

MIDDLE ATMOSPHERIC WATER VAPOR OBSERVED BY THE *SPACELAB ONE* GRILLE SPECTROMETER

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Abstract—Two water vapor atmospheric concentration profiles have been obtained, one at 33°N, 59°E and the other at 68°S, 124°W, during the *Spacelab One* flight respectively on 2 and 1 December 1983. These profiles extend from the middle stratosphere up to mesopause and show significant differences above the altitude of 70 km, the Antarctic profile showing then higher concentrations. This result correlates with *Spacelab One* carbon monoxide observations and SME ozone results as far as the hydroxyl radical chemistry is concerned.

1. INTRODUCTION

Middle atmospheric water vapor has been widely discussed since the discovery of noctilucent clouds about one hundred years ago (see Avaste *et al.*, 1980) and the study of mother-of-pearls clouds by polar expeditions (see Stanford, 1974). Later, a controversy between the proponents of the dry and wet stratosphere was theoretically settled in favor of the low values by Brewer (1949) (see also Ellsaesser, 1983). However, considerable disagreements subsisted in water vapor stratospheric observations by various techniques, reviewed by Harries (1976). The recent stratospheric data set of the LIMS experiment on *Nimbus 7* (Remsberg *et al.*, 1984) now shows a water vapor picture consistent with stratospheric transport and methane oxidation.

In the mesosphere, rocket soundings (Avaste *et al.*, 1980; Grossmann, 1982 and references therein) have shown a wide range of values leading one to suspect either instrument contamination or input from an extraterrestrial source. Mesospheric water vapor data now also begin to be available from microwave ground based determinations (Bevilacqua *et al.*, 1983).

The purpose of this paper is to present two complete vertical distributions obtained, one in the middle northern latitudes and the other at high southern latitudes. They both display similar H₂O mixing below the 70 km altitude with a rapid decrease in the Northern Hemisphere above this altitude.

2. OBSERVATION

The grille spectrometer observes the absorption of solar radiation by the Earth's limb at sunrises and sunsets. The instrument and its operations during the *Spacelab One* flight have already been described (Lemaître *et al.*, 1984; Muller *et al.*, 1985).

It is essentially a scanning infrared spectrometer, with a spectral resolution better than 0.1 cm^{-1} , able to cover spectral intervals in the 2–10 μm range. In order to achieve good altitude resolution, these intervals are limited to a few wavenumbers with the possibility to change from one interval to the other at 12 different limb altitude transitions according to a preplanned sequence.

Water vapor measurement was one of the prime objectives of the mission and spectral windows were chosen in both the intense 6.3 and 2.7 μm bands. Unfortunately, a low signal-to-noise ratio in the HgCdTe channel, used to cover the 6.3 μm band, prevented its use in the upper mesosphere. On the contrary, the InSb detector has its best possible performance in the 2.7 μm region and thus the results obtained in the Northern Hemisphere in the 3811.90–3825.01 cm^{-1} interval were of good quality; unfortunately this interval could not be reprogrammed in the Southern Hemisphere. To obtain water vapor data in this latter case, we used the 1918 cm^{-1} water vapor line observed at the edge of the 1914.15 cm^{-1} interval which was primarily intended

TABLE 1

Observation	Date	Lat.	Long.	Nature
06	1 Dec. 1983	68°S	124°W	Sunrise
13	2 Dec. 1983	33°N	59°E	Sunset

for nitric oxide observations (Laurent *et al.*, 1985). The conditions of both occultations are indicated in Table 1. Sunset was observed thus at middle northern winter latitudes while sunrise was taking place in the summer sunlit Antarctic regions. The spectra were checked first for contamination by spacecraft-released water vapor by scanning the Earth's limb between 250 and 200 km altitudes. At the instrument's resolution, the relevant spectra did not show any evidence for water vapor; the upper limit for the water vapor column density around the *Orbiter-Spacelab* system was 1.5×10^{15} molecule cm^{-2} . An average of spectra for this altitude range is shown on Fig. 1. As also shown on Fig. 1, this same spectral window was scanned again between the altitude of 100 km down to a limb altitude in the range 20–25 km where sun acquisition was lost. In the Southern Hemisphere, the nitric oxide window was scanned from sun acquisition near 20 km up to 250 km grazing sun rays altitude.

TABLE 2. WATER VAPOR LINE PARAMETERS. UNITS ARE RECIPROCAL CENTIMETERS EXCEPT FOR STRENGTHS WHICH ARE IN CENTIMETERS (ROTHMAN *et al.*, 1983)

Wavenumber	Strength	Halfwidth	Energy of the lower level
1918.007	9.74×10^{-21}	0.0509	488.134
1918.036	2.92×10^{-20}	0.0515	488.108
3816.092	2.10×10^{-19}	0.0942	79.496
3818.341	9.16×10^{-22}	0.0815	709.606
3819.905	9.30×10^{-21}	0.0940	136.762
3824.281	3.47×10^{-21}	0.0923	142.279

3. INVERSION OF THE SPECTRA

Water vapor data have already been published (Lippens *et al.*, 1984; Ackerman and Girard, 1985) using an iterative technique based on the inversion of the curve of growth of individual lines. The lines involved are listed in Table 2 and were used according to their intensity from 80 to 30 km altitude so that the curve of growth is always close to the linear part. The results were then checked by comparison of observed and synthetic spectra. The grille spectrometer data published by Laurent *et al.* (1984) using saturated H_2O lines have been described as preliminary at the

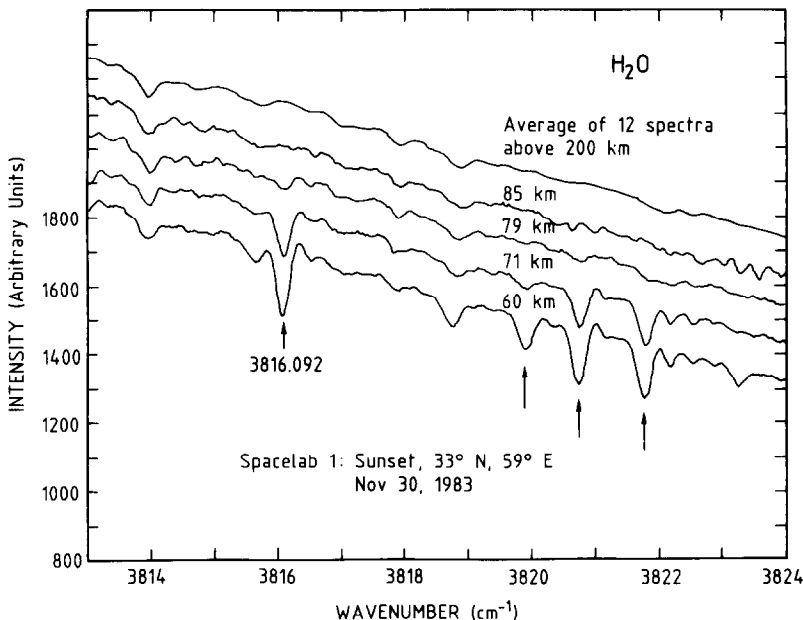


FIG. 1. SEQUENCE OF SPECTRA OBTAINED IN THE $2.7 \mu\text{m}$ WATER VAPOR BAND DURING A SUNSET IN THE NORTHERN HEMISPHERE, THE ALTITUDES INDICATED ON THE SPECTRA INDICATE THE HEIGHT OF THE TANGENT POINTS OF SOLAR RADIATION IN THE ATMOSPHERE.

Vertical scales for each spectra are offset by 100 and the zero of the ordinate corresponds to complete absorption.

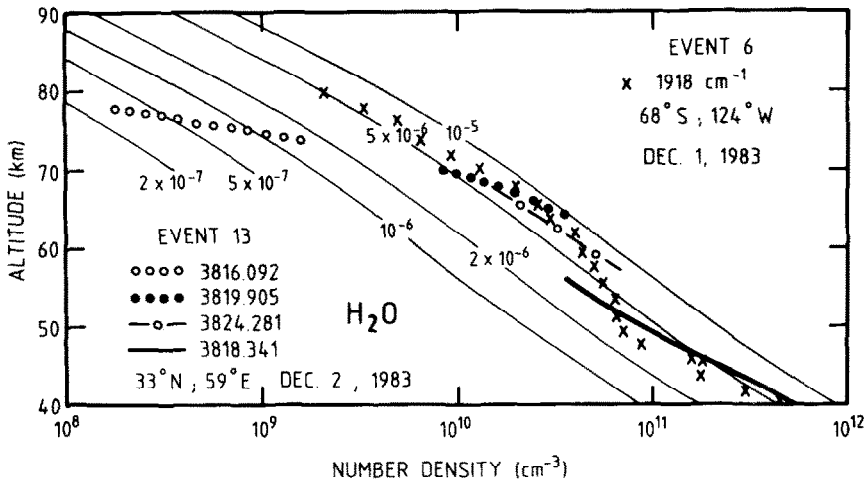


FIG. 2. OBTAINED VERTICAL DISTRIBUTIONS OF WATER VAPOR CONCENTRATIONS AS A FUNCTION OF ALTITUDE. Event 6 is a sunrise while event 13 is a sunset. The Southern Hemispheric results of event 6 are significantly higher in the 70–80 km range than those of event 13.

time of publication and this article intends to provide a definitive analysis.

A new automatic retrieving technique (Eichen, 1981; Alamichel *et al.*, 1986) was used in order to check the Ackerman and Girard (1985) results. The inversion algorithm compares in a given spectral interval the computed transmittances with the observed ones and minimizes the residual error (root mean square of the differences, taken every 0.01 cm^{-1}) between homologous observed and synthetic spectra. The new technique (Alamichel *et al.*, 1986) permits one to take fully into account the instrumental transfer function and the lines of all interfering gases, essentially CO_2 for the $2.7 \mu\text{m}$ interval and NO , CO_2 and solar CO for the H_2O line at 1918 cm^{-1} . The simulation of solar CO was accomplished using the Minnaert's formula as described by Blatherwick *et al.* (1980) and a spectroscopic data base kindly provided by Goldman (1984). Solar CO was first adjusted to fit perfectly the spectra observed between 250 and 200 km. CO_2 was simulated using the AFGL line parameters (Rothman *et al.*, 1983) and assuming the vertical distribution determined during this *Spacelab* flight (Lippens *et al.*, 1984). The temperature profile taken from the U.S. Standard Atmosphere for a mid-latitude spring fall model permits one to fit the CO_2 lines for all latitudes. This confirms the low sensitivity of absorption measurements to temperature and justifies the use of a standard temperature profile, since transitions from low energy levels have been used. The H_2O vertical distributions were fitted in both cases; the residual of fit is better than 1% of the total transmission and compares favorably with results obtained

from similar regression techniques (Blatherwick *et al.*, 1980). The final H_2O vertical distributions are shown on Fig. 2 for both observations.

The uncertainty stems from various sources: the uncertainty in spacecraft altitude and position, deviations from the mid-latitude spring fall U.S. Standard Atmosphere and accuracy of the Rothman *et al.* (1983) AFGL lines parameters. Our CO_2 results (Lippens *et al.*, 1984) confirm the altitude determination from orbital data, leading to a 15% error in the inversion processes. Comparison of the U.S. Standard Atmosphere with the corresponding lower stratospheric meteorological satellite sounding (Planet, 1984) has shown differences in temperature of about 5 K which do not have a significant effect on absorption measurements. Another cause of uncertainty is introduced by the AFGL line intensities which are quoted to be accurate to 15%, the accuracy being higher for the strongest lines, as those observed in the upper atmosphere. The combination of these factors would thus lead to an accuracy of 30% peak-to-peak for the concentration data presented here.

4. DISCUSSION AND CONCLUSIONS

The two vertical distributions obtained in this work both display a slowly varying mixing ratio with values ranging from 3 ppm in the upper stratosphere to 8 ppm in the mesosphere below 70 km; a steep decrease being observed at higher altitudes. In the Northern Hemisphere at 33°N , the limit of detectability is reached at the altitude of 78 km, while at 68°S , the H_2O line becomes undetectable slightly above 80 km,

and no significant decrease of H₂O mixing ratio is observed below. In this respect the Northern Hemisphere abundance of water vapor at 78 km is an order of magnitude lower than the corresponding Southern Hemisphere result. The impossibility to obtain data at high northern latitudes prevents a meaningful comparison with the results obtained using a rocket-borne infrared radiometer instrument by Grossmann *et al.* (1985) who determine a H₂O mixing ratio between 3 and 8 ppm at altitudes ranging from 70 to 120 km in arctic winter conditions. In our case, the difference is highly significant between the Northern and the Southern Hemisphere, especially in view that the 1918 cm⁻¹ water vapor line is five times weaker than the strongest 3816.092 cm⁻¹ line used in the northern determination. More observations of water vapor at different seasons and latitudes are clearly needed to deduce a general picture. They will be scheduled for flights of the grille spectrometer during the Earth Observation Missions program.

Rocket observations of ionospheric composition by Swider and Narcisi (1975) during a polar cap absorption event at high northern winter latitudes provide a water vapor data set which is strikingly similar to the upper part of our Northern Hemisphere vertical distribution. These data compare well with the one-dimensional models of Shimazaki and Laird (1972) and George *et al.* (1972).

Our results also correlate with the observations of CO (Lippens *et al.*, 1984; Vercheval *et al.*, 1986) obtained during the same flight and with the mesospheric ozone data (Thomas *et al.*, 1984a,b) deduced from SME observations of the O₂(¹Δg) 1.27 μm emission. The values of CO at 80 km obtained by Vercheval *et al.* (1986) are an order of magnitude higher at 44°N than those at 68°S, while the ozone values reported by Thomas *et al.* (1984b) are a factor of about three higher at 40°N than at 68°S at the same time of the year in both 1982 and 1983, the latter observation being simultaneous with ours.

Both Vercheval *et al.* (1986) and Thomas *et al.* (1984b) suggest the influence of enhanced hydroxyl radical as a possible explanation for the low CO and O₃ abundances, while the water vapor determinations presented here point to the source of this radical: active hydrogen chemistry related to dissociation of water vapor by solar radiation (Nicolet, 1981).

The two observations of water vapor reported here compared with our near simultaneous observations of carbon monoxide (Vercheval *et al.*, 1986) support the hypothesis made by Solomon *et al.* (1985) that enhanced H₂O abundances in the mesosphere lead to reduced vertical amounts of CO. In relation with this aspect, Thomas *et al.* (1984b) and Garcia and Solomon

(1985) propose that waves forced by tropospheric perturbations would propagate in a seasonally variable fashion through the stratosphere and mesosphere and finally break at the mesopause, enhancing mixing at this level and higher. The complex interaction of chemistry and transport suggested by this mechanism could be assessed only by having much more sophisticated models of the atmosphere on one hand and, on the other, a long term observation program of global middle atmospheric and thermospheric composition.

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