OBSERVATIONS OF WATER VAPOUR ON BOARD LONG-DURATION SUPER PRESSURE BALLOON USING FLASH-B LYMAN-ALPHA HYGROMETER

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ABSTRACT

We present the results of Lagrangian water vapour observations inside the polar vortex obtained on board CNES 12 m super pressure balloon (SPB) launched from Esrange, Sweden in March 2007. The balloon, carrying the householding gondola ISBA and FLASH-B hygrometer, was drifting at around 70 mBar pressure level for 9 days, made a full circle around the North pole and safely landed not far from the launching site.

FLASH-B, a lightweight and compact Lyman-alpha instrument is designed for night time flights on board of small meteorological balloons. For the long-duration balloon experiment FLASH-B design was adapted for long-term operation at stratospheric conditions. The instrument was running on battery power for 7 days and provided long series of accurate water vapour observations in a moving air parcel.

1. INTRODUCTION

Water vapour is a key component of the climate system. It is the most potent greenhouse gas, and its condensed forms (liquid and ice) exert a profound influence on both incoming solar and outgoing infrared radiation. Climate models find that predictions of climate change are very sensitive to water vapour and cloud feedback: water vapour feedback alone doubles the effect of an increase in other greenhouse gases. Water vapour is also, by its presence or its absence, an important component of atmospheric chemistry. The fact that the stratosphere is very dry, with only 4 to 6 water molecules per million, is essential in the ozone chemistry. Although modeling of the future evolution of the stratosphere is still in its infancy, variations of vapour water are likely to be a determining factor and the available records already display signs of a recent evolution. Despite of the recent progress in water vapour measurement techniques, there is still a lack in accurate data on water vapour in the upper troposphere and stratosphere. Indeed, measurement of water vapour in the upper troposphere and lower stratosphere is a technically complicated task due to large vertical gradients of humidity around the tropopause. Satellite observations, providing global coverage, are of limited use because of systematic biases, poor precision, frequent presence of clouds, but particularly because of their broad 3-5 km vertical resolution in a region of large vertical gradients as shown by Montoux et al., [2007]. In-situ balloon and aircraft-borne observations of water vapour provide the most valuable material for studies of chemical, dynamical and transport processes in the stratosphere, including the processes influencing ozone chemistry.

Observations of water vapour from the long-duration balloon platforms were described by [1], [2], [3] and others. Long duration balloon provide an unique opportunity to study variation of the air composition in a moving parcel, thus representing a Lagrangian approach to atmospheric observations. Here we present the results of water vapour observations on board long-duration super-pressure balloon using lightweight Lyman-alpha hygrometer FLASH-B. The structure of the paper is such that the description of the FLASH-B instrument design and experimental set up are given in sections 2 and 3 respectively, while the results and discussion are given in section 4, followed by the summary in section 5.

2. FLASH-B INSTRUMENT

The FLASH-B (FLuorescence Advanced Stratospheric Hygrometer for Balloon) instrument is the Lyman-alpha hygrometer developed at the Central Aerological

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Observatory for balloon-borne water vapour measurements in the upper troposphere and stratosphere [4,5]. The instrument is based on the fluorescent method [6,7], which uses the photodissociation of H2O molecules at a wavelength λ < 137 nm followed by the measurement of the fluorescence of excited OH radicals. The source of Lyman-alpha radiation (λ=121.6 nm) is a hydrogen discharge lamp, while the detector of OH fluorescence at 308 -316 nm is a Hamamatsu R647-P photomultiplier run in photon counting mode with a narrow band interference filter selecting the fluorescence spectral region. The intensity of the fluorescent light sensed by the photomultiplier is directly proportional to the water vapour mixing ratio under stratospheric conditions (10–150 hPa) with small oxygen absorption (3% at 50 hPa). The H2O measurement range is limited to pressures lower than 300-400 hPa due to strong Lyman-alpha absorption in the lower troposphere.

The instrument uses an open optical layout design [8], where the optics is looking directly outside. Such arrangement is suitable for nighttime measurements only at solar zenith angle larger than 980. The co-axial optical layout allows a reduction in the size of the instrument to 106 x 156 x 242 mm for a total weight of about 0.5 kg without batteries. The hygrometer is coupled with a Vaisala RS-80 radiosonde providing telemetry as well as pressure and temperature measurements.

Each FLASH-B is calibrated in the laboratory before flight. A description of the procedure can be found in [9]. The detection limit for a 4-second integration time at stratospheric conditions is of the order of 0.1 ppmv, while the accuracy is limited by the calibration error. The total uncertainty is less than 10% at stratospheric mixing ratios greater than 3 ppmv. Accuracy and good performance of the FLASH-B instrument have been confirmed through point-by-point comparisons with the NOAA-CMDL frost point hygrometer during the LAUTLOS-WAVVAP intercomparison campaign [9] showing excellent agreement between both instruments with a mean deviation of -2.4 +/- 3.1 % (1 standard deviation) for data between 15 and 25 km.

2. EXPERIMENTAL SET UP

In the long-duration balloon experiment FLASH-B was operating on board CNES 12 m diameter super pressure balloon (SPB) launched from SSC Esrange, Sweden on 05 March 2006. The balloon, carrying the householding gondola ISBA and FLASH-B hygrometer, was drifting at around 70 mBar pressure level (18 km) for 9 days, made a full circle inside the polar vortex around the North pole and safely landed about 300 km south from the launching site. The payload was successfully recovered and returned to the CAO laboratory. Re-calibration of the hygrometer did not reveal any drifts in the instrument’s sensitivity.

For this experiment FLASH-B design was adapted for long-term operation at stratospheric conditions. The FLASH-B payload comprised two vertically arranged styrofoam boxes painted black for efficient absorption of sun radiation during the day. The FLASH-B payload was hanging on a 15 m cable beneath the ISBA gondola. The upper box housed 25 SAFT G20 3V battery cells arranged in the 5-cell packages interconnected in-parallel so that the supply voltage of FLASH-B amounted to 15 V. FLASH-B power was triggered by a simple photodiode light detector, restricting the instrument operation to the night time, The measurements were acquired during night-time only in measurement cycles of 8 minutes long followed by a 2 minutes long transmission of the recorded data into the ISBA gondola memory and 2 hours of idle operation. The half-duplex serial RS485 exchange protocol was used for data transmission at 2400 baud rate between FLASH-B and householding gondola ISBA. A separate digital channel was used to acknowledge data receipt from FLASH-B. During the measurement cycle FLASH-B data is stored into internal memory of the hygrometer. After the measurement cycle is over, FLASH-B sends a code word to ISBA to request the data transmission session. The transmitted data are CRC checked and stored into ISBA internal memory to be afterwards transmitted over ARGOS channel to the ground.

The thermal regime of the FLASH-B instrument was maintained by the 3 heating resistors running constantly inside the FLASH-B housing as well as by the thermostating system of photomultiplier (PMT) unit, running during night time only and maintaining PMT temperature at -10 ºC. During the day time, the payload was efficiently heated by the sun. Thermo-regulating system of the FLASH-B experiment was optimized to allow for longest operation of the instrument at favorable thermal conditions. The instrument was running on battery power for 7 days. The pressure and temperature was measured using Vaisala RS80 radiosonde sensors integrated into hygrometer package.

3. RESULTS AND DISCUSSION

The launch of super pressure balloon was conducted on 05 March from SSC Esrange by the CNES balloon team. The balloon was drifting at 70 ± 4 mBar pressure level corresponding to the altitude 17.9±0.3 km or 450±13 K potential temperature level. The balloon trajectory was governed by the circumpolar circulation inside the polar stratospheric vortex. The ambient temperature along the flight was varying between -63 ºC and -75 ºC.

3.1 Contamination issue

An important issue arising in the balloon experiments for stratospheric water vapour measurement is contamination of the analyzed volume due to water vapour outgassing from the payload. Indeed, the stratosphere is several orders of magnitude drier than the lower troposphere and the water absorbed by the payload on the ground would desorb in the stratosphere, contaminating the analyzed air. In a short-term balloon flights FLASH-B is located on the payload with the optics pointed downwards in order to ensure contamination-free measurements during payload descent, when the instrument is probing undisturbed air. The ascent measurements in such configuration are normally affected by the water contamination, introducing positive bias into the measurements increasing with altitude. Figure 1 shows the ascent and descent water vapour profiles obtained in the short-term FLASH-B flight conducted at Esrange on 23 February 2007, 10 days prior to the SPB long-duration flight. One can see that the ascent and descent profiles agree well in the lower stratosphere up to 18 km, where water vapour is not expected to vary within a short time scale. Above 18 km the ascent profile clearly shows the signs of contamination effect.

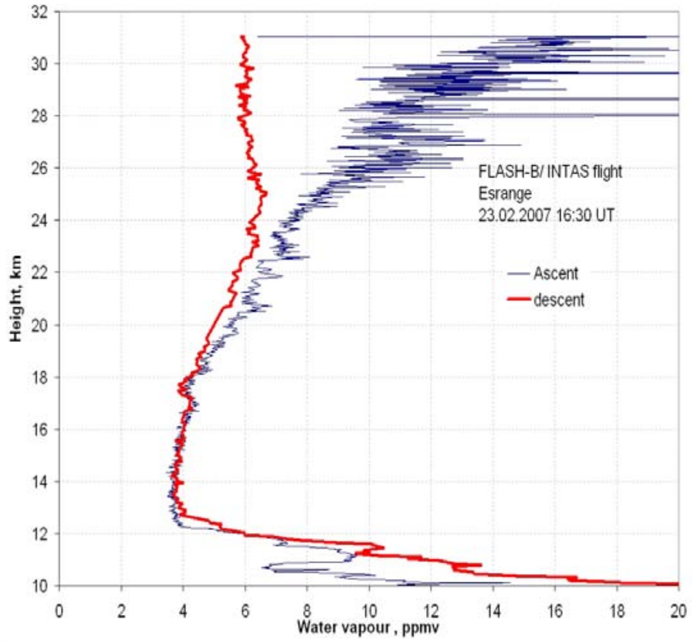

Figure 1. Vertical water vapour profiles obtained during in short-term balloon sounding conducted from Esrange on 23.02.2007.

In order to reduce the effect of water outgassing in the long-duration flight, FLASH-B payload was hanged on a 15 m cable below the gondola, however the effect of contamination was still noticeable during the first 3 days of the flight as demonstrated in Figure 2. Figure 2a shows a fragment of water vapour and pressure measurements during the first day of flight. The water vapour series clearly show oscillations in mixing ratio tightly correlating with the balloon vertical motion, as can be seen from the pressure series plotted versus reversed right axis. The descent measurements, marked with green filled circles on the plot in Fig 2, represent clear, free of contamination data. The signs of contamination were observed to deplete during the first 3-4 days of the flight, completely vanishing by the 5th day of flight as suggested by Fig. 2b demonstrating no oscillation in water vapour mixing ratio.

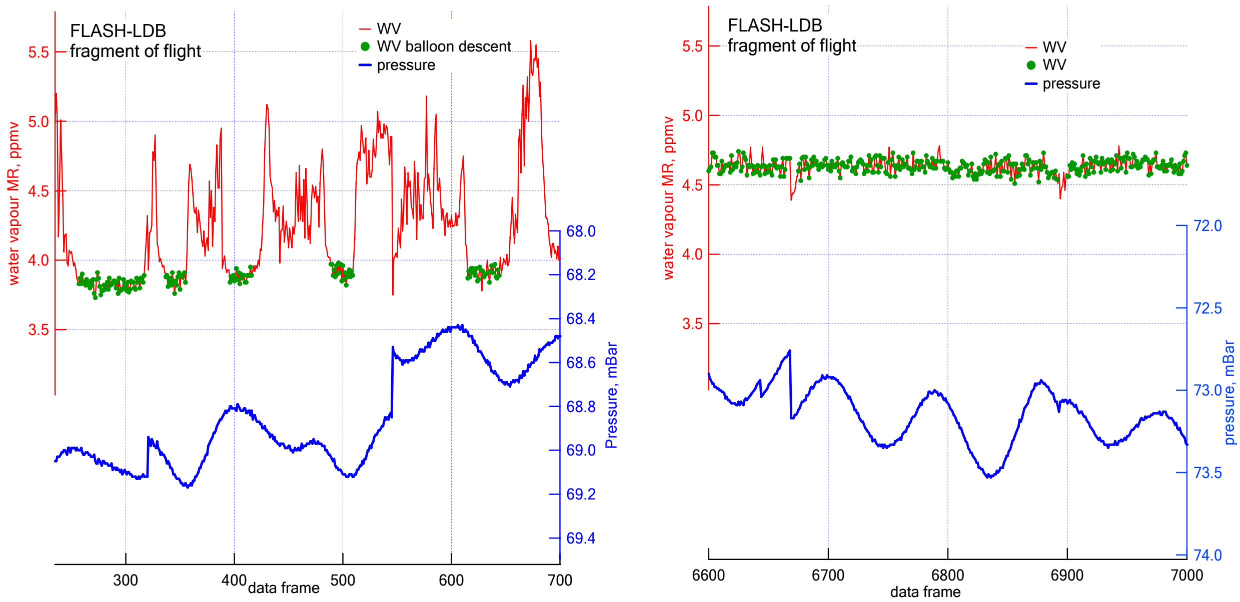

Figure 2. Water vapour and pressure from the two different flight fragments; first day of flight (left panel) and fifth day of flight (right panel). The contamination-free water vapour data are marked with green circles. The right axis (pressure) is reversed.

3.2 Results of water vapour measurements

Figure 3 shows the result of water vapour measurement during the long-duration balloon experiment along with the balloon float altitude. The horizontal axis of the plot in Fig. 3 refers to the number of measurement data frame, i.e. the axis is scaled to the operation cycles of FLASH-B instrument and bound to the day of March. Only contamination-free water vapour data are shown in the plot of Fig. 3, as can be concluded from the sparseness of data for the first part of the data series. While the balloon float altitude is slowly decreasing from 18.1km to 17.6 km (68 mBar to 73 mBar) until the 8th of March, the water vapour mixing ratio is shown to increase from 3.8 tp 4.5 ppmv during this time period. Since water vapour mixing ratio generally has a positive vertical gradient inside polar vortex in this height region, such relation between observed water vapour and altitude might seem inconsistent. However, as demonstrated in Fig. 1, showing water vapour vertical profile obtained in the balloon sounding from Esrange prior to the SPB flight, there is a well distinguished layer of drier air at around 18 km. This layer was detected during both ascent and descent measurements, which proves that it is not an instrumental artifact. Furthermore, a balloon flight with FLASH-B instrument conducted from Sodankyla, 400 km East from Esrange also showed local minimum at the same level. These indications lead to conclude that the layer of drier air detected by independent balloon soundings at different Arctic locations is related to a distinct filament of drier air mass, probably advected from outside the vortex. Thus, the increase of water vapour during the first days of the long-duration flight can be attributed to the features of water vapour vertical structure inside the polar vortex.

By the 8th of March the water vapour levels off to the value of 4.6 ppmv, which is very consistent with the results of short-term balloon soundings. On the last day of flight the increase of balloon float altitude is correlated with increase of water vapour, which, as we demonstrated above, is related to the filament of drier air.

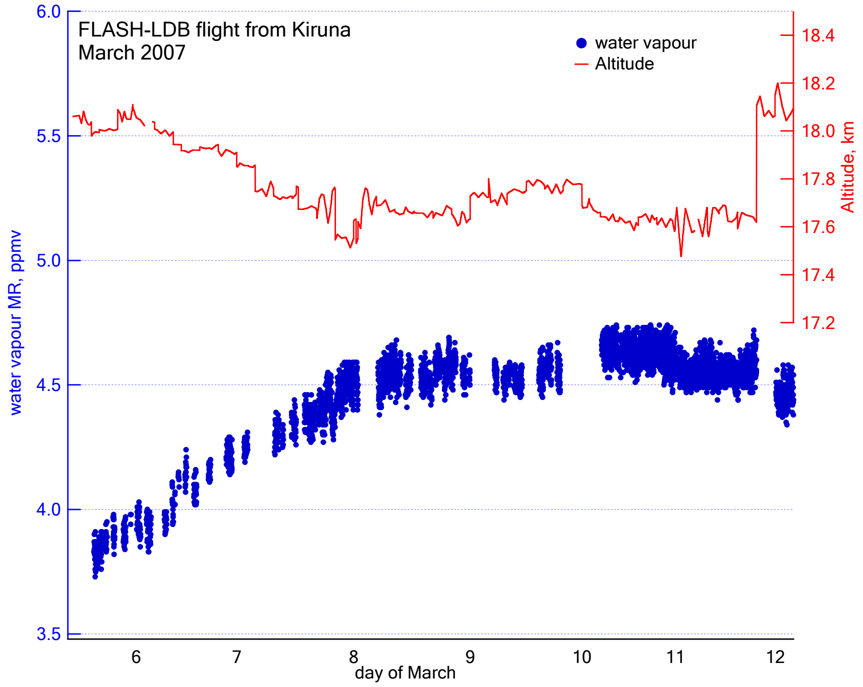

Figure 3. The results of water vapour mixing ratio measurements using FLASH-B in the long-duration balloon experiment. The balloon float altitude is plotted versus right vertical axis.

4. SUMMARY

The paper presents the results of quasi-lagrangian water vapour observations inside the polar vortex obtained on board CNES 12 m super pressure balloon launched from Esrange, Sweden in March 2006. The balloon, carrying the householding gondola ISBA and FLASH-B hygrometer, was drifting at around 70 mBar pressure level for 9 days, made a full circle around the North pole and safely landed not far from the launching site.

The measurements of water vapour were conducted using, a lightweight and compact Lyman-alpha balloon instrument FLASH-B. For the long-duration balloon experiment FLASH-B design was adapted for long-term operation at stratospheric conditions. The instrument was running on battery power for 7 days and provided long series of accurate water vapour observations in a moving air parcel.

At the first 3 days of the long-duration flight water vapour measurements were partly affected by contamination, i.e. water outgassing from the instrument surfaces during the balloon upward motion. The contamination effect was gradually depleting and disappeared completely by the forth day of flight. During the first two days, the drift altitude decreased from 68 mBar to 73 mBar, whereas the water vapour readings increased from 3.8 ppmv to 4.5 ppmv. In the course of the following days the drift altitude varied a little and the water vapour remained at 4.5-4.6 ppmv level, which corresponds to typical values inside the polar vortex at the given season. The stability of water vapour readings suggests stable and reliable operation of the FLASH-B hygrometer on board long-duration balloon.

REFERENCES

1. Ovarlez, J. (1991), Stratospheric Water Vapor Measurement in the Tropical Zone by Means of a Frost Point Hygrometer on Board Long-Duration Balloons, J. Geophys. Res., 96(D8), 15541-15545.
2. Montoux, N., Hauchecorne, A., Pommereau, J.-P., Durry, G., Morel, B., Jones, R. L., Lefèvre, F., and Bencherif, H.: Evaluation of balloon and satellite water vapour measurements in the Southern tropical UTLS during the HIBISCUS campaign, Atmos. Chem. Phys. Discuss., 7, 6037-6075
3. Goutail, F., and J.P. Pommereau, In situ stratospheric water vapor measurements on board long duration balloons, Proc. 8th ESA Symp on European Rocket and Balloon Programmes, ESA SP-270, 1987.
4. Yushkov, V., Merkulov, S. and Astakhov V.: Optical balloon hygrometer for upper stratosphere and stratosphere water vapour measurements, in Optical remote sensing of the atmosphere and clouds edited by J.Wang, B.Wu, T.Ogawa, Z-h.Guans, Proc. SPIE, 3501, 439-445, 1998.
5. Yushkov, V., Sitnikov, N., Zaitcev, I., Pommereau, J.-P. and Garnier, A.: Stratospheric water vapor measurements in the winter arctic with optical fluorescence hygrometer on short and long duration balloons, in: Proceedings of the 15th ESA Symposium on European Rocket and Balloon programmes and Related Research, Biarritz, France, ESA SP-471, 28-31 may 2001, Warmbein, B. (ed.), ESA, 263-268., 2001.
6. Kley, D. and Stone, E.J.: Measurements of water vapor in the stratosphere by photodissotiation with Ly-alpha (1216A) light, Rev. Sci. Instrum., 49, 661-697, 1978.
7. Khaplanov, M., Astakhov, V., Lukjanov, A., Kretova, M.,and Yushkov, V. Fluorescent hygrometer for middle atmosphere measurements, Proc. 19th Annual European Meeting on Atmospheric Studies by Optical Methods, 540-545, 1992.
8. Bertaux, J. L. and Delannoy, A.: Premieres mesures stratosphériques par un hygromètre a fluorescence ultraviolette, C.R.Acad.Sc.Paris, 286, 191-194, 1978.
9. Vömel, H., Yushkov, V., Khaykin, S., Korshunov, L., Kyrö, E., and Kivi R.: Intercomparisons of Stratospheric Water Vapor Sensors: FLASH-B and NOAA/CMDL Frost-Point Hygrometer, J. Atmos. Oceanic Technol., 24, 941–952, 2007.