five to ten before analysis); *A* is the integrated column of HCl above 11.9 km, in units of $10^{15}$ molecules per square centimeter. The quantity *s* is the uncertainty in the mean, determined from the sample standard deviation divided by the square root of the number of groups of spectra analyzed. This uncertainty differs from that reported in (*3*); the uncertainties reported in (*3*) must be multiplied by a factor of 2.7 to be equivalent to the values given here. The uncertainty in the mean represents only the statistical variation; the absolute accuracy is estimated to be ±20 to 25 percent, and the precision is estimated to be ±10 percent.

| Map symbol (Fig. 1) | Date | Latitude (°N) | Longitude (°W) | HCl column | | |
|---|---|---|---|---|---|---|
| | | | | *n* | *A* | *s* |
| | | *Posteruption data* | | | | |
| A | 6 July 1982 | 34.1 | 108.9 | 20 | 1.46 | 0.01 |
| B | 7 July 1982 | 36.6 | 106.5 | 30 | 1.40 | .04 |
| C | 15 September 1982 | 40.0 | 104.3 | 10 | 1.29 | |
| D | 19 September 1982 | 33.0 | 112.5 | 15 | 1.22 | .02 |
| E | 22 September 1982 | 31.4 | 98.7 | 15 | 1.63 | .35 |
| F | 23 September 1982 | 30.0 | 96.8 | 25 | 1.90 | .28 |
| G | 24 September 1982 | 22.0 | 96.1 | 30 | 1.24 | .10 |
| H | 25 September 1982 | 27.1 | 95.8 | 35 | 1.45 | .16 |
| I | 1 October 1982 | 30.6 | 98.8 | 45 | 1.79 | .10 |
| | | *Preeruption data* | | | | |
| | 11 February 1978 | 22.5 | 96.1 | 20 | 0.78 | .07 |
| | 12 February 1978 | 34.4 | 102.4 | 40 | 1.26 | .14 |
| | 24 June 1978 | 18.3 | 92.3 | 40 | 0.75 | .08 |
| | 2 July 1978 | 24.5 | 95.8 | 25 | 0.69 | .05 |
| | 3 July 1978 | 31.7 | 97.5 | 20 | 0.88 | .15 |
| | 11 July 1978 | 40.8 | 108.1 | 10 | 1.56 | |
| | 10 December 1979 | 40.9 | 110.2 | 5 | 1.18 | |

vations, although the interpretation of $O_3$ observations will be difficult because of the number of chemical and radiative effects modified by the volcanic cloud. Stolarski and Cicerone (*1*) originally suggested that the direct injection of chlorine into the stratosphere by volcanoes could result in substantial $O_3$ destruction, but this source of stratospheric chlorine has largely been dismissed in comparison with other sources. The observation that a single, large volcanic event can increase the stratospheric HCl burden by 40 percent over a large part of the globe should lead to a reassessment of the role of volcanoes in stratospheric chlorine chemistry.

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**References and Notes**

1. R. S. Stolarski and R. J. Cicerone, *Can. J. Chem.* **52**, 1610 (1974).
2. R. J. Cicerone, *Rev. Geophys. Space Phys.* **19**, 123 (1981).
3. W. G. Mankin and M. T. Coffey, *J. Geophys. Res.* **88**, 10776 (1983).
4. J. B. Pollack, O. B. Toon, E. F. Danielsen, D. J. Hofmann, J. M. Rosen, *Geophys. Res. Lett.* **10**, 989 (1983).
5. C. A. Barth, R. W. Sanders, R. J. Thomas, G. E. Thomas, B. M. Jakosky, R. A. West, *ibid.*, p. 993.
6. J. F. Vedder, E. P. Condon, E. C. Y. Inn, K. D. Tabor, M. A. Kritz, *ibid.*, p. 1045; W. F. J. Evans and J. B. Kerr, *ibid.*, p. 1049.
7. D. J. Hofmann and J. M. Rosen, *ibid.*, p. 313; M. P. McCormick and T. J. Swissler, *ibid.*, p. 877; J. J. DeLuisi, E. G. Dutton, K. L. Coulson, T. E. DeFoor, B. G. Mendonca, *J. Geophys. Res.* **88**, 6769 (1983).
8. E. Dutton and J. DeLuisi, *Geophys. Res. Lett.* **10**, 1013 (1983); F. C. Witteborn, K. O'Brien, H. W. Crean, J. B. Pollack, K. H. Bilski, *ibid.*, p. 1009.
9. B. Gandrud and A. Lazrus, personal communication.
10. J. Noxon, personal communication.
11. W. G. Mankin, *Opt. Eng.* **17**, 39 (1978).
12. J. B. Pollack, O. B. Toon, E. F. Danielsen, D. J. Hofmann, J. M. Rosen, in (*4*); M. P. McCormick and T. J. Swissler, *ibid.*, p. 877.
13. L. S. Rothman, A. Goldman, J. R. Gillis, R. R. Gamache, H. M. Pickett, R. L. Poynter, N. Husson, A. Chedin, *Appl. Opt.* **22**, 1616 (1983); L. S. Rothman, R. R. Gamache, A. Barbe, A. Goldman, J. R. Gillis, L. R. Brown, R. A. Toth, J.-M. Flaud, C. Camy-Peyret, *ibid.*, p. 2247.
14. R. J. Cicerone, S. Walters, S. C. Liu, *J. Geophys. Res.* **88**, 3647 (1983).
15. S. A. McKeen, S. C. Liu, C. S. Kiang, *ibid* **89**, 4873 (1984).
16. We acknowledge the excellent support by personnel of the National Center for Atmospheric Research Research Aviation Facility which made these observations possible. We also appreciate the communication of research results prior to publication by A. Lazrus and B. Gandrud, by J. Noxon, by S. A. McKeen, S. C. Liu, and C. S. Kiang, and helpful discussions with R. J. Cicerone. The National Center for Atmospheric Research is sponsored by the National Science Foundation.

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# Suramin Protection of T Cells in Vitro Against Infectivity and Cytopathic Effect of HTLV-III

Abstract. *A recently discovered member of the human T-cell leukemia virus (HTLV) family of retroviruses has been etiologically linked to the acquired immune deficiency syndrome (AIDS). This virus, which has been designated HTLV-III, is tropic for OKT4-bearing (helper-inducer) T cells. Moreover, the virus is cytopathic for these cells. Suramin is a drug used in the therapy of Rhodesian trypanosomiasis and onchocerciasis, and it is known to inhibit the reverse transcriptase of a number of retroviruses. Suramin has now been found to block in vitro the infectivity and cytopathic effect of HTLV-III at doses that are clinically attainable in human beings.*

Approximately 3 years ago, an apparently new and unexplained disorder called acquired immune deficiency syndrome (AIDS) was recognized (*1–3*). The disorder is a pandemic immunosuppressive disease that predisposes to life-threatening infections with opportunistic organisms and to certain neoplasms (especially Kaposi's sarcomas and occasionally lymphomas), which may be signs of the underlying immune impairment. Characteristically, AIDS is associated with a progressive depletion of T cells, especially the helper-inducer subset bearing the OKT4 surface marker (*2*). No therapy is known to cure AIDS.

The hypothesis that AIDS is caused by a member of the human T-cell leukemia virus (HTLV) family of retroviruses first received direct empirical support in 1983 (*4, 5*). For example, Essex and Lee and their colleagues discovered the presence of antibodies to cell membrane antigen of HTLV-I–infected T cells in serum samples from more than 40 percent of patients with AIDS (in the most sensitive range of their assay) (*6*). This antigen is now known to be expressed on the envelope of HTLV-I (*7*). At the same time, three observations reinforced the possibility that a then-uncharacterized member of the HTLV family might be playing a role in the pathogenesis of AIDS: (i) The report by Barré-Sinoussi *et al.* (*5*) of a new retrovirus, termed lymphadenopathy-associated virus (LAV), isolated from a homosexual man, who was thought to have a possible prodrome of AIDS. These workers, in the first paper describing their findings, concluded that the new retrovirus belonged in the HTLV family but that it was distinct from the other members then defined. (ii) Detection of AIDS sera containing antibodies to a membrane (HTLV envelope) protein but lacking antibodies to certain internal core structural proteins of HTLV-I and HTLV-II (*4*). (iii) The infrequent isolation of HTLV-I and HTLV-II from AIDS patients, even in the presence of antibodies to HTLV-I envelope determinants (*4*).

In the spring of 1984 several converging lines of investigation linked a cytopathic member of the HTLV family of retroviruses to the pathogenesis of AIDS (*8, 9*). The retrovirus, which is now known to play a role in the etiology of AIDS, is referred to as HTLV-III; this virus preferentially infects and destroys OKT4$^+$ (helper-inducer) T cells (*10*). Detectable viral replication in vivo characterizes the HTLV-III infection seen in AIDS, at least early in the disease. By contrast, only on rare occasions (*11*) has it been possible to detect viral replication in vivo in adult T-cell leukemia, which is caused by HTLV-I, the prototypical member of the HTLV family. The discovery of HTLV-III offers researchers new strategies for the experimental therapy of the disease, including the use of drugs that inhibit reverse transcriptase (*12*).

All retroviruses (including HTLV-III) require the enzyme called reverse transcriptase in their natural cycle of replication (*13*). The reverse transcriptases of retroviruses infecting humans and animals have similar amino acid sequences (*14*). In 1979, de Clercq reported that suramin (molecular weight, 1429)—a drug used to treat Rhodesian trypanosomiasis and onchocerciasis—was a potent competitive inhibitor of the reverse transcriptase of a number of animal retroviruses (*15*). Since the first paper by Gallo and his colleagues describing HTLV-I in adult T-cell leukemia was not published until 1980 (*16*), this finding generated little clinical interest. Moreover, in this human retrovirus–associated disease, a role for an inhibitor of reverse transcriptase is not easy to envision, since the virus induces a monoclonal transformation (*17*). By the time frank malignancy is evident, there would appear to be no further need for viral replication, and therefore, for reverse transcriptase activity, in the disease process. However, the situation in AIDS appears very different. Retroviral infection of many cells appears to be necessary for the development of this disease. Therefore, inhibitors of reverse transcriptase are worth exploring as new modalities of therapy.

We now report that suramin can block the in vitro infectivity of HTLV-III (in