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FOREWORD

This text will be published in the ATLAS 1 Geophysical Research Letters special issue.

AVANT-PROPOS

Ce texte sera publié dans le numéro spécial ATLAS 1 de Geophysical Research Letters special issue.

VOORWOORD

Deze tekst zal in de ATLAS 1 Geophysical Research Letters special issue verschijnen.

VORWORT

Dieser Tekst wird in den ATLAS 1 Geophysical Reserch Letters special issue publiziert werden.

SECOND FLIGHT OF THE SPACELAB GRILLE SPECTROMETER DURING THE ATLAS-1 MISSION

by

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Abstract

The SPACELAB grille spectrometer on its second space flight took advantage of the favorable timeline and of the extra day to perform more than 65 successful solar occultation runs. It succeeded in obtaining spectra pertinent to its ten target molecules in the full range of altitudes available to the solar infrared occultation technique. These ten molecules are H_2O, CO, CO_2, CH_4, NO, NO_2, N_2O, HCl, HF and O_3. A preliminary analysis of an HCl observation is presented showing no significant change of upper atmospheric hydrogen chloride in comparison with previous data.

Résumé

Lors de son second vol, le spectromètre à grille SPACELAB a bénéficié d'un programme d'opération favorable et d'un jour supplémentaire pour observer avec succès au-dessus de 65 occultations. Des données concernant les dix molécules cibles ont été obtenues dans l'intervalle complet des altitudes accessibles à la technique d'occulation infrarouge solaire. Ces dix molécules sont : H_2O, CO, CO_2, CH_4, NO, NO_2, N_2O, HCl, HF et O_3. Une analyse préliminaire d'une observation de HCl est présentée et ne montre pas de changement significatif de l'acide chlohydrique dans l'atmosphère supérieure par rapport aux données antérieures.

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Samenvatting

Tijdens zijn tweede ruimtevlucht heeft de SPACELAB raster-(Grille) spectrometer nuttig gebruik gemaakt van de gunstige timeline en van de toegekende extra dag om gedurende meer dan 65 zonsoccultaties succesvolle waarnemingen te doen. Het instrument slaagde erin atmosferische spectra te registreren met informatie over de 10 beoogde minderheidsgassen, over het volledige hoogtebereik dat haalbaar is met de techniek van infrarood spectrometrie tijdens zonsoccultaties. Deze 10 moleculèn zijn : H_2O, CO, CO_2, CH_4, NO, NO_2, N_2O, HCl, HF en O_3. Een eerste analyse van een waarneming van HCl wordt vastgesteld : ze toont geen beduidende verandering in de hoeveelheid HCl in de hogere stratosfeer, in vergelijking met vroegere gegevens.

Zusammenfassung

Dank dem günstigen Arbeitsplan und dem zusätzlichen Flugtag, ist das Gitterspektrometer in der Lage gewesen, bei seinem zweiten Flug, mehr als 65 Okkultationen zu beobachten. Daten betreffend die zehn untersuchten Moleküle wurden erhalten. Sie beziehen sich auf dem ganzen Höhebbereich wo die Technik der Okkultation der infraroten Sonnenstrahlung anwendbar ist. Die zehn Moleküle sind : H_2O, CO, CO_2, CH_4, NO, N_2O, HCl, HF und O_3. Eine vorläufige Analyse einer HCl Beobachtung wird vorgestellt. Sie zeigt keine bedeutsame Änderung der Konzentration der Chlorsäure in der oberen Atmosphäre im Vergleiche mit früheren Ergebnissen vor.

INTRODUCTION

The purpose of the ATLAS missions, onboard the American Space Shuttle, is to study the evolution of atmospheric properties over an entire solar cycle. The grille spectrometer, which already flew onboard Spacelab-1 and was used for several balloon and airplane observations since 1972, measures vertical concentration profiles of trace gases. It uses the method of infrared absorption spectrometry during sunrise or sunset periods, with the sun as the source of light. The largest amount of absorbing molecules is observed along the optical path through the Earth atmosphere at various tangent altitudes from the stratosphere up to the lower thermosphere, leading to concentration profiles with an instrumental vertical resolution of about 4 km.

This paper gives a balance of the grille spectrometer observations performed during the ATLAS-1 flight, and presents an example of data retrieval. Because of the strong interaction between chlorine and stratospheric ozone, a preliminary analysis of a vertical profile of hydrogen chloride has been chosen.

EXPERIMENT

The grille spectrometer flew for the first time in space (Lemaître et al, 1984) onboard SPACELAB-1, with a launch on November 28, 1983. The flight came up to its objectives (see final review by Girard et al., 1988) despite an orbit entirely sunlit during the last six days of the ten days mission and numerous technical difficulties uncountered for this spacelab test flight. Still, this mission provided an early data base very useful for comparisons with later flights. On the basis of the SPACELAB-1 grille experience, the scientific program (spectral windows, altitude range for each window) was optimized for the ATLAS-1 mission (Camy-Peyret et al., 1992).

During the design of the final ATLAS-1 timeline in the middle of 1991, the ATLAS-1 investigators and the NASA engineers agreed on an attitude timeline divided into solar, plasmas, astronomical and earth observation periods, with the objective of maximizing observation opportunities for the suite of payload instruments. The crew and P.I. teams were extensively trained in procedures designed to overcome possible mission contingencies and to return to the scheduled timeline as soon as possible. The telemetry and telecommand links between the payload and the ground based stations were also greatly improved due to the presence of two relay satellites and a new organization of the NASA Payload Operation Center.

The use of a NASA provided high pressure nitrogen vessel (GN2) for cooling the detectors by Joule-Thomson expansion, and a new procedure against overheating of the instrument electronics consisting of radiative cooling keeping the heliostat open, allowed to run more occultation observations than during the SPACELAB-1 mission. The calibration, performed about four hours after launch, confirmed correct operation of the instrument. After correction of a few target errors due to the launch delay, the observations followed nominally except for the sunrises that were affected by late sun acquisition due to the fact that a wrong positioning of its multi-layer insulation hindered the heliostat from correct pointing. The real-time data quality was good, permitting optimization of the scientific program through uplink of some new spectral windows and new altitude ranges for each window. Emission observations were attempted, but the signal did not allow any reliable analysis : after two trials it was decided to cancel all emission runs in order to save ressources.

Figure 1 shows the geographical distribution of the observations for each species.

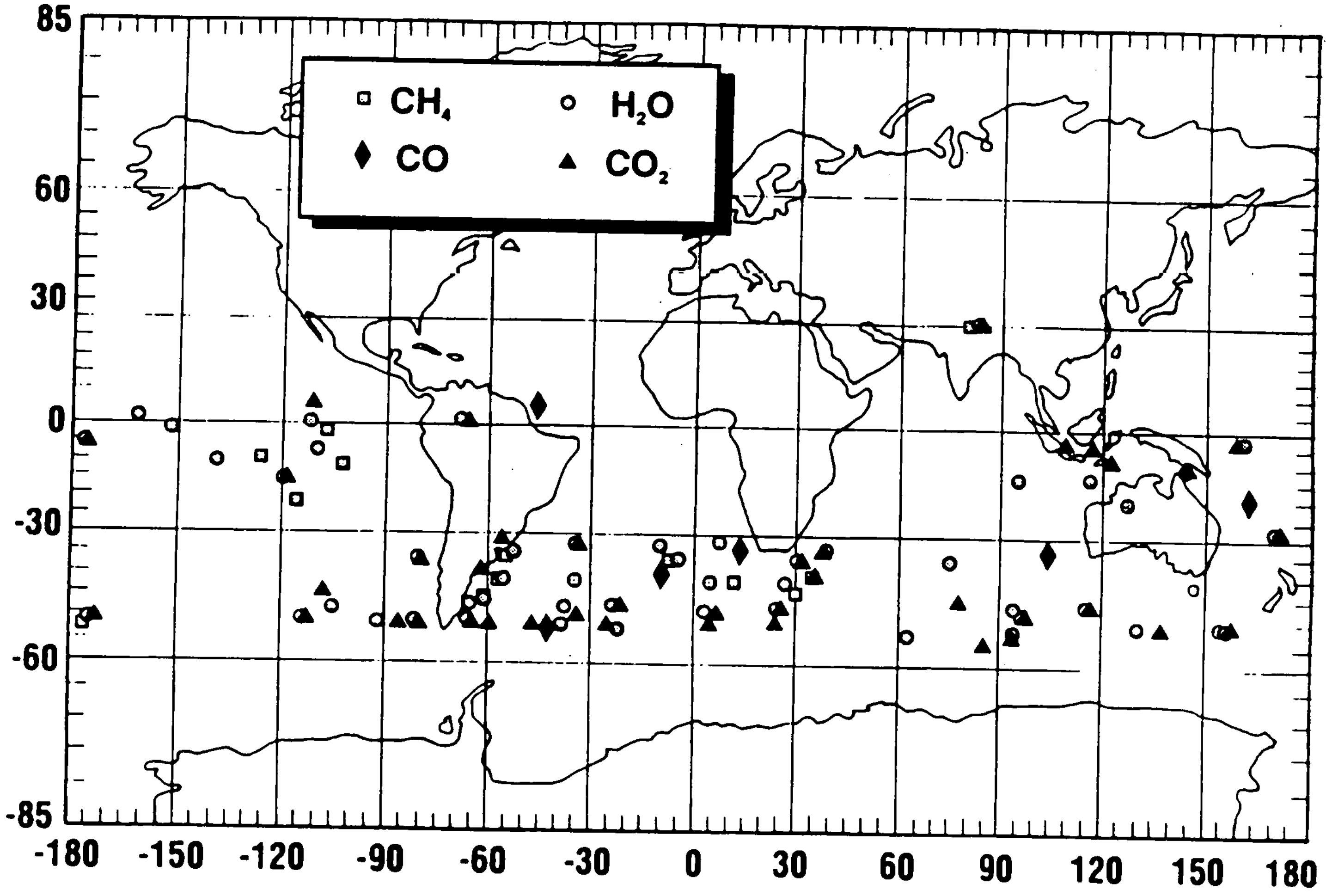

Fig. 1a.- Geographical distribution of trace observations : CH_4, H_2O, CO and CO_2.

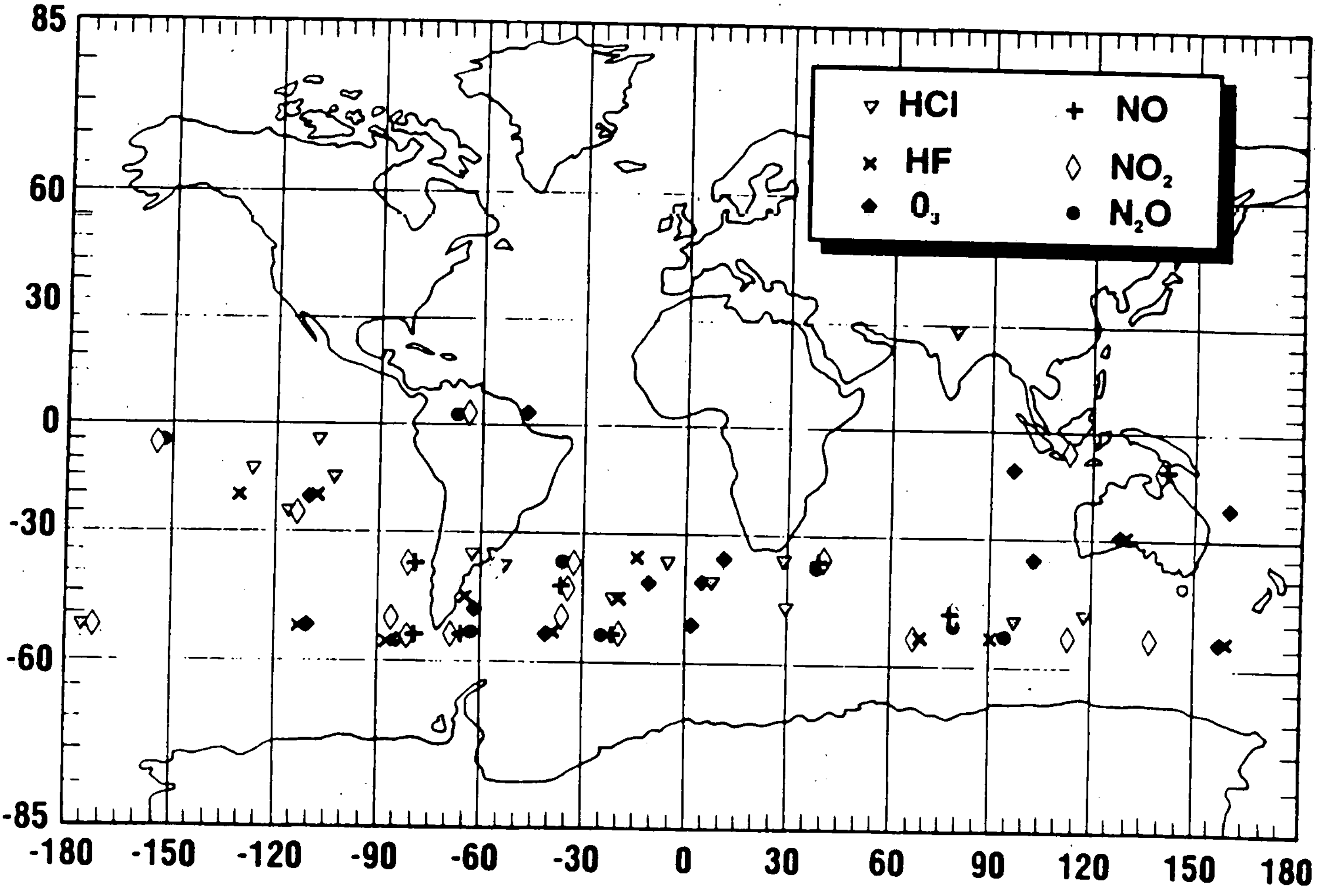

Fig. 1b.- Geographical distribution of trace species observations : HCl, HF, O_3, NO, NO_2 and N_2O.

SAMPLE ANALYSIS

The occultation performed during the sunset in orbit 124 (54°S, 153°E) is chosen as an example of an absorption run because of the importance of hydrogen chloride measurements in the middle atmosphere. In particular, HCl, in the 40 to 50 km altitude range is a good indicator of the total active chlorine in the stratosphere (W.M.O., 1985).

The spectral window covers the $H^{35}Cl$ line at 2944.9 cm^{-1}, some lines of CH_4, and a few solar lines. The HCl profile has been derived between 30 and 55 km, using 9 consecutive spectra (numbered 33 to 40) just before loss of sun. The measurements below 30 km were perturbed by the Pinatubo aerosols obscuring the lower part of the atmosphere. Figure 2 shows spectra obtained in this altitude range. Two independent retrieval methods were used in this work. The first one is based on an algorithm proposed by Mill, starting from the lower level and iterating to the highest tangent height available spectrum. The second one uses a least squares global fit method : all the spectra are included simultaneously in order to retrieve the vertical concentration profiles together with the background. Identical parameters of the instrumental function are used in both computations. The concentration values and uncertainty limits resulting from both methods are in good mutual agreement. The tangent heights used in the computation are derived from the orbital analysis performed by Marshall Space Flight Center orbit engineers during and at the end of the flight and are still preliminary.

Figure 3 shows the agreement obtained between observed and computed spectra around the HCl line. Because of uncertainties remaining on the orbit parameters, retrievals have been made for the nominal values of the tangent heights, and for a tangent height uncertainty equal to plus or minus 1 km. The final values reported in Table 1 and on Figure 4 are combined envelopes and uncertainties of both methods at any given level. A preliminary uncertainty analysis of the retrieved HCl profile has been performed including the measurement noise. The 68 %

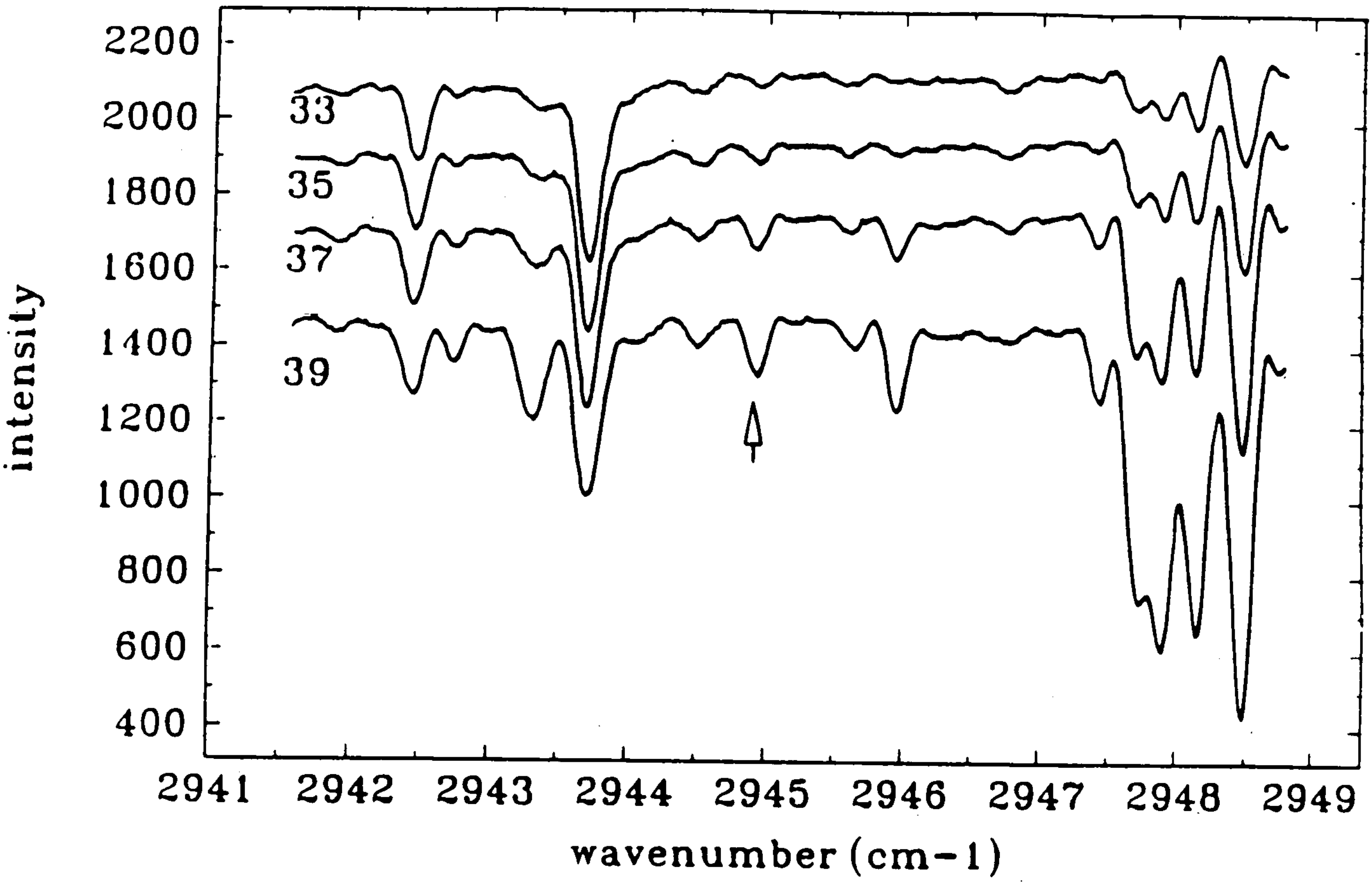

Fig. 2.- Spectra recorded at sunset 124. The amplitude of the signal is shown versus wavenumber (cm^{-1}), nominally for spectrum 33; the others are successively shifted downwards by 200 amplitude units. Several solar absorption features appear in the spectral range. The HCl line at 2944.9 cm^{-1} is indicated by the arrow. The tangent altitudes of the line of sight to the sun's center of this absorption line are 55.7, 48.5, 41.2 and 33.8 km for spectra 33, 35, 37 and 39, respectively.

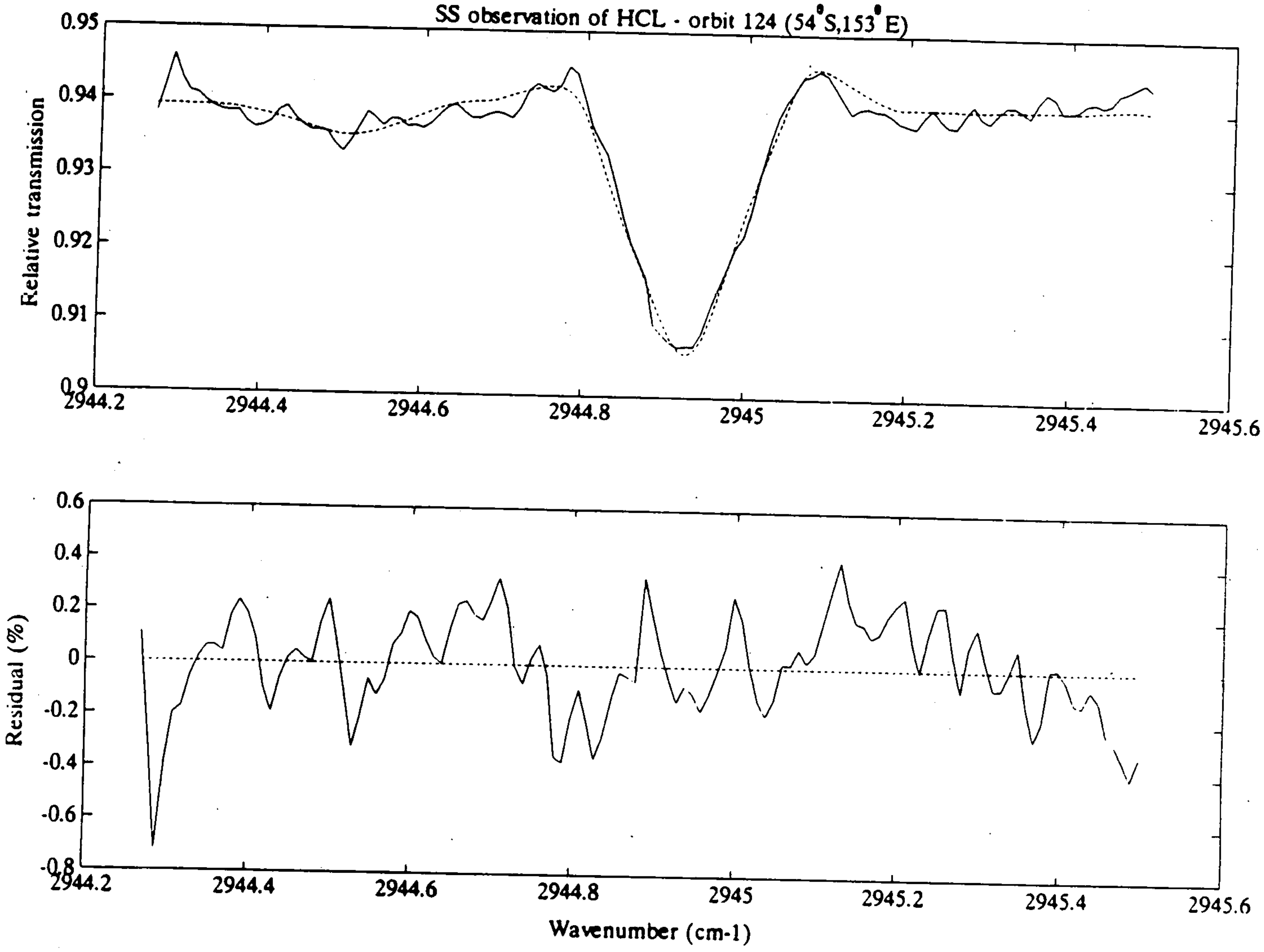

Fig. 3.- The upper graph shows part of spectrum 37 versus wavenumber (in cm^{-1}) as the continuous line, the dashed line representing the computed spectrum. The lower graph shows the relative difference between computed and observedd values (residual in %).

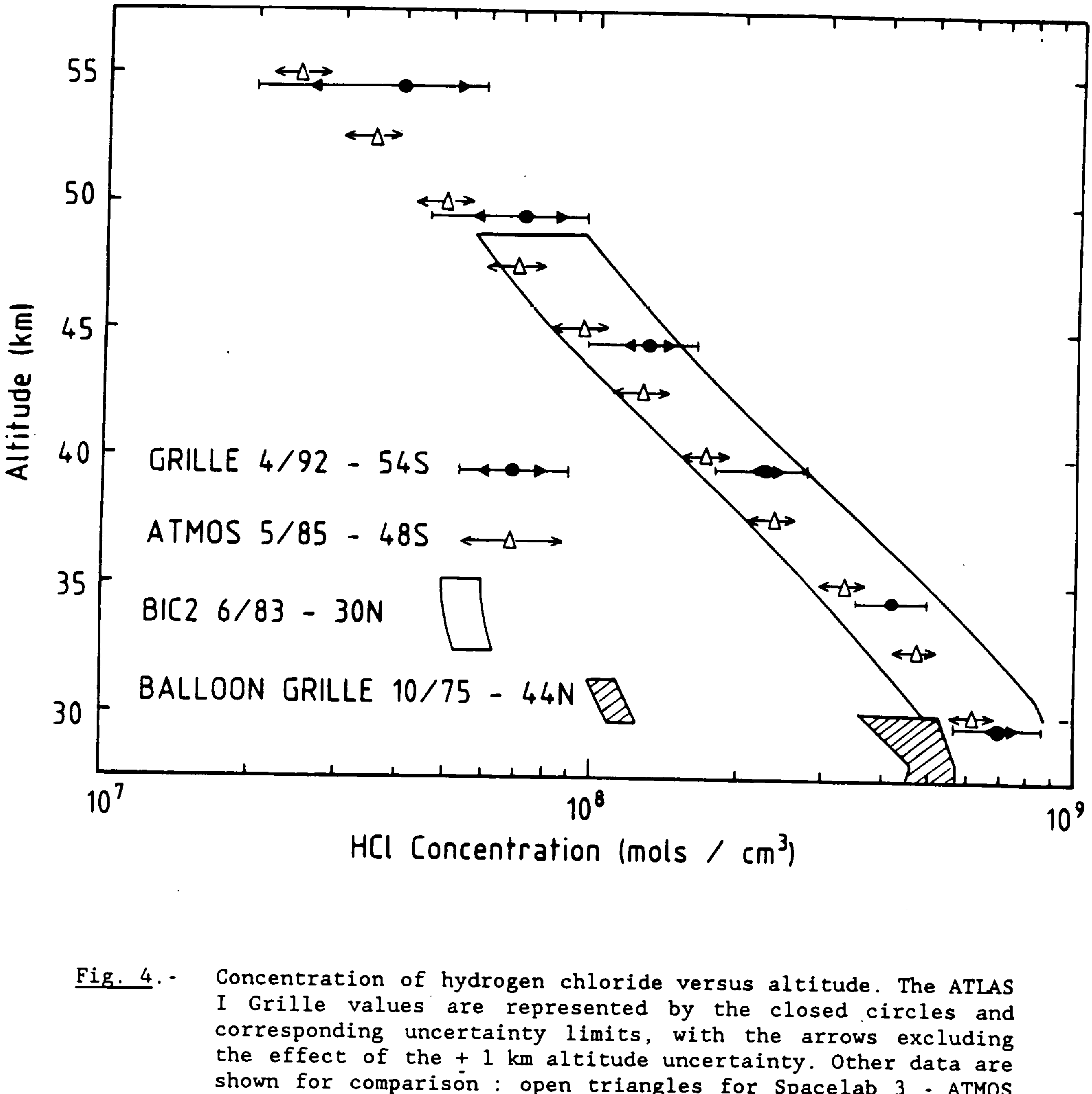

Fig. 4.- Concentration of hydrogen chloride versus altitude. The ATLAS I Grille values are represented by the closed circles and corresponding uncertainty limits, with the arrows excluding the effect of the ± 1 km altitude uncertainty. Other data are shown for comparison : open triangles for Spacelab 3 - ATMOS 1985 (Zander et al. 1990), clear envelope for BIC 1983 (W.M.O., 1985) and striped envelope for 1975 balloon data (De Mazière et al., 1989).

TABLE 1 : Results from the sunset in orbit 124.

ALTITUDE (km)	TEMPERATURE (K)	NUMBER DENSITIES (cm^{-3})		HCl MIXING RATIO (ppbv)
		AIR	HCl	
55	250	1.10×10^{16}	$(3.7 \pm 1.4) \times 10^{7}$	3.4 ± 1.3
50	263	2.01 "	(6.7 ± 1.5) "	3.34 ± 0.75
45	258	3.90 "	$(1.22 \pm 0.15) \times 10^{8}$	3.12 ± 0.38
40	240	8.25 "	(2.15 ± 0.18) "	2.61 ± 0.22
35	230	1.77×10^{17}	(3.95 ± 0.10) "	2.22 ± 0.06
30	224	3.82 "	(6.99 ± 0.46) "	1.83 ± 0.12

The error resulting from the ± 1 km tangent height altitude uncertainty is of order of ± 14% and is not included in the above uncertainty limits that only represent the 68% statistical confidence intervals.

statistical confidence intervals are given in Table 1. The inclusion of the +/- 1 km tangent height uncertainty increases the uncertainty on the retrieved values as indicated on Figure 4 and in Table 1.

Also shown in Figure 4 for comparison are the HCl vertical concentration profiles derived by ATMOS during the SL-3 flight in April-May 1985 (Zander et al., 1990) and during the BIC-2 balloon campaign in the second half of June 1983 (W.M.O, 1985). At the lowest altitude level of this retrieval, the actual Grille data join data taken during a balloon flight of a similar grille spectrometer in 1975 (De Mazière et al., 1989).

The overall data set does not give a clear indication of any steady long-term trend in the HCl stratospheric concentration. However, HCl is known to vary with season and latitude and the BIC-2 results have large uncertainties. Therefore, restricting the comparison to the ATMOS '85 and GRILLE '92 data, an increase of the HCl concentration becomes apparent, which is of order 18 to 28% between 35 and 45 km at which altitudes the relative uncertainties of both data sets are smallest and non-overlapping.

It has been verified by us that the slight difference between the HITRAN '92 parameters used by us and the ones used in the ATMOS '85 retrieval for the HCl R2 line cannot account for this increase. One must keep in mind however that erroneous estimation of the tangent altitudes of the spectra by only ± 1 km may alter this conclusion significantly, as shown in Fig. 4. So care should be exercised and more HCl observations analysed before generalizing this early conclusion.

CONCLUSIONS

During the ATLAS-1 mission, the grille spectrometer has performed more than 65 solar occultation runs. The analysis of the recorded spectra has just started. It appears that no data retrieval will be possible below 25 to 30 km altitude due to volcanic aerosols.

The first preliminary results on HCl at 54°S seem to indicate an increase of order 20 to 25% at about 40 km altitude in comparison with 1985. This conclusion needs to be confirmed by analysis of more observations and better determination of the orbital parameters.

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REFERENCES

CAMY-PEYRET, C., N. PAPINEAU, R. ARMANTE, V. ACHARD, J. BESSON, C. MULLER, M. DE MAZIERE, C. LIPPENS, J. VERCHEVAL, M. ACKERMAN and D. FRIMOUT, L'expérience de spectrométrie à grille à bord de la navette spatiale lors de la mission ATLAS I, La recherche Aérospatiale, 3, 67-74 (1992).

DE MAZIERE, M., C. LIPPENS and C. MULLER, Observations of stratospheric HCl : 1975-1985, in "Our Changing Atmosphere", Crutzen, P.J., Gerard, J.-C. and Zander, R., Ed. University of Liège, 61-68 (1989).

GIRARD, A., J. BESSON, D. BRARD, J. LAURENT, M.P. LEMAITRE, C. LIPPENS, C. MULLER, J. VERCHEVAL and M. ACKERMAN, Global results of grille spectrometer onboard Spacelab 1, Planet. Space Sci., 36, 291-299 (1988).

LEMAITRE, M.P., J. LAURENT, J. BESSON, A. GIRARD, C. LIPPENS, C. MULLER, J. VERCHEVAL and M. ACKERMAN, Sample performance of the grille spectrometer, Science, 225, 171-172 (1984).

W.M.O., World Meteorological Organization, Global Ozone Research and Monitoring Project Report no. 16 (1985).

ZANDER, R., M.R. GUNSON, J.C. FOSTER, C.P. RINSLAND and Z. NAMKUNG, Stratospheric $ClONO_2$, HCl and HF concentration profiles derived from atmospheric trace molecule spectroscopy experiment Spacelab 3 observations : an update, J. Geophys. Res., 95, 20519-20525 (1990).