

I N S T I T U T D ' A E R O N O M I E S P A T I A L E D E B E L G I Q U E

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from infrared spectra

by

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B E L G I S C H I N S T I T U U T V O O R R U I M T E - A E R O N O M I E

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FOREWORD

This text has been presented at the Fall Meeting of the American Geophysical Union (December 3-7, 1984).

AVANT-PROPOS

Ce texte a été présenté à la réunion d'automne de l'American Geophysical Union (3-7 décembre 1984).

VOORWOORD

Deze tekst werd voorgesteld tijdens de herfstvergadering van de American Geophysical Union (3-7 december 1984).

VORWORT

Dieser Text wurde präsentiert während der Herbst-tagung der American Geophysical Union (3-7 Dezember 1984).

CO₂ AND CO ABUNDANCES BELOW 130 KM ALTITUDE
FROM INFRARED SPECTRA

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Abstract

The observation of infrared absorption lines by means of a grill spectrometer on board Spacelab 1 has allowed the determination of CO₂ and CO abundances in the low thermosphere and in the middle atmosphere. It is shown that the results can be well represented by theoretical models based on the interaction processes between solar UV radiation, CO, CO₂ and OH molecules.

Résumé

L'observation de raies d'absorption infrarouge au moyen d'un spectromètre à grille à bord de Spacelab 1 a permis la détermination des concentrations de CO₂ et CO dans la basse thermosphère et dans l'atmosphère moyenne. On montre que les résultats obtenus peuvent être représentés valablement par des modèles théoriques basés sur les processus d'interaction entre la radiation ultraviolette solaire, les molécules CO, CO₂ et OH.

Samenvatting

De waarneming van infrarode absorptielijnen door middel van een rasterspectrometer aan boord van Spacelab 1 heeft toegelaten CO_2 en CO concentraties te bepalen in de lage thermosfeer en de midden-atmosfeer. Er wordt aangetoond dat de resultaten op degelijke wijze kunnen voorgesteld worden door theoretische modellen gebaseerd op de wisselwerkingsprocessen tussen de ultraviolette zonnestraling, CO, CO_2 en OH moleculen.

Zusammenfassung

Die Beobachtung von infraroten Absorptionslinien mittels eines Gitterspektrometers an Bord Spacelab 1 hat ermöglicht CO_2 und CO Konzentrationen zu bestimmen in der Niederthermosphäre und der Mittelatmosphäre. Man zeigt das die Resultaten auf solider Weise können präsentiert werden durch theoretische Modellen basiert auf den Wechselwirkungsprozessen zwischen der ultravioletten Sonnenstrahlung, CO, CO_2 un OH Molekülen.

INTRODUCTION

During Spacelab 1 mission, a grille spectrometer operating on the Spacelab pallet has observed trace species in the low thermosphere and in the mesosphere by pointing the Sun at sunrise or sunset. Preliminary data on CH₄, CO₂, CO, H₂O, NO and NO₂ molecules have already published (Lemaître et al., 1984; Lippens et al., 1985; Laurent et al., 1984).

We wish to report here results obtained for the CO₂ and CO molecules in order to compare them with those provided by theoretical models.

OBSERVATION

Several portions of absorption runs were scheduled during the Spacelab 1 mission to observe CO₂ at the highest possible altitudes where its mixing ratio has been already shown to depart from its homospheric values. As an example, figure 1 shows the spectrum obtained during event 14 when the sunlight was grazing the Earth at an altitude of 117 km. The region of the strongest absorption lines was chosen, that is to say near a wave number of 2360 cm⁻¹. One can note the very large resolution of the spectrum. Retrieved number densities for two runs are shown in figure 2. The nearly parallel lines represent constant volume mixing ratios from 310⁻⁸ to 310⁻⁴. Event 13 has been studied in detail and the results from two lines are shown. Up to 100 km altitude, the CO₂ volume mixing ratio follows closely the 310⁻⁴ value and drops abruptly above by a factor of 10 over 15 kilometers. These results are in good agreement with the mass spectrometric data and give great confidence in the data used from the instrument.

In addition, two absorption runs provided data on carbon monoxide CO. In the same figure 2, one can see the number density of

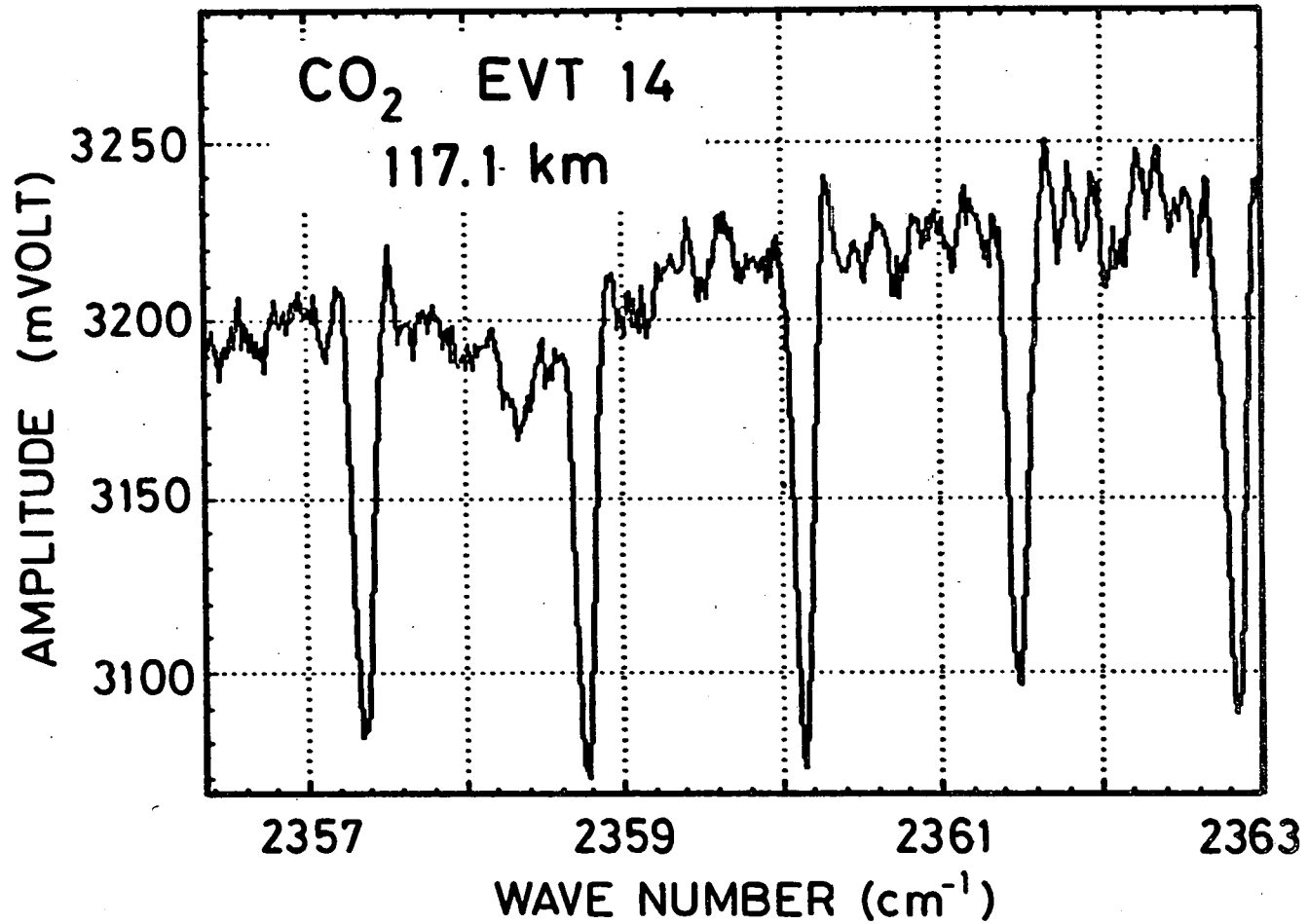


Fig. 1.- CO₂ absorption spectrum recorded at sunlight tangent altitude equal to 117 km.

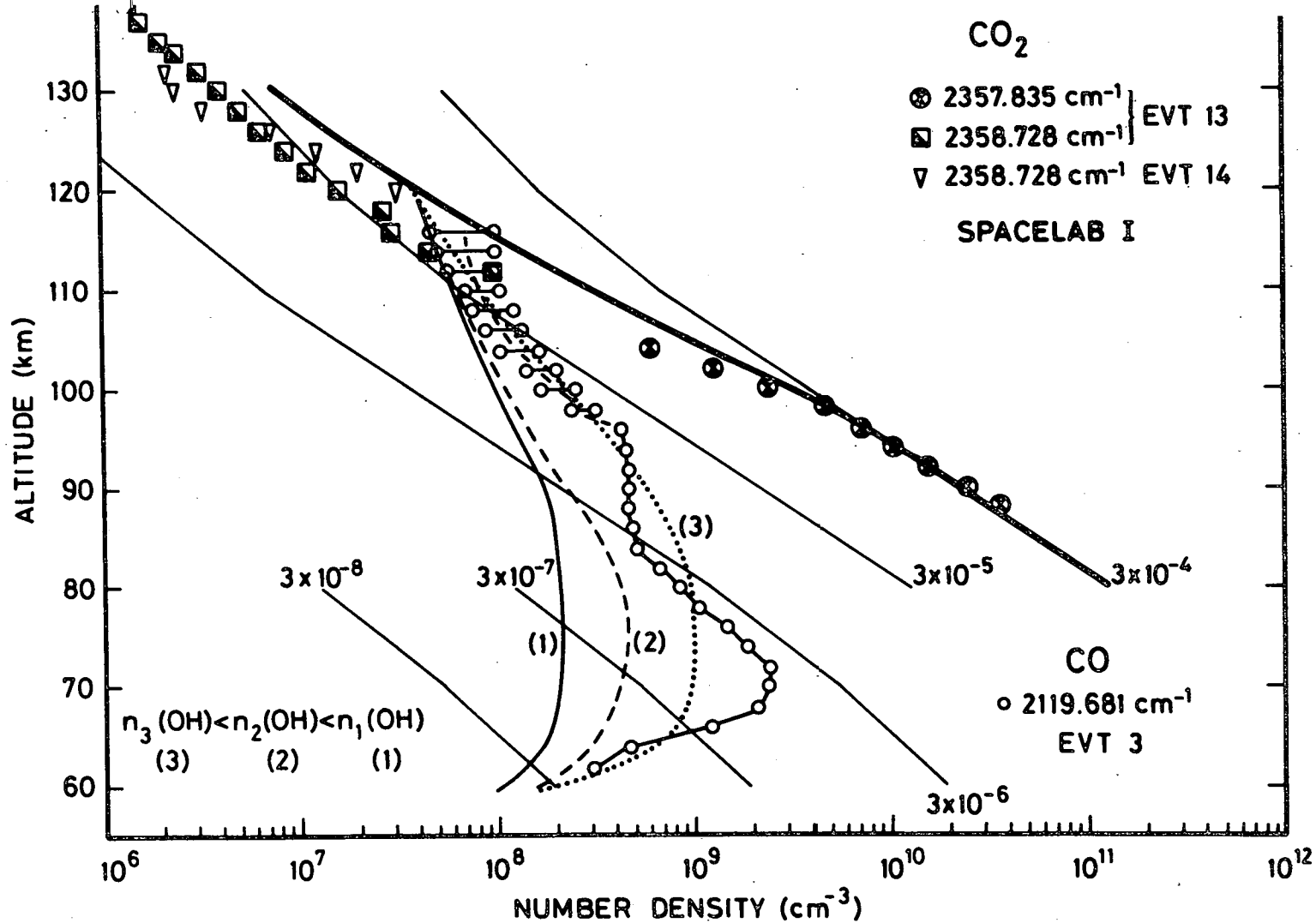


Fig. 2.- Number density of CO₂ and CO versus altitude using two different CO₂ absorption lines and the P₆ CO line. The nearly parallel lines represent constant volume mixing ratios from 3×10^{-8} to 3×10^{-14} . The curves (1), (2) and (3) are theoretical profiles of CO number density obtained with the three adopted vertical distributions of $n(\text{OH})$ shown in figure 5. The solid line is the theoretical profile of CO₂ number density.

CO using the P_6 CO line which is shown in figure 3 at a wave number of 2119.68 cm^{-1} , this observation corresponding to a grazing ray at 92.6 km. This absorption was observed at sunset in the northern hemisphere. The dotted line simulates the CO solar line in such a way that the difference between the two curves gives the atmospheric absorption due to CO. This P_6 line is contaminated by ozone [O_3] absorptions below 60 km precluding CO determinations at lower altitudes. In figure 2, one can observe the large increase of the CO mixing ratio at altitudes where the CO_2 photodissociation by the solar H Lyman α radiation takes place and where the water vapor H_2O abundance vanishes abruptly. The CO largest number density is observed near 70 km altitude, close to the H Lyman α photoproduction peak. Vertical distributions of carbon monoxide in the mesosphere and in the thermosphere combined with distribution of carbon dioxide shows for the first time where these two constituents present equal abundances. Measurements indicate an equal abundance at 115 ± 5 km.

Figure 4 shows, by the continuous curve, the profile of CO from the weaker R_2 line for an observation which took place at sunrise in the southern hemisphere. The R_2 line provided data down to the low stratosphere where a mixing ratio value equal to 10^{-8} is reached at 30 km altitude in agreement with balloon borne measurements. The dotted line represents the profile shown in figure 2. The comparison between the two observed distributions indicates a large variability of the mesospheric carbon monoxide, indicating the need for more measurements.

COMPARISON WITH MODELS

The observations of CO and CO_2 have been compared with model results. Models have been constructed for the altitude interval from 60 up to 120 km altitude by considering first the photodissociation of CO_2

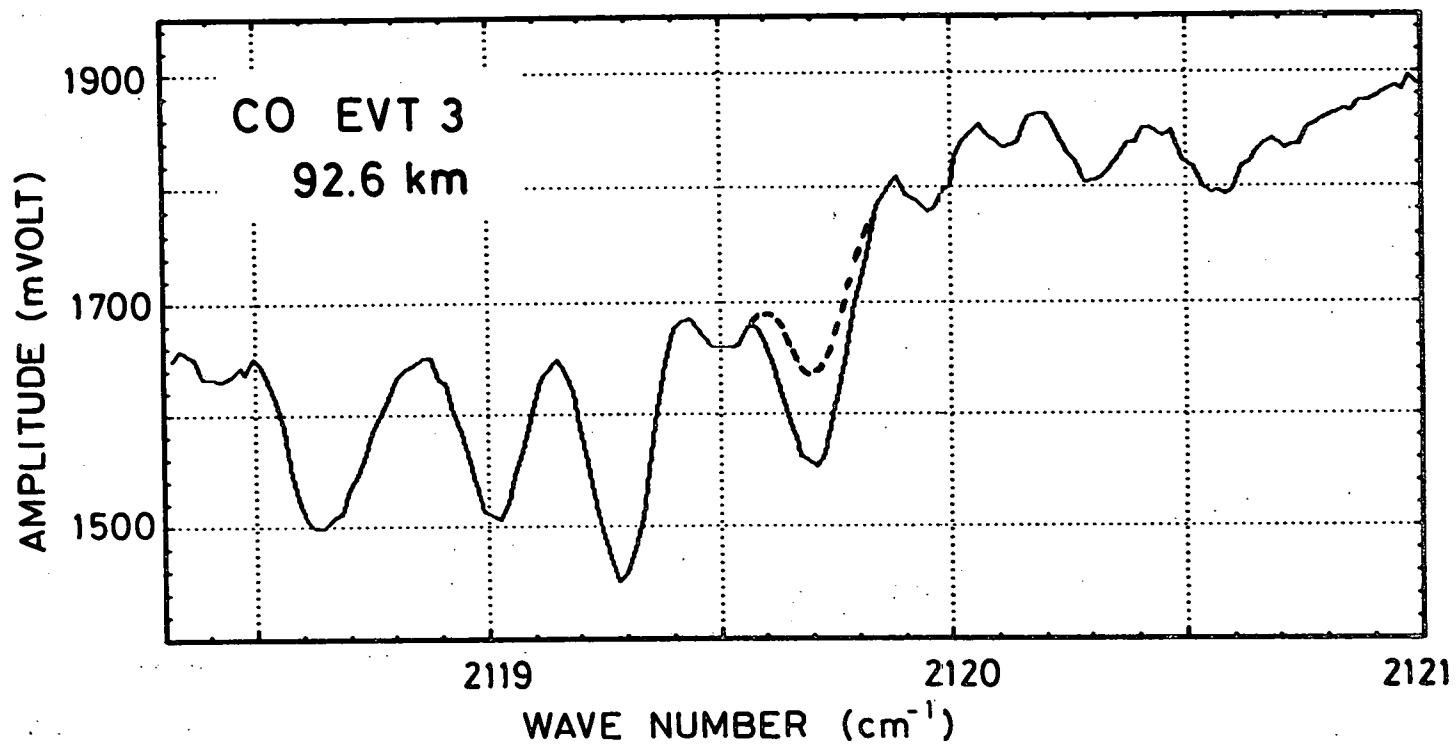


Fig. 3.- CO absorption spectrum recorded at sunlight tangent altitude equal to 92.6 km. P6 line appears at a wave number of 2119.68 cm⁻¹. The dotted line simulates the CO solar line.

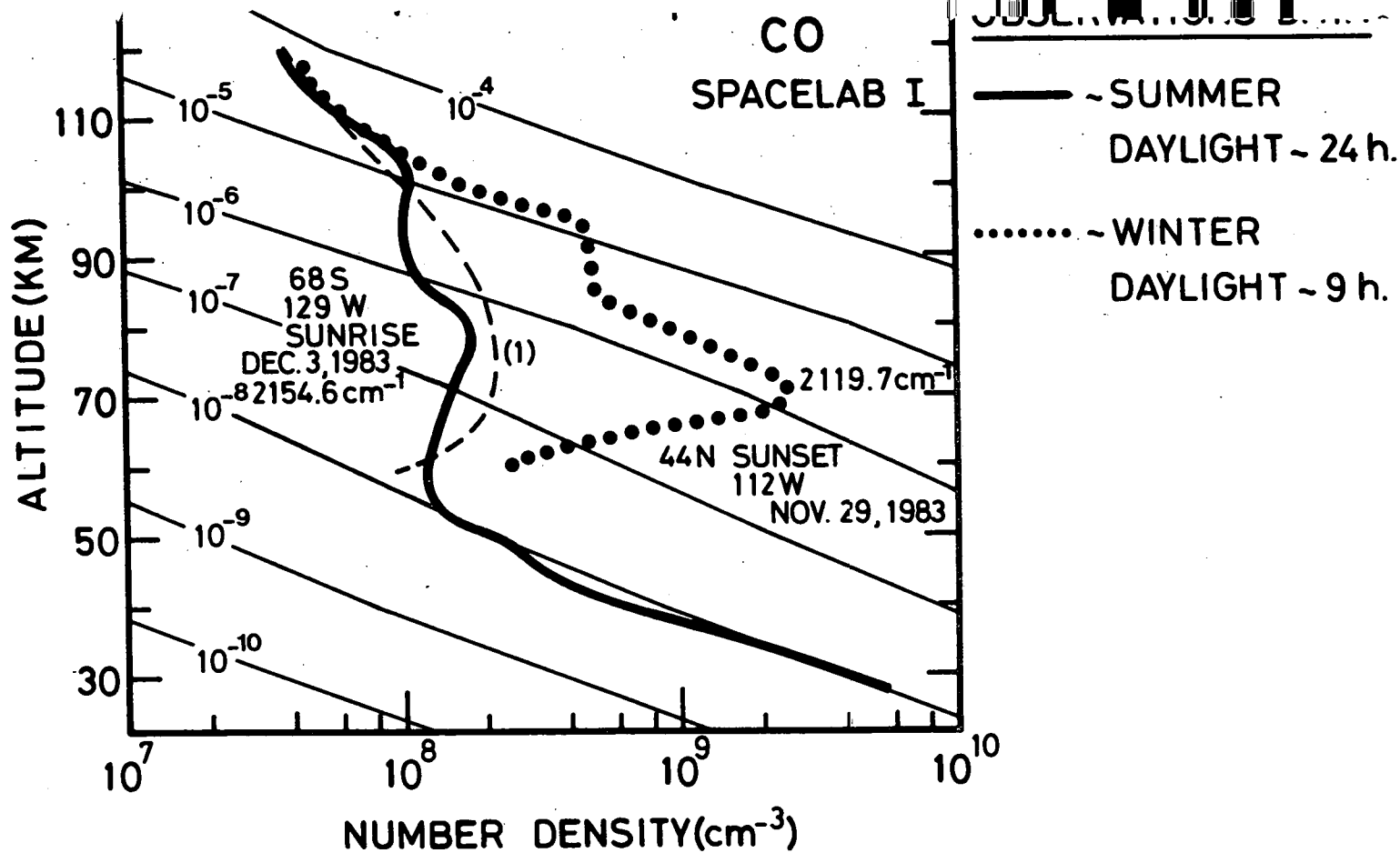


Fig. 4.- Carbon monoxide number density versus altitude retrieved from two solar occultation runs, one in the southern hemisphere at sunrise and the other one in the northern hemisphere at sunset. The geographic coordinates of the solar rays tangent points at 50 km altitude are indicated. Two different absorption lines were used of which the wavenumbers are indicated. The nearly parallel lines represent constant volume mixing ratios from 10^{-10} to 10^{-4} . The dates of data capture are also given. The dashed line (1) is the theoretical profile of CO number density obtained with the vertical distribution $n_1(\text{OH})$ shown in figure 5.

second, the destruction reaction of CO by OH molecules leading to reformation of CO₂ (CO + OH → CO₂ + H). We have considered steady-state conditions, solar conditions corresponding to solar zenith angle of 75° and atmospheric parameters taken from the standard atmosphere due to Nicolet (Nicolet, 1980). In these models, two parameters play a major role : the eddy diffusion coefficient and the vertical profile of the OH molecule abundance.

We have adopted the 3 vertical profiles of n(OH) shown in figure 5. The first one called n₁(OH) is characterized by number densities which are generally the greatest given in the literature with values between 10⁷ and 210⁷ cm⁻³ below 80 km altitude. The second profile, called n₂(OH), is similar to the first one but with values nearly two times smaller. Finally, one consider a third profile n₃(OH) with a very abrupt decrease already above 70 km; this third profile can be related with the rapid decrease, at the same altitude, of the water vapor abundance which was also observed in the northern hemisphere during sunset and which has been described elsewhere (Lippens et al., 1984).

Theoretical profiles were obtained by solving transport and continuity equations and by adopting a vertical profile for the eddy diffusion coefficient which provides the best agreement with the observations of CO and CO₂, giving especially a maximum of n(CO) at about 70 km altitude and a value, at 60 km, which nearly corresponds to the photochemical equilibrium between CO and CO₂.

In figure 2, we show the model curves obtained with the 3 adopted vertical profiles of n(OH). As it can be expected, the CO number density is decreasing when n(OH) is increasing. For instance, at 75 km, there is a variation of the CO number density by a factor of 5 between the two extreme curves (1) and (3), that is to say when the OH abundance varies by a factor of 10 at the same altitude. It can be seen that the distribution n₃(OH), with the smallest values of n(OH), is

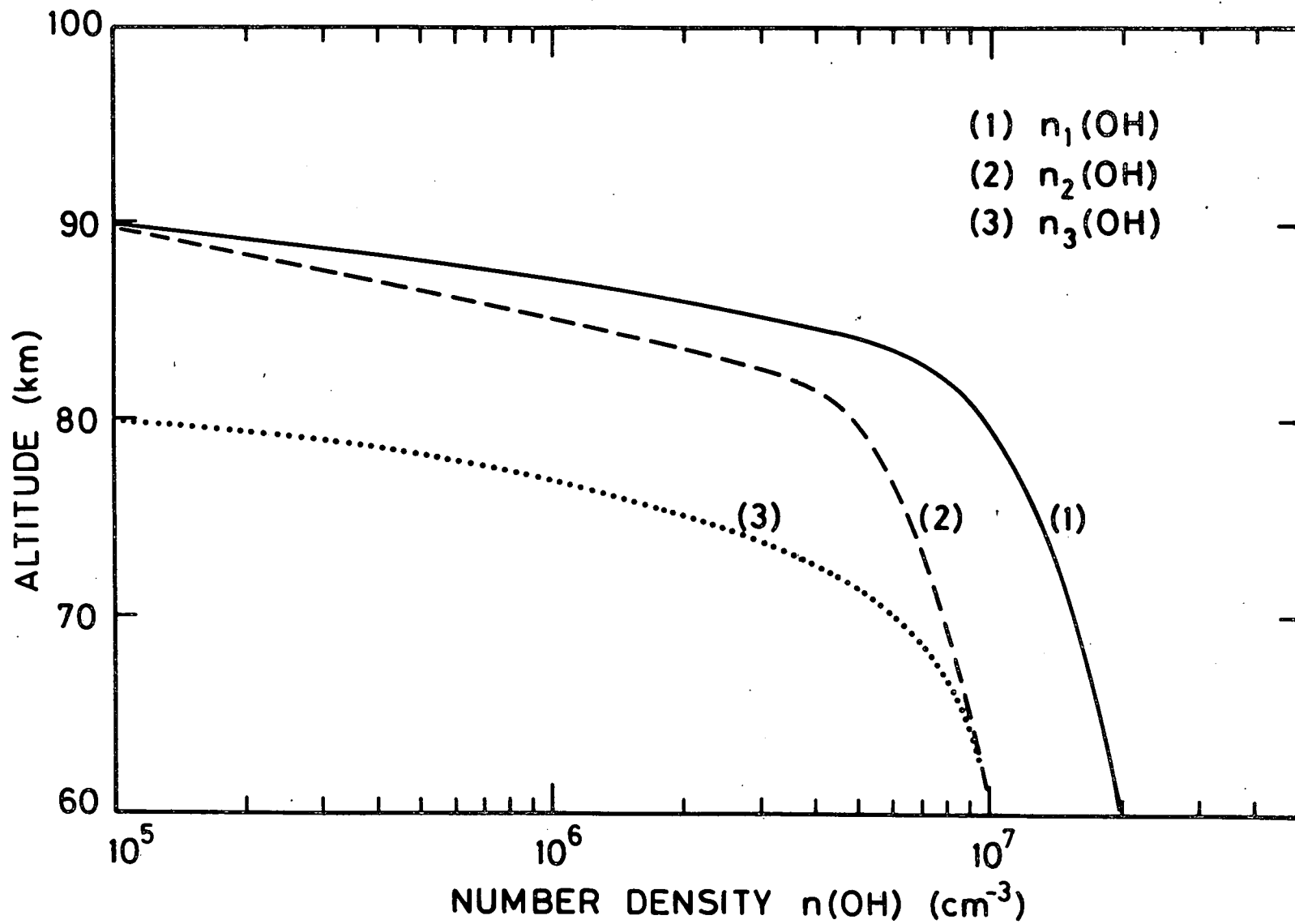


Fig. 5.- Vertical distributions of OH number density used in calculations of theoretical profiles of CO abundance.

the best one to lead to an agreement with the observations. This conclusion gives some guaranty to the measurements of H_2O already mentioned.

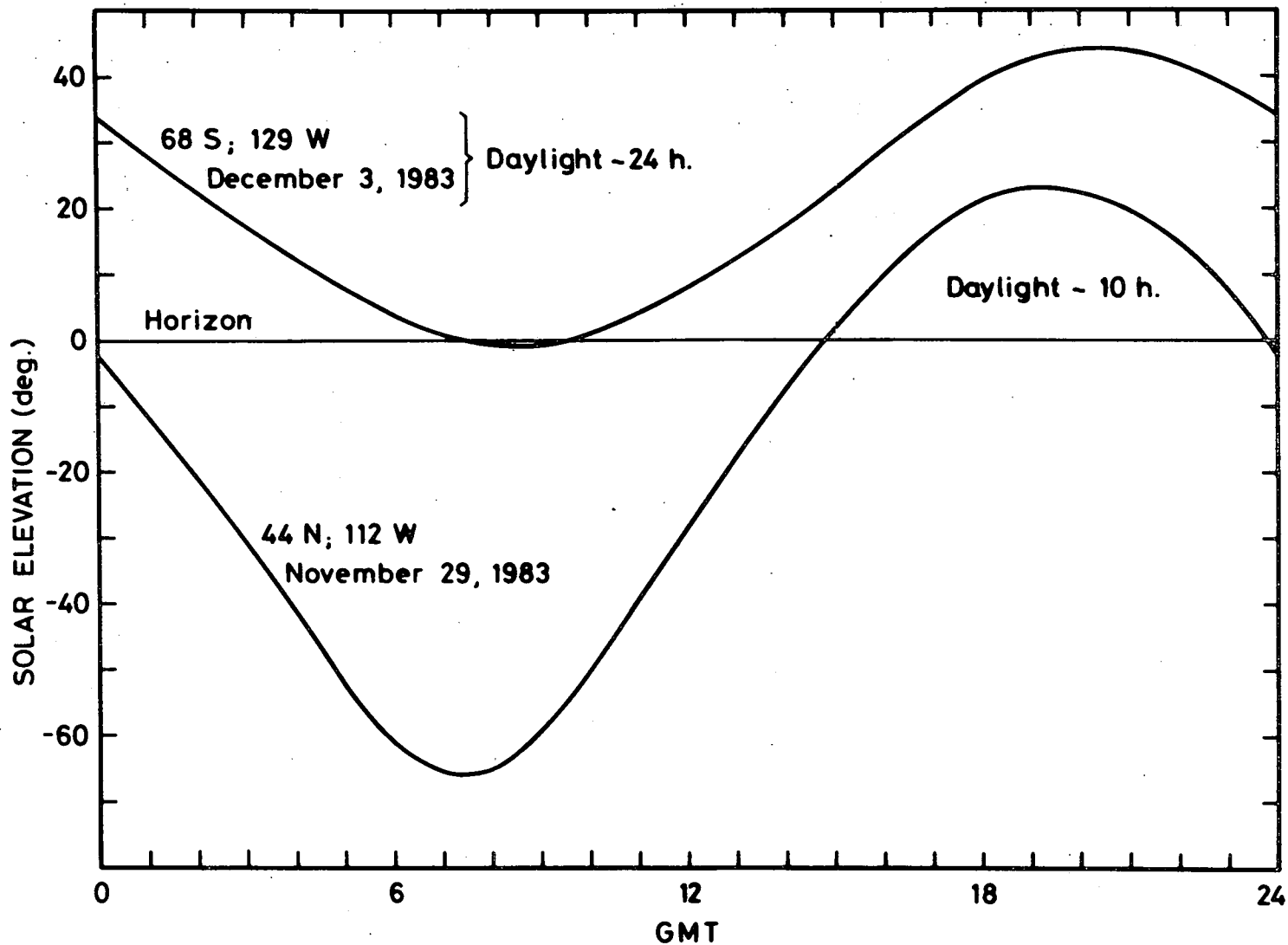
For the CO_2 molecule, the solid line shows that the agreement is perfect up to 100 km and relatively good at higher altitudes.

On the other hand, as shown in figure 4, the agreement with the observations of CO in the southern hemisphere, is obtained with the $n_1(OH)$ distribution, that is to say with the greatest values of $n(OH)$. So, two very different vertical profiles of $n(OH)$ must be considered to get an agreement with the observations in the two hemispheres. This is probably due to the very large difference in solar conditions in the two hemispheres : summer in the southern hemisphere and winter in the northern hemisphere. As we can see in figure 6, in the southern hemisphere, the sun was almost always above the horizon during the day whereas in the northern hemisphere, daylight had only a duration of about 10 hours. So, water vapor abundances and therefore OH abundances must be very different during the two series of observations with higher values in the southern hemisphere.

Finally, figure 7 shows the best fit eddy diffusion profiles corresponding to the three adopted values of OH number density. $D(CO_2)$ is the diffusion coefficient for CO_2 which plays the leading role above 100 km. Concerning the eddy diffusion coefficient, we can see that there is a satisfactory agreement with the values obtained by (Allen et al., 1981).

CONCLUSION

The results obtained from the grille spectrometer experiment, on the CO and CO_2 molecules, are in good agreement with spectrometric data in the thermosphere, and balloon borne instruments in the strato-



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Fig. 6.- Solar elevation versus time in hours (GMT) for December 3, 1983 in the southern hemisphere (68 S) and for November 29, 1983 in the northern hemisphere (44 N).

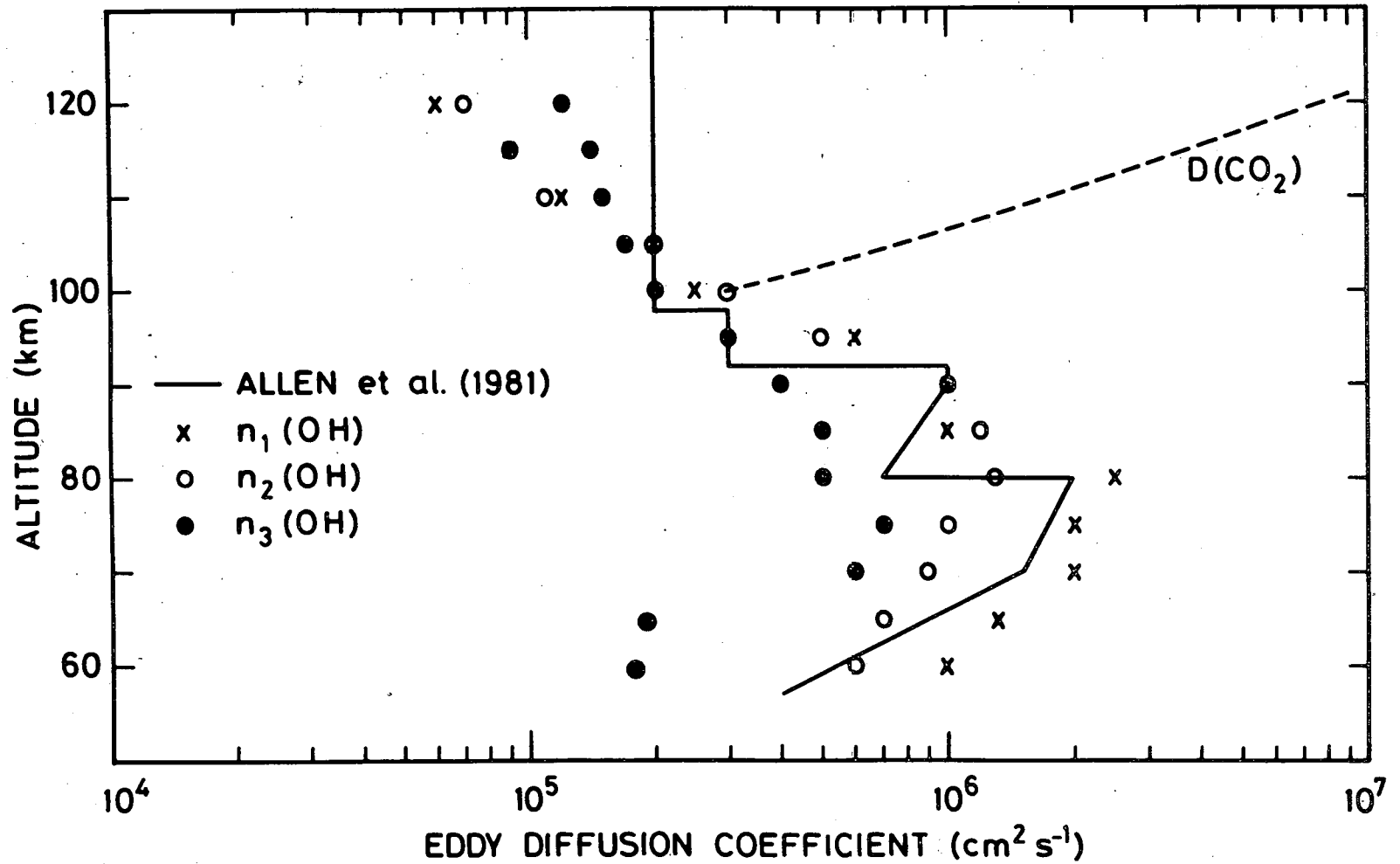


Fig. 7.- The best fit eddy diffusion coefficient derived in this paper corresponding to the three adopted vertical profiles of OH number density. The solid line is the eddy diffusion coefficient derived by Allen et al. (1981). The dashed curve indicates the diffusion coefficient for CO₂ used in this paper.

sphere; they can also be well represented by theoretical models based on the interaction processes between solar UV radiation, CO, CO₂, and OH molecules.

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