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Hygrometer for long duration stratospheric measurements ($\geq$1 month)

VENTURA CASSELYN LEON
Electronics Department, Universidad de Las Américas
Cholula. Pue., Mexico

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ABSTRACT. Photodissociation of minor species, with the aid of ultraviolet sources is used here to improve a hygrometer for stratospheric *in situ* measurements between 18 and 31 km. The water vapor mixed with the air is measured by detecting the spontaneous luminescence from the OH radical at a 3100 Å wavelength. The radical loses this energy when the water vapor is photodissociated with a Lyman-α photon beam inside the photolysis chamber. As the instrument has been designed for long duration balloon flights, we have used space materials and space technical methods for its construction. This combination has greatly diminished its volume and weight, allowing it at the same time to resist high temperature and pressure gradients. This new generation of hygrometers will give precise temporal and latitudinal measurements of the atmospheric water content, resulting in a better understanding of the atmospheric dynamics and the transport phenomena of this element.

RESUMEN. La fotodisociación de constituyentes minoritarios con fuentes de emisión ultravioletas, es usada aquí en un higrómetro para mediciones estratosféricas *in situ* entre 18 y 31 km. El vapor de agua mezclado con el aire se mide detectando la luminiscencia espontánea del radical OH en una longitud de onda de 3100 Å. El radical pierde esta energía cuando el vapor de agua es fotodisociado con un haz de fotones Lyman-α en la cámara de medida. Como el instrumento ha sido diseñado para ser usado en globos estratoféricos de gran duración, se usaron métodos y materiales de características espaciales en su construcción. Combinando esto, se redujo considerablemente su peso y su volumen, capacitándolo además para resistir gradientes importantes en temperatura y presión. Con esta generación de higrómetros se obtendrán medidas precisas, tanto temporalmente como latitudinalmente del contenido del vapor de agua atmosférico, lo cual significará una mejor comprensión de la dinámica atmosféca, así como del fenómeno de transporte de este elemento.

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1. INTRODUCTION

Water vapor vertical profiles obtained with short duration stratospheric hygrometers has aroused serious controversies about the measured mixing ratios [1–3]. This can make us believe, that the atmospheric water vapor content is independent of the altitude, situation that has complicated the study of the atmospheric inhomogeneities and the transport phenomena when we do not have precise humidity measurements on the limit layer. Some studies made at 2 and 5 km over the tropopause [4] in tropical and moderate regions, show a minimal value of water vapor concentration. This dryness level could indicate that the global air circulation theory is correct [5] that is, the air arrives to the stratosphere in important quantities, after crossing the tropical tropopause. This circulation and transport phenomena can be applied to other species which have a probable tropospheric origin. Among the methods used until now to make these measurements, we can mention the sampling methods with stratospheric balloons [6]; there are also techniques using rockets [7] and the dew-point method used during several years by Mastenbrook. Direct sampling methods or *in situ* measurements become more difficult as altitud increase owing mainly to the contamination of the instrument at the passage through the cloud layers of the low atmosphere. Outgassing from the materials used in the instrument construction or the association of ionized species [8] during a phase change can represent an additional complication. Considering these differences on the measurements, the idea of long duration stratospheric balloon flights was born. It has been shown [9] that most of the contamination problems will be eliminated if the instrument has the necessary outgassing time in the stratosphere before the beginning of the photodissociation measurements. This demands a total change in the instrument and balloon conception [10]. A photodissociation chamber weighing actually ≈ 200 kg must be modified to weight only 2 or 3 kg. This means a high degree of electronics, optical and mechanical miniaturization with the substitution of the pressurized stainless steel container that protects it. To eliminate this heavy container, silicone, which is a very light material with space characteristics, has been used. With this improved hygrometer, we expect to start again [16] the long duration water vapor stratospheric measurements. Combining also a thermodinamical stratospheric air circulation [17] a ballon will be capable to stay longer with a very reduced instrumental charge.

2. THE PHOTODISSOCIATION CHAMBER

Water vapor measurements are done inside a chamber free of external parasitic light, as shown in Fig. 1. In the interior a hydrogen arc lamp produces an ultraviolet emission that illuminates the air that circulates all the time through the photodissociation zone. Since the emission from the lamp has a large spectrum, two filters located a few centimeters over the lamp window are necessary to prevent emissions other than the Lyman-α at a 1216 Å wavelength. The H_2O molecules mixed with the air found in the middle of the photon beam path are photodissociated producing OH radicals at the $A^2\sum^+$ energy level with a quantum yield [11] ρ of $\approx 5\%$. The radical life time in this energy level goes from 0.7 to 1μ s producing [2, 12] a fluorescent emission at a 3100 Å wavelength when it returns to the $X^2\pi$ state. This spontaneous emission is detected by a photomultiplier tube placed near the photodissociation zone. As the flux coming from the lamp can be absorbed [13], either by the H_2O or by the O_2, a nitric-oxyde counter is used to monitor this absorption. The measurement chamber is shaped as a hollow parallelepiped of 1 mm thickness, composed of three main axis: the photodissociation axis, the detection axis on the horizontal cross section and the air circulation axis in the vertical direction. The first one is formed by the Lyman-α lamp, lodged in a 62 mm diameter aluminium cylinder, fixed to one of the walls together with one of the filters and a light trap by means of two

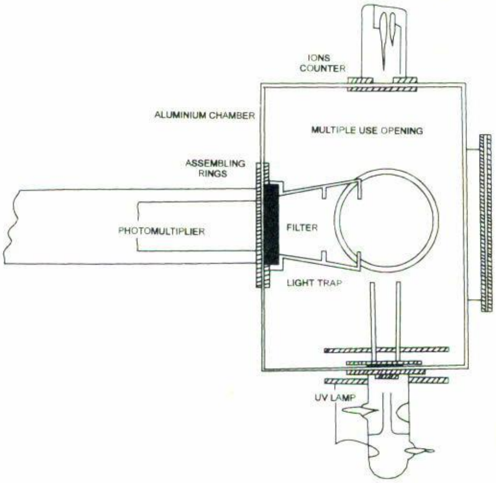

FIGURE 1. Geometrical characteristics and elements distribution inside the water vapor chamber.

thin aluminium rings. At the opposite end, the NO counter is separated 17 cm from the UV lamp. The detection axis consists of a H-292 Hamamatsu photomultiplier tube, with an external filter centered at a 3100 Å wavelength; the right angle intersection between the photodissociation and detection axis occurs at 8 cm from the photomultiplier window. For further applications the hygrometer chamber has been designed with a general use aperture which could be used to install another NO counter or another photomultiplier if required.

All the hygrometer's high voltage sections, have been protected with silicone [14] against the atmospheric temperature and pressure changes. This treatment yields a complete long duration stratospheric hygrometer capable of rising between 18 and 31 km during more than one month. Its weight is only 1.4 kg, in agreement with the MIR Standards [15] where the maximum allowed load is 35 kg with all the communications and control systems included. The distribution of optical elements is shown in Figs. 1 and 2 with the adjustable light traps, the NO counter and its spectral response, and the photomultiplier tube with the filtered spectrum arriving to it. From all the radiated luminescence coming from the photodissociation zone, the photomultiplier only sees a part. This part depends on the volume defined by the light trap dimensions and by the aperture beam angle of the UV lamp at that photodissociation distance. Initially this angle is $\approx 50°$ but the light traps can be adjusted by increasing the angle, according to the signal to noise requirements.

3. CALIBRATIONS AND SENSITIVITY IMPROVEMENTS

The calibration procedure is simple without asking for very complicated instruments. It is mainly based over the theoretical considerations developed by Bertaux and Delannoy [2, 13]. For the calibrations, two hygrometers were employed, measuring simultaneously a volume with the same water content. Nitrogen was the principal gas with a few

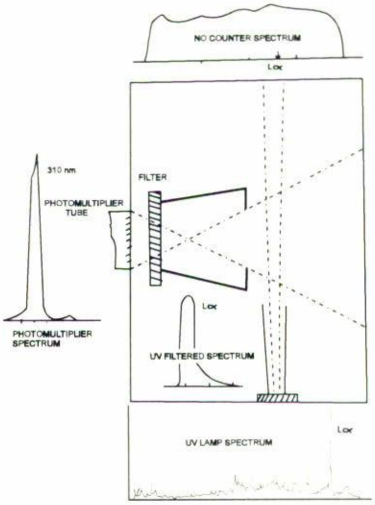

FIGURE 2. Filtered and not filtered spectra for the photodissociation and detection elements inside the photolysis chamber.

mixed ppmv (10^{-6} mixing ratio) molecules. This gas is transparent for wavelengths from 120 to 135 nm [5]. Under these considerations the optical thickness in the photodissociation chamber is only attributed to the water content. Measured flux with the NO counter from the source, with water content or without water content inside the chamber can be estimated according to

$$F_m = \sum_i F_i \exp\left(-\sigma_i(\mathrm{H_2O})(\mathrm{H_2O})L\right), \tag{1}$$

where $\sigma_i(\mathrm{H_2O})$ is the water vapor absorption cross section at i spectrum, L represents the photodissociation length, and $(\mathrm{H_2O})$ stands for the water vapor content. $F_0 = \sum_i F_i$ is the measured flux in an empty chamber. If the water vapor optical thickness τ is low, we can assume

$$\tau = \ln\frac{F_m}{F_0} \approx 1 - \frac{F_m}{F_0}. \tag{2}$$

With the same conditions of low water content the registered flux F_m is now

$$F_m \approx \sum_i F_i\Big[1 - \sigma_i(\mathrm{H_2O})(\mathrm{H_2O})L\Big] \approx F_0 - \Big[\sum_i F_i\sigma_i(\mathrm{H_2O})\mu L(\mathrm{N_2})\Big], \tag{3}$$

where μ is the mixing ratio.

The final optical thickness τ after this assumptions, can be calculated with the expression

$$\tau \approx \frac{J_{\mathrm{H_2O}}(P=0)}{F_0} L(\mathrm{N_2})\mu, \tag{4}$$

where P is the pressure and $J_{\mathrm{H_2O}}$ is the photodissociation coefficient.

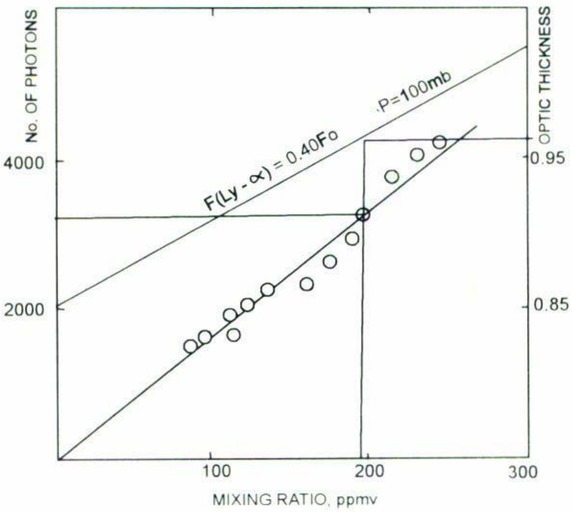

FIGURE 3. Water vapor calibration measurements under constant pressure conditions.

Giving numerical values, the optical thickness is

$$\tau = 1.6 \times 10^{-16}(\mathrm{N}_2)\mu.$$

In order to perform these calibrations, nitrogen must be almost pure. Quenching differences between the OH^+ radical and the oxygen O_2 need instrument corrections by a factor varying from 1 to 2. Partially to avoid these problems, dry air was used as the principal gas (nitrogen or air containing less than 5 ppmv (5×10^{-6} H_2O mixing ratio). Measurable optical thickness is due to the additional contributions of water and vapor. Air pressure was selected between 10 to 100 mb, which are the atmospheric flight pressures that the long duration MIR (Montgolfière infrarouge) balloon will find.

Optical filters at the output of the Lyman-α source diminishes secondary parasitic light coming from others photodissociations inside the chamber. The calibrations results shown in Fig. 3 were obtained at a 100 mb. These measurements permitted parasitic light estimations, that were practically eliminated with the aid of silicon traps or baffles as shown in Fig. 1. The sensitivity I_M or the number of photons counted by the photomultiplier tube in this new chamber in a second is

$$I_M = 51.2\,\mu\, I_{35\mathrm{km}}. \tag{5}$$

The photon intensity I_M is calculated after having measured all the optical parameters in the new chamber with the following equation:

$$I_M = T_{t2}\, \emptyset_M\, I_{(0,0)}\, F_L\, \Delta_L\, F_{PM}/4\pi L^2 \tag{6}$$

where $\emptyset_M$ is the photomultiplier quantum yield, T_{t2} represents the transmission of the optical filter, F_L and F_{PM} are the PM and lamp detection cross section, respectively. The length of photodissociation volume is represented by Δ_L.

The transition equation $I_{(0,0)}$ valid for the troposphere and stratosphere up to 35 km altitude is

$$I_{(0,0)} = \mu\, J\, \emptyset\, A_{(0,0)}/k_q^{\text{air}} \tag{7}$$

where k_q^{air} stands for the air quenching coefficient, $\emptyset$ represents the quantum yield for production of excited radicals. The Einstein transition probability and the photodissociation coefficient are represented by $A_{(0,0)}$ and J, respectively.

According to the intensity value found above, the sensitivity of the new instrument has been increased in comparison with the sensitivity of the short duration stratospheric instrument. At the same time, as the instrument is not protected with a pressurized stainless steel container that could prevent the system to cool fast enough in the stratosphere, the signal to noise ratio is better. As soon as the temperature decreases from +25° to −60° the photomultiplier dark current diminishes from 78 photon counts per second to ≈ 3 photon counts per second. The whole instrument with silicon light traps, silicon protected NO conter, silicon protected UV lamp, silicon protected photomultiplier and aluminium chamber is shown in Fig. 3.

4. CONCLUSIONS

We have developed a very light hygrometer for stratospheric H_2O measurements, which is well adapted for long duration flights, after having used space techniques for the construction. Several geometrical and optical improvements have been made, mostly to increase the signal to noise ratio. The instrument is also capable of resisting the temperature and pressure variations found between 19 and 31 km high. The weight ot this hygrometer being of only 1.5 kg, an approximately 500% weight improvement has been accomplished by comparison with the short duration stratospheric instrument.

5. ACKNOWLEDGMENTS

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