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Ground-based visible measurements at the
Jungfraujoch station since 1990

by

M. Van Roozendael, M. De Mazière and P.C. Simon

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FOREWORD

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GROUND-BASED VISIBLE MEASUREMENTS AT THE JUNGFRAUJOCH STATION SINCE 1990

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Abstract—Ground-based observations of nitrogen dioxide and ozone total columns have been performed since June 1990 at the International Scientific Station at the Jungfrauoch (45°N, 8°E). Measurements are made twice a day, at sunrise and sunset, by looking at the sunlight scattered at zenith in the visible range. NO₂ and O₃ vertical abundances are deduced by the differential absorption method. The error sources of the method are discussed in detail. For most observation conditions, the precision of measurement is estimated at about 11% for NO₂ and 6% for O₃. However larger errors might be encountered occasionally due to tropospheric pollution or enhanced multiple scattering in thick clouds. It is shown that the signature of such events can be detected in the evolution of the retrieved vertical column during the twilight period. A systematic method to detect and reject data significantly biased is described and applied to the NO₂ time-series of measurements.

Résumé—Des observations de la colonne totale du dioxyde d'azote et de l'ozone ont été effectuées depuis juin 1990 à la Station Scientifique Internationale du Jungfrauoch (45°N, 8°E). Les mesures sont faites deux fois par jour, à l'aurore et au crépuscule, par observation de la lumière solaire diffusée au zénith dans la région du visible. Les contenus verticaux de NO₂ et d'ozone sont déterminés par la méthode d'absorption différentielle. Les sources d'erreur de la méthode sont discutées en détail. Pour la plupart des conditions d'observation, la précision de mesure est estimée à environ 11% pour le NO₂ et 6% pour l'ozone. Cependant de plus grandes erreurs peuvent être rencontrées occasionnellement en cas de pollution troposphérique ou lorsque la diffusion multiple est importante dans des nuages épais. On montre que la signature de tels événements peut être détectée à partir de l'évolution de la colonne verticale déterminée au cours de la période crépusculaire. Une méthode systématique pour détecter et rejeter les données significativement erronées est décrite et appliquée à la série temporelle de mesures de NO₂.

Abstract—Sinds juni 1990 worden metingen uitgevoerd van de totale kolomhoeveelheden ozon (O_3) en stikstofdioxide (NO_2) vanop het International Scientific Station of the Jungfraujoch ($45^\circ N$, $8^\circ E$). De observaties gebeuren tweemaal per dag, bij zonsopgang en -ondergang; de hoeveelheden NO_2 en O_3 worden afgeleid met de methode van differentiële absorptiespectroscopie (DOAS) uit de waarneming van het in het zenit verstrooid zonlicht, in het zichtbaar-licht gebied van het spectrum. De bronnen van fouten geassocieerd aan deze methode worden besproken. In de meeste omstandigheden is de geschatte precisie van de metingen ongeveer 11% voor NO_2 en 6% voor O_3 . In geval van troposferische storingen (vervuiling) of verhoogde veelvuldige verstrooiing in zware wolken kan de onzekerheid verhogen. Er wordt aangetoond hoe zulke omstandigheden herkend kunnen worden in de evolutie van de afgeleide verticale kolom gedurende de periode van de occultatie. Een systematische methode ter herkenning en verwerping van waarnemingen met een beduidende afwijking wordt beschreven en de toepassing ervan wordt getoond op een serie metingen van NO_2 .

Zusammenfassung—Die gesamte Säule von Stickstoffdioxid und Ozon wird in der internationalen wissenschaftlichen Station des Jungfraujoches ($45^\circ N$, $8^\circ O$) seit Juni 1990 beobachtet. Die Messungen erfolgen zweimal täglich, bei Sonnenaufgang und Dämmerung, indem das im sichtbaren Bereich am Zenit gestreute Sonnenlicht beobachtet wird. Die senkrechten NO_2 und Ozongehalte werden durch die Methode der Differentialabsorption bestimmt. Die mit dieser Methode verbundenen Fehlerquellen werden im einzelnen erörtert. Für die meisten Beobachtungsbedingungen wird die Messgenauigkeit für NO_2 auf ca. 11% und für Ozon auf ca. 6% geschätzt. Es können jedoch gelegentlich, im Falle einer troposphärischen Verschmutzung oder einer beträchtlichen multiplen Streuung in dicken Wolken, grössere Fehler auftreten. Es wird gezeigt, dass solche Ereignisse durch die Entwicklung der in der Dämmerungszeit erfassten senkrechten Säule ursachengemäss bestimmbar sind. Eine systematische Methode zum Anzeigen und Ausschliessen signifikant fehlerhafter Daten wird beschrieben und für die Zeitreiheder NO_2 -messungen angewandt.

INTRODUCTION

Ground-based visible spectrometers looking at the scattered sunlight at zenith were first designed in the 70's for the study of stratospheric NO_2 which was measured by its absorption around 450 nm.^{1,2} With the availability of the photodiode array (PDA) detectors in the second half of the 80's, a new generation of instruments were developed. Covering a larger spectral range with high signal to noise ratio, diode array spectrometers allow the simultaneous detection of additional constituents like O_3 measured in the visible Chappuis bands³, OClO and BrO in the UV part of the spectrum^{4,5}, as well as polar stratospheric clouds.⁶ Because the observations are performed at twilight up to a solar zenith angle (SZA) of 93° , UV-visible instruments can be operated throughout the year at all latitudes up to and even beyond the polar circle. In addition, the scattered light at twilight crosses the stratosphere with long paths and the troposphere with short paths which enables measurements to be performed on cloudy days and reduces the sensitivity to the tropospheric column.

For several years, the technique has been used by several research groups for the monitoring of stratospheric O_3 and related species at high and mid- latitudes. Concurrently UV-visible spectrometers were selected in 1991 as one of the primary instruments needed for the Network for Detection of Stratospheric Changes (NDSC). In this context, observations using a "Système d'Analyse par Observations Zénithale" (SAOZ)⁷ were initiated in 1990 at the International Scientific Station at the Jungfraujoch (ISSJ) which is, with the "Observatoire de Haute Provence" (OHP), the Northern mid-latitude NDSC station. A time-series of data covering three years is now available. Starting before the eruption of Mt Pinatubo in June 1991, the data show in particular the effect of the aerosol on the NO_2 column at Northern mid-latitude.⁸ In order to assess the degree of accuracy and precision of the SAOZ measurements performed at ISSJ, this work focus on the discussion of the instrumental and/or retrieval error sources of the method. Special attention is payed to tropospheric perturbations which are regularly observed at Northern mid-latitude due to pollution, or enhanced scattering in the presence of heavy fogs and snow showers.

INSTRUMENT AND DATA REDUCTION

The ISSJ is located in the Swiss Alps (46.5°N , 8.0°E) at an altitude of 3580 m. The SAOZ observations started in June 1990. After one year of operation, the instrument was replaced at the end of October 1991 by a new version equipped with an improved detector. No data were obtained from June to October 1991 due to the request for the first instrument at another site in summertime and the delivery time of the second one.

The SAOZ instrument, made by Atmos Equipment, has been described in a previous paper.⁸ It is based on a Jobin-Yvon spectrometer (model CP 200) coupled first to a 512-elements Hamamatsu PCD diode array detector, replaced in October 1991 by a 512 diodes Hamamatsu NMOS detector with much lower dark current resulting in a better signal-to-noise ratio of the spectra recorded at low sun.

Observations of the scattered sunlight are performed during the whole day with

an increased rate at twilight between 80 and 96° SZA. Narrow absorption features due to the absorption by O₃, NO₂, O₄ and H₂O are detected in the twilight spectra by the differential absorption method in the visible range. The corresponding abundances are determined according to the procedure described in Ref. 3. NO₂ column amounts are retrieved from absorption spectra between 405 and 455 nm, while O₃ is measured between 450 and 560 nm. Interfering absorption features at 470 and 510 nm due to tropospheric O₄ and H₂O are removed. Data below the limit of detection are rejected when the differential absorbance is smaller than the residual noise. Because the precision of the spectral analysis is improved when reference and observed spectra are recorded with the same detector, two different reference spectra were selected respectively from PCD and NMOS data. Both were obtained on a clear day in June at high sun in order to minimize the residual absorptions by stratospheric and tropospheric constituents. The conversion from slant to vertical abundances is obtained by use of single-scattering airmass factors (AMF).⁹

ERROR ANALYSIS

The differential absorption method consists to fit absorption cross-sections to the logarithm of the ratio between the observed and a reference spectrum. The primary output is the line-of-sight amount, or slant column (S), given by the Lambert-Beer's law:

$$S = \frac{-\ln(I/I_0)}{\sigma} \quad (1)$$

where σ is the absorption cross-section, and I and I₀ respectively the intensities of the observed and reference spectra. The conversion from slant to vertical path is obtained using the relation:

$$v = \frac{S + q_r}{\Phi} \quad (2)$$

where (Φ) is the airmass factor and q_r, the residual amount in the reference spectrum.

By calculation of the error propagation in Eq. (2) we find the total uncertainty on v (δv) as a function of the errors associated with the spectral analysis, the determination of the reference spectrum residual amount and the airmass factor calculation:

$$\delta v^2 = \left(\frac{S}{\Phi}\right)^2 \left(\frac{\delta S}{S}\right)^2 + \left(\frac{\delta q_r}{\Phi}\right)^2 + \left(v \frac{\delta \Phi}{\Phi}\right)^2 \quad (3)$$

The estimated contributions to the absolute error on NO₂ and O₃ total amounts are represented versus SZA in Figs 1 and 2 for both detectors successively used at ISSJ (PCD values on top figures and NMOS values on bottom ones). As shown by Eq. (3), the absolute error δv depends on v. In this calculation, the NO₂ and O₃ columns were fixed, respectively, to 3 × 10¹⁵ molec/cm² and 300 DU.

The uncertainty associated to the spectral analysis comes from the least-squares fit between log-ratio spectrum and absorption cross-sections (measurement error), and from the laboratory cross-sections themselves. The uncertainty on the absorption cross-section essentially introduces a systematic contribution to the total

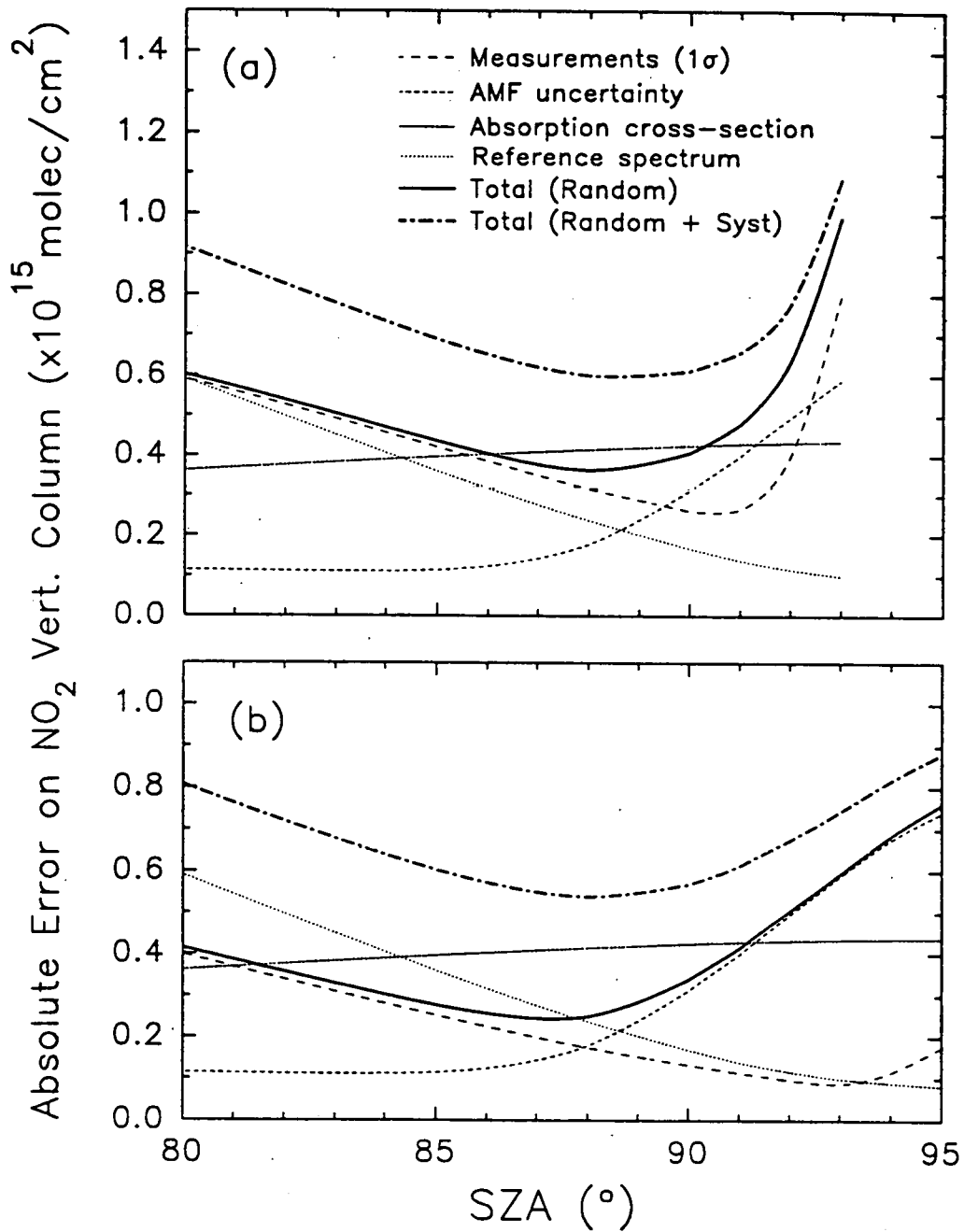


Figure 1. Error budget (absolute errors) of the total NO₂ measurements as a function of the SZA. (a) Error on columns obtained with the Hamamatsu PCD detector; (b) same as (a) but with the Hamamatsu NMOS detector.

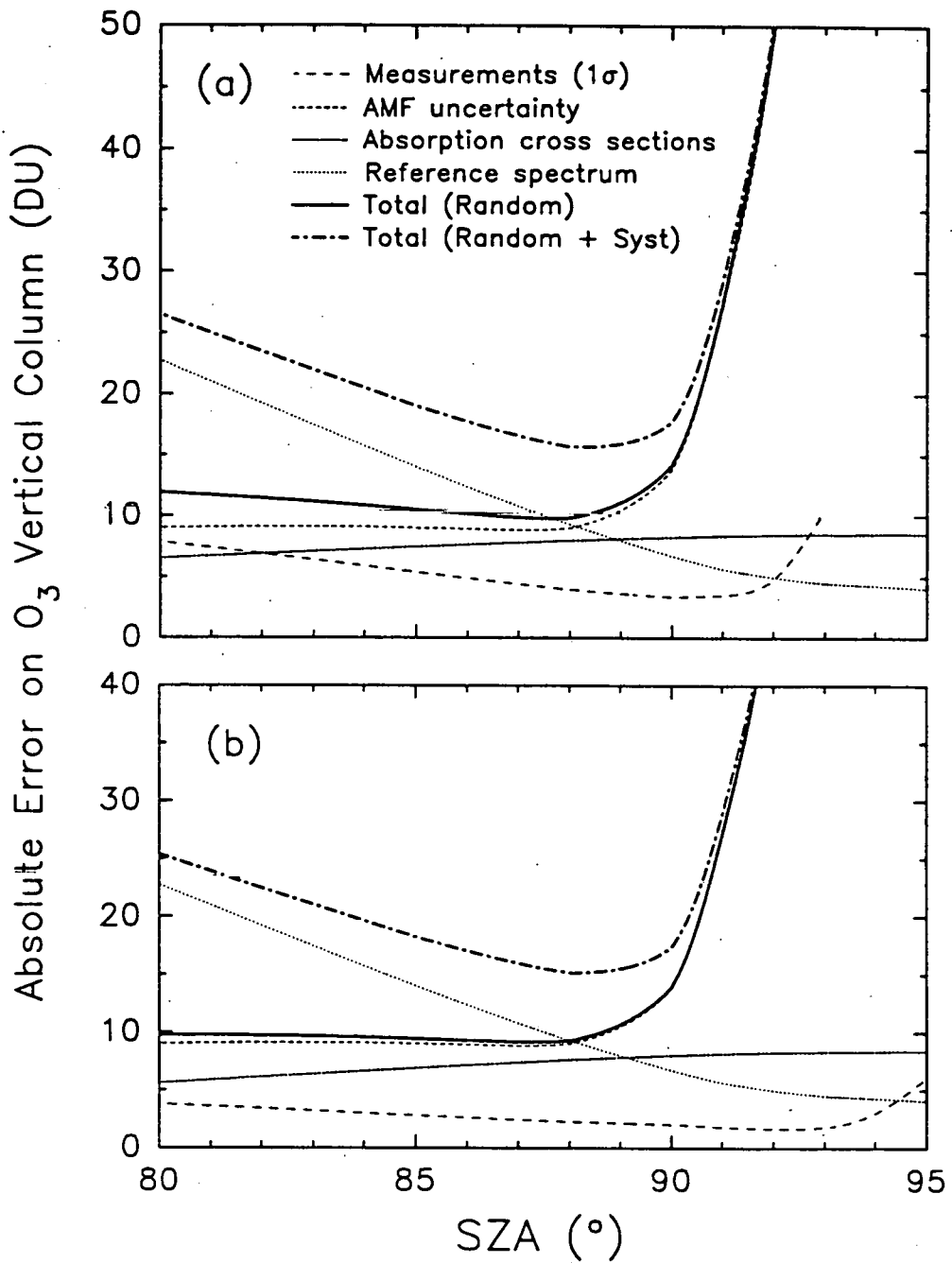


Figure 2. Same as figure 1, but for total O₃ measurements.

error which is about 3% for O₃ in the Chappuis bands.¹⁰ In this spectral region, the temperature dependence of the O₃ cross-sections is generally considered as negligible, although recent data indicate a small dependence of about 3% between 298 and 220 K.¹¹ The error on the NO₂ cross-sections is dominated by their badly known temperature dependence [see the recent review by Roscoe and Hind].¹² In this work, values measured at room temperature were used (*Johnston*, unpublished results) leading to an estimated uncertainty of about 15%. Due to the fluctuations of the stratospheric temperature, this temperature sensitivity introduces an additional pseudo-random contribution to the error on the column of about 3%.¹³ Errors associated to the least-squares fit are due to detector noise, instrumental imperfections (small wavelength scale and resolution changes, etaloning and nonlinearities of the detector, stray-light, polarisation effects, ...) as well as errors or unknowns in the signal modelling (Ring effect, unknown absorbers, wavelength dependence of AMFs, ...). Part of them are pseudo-random in nature and, as such, can be estimated statistically from the least-squares fit procedure. Figure 3 shows the evolution of the NO₂ statistical error (1 σ) versus SZA, determined for PCD (a) and NMOS (b) data sets (all data between 75 and 95° SZA). The improvement obtained with the NMOS detector at large SZA is obvious. An additional nonrandom contribution to the error has to be considered because of the existence of systematic features in residual spectra. If some of those features were significantly correlated with NO₂ or O₃ differential spectra, a bias larger than the calculated error could occur.¹³ A crude estimate of the size of any such biases was obtained by retrieving some NO₂ and O₃ values using slightly different wavelength intervals as well as different reference spectra. The differences obtained were comparable to the statistical uncertainties.

The error in the determination of the small residual amounts of NO₂ and O₃ in the reference spectra was evaluated from Bouguer-Langley analysis of the whole data set. The procedure used is described in more detail in the next paragraph.

The uncertainties on the airmass factor calculation have been studied by several authors. Goutail et al.¹⁴ have investigated the sensitivity of O₃ AMFs to atmospheric temperatures and ozone distribution using a single scattering model. They show that, up to 91° SZA and in the absence of large amounts of stratospheric aerosols, the error on the AMF when using a constant value calculated with mean temperature and absorber vertical profiles is lower than 8%, the most important contribution being the uncertainty on the absorber distribution. Multiple scattering calculations by Perliski and Solomon¹⁵ and Lenoble and Chen¹⁶ are in agreement with this conclusion. At larger SZA, the AMFs become highly sensitive to multiple scattering, albedo, refraction and to the vertical distribution of the absorber so that the retrieval of stratospheric vertical columns at SZA > 92° is not recommended. Results of AMF calculations for NO₂^{15,17-18} lead to similar conclusions. The estimated uncertainty at 90° SZA is about 10%.

In summary, at low SZA, the main contributions to the total error on NO₂ [see Fig. 1] are the measurement noise and the uncertainty on the reference residual amount. At large SZA, the precision is limited by the AMF uncertainty for NMOS data, while PCD results are dominated by the measurement noise. The uncertainty on O₃ follows the same trends as NO₂ but, in this case, the relative contribution of the AMF uncertainty is more important so that PCD and NMOS

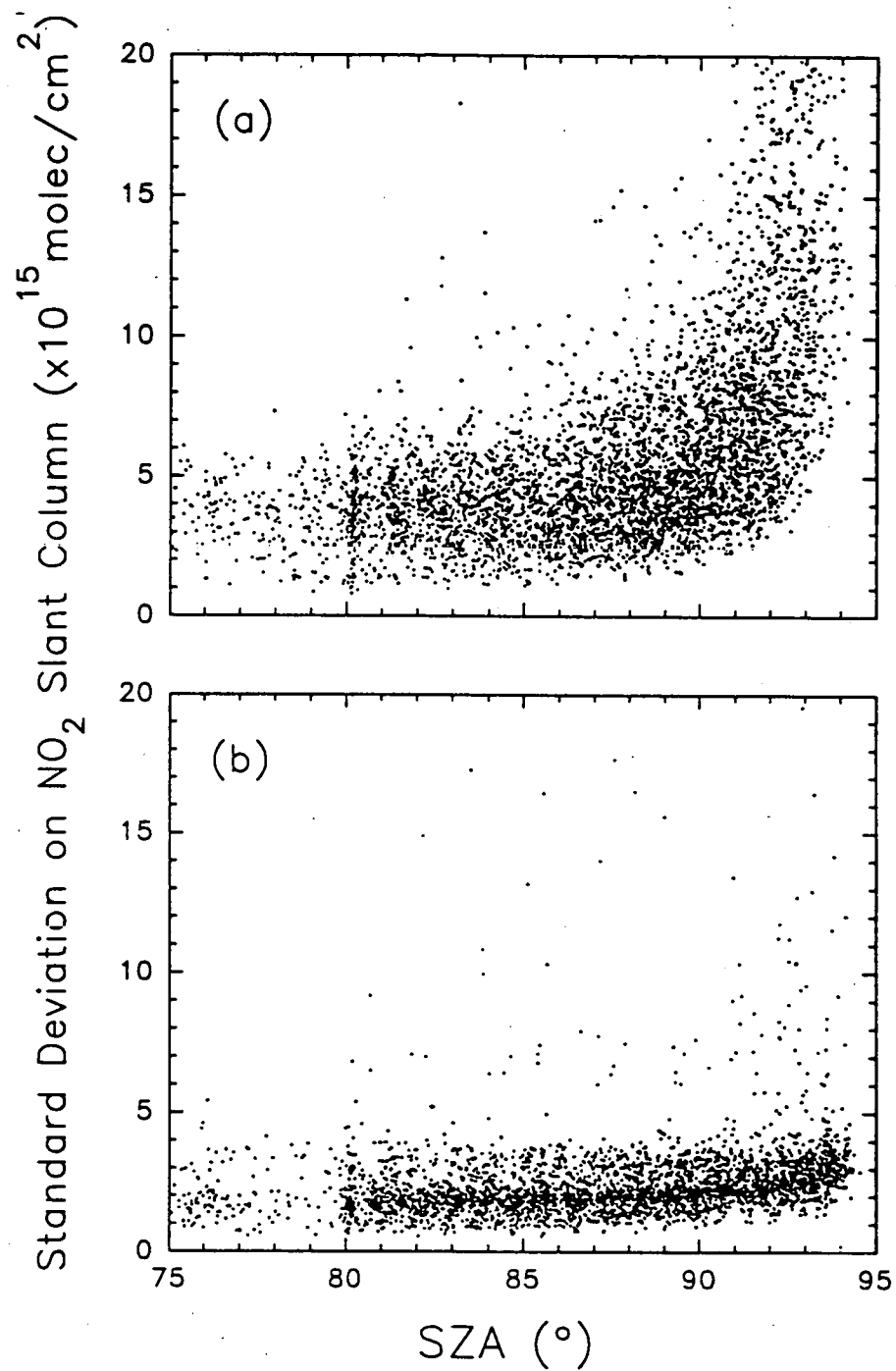


Figure 3. Standard deviations of the least-squares fit (1σ) associated to the NO₂ slant columns retrieved between 75 and 95° SZA (a) with the PCD detector and (b) with the NMOS detector.

results show similar precision around 90° SZA. For both constituents, the best precision is obtained between 87 and 91° SZA. The error budget at 90° SZA, expressed in terms of relative errors, is given in Table 1.

Table 1. Error budgets of total NO₂ (3×10^{15} molec/cm²) and total O₃ (300 DU) at 90° SZA.

Error source	Type	NO ₂		O ₃
		PCD	NMOS	
Measurement (1σ RMS)	Random	8 %	4 %	1 %
Air Mass Factor	Random	10 %	10 %	5 %
Absorption cross-sections	Systematic	15 %	15 %	3 %
Reference spectrum	Systematic	13 %	10 %	2 %
Total precision		13 %	11 %	6 %
Total accuracy		24 %	21 %	7 %

ADDITIONAL PERTURBATIONS

The error analysis given above is valid for most observational conditions. However larger error might be encountered occasionally due to:

- the release of large amounts of aerosols in the stratosphere following volcanic eruptions like that of Mt Pinatubo in June 1991,
- tropospheric pollution and/or enhanced multiple scattering in presence of thick clouds and snow showers.

The presence of significant aerosol loading in the stratosphere has been shown to perturb UV-visible measurements because changes in the scattering geometry result in changes of the effective optical path of the zenith scattered light. However the amplitude of the effect depends largely on the altitude distributions of both stratospheric absorbers and aerosols. The geometrical effect of the Mt Pinatubo aerosol layer on UV-visible observations was investigated by several authors using different models of the radiative transfer through the atmosphere.^{16,17,19,20} These calculations showed that the impact of the scattering geometry change on the NO₂ retrieval was negligible because the Mt Pinatubo aerosols remained essentially below the bulk of this constituent. On the contrary ozone columns whose bulk is located at lower altitude than NO₂ were significantly underestimated during the 1991-1992 period. The correction of these data is theoretically possible but difficult because it requires the calculation of specific AMFs using available measurements of the aerosol vertical distribution above the Alps.

In usual conditions, the contribution of the tropospheric column to the total absorption seen at twilight is small. This well known advantage of the method is due to the low tropospheric abundances of both NO₂ and O₃ (< 10% of the total column) and to the fact that the effective optical path in the troposphere at twilight

is small compared to the stratospheric one. In most cases, the tropospheric contribution to the slant column amount measured at 90° SZA is lower than 4% for O₃ and lower than 2% for NO₂. However significant tropospheric perturbations might arise occasionally due to:

- the transport, from industrialized area to the ISSJ, of polluted air masses containing high NO₂ or O₃ concentrations near the surface,
- the occurrence of heavy fogs or snow showers enhancing the tropospheric multiple scattering and therefore the light path in the lower troposphere.

Pollution and fogs or snow showers lead to increase the tropospheric contribution to the slant column. In addition, large tropospheric scattering increases the absorption by O₄ and H₂O. Because the spectra of O₄ and H₂O interfere with that of O₃ and NO₂, and because the fit to their spectra is not exact, the retrieved columns of O₃ and NO₂ can be biased by a certain amount.

Figure 4 shows a typical example of tropospheric perturbation observed at ISSJ on 5 February 1992. The sunrise (white circle) and sunset (black circle) slant columns of NO₂, O₄ (measured at 470 nm), H₂O (510 nm) and O₃ are represented with their associated error bars (standard deviation of the fit at 1 σ) as a function of the AMFs for O₃. The O₃ and NO₂ slant columns are the sum of the amounts in the reference spectrum and the amounts from the spectra fits. Missing H₂O values at sunset are below the detection level. The transition between conditions of high tropospheric scattering at sunrise and normal conditions at sunset is revealed by the O₄ and H₂O slant columns. This interpretation is supported by the weather bulletin of the same day which reports snow shower at sunrise moving to a 50% cloud cover at sunset. Large O₄ and H₂O columns at sunrise are accompanied by a significant bias of the O₃ slant amounts due to the increased optical path in the troposphere and/or to spectral interferences with O₄ and H₂O. The perturbation of the NO₂ column is much larger and results probably from the combined effects of an increase of the surface NO₂ concentration and tropospheric multiple scattering.

Tropospheric perturbations were considered at two levels of the retrieval process: the determination of the residual amount in the reference spectrum and the calculation of the mean twilight column.

Residual amount in the reference spectrum

As mentioned already, the O₃ and NO₂ amounts in the reference spectrum are obtained from Bouguer-Langley plot which consist in plotting slant column amounts versus AMFs. According to Eq. (2), this is a linear relation whose intercept at zero AMF (or offset) provides the residual amount (q_r). Note that the simple Langley plots analysis cannot be used for NO₂ because of the diurnal variation of this molecule. Instead, as suggested by Lee et al. (private communication), we use a modified form of Eq. (2):

$$S = \bar{v}\Phi' - q_r \quad (4)$$

where \bar{v} is the daily mean NO₂ column and Φ' is a reduced AMF given by:

$$\Phi' = \Phi \{ 1 + f(t) \} \quad (5)$$

f(t) is a function describing the diurnal variation of NO₂. Assuming a simple

SAOZ, Jungfraujoch. 5 Feb. 1992

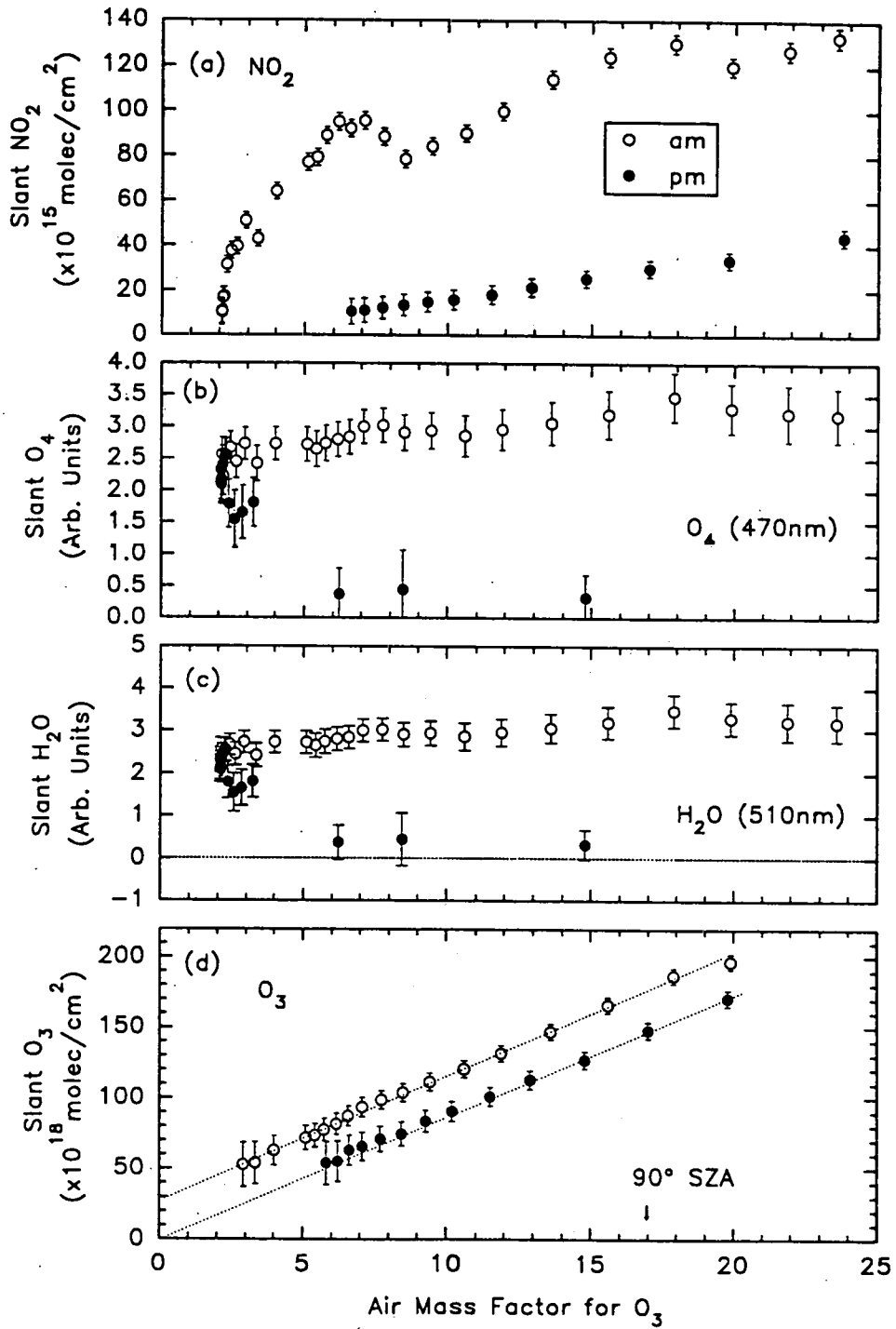


Figure 4. Morning and evening slant column amounts of NO_2 , O_4 , H_2O and O_3 plotted against AMFs for O_3 , showing a tropospheric multiple scattering event observed at ISSJ on 5 February 1992. The dotted lines in plot (d) are only a guide.

monotonical increase, we get:

$$f(t) = \frac{v'}{\bar{v}} (t - \bar{t}) \quad (6)$$

where $v' = dv/dt$ and \bar{t} is noon. The $\frac{v'}{\bar{v}}$ ratios are estimated using the available NO_2 climatology at ISSJ.

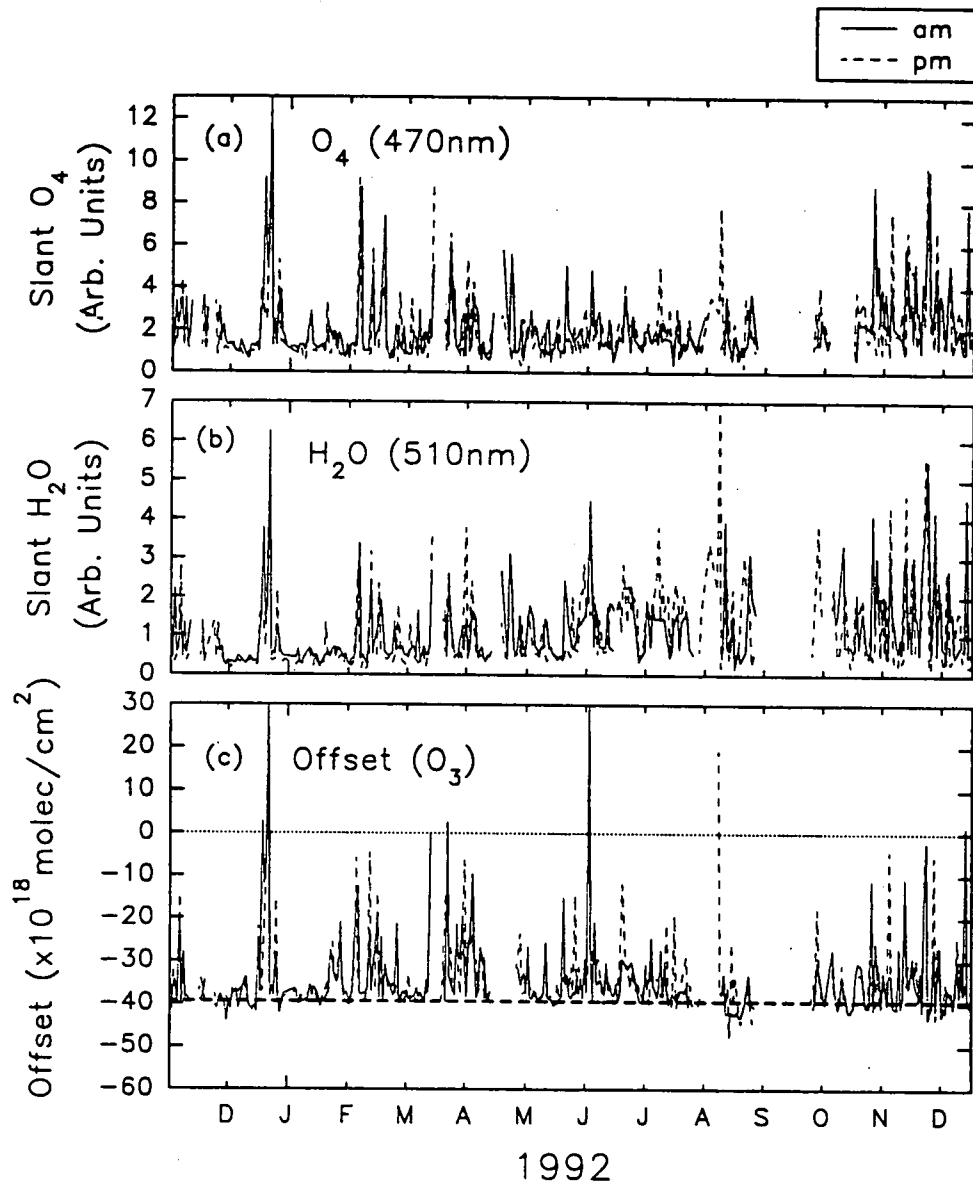


Figure 5. Time-series of daily sunrise and sunset O₄ (a) and H₂O (b) slant amounts together with O₃ offsets (c) calculated from Bouguer-Langley plots for the period between November 1991 and December 1992.

According to Roscoe et al.²¹, residual amounts should be estimated every day in a time-series because this allows to reveal possible instrumental artefact. However, as shown in Fig. 4, tropospheric perturbations give rise to biased offsets which must be filtered out. Here we suggest a slightly different filter than the one used by Roscoe et al.²¹ Figure 5(c) presents the raw time-series of O_3 offsets determined at sunrise (solid line) and sunset (dashed line) between November 1991 and December 1992. In comparison the upper curves show O_4 and H_2O slant columns at twilight determined by averaging the data between 87 and 91° SZA. The significant correlation between O_3 offsets and columns of tropospheric O_4 or H_2O justifies the elimination of the offset spikes before determining the O_3 residual amount (thick dashed line).

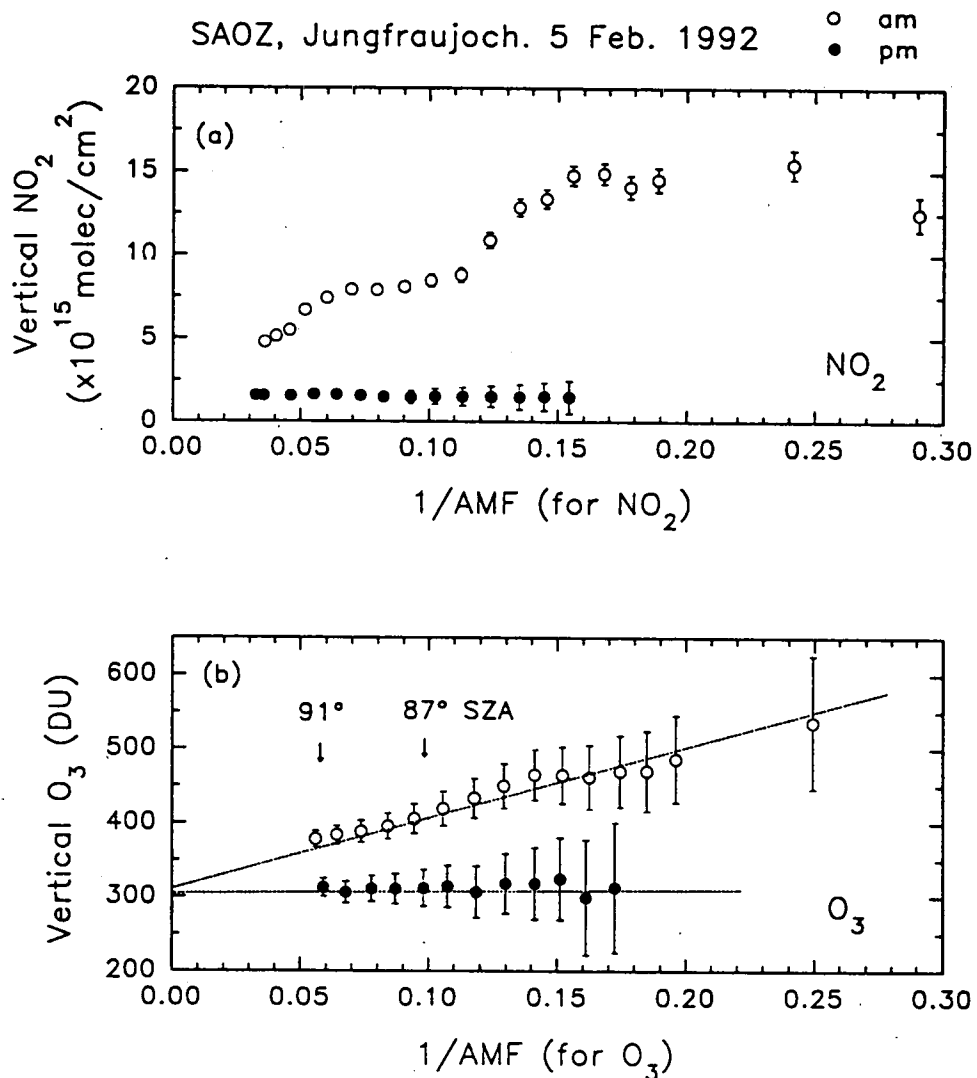


Figure 6. Effect of the tropospheric multiple scattering event of 5 February 1992 on the retrieved vertical columns of NO_2 (a) and O_3 (b). The dotted line in plot (b) is only a guide.

Daily twilight vertical columns

As the precision and accuracy of the vertical column determination are maximized around 90° SZA [see Figs 1 and 2], it is generally agreed to retrieve twilight values from a weighted average of the individual data recorded between 87 and 91° SZA. Vertical columns determined in this SZA range are expected to be constant within their respective precision (except for small changes due to the diurnal variation of NO₂). This is not true in case of tropospheric perturbation. Because the contribution of the tropospheric column to the signal is larger at high sun, tropospheric perturbations are detected by an apparent diminution of the vertical column as a function of the SZA. The shape of this diminution can be roughly estimated if the vertical column and the AMF are split into their tropospheric and stratospheric parts:

$$v = v_{tr} + v_{st} \quad (7)$$

$$v\Phi = v_{tr} \Phi_{tr} + v_{st} \Phi_{st} \quad (8)$$

Since $v\Phi$ is the total slant column (slant column plus the amount in the reference spectrum), the retrieved vertical column (v_{zs}) can be written as:

$$v_{zs} = v_{tr} \frac{\Phi_{tr}}{\Phi^o} + v_{st} \frac{\Phi_{st}}{\Phi^o} \quad (9)$$

where Φ^o is the AMF used in the retrieval process (corresponding to unperturbed conditions). If the stratospheric AMF is not perturbed ($\Phi_{st} = \Phi_{st}^o$), Φ_{st} can be expressed as a function of Φ^o and Φ_{tr}^o using Eq. (8). Introducing f_{tr}^o and f_{st}^o , defined as the tropospheric and stratospheric fractions of the total column considered for the AMF calculation ($f_{tr}^o = v_{tr}^o / v^o$ and $f_{st}^o = v_{st}^o / v^o$), Eq. (9) is transformed to show explicitly the SZA dependence of the retrieved vertical column:

$$v_{zs} = \frac{v_{st}}{f_{st}^o} + \frac{1}{\Phi^o} (v_{tr} \Phi_{tr} - v_{st} \frac{f_{tr}^o}{f_{st}^o} \Phi_{tr}^o) \quad (10)$$

If $\Phi = \Phi^o$, it is easy to verify that the terms between brackets cancel out: v_{zs} is thus constant and equal to v . Tropospheric perturbations correspond to an increase of v_{tr} or Φ_{tr} (or both). For large perturbations, the last term in Eq. (10) becomes negligible which leads to the simplified equation:

$$v_{zs} \approx \frac{v_{st}}{f_{st}^o} + (v_{tr}^{pollut} \Phi_{tr}) \frac{1}{\Phi^o} \quad (11)$$

If we assume that both tropospheric abundance (v_{tr}^{pollut}) and tropospheric AMF (Φ_{tr}) not vary significantly during the twilight period, the retrieved vertical column is expected to be a linear function of the inverse of Φ^o with a slope equal to the tropospheric line-of-sight amount. Figure 6 shows the NO₂ and O₃ vertical columns determined for the same event as in Fig. 4. We can see that the O₃ observations at sunrise follow reasonably well the linear evolution predicted by Eq. (11). In agreement with the same equation, the intercept at zero AMF⁻¹ is very close to the unperturbed sunset vertical column. In the case of NO₂, the variability is higher, due probably to the instability of the NO₂ surface abundance,

but the increase of the retrieved column at small SZA, characteristic of the tropospheric perturbation, is quite obvious.

Based on these considerations, a systematic procedure was adopted to detect and reject the data significantly perturbed by tropospheric pollution or multiple scattering. Its application to the NO₂ case is illustrated in Fig. 7. For each sunrise and sunset twilight period, plots of the vertical column versus the inverse of the AMF are drawn and the slopes are calculated [see Fig. 7(a)]. The signature of the tropospheric perturbations is found in large deviations from the null slope (positive or negative). Arbitrarily we decide to remove all data with slopes larger than twice the average value. The total number of data rejected is about 15% at sunrise and 10% at sunset. Figures 7(b) and 7(c) show the effect of the filtering on the NO₂ vertical columns recorded between November 1991 and July 1993. The improvement in the reliability of the time-series is demonstrated by the significant reduction of the scatter. In particular, the large peaks seen in the raw data [see Fig. 7(b)] are completely removed. A similar treatment can be applied to the O₃ data set.

CONCLUSION

The SAOZ measurements of NO₂ and O₃ performed at ISSJ since June 1990 have been discussed with regards to the possible error sources of the method. At 90° SZA, the precision on the NO₂ (O₃) column determination is estimated to 11% (6%). In addition, the role played by tropospheric perturbations as an uncertainty source has been investigated. It is shown that pollution events or enhanced tropospheric scattering, leading to significant bias of the data, can be detected from the SZA dependence of the retrieved vertical columns. This aspect is important for all SAOZ instruments operated at European sites, including Northern Scandinavia. The validation of the SAOZ measurements at ISSJ is of particular importance in the context of the NDSC. In this perspective, intercomparisons with other instrumental techniques will be performed in a near future in the framework of research programmes supported by the European Community.

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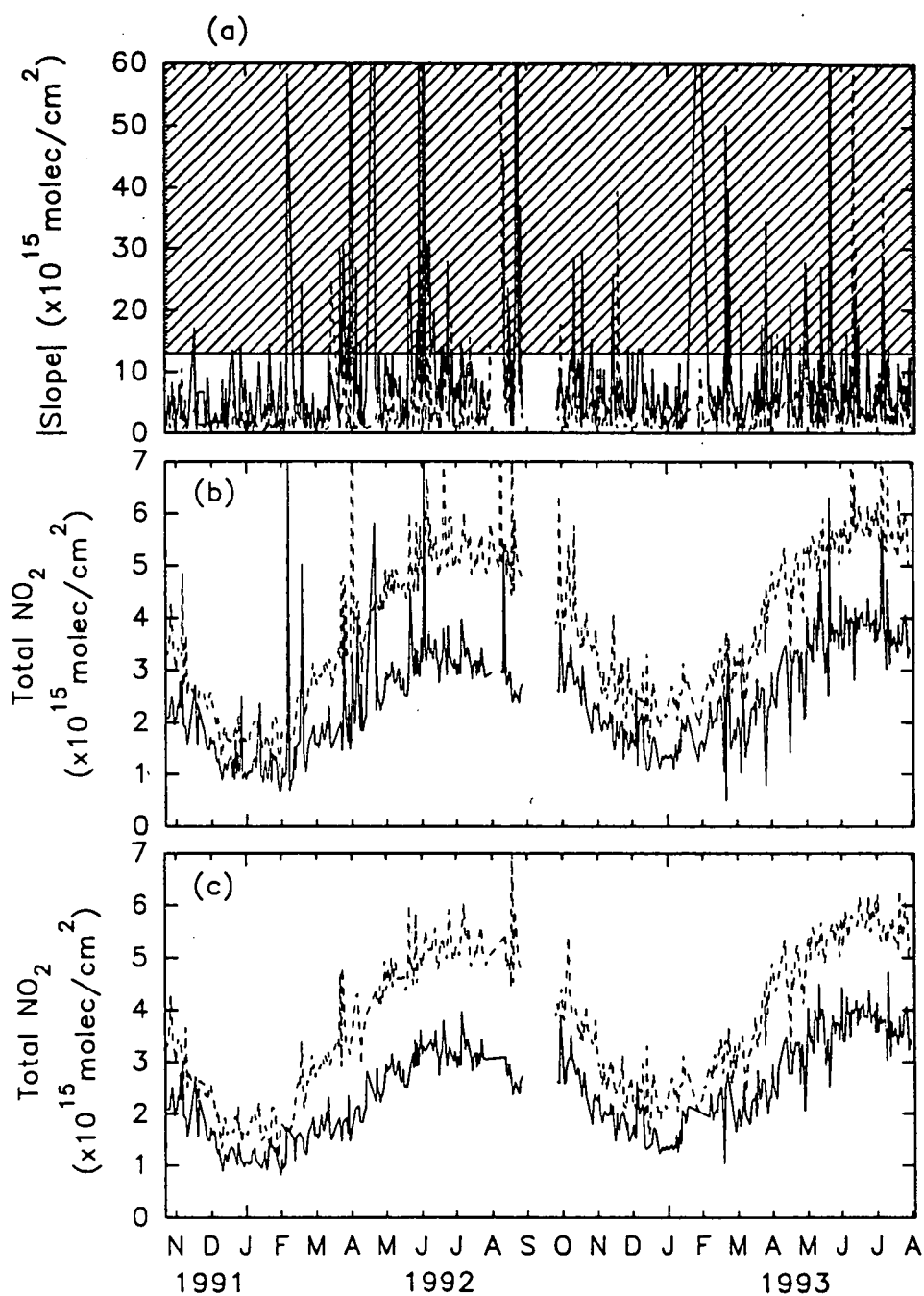


Figure 7. (a) Absolute value of the slopes determined from plots of the NO_2 vertical column versus the inverse of the AMF, used to detect tropospheric perturbations (see text). The data above the limit, arbitrarily fixed at twice the mean value (hatched region), are rejected; (b) time-series of NO_2 total columns between November 1991 and July 1993 (raw data); (c) same as (b) but after elimination of the values biased by tropospheric perturbations.

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