FLASH-B
Fluorescent Lyman-Alpha Stratospheric Hygrometer for Balloon

Instrument description and data processing manual.

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1. Description of the instrument

1.1 Overview

The FLASH-B instrument was developed at Central Aerological Observatory of RosHydroMet, Russia for balloon-borne water vapor measurements in the upper troposphere and stratosphere (*Yushkov et al., 1998, Khaykin et al., 2009, 2013)*. 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 an narrowband interference filter for selecting the fluorescence spectral region. The intensity of the fluorescent light sensed by the photomultiplier is directly proportional to the water vapor mixing ratio under stratospheric conditions (30 – 150 hPa) with small oxygen absorption (3% at 50 hPa).

The instrument uses the open layout, where the optics is looking directly into the outside air. This arrangement is suitable only for nighttime measurements with a solar zenith angle larger than 98^0, at which sun light no longer reaches the detector. The co-axial optical layout allows reducing the size of the instrument to 106x156x242 mm with a total weight of 0.55 kg.

The accuracy of the FLASH-B instrument is determined by the calibration error estimated as 4% in the 3 – 100 ppmv range. The measurement precision is 5.5% calculated for 4 seconds integration time at stratospheric conditions. The total uncertainty of the measurement is less than 10% at the stratospheric mixing ratios greater than 3 ppmv increasing to about 20% at mixing ratios less than 3 ppmv.

Unlike the more sophisticated hygrometers based on the fluorescence technique, FLASH-B doesn't use VUV photon flux control. However the hydrogen glow-discharge lamps used in the FLASH-B instrument have been proved to have very stable intensity of the Lyman-alpha emission over both operation and storage time. Every lamp is subjected to continuous laboratory tests for stability of the emission intensity which is checked before the flight.

Temperature of the lamp can vary during the flight experiment, however the laboratory studies have shown that the temperature-induced drift of the lamp flux does not exceed 0.016% / ^{0}C, meaning that the error introduced by the lamp temperature variations is negligible.

The background signal caused by the night sky emissions in the absence of fluorescence light is detected using lamp modulation with 1 kHz square wave with 1/1 duty cycle and synchronous demodulation of the signal received. The background signal is detected while the lamp is off and then subtracted from the fluorescence signal.

1.2 Lyman-alpha source

The source of vacuum UV (VUV) radiation used in the FLASH-B instrument is a hydrogen glow-discharge lamp filled with a mixture of hydrogen and helium at the total pressure of 10 hPa with VUV flux amounting to 10^{14} quanta per second. The VUV lamp is a key component of fluorescent hygrometer since the stability of its emission determines conversion factor and metrological characteristics of the instrument. Coaxial optical scheme of the hygrometer, where the analyzed volume is located outside the instrument does not allow for in-flight monitoring of lamp emission intensity. However this is not necessary for the glow discharge lamp applied in the fluorescent hygrometer.

1. Every lamp is subjected to long and short stability tests using absolute instrument for measurement of Lyman-alpha radiation intensity based on ionization method.
2. An indicator of lamp emission stability is the hygrometer conversion factor, which is determined through calibration of the instruments using reference frost point hygrometer. Repeatability of calibrations is the proof of lamp emission stability.
3. Laboratory studies showed that within the range of operating temperatures of the lamp (- 70ºC .. + 30° C) the change of lamp emission intensity does not exceed 3%, which is included into the total uncertainty of the instrument.
4. The intensity of Lyman-alpha radiation in the lamp applied is in linear relation with the discharge current value. The lamp power supply scheme provides direct current stabilization better than 1%
5. An important indirect evidence of stable lamp performance during flight is the precise match of ascent and descent measurements in the stratosphere below 70 mBar, where the water outgassing from balloon and payload does not affect the ascent measurements, while the spatial and temporal variability of water vapour is negligible between stratospheric ascent and descent measurements.

The VUV light sources containing the mixture of hydrogen and helium are known to have the stray helium line emission which overrides the spectrum of hydroxyl fluorescence and thus may cause spurious signal from backscattering of this emission. The FLASH-B instrument uses the hydrogen lamp in which the 270-320 nm emission is suppressed by a special window-filter. This window-filter is made using monocrystalline magnesium fluoride with an absorbing layer vacuum-deposited on its inner surface. In this way, up to 50% transmission at the 121.6 nm line and selective absorption at 300 nm are achieved. In addition the instrument uses the narrowband interference filter centered at 310 nm with 8 nm bandwidth and out-of-band extinction of 10^{-5} thus reducing the possible effect of the stray light backscattering.

1.3 Calibration

The FLASH-B hygrometer is not an absolute instrument for water vapor measurements, as such and every hygrometer has to be calibrated in the laboratory before flight. Laboratory studies have shown that the calibration coefficients do not change over time.

A laboratory facility capable of simulating atmospheric conditions is used for the calibration. In particular, the large range of water vapor mixing ratios (1–1000 ppmv), pressure (1000–3 hPa), and temperature (down to 190 K) can be produced by the calibration system. The calibration procedure is performed as follows: after purging the system with dry air for 1–2 h, the airflow boosted by a compressor is dried passing a silica gel dehumidifier and then divided into two branches, one of which is moistened in an H_2O bubbler. The airflows of both branches are mixed together via two flow controllers, producing variable H_2O mixing ratios. The mixed airflow is then divided, with one branch flowing through a commercial reference dew point mirror hygrometer (Swiss MBW 373L) to determine the H_2O mixing ratio, and the other branch entering a stainless steel chamber, which can be cooled down to 210 K in a low-temperature freezer. The pressure in the chamber is reduced using a vacuum pump to 50 hPa. A calibration run starts at the lowest H_2O mixing ratio and increases the H_2O mixing ratio in steps (e.g. 3 ppmv, 15 ppmv, 50 ppmv, 100 ppmv, 200 ppmv, 400 ppmv). Every calibration level is measured for about 15 min. The procedure is repeated at different pressure levels. The calibration fit function is linear in the pressure range 30–300 hPa and water vapor mixing range 1 – 500 ppmv. At higher pressure and humidity the VUV absorption by oxygen and water vapor has to be taken into account. The result of calibration is an ensemble of 5 calibration fits, each corresponding to a certain pressure level (e.g. 50 hPa, 100 hPa, 150 hPa, 200 hPa, 300 hPa). Quantitatively, the calibration result is expressed by the coefficient K_1, representing conversion factor at 50 hPa.

The total uncertainty of the calibration is determined by the following factors: uncertainty of the frost point measurement (0.1 K), uncertainty of the temperature dependence of the water vapor partial pressure, error in pressure determination, error accounting for inconsistency of the air sampled by the reference dew point hygrometer and the air inside the chamber, instability of the VUV intensity of the lamp. The total relative error of the calibration determined as the standard deviation between the successive calibration runs, amounts to 4%.

Every instrument is calibrated at least five times within 1-2 month period in order to detect possible drift in conversion factor and to increase the accuracy of calibration.

1.4 Operational layout for small (weather) balloons

The FLASH-B hygrometer being a compact and light-weight sonde can be flown on a small weather balloons equipped with a parachute for a slow descent and a 50 m unwinder for holding the hygrometer away from balloon. The instrument is placed into a styrofoam box covered with metal foil to prevent water desorption from the styrofoam. The flight box has battery compartment embedded. The flight configuration of FLASH-B is such that the analyzed volume is located beneath the downward looking optics 31 mm away from the lens. The internal pressure sensor controls PMT power supply in such a way that the PMT power is off during the launch procedure to protect the photocathode from the ground light. When the sonde reaches 1900 m altitude, the controller switches on PMT power.

1.4.1 Contamination effect

The measurements during balloon ascent in the stratosphere typically above 90 hPa are affected by contamination due to water outgassing from the instrument surfaces and the balloon. The contamination effect is observed in the data as noise, positive spikes (due to payload swings) and becomes more pronounced with decreasing pressure due to longer free run of water molecules. The contribution of contamination can reach 100 ppmv or higher at 30 km altitude. The flight studies showed that the starting level of ascent contamination (i.e. the altitude above which the contamination effect becomes apparent) depends on various factors, such as instrument storage conditions, tropospheric humidity, presence of liquid clouds, payload design e.t.c.

The measurements during the descent below parachute in undisturbed air with the instrument’s optics pointed down) can be considered contamination-free as shown by the drop of water vapour immediately after the burst of balloon at ceiling altitude. The vertical resolution of the measurements depends on the descent rate that is around 50 m (at 4 second integration time) in the lower stratosphere provided normal parachute performance.

1.4.2 Payload arrangement

Based on a long-term experience it is recommended to follow the rules of assembling a FLASH-B payload as listed below.

1. No instruments or cables in the payload should be located below the level of FLASH-B lens.
2. FLASH-B lens should look down. Alternative lens pointing (e.g. lens looking sideward or upwards) may result in contamination effect occurring during both balloon ascent and descent. The downward lens looking position ensures clear descent measurements.
3. The radiosonde interfaced to FLASH-B should be held away from the hygrometer at least 40 cm to prevent possible radio interference and additional contamination from the sonde flight box.
4. Other instruments in the payload (especially those carrying uncovered styrofoam) should be held away from FLASH-B as far as possible.
5. FLASH-B sonde, radiosonde and connecting cables should be firmly fixed to the payload bar.

1.5 Adaptation of FLASH for Strateole2 flights as part of RACHuTS VPP

The expected operation cycle of FLASH within RACHuTS is as follows: daytime standby mode at which the PMT and electronics is maintained at -20 C but L-alpha lamp and PMT are off (consumption 50 – 500 mA) and nighttime measurement cycle with all systems on, which leads to consumption of 900 mA max. Depending on the flight planning (and possibly some adjustments during the flight, if necessary), the nighttime measurement cycle could either be restricted to reeling sessions or include also measurements in the docked position.

1.5.1 Chamber tests and calibration

In order to ensure stable performance of FLASH sondes under TTL3 balloons flight conditions, the instruments were subjected to continuous tests in stratospheric simulation chamber (see Sect. 1.3 for description of the chamber). The tests were performed under a broad range of ambient conditions, as close as possible to those expected for TTL balloon flights, i.e. temperature range -80 .. -50 C, pressure range 50 .. 120 mBar, water vapor mixing ratio range 1 .. 100 ppmv. The design of the tests was to reproduce the actual flight operation cycle, i.e. nighttime measurement sessions at variable water vapour and daytime standby mode. The tests in simulation chamber, spanning 5 days for each instrument, were conceived to ensure:

i) night-to-night stability of hygrometer readings at constant water vapor mixing ratios (~1 - 3 ppmv), controlled by MBW 373L frost point hygrometer;
ii) hassle-free transition from the standby to measurement mode;
iii) repeatability of calibrations in the range of mixing ratios 1 – 100 ppmv.

The tests showed that all three above criteria are fulfilled, in particular:

i) After a standby period spanning 1 h to 12 h with chamber stabilized at low temperature and mixing ratio, the hygrometer readings after switching to measurement mode were equal to those before the standby period.
ii) While the PMT and the microcontroller are continuously maintained at -20 C, the L-alpha lamp exposed to ambient air cools down close to ambient temperature when switched off. The lamp ignited successfully at low temperatures and self-heated to an equilibrium temperature of -15 C in 35 – 40 minutes with heating rate starting at 4 C/minute and slowing down to 0.5 C/minute after the first 10 minutes of pre-heating. During the lamp pre-heating period, the hygrometer readings were drifting down by 10 – 15 % and stabilized at the expected level (i.e. the one recorded during the previous measurement session) after the lamp has reached its equilibrium thermal state. After having been switched off,, the lamp cools down with a mean rate of 0.5 C/minute.
iii) Calibrations were done by changing the humidity in the chamber from 1 to 100 ppmv and measuring the ratio between the fluorescence signal readings at different humilities. For the calibration, the chamber was maintained at - 40 C, that is to avoid condensation of water vapor on the chamber walls on one hand and have the PMT and lamp running at the nominal Strateole2 operation temperature. Calibration of the two hygrometers showed a sensitivity of 65 – 85 counts per ppmv and repeatability better than 8%. The maximum expected sky background counts are below 20 counts for clear-sky conditions and below 200 for moonlit high-level clouds.

1.5.2 Operation cycle, payload arrangement and contamination

As follows from the results of low-temperature tests, up to 40 minutes of lamp pre-heating is required before the start of a measurement (reeling) session. It may thus be reasonable to keep FLASH in measurement mode since 40 minutes before the first reel out until the end of the last reel in. The disadvantage of such operation cycle is somewhat higher energy consumption (with the lamp drawing additional 200 mA) and potentially shorter lifetime of the lamp. The latter is most likely a minor factor, given that the lamp's nominal MTBF is at least 1000 hours.

For payload arrangement, the preferred lens orientation is downward or sideward in the direction opposite to COBALD orientation (to avoid light contamination inside the clouds). No objects should be in the FLASH field of view.

Water contamination due to outgassing from the payload (in the docked position and during the reel in) is expected to occur only during the first couple of days. As follows from our experience with FLASH flights onboard long-duration balloons in the Arctic during early spring, it takes up to 70 hours for the main gondola to dry completely. For the Strateole2 flight conditions in the tropics, the drying will most likely take much shorter time.

1.6 Technical characteristics

Range of water vapour measurements	***0.5...1000 ppmv***
Detection limit	0.1 ppmv
Measurement cycle length	1 sec
Recommended integration time	4 sec
Measurement precision	5.5 %
Total uncertainty	<10 % (1σ)
Pressure range	300… 5 mBar
Weight excl. batteries	0.55 kg
Nominal PMT voltage	1140 Volts
Nominal lamp current	4 mA
Power consumption (peak values)	
measurement, heater on	900 mA
measurement, heater off	400 mA
standby mode, heater on	500 mA
standby mode, heater off	50 mA
Required power	10-14 Volts
Interface	**X-data**

2 FLASH-B interface and data processing.

The FLASH-B controller sends out data frame every 1 second. The data frame consists of fluorescence and background signal count rates from the PMT counter and 8 auxiliary parameters from AD converter. Depending on the type of external interface, the sequence and the format of the output channels may differ.

2.1 X-data interface data format.

Communication is done through UART serial port with 3V TTL levels. The FLASH-B X-data line has the length of 58 bytes in binary code and contains 12 FLASH-B parameters each of 2 bytes and a <CR> at the end. The list of parameters is as follows:

Time (data frames since power on), fluorescence signal count rate, background signal count rate, PMT temperature, PMT voltage, lamp current, lamp voltage, lamp temperature, supply voltage, controller temperature, instrument serial number, firmware version.

Data line example:

xdata=3D0100AFA010E061E06890E9A0280082004890D4404EF087077

The conversion of these parameters into physical values is described below.

"xdata=" - header of row data, fixed constant;

"3D" - #61 - instrument identification for Intermet classification (may be changed by request);

"01" - Daisy chain index (01 if it placed at the end). Full daisy chain feature is not supported, so placing other instruments after FLASH-B in line is not recommended;

"0" - Version of protocol string. Added by request MOL in Lindenberg for define different data formats string if it apply. (may be removed by request);

"0AFA" - Time (frames from power on). Due of frames come out each second, could be used as number of seconds after power FLASH-B on;

"010E" - fluorescence signal count rate (*S*) in counts;

"061E" - background signal count rate in counts;

"0689" - ‘Internal temperature’: Temperature of PMT unit (tpmt), degrees Celsius

T_{pmt} =-21.103*LN(tpmt *0.00061*30/(4096*0.00061-(tpmt *0.00061))) + 97.106

"0E9A" - ‘PMT voltage’: photomultiplier voltage (Upmt), Volts

U_{pmt}= Upmt *0.305

"0280" - ‘Lamp current’: current of VUV lamp (Ilamp), mA.

I_{lamp}= Ilamp *0.0061

"0820" - Lamp firing voltage, (Ulamp), V.

U_{lamp}= Ulamp * 0.123

"0489" - ‘Lamp temperature’: Temperature of VUV lamp (Tlamp), degrees Celsius

T_{lamp} =-21.103*LN(Tlamp *0.00061*30/(4096*0.00061-(Tlamp *0.00061))) + 97.106

"0D44" - ‘Supply voltage’: Supply voltage (Ubat), volts

U_{bat}= Ubat *0.003477

"04EF" - 'Controller temperature' Temperature of microcontroller (Tmc), degrees Celsius

T_{mc} =(Tmc *0.00061-0.78)/-0.0013+25

"0870" - 'instrument serial number' = 2160

"77" - 'firmware version' = 11.9 (may be removed or replaced on request);

Description of connector pins is provided in Appendix 1.

2.2 Manual command interface description.

FLASH controller uses a standard UART with 3 V TTL levels port for exchange data with PC and update firmware. For communicate with RS232 and USB ports need using special converters and terminal software.

Operating of FLASH-B instrument may be in two modes: "manual" and "auto".

In "auto" mode the instrument works normally and sends results of measurements every second in row data according x-data protocol, as described in 2.1.

"Manual" mode using for laboratory calibration and tests mostly. But it would be used keep instruments warm between measurements with switch off lamp and PMT. In this mode manual control a lamp power and PMT power are available. Additionally are reading of any measurement channels could be separately. The thermostat control may be switch on/off also.

Switching between modes is possible by sending command and getting confirmation.

Manual commands:

(Request means sending command to FLASH-B, and Answer means sending confirmation back from FLASH-B)

Request "A" - switch to "Auto" mode;

Answer "Automatic measure#CR#LF" - the FLASH-B switched to automatic measurement, lamp is On, PMT is On, data row will start sending each second.

Request "a" - switch to "Manual" mode;

Answer " Manual mode#CR#LF" - the FLASH-B switched to manual mode, lamp is Off, PMT is Off, stop sending data row. Thermostating system still keep instrument stable. Waiting manual commands.

Request "v" - firmware version;

Answer " FLASH-B V11.9#CR#LF" - print firmware name and number of firmware version. Doesn’t change FLASH-B condition, used only to test communication.

Request "r" - switch off PMT;

Answer "!#FF" - the PMT is power Off. Channels "Sig" and "BKG" must be equal to zero.

Request "R" - switch on PMT;

Answer "!#FF" - the PMT is power On. Channels "Sig" and "BKG" will read measurement value.

Request "l" - switch off Lamp;

Answer "!#FF#FF" - the Lamp is power Off. Channels "Sig" and "BKG" must be equal and show very small values (provided full isolation from ambient light). Power consumption will decrease by ~150 mA

Request "L" - switch on Lamp;

Answer "!#FF#FF" - the Lamp is power On. Channels "Sig" and "BKG" will be different. Power consumption will increase by ~150 mA

Request "h" - switch off Thermostat;

Answer "!#FF#FF" - the Thermostat system is stop and Heater is power Off. Power consumption will decrease by ~700 mA

Request "H" - switch on Thermostat;
Answer "!#FF#FF" - the Thermostat system is start and Heater is power On. Power consumption will increase by ~700 mA if cooled below -20 C

Request "k" - decrease PMT voltage;
Answer "!#FF#FF" - PMT voltage decreases by ~1V. This action will decrease PMT sensitivity. This setting is not stored and will return to default value after reset.

Request "K" - increase PMT voltage;
Answer "!#FF#FF" - the PMT voltage increases by ~1V. This action will increase PMT sensitivity. This setting is not stored and will return to default value after reset.

Request "z" - decrease Lamp current;
Answer "!#FF#FF" - the Lamp current decreases by ~0.1mA. This action will decrease Lamp brightness. This setting is not stored and will return to default value after reset.

Request "Z" - increase Lamp current;
Answer "!#FF#FF" - the Lamp current increases by ~0.1mA. This action will increase Lamp brightness. This setting is not stored and will return to default value after reset.

Request "0" - reads #0 channel value;
Request "1" - reads #1 channel value;
Request "2" - reads #2 channel value;
Request "3" - reads #3 channel value;
Request "4" - reads #4 channel value;
Request "5" - reads #5 channel value;
Request "6" - reads #6 channel value;
Request "7" - reads #7 channel value;
Answer "#HB#MB#LB#FF" - return measured value from #.. channel. Where #HB - high byte, #MB - middle byte, #LB - low byte, #FF - end marker.
These commands are used by the dedicated laboratory test software for calibration. Content of each channels may be changed on request.

2.2 Water vapour mixing ratio calculation.

The photomultiplier with an interference filter measures the intensity of fluorescence of OH* radicals produced when H_2O molecules are exposed to Lyman-α radiation. The intensity of fluorescence is obtained as

$$J = [OH^*] \cdot A = \frac{[H_2O] \cdot \psi_\lambda \cdot \sigma_{H_2O} \cdot \varphi \cdot A}{A + k_q \cdot [air]} \cdot e^{(-\sigma_{O_2} \cdot [O_2] \cdot L - \sigma_{H_2O} \cdot [H_2O] \cdot L)} \qquad (1)$$

where L- the length of the absorption between the lamp and the analyzed volume.
$[OH^*]$, $[H_2O]$, $[air]$, $[O_2]$ - number densities of $OH^*(A^2\Sigma^+)$, H_2O ,air and O_2 respectively;
A - Einstein transition probability ;
ψ_λ- photon flux of the light source;
σ_{H_2O} , σ_{O_2} - cross sections of water vapor and oxygen for Lyman -α respectively;
φ - the quantum yield of photodissociation;
k_q - quenching coefficient;

At pressures higher than 10 mBar, $k_q \cdot [air]$ >> A and the equation (1) can be approximated to:

$$J = \frac{[H_2O]}{[air]} = \frac{\psi_\lambda \cdot \sigma_{H_2O} \cdot \varphi \cdot A}{k_q} \cdot e^{(-\sigma_{O_2} \cdot [O_2] \cdot L - \sigma_{H_2O} \cdot [H_2O] \cdot L)} \qquad (2)$$

Thus, at stratospheric conditions the fluorescence intensity is directly proportional to water vapour mixing ratio. The equation (2) can be simplified to

$$J = C \frac{[H_2O]}{[air]} \qquad (3)$$

The factor *C* includes molecular coefficients from the literature as well as instrument specific quantities such as VUV source flux. If *C* is a constant, the number of detected fluorescence photons is proportional to the H_2O mixing ratio $[H_2O]/[air]$ for measurements in the upper troposphere and lower to middle stratosphere. The factor *C* is determined in the laboratory calibrations.

In reality, *C* is a function of ψ_λ and thus depends on the photon flux in the fluorescence volume, which in turn depends on variations of the lamp intensity and absorption by atmospheric gases. In the (VUV) spectral region, absorption by oxygen and water vapour has to be taken into account. The Lyman-α line at λ = 121.6 nm coincides with a narrow deep minimum in the oxygen absorption cross section and thus enables measurements with the fluorescence technique down to the middle troposphere.

Lyman-alpha absorption in the troposphere.

The optical design of the FLASH-B instrument is such that the focal point of the lens is fixed at 31 mm away from the lamp window, meaning that the analyzed volume is centered around this point. The Lyman-alpha radiation is absorbed on the way from the lamp window to the focal point of the lens by oxygen and water molecules. The total transmission of Lyman-alpha radiation depends on the number concentration of the respective molecules and varies from 0.99 in the stratosphere to about 10^{-5} at tropospheric boundary level.

In order to account for the dilution of the lamp VUV flux an empirical correction function is used. This function has been obtained in the laboratory studies and further improved in the field experiments and comparisons. The correction function uses pressure and temperature information to calculate number concentration of air and oxygen and assumes a vertical distribution of water vapour to estimate the number concentration of water molecules. As shown by the comparisons against Vaisala RS-92 humidity data, the absorption correction function works well at the transmission rates higher than 0.56, which corresponds roughly to 7 km (300 mBar). Below this threshold the transmission of Lyman-alpha in the troposphere increases rapidly due to abundance of water in the lower troposphere and fluorescence intensity becomes inversely proportional to water vapour mixing ratio.

Quenching of OH* radicals.

As follows from the equation (2), the quenching of the excited OH* radical by the air molecules is what makes the fluorescence intensity proportional to water vapour mixing ratio. However at low pressures (below 10 mBar) the quenching becomes relatively small and the equation (3) can no longer be used as the fluorescence signal becomes proportional to water molecules number density. In order to account for this effect a theoretically obtained quenching correction is applied to the data. The effect of this correction is such that at 36 mBar the correction has no effect on the data and increases to about 12% at 10 mBar.

Measurement of background light.

In the recent version FG 4.1 of the FLASH-B instrument's electronics the lamp is modulated at 900 Hz frequency with 1/1 duty cycle to allow for subtracting the background light from the total count rate measured during the lamp on period. It should be noted though that the hydrogen lamp is operated in a glow discharge mode so that the supplying current does not go completely off in the 'lamp off' mode but decreases to about 2-3 % of its nominal. As the lamp emission intensity is directly proportional to the supply current, the lamp is weakly glowing during the 'lamp off' period, which causes some fluorescence detected by the PMT. This effect has been studied and quantitatively estimated in the laboratory and is accounted for in ground processing.

Calculation of the measurand.

The calculation of the measurand (μ - water vapour mixing ratio, ppmv) involves fluorescence signal count rate (S), ambient pressure supplied by radiosonde, mBar (P), ambient temperature supplied by a radiosonde, degrees Celcius (t) and calibration factor K_1 supplied with a FLASH-B unit. The fluorescence signal count rate (S) is defined by subtracting the 'lamp off' count rate from the 'lamp on' count rate, which is done by the on board controller.

The fluorescence signal count rate values are subject to plausibility check and outliers filtration. The resulting series of S should be averaged over 4 s interval in order to achieve the necessary measurement precision.

If $P < 36$

$$\mu = K_1 * S * (1+0.00041*P+0.00043*K_1^2*P*S)*0.956*(1+0.00781*(t+273.16)/P) \quad (4)$$

If $P > 36$

$$\mu = K_1 * S * (1+0.00041*P+0.00043*K_1^2*P*S) \quad (5)$$

Appendix 1.

Pin	Signal	Description
1	UARTout	Serial data from FLASH-B to PC
2	UARTin	Serial data from PC to FLASH-B
3	3.3 V	3.3 V internal power line
4	GND	Ground
5	DLOAD	Download Firmware
6	GND	Ground
7	DAC1out	Output DAC 1
8	DAC1out	Output DAC 2
9	ADC9	Input ADC 9 channel
10	ADC10	Input ADC 10 channel
11	ADC7	Input ADC 7 channel
12	ADC8	Input ADC 8 channel
13	ADC5	Input ADC 5 channel
14	ADC6	Input ADC 6 channel
15	ADC4	Input ADC 4 channel
16	ADC2	Input ADC 2 channel
17	A1out	Digital Output 1
18	A0out	Digital Output 0
19	PWM	PWM output
20	A2out	Digital Output 2
21	SO	SPI serial data
22	SCK	SPI clock data
23	GND	Ground
24	CS	SPI chip select data
25	GND	Ground
26	+9 V	9 V internal stabilizer output