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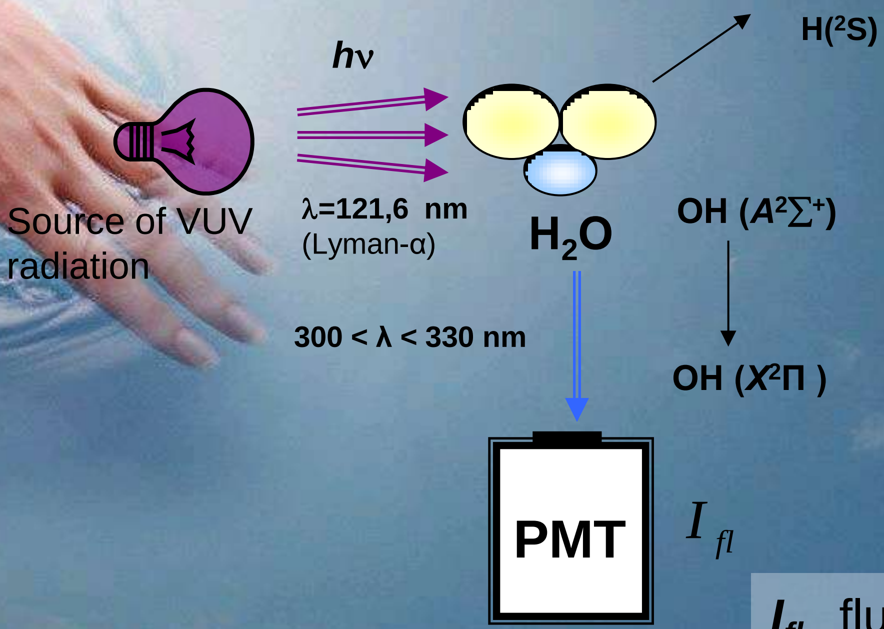
Fluorescence Lyman-Alpha Stratospheric Hygrometer for Balloon (FLASH-B)

9th GRUAN Implementation-Coordination Meeting (ICM-9) 12-16 June 2017 Helsinki, Finland

Measurement method



$H_2O + h\nu \rightarrow OH\ (A^2\Sigma^+) + H(^2S)$

Fluorescense
$OH\ (A^2\Sigma^+) \rightarrow OH\ (X^2\Pi) + h\nu'$

Quenching
$OH\ (A^2\Sigma^+) + N_2,\ O_2 \rightarrow$ **products**

$$I_{fl} = \frac{[H_2O]\cdot J \cdot \varphi \cdot A}{k_q \cdot [air] + A}$$

at P > 7 hPa $k_q \cdot [air] \gg A$

I_fl – fluorescense intensity

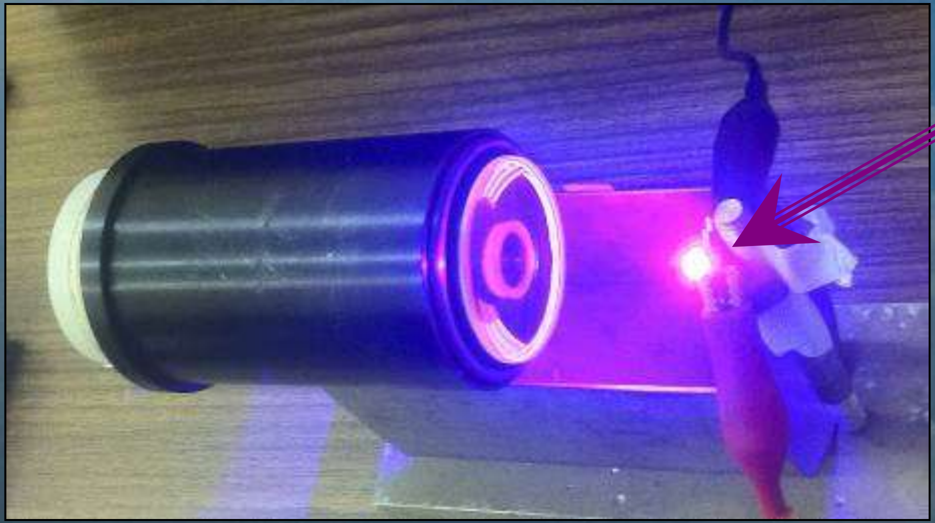
J - photodissotiation rate

φ= 0,05 - quantum efficiency for excited OH production

A=$1{,}26\cdot10^6$ s^{-1} – Einstein coefficient,

$k_q^{air.}$ = $2{,}3\cdot10^{-11}$ $sm^3\,s^{-1}$ – quenching coefficient of the excited OH in air

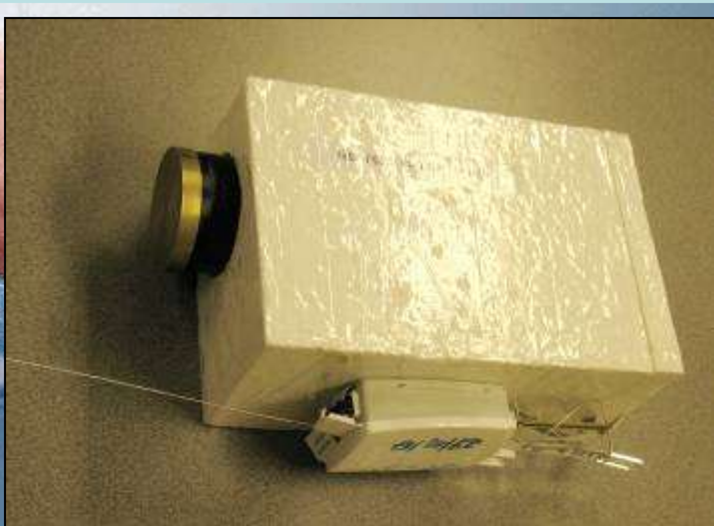
Open layout design



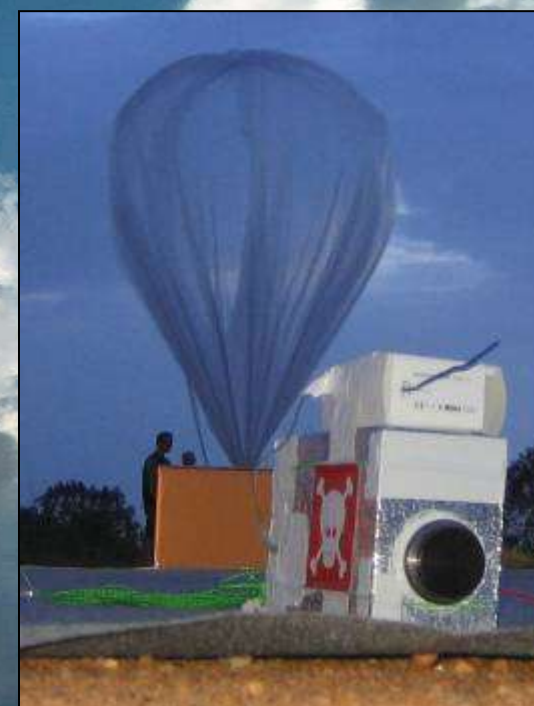
The analyzed volume is located outside the instrument at about 5 cm distance from the lamp window.

The fluorescent light, collected by the system of 3 quartz or plastic lenses concentrically arranged around the lamp, is focused onto the PMT cathode.

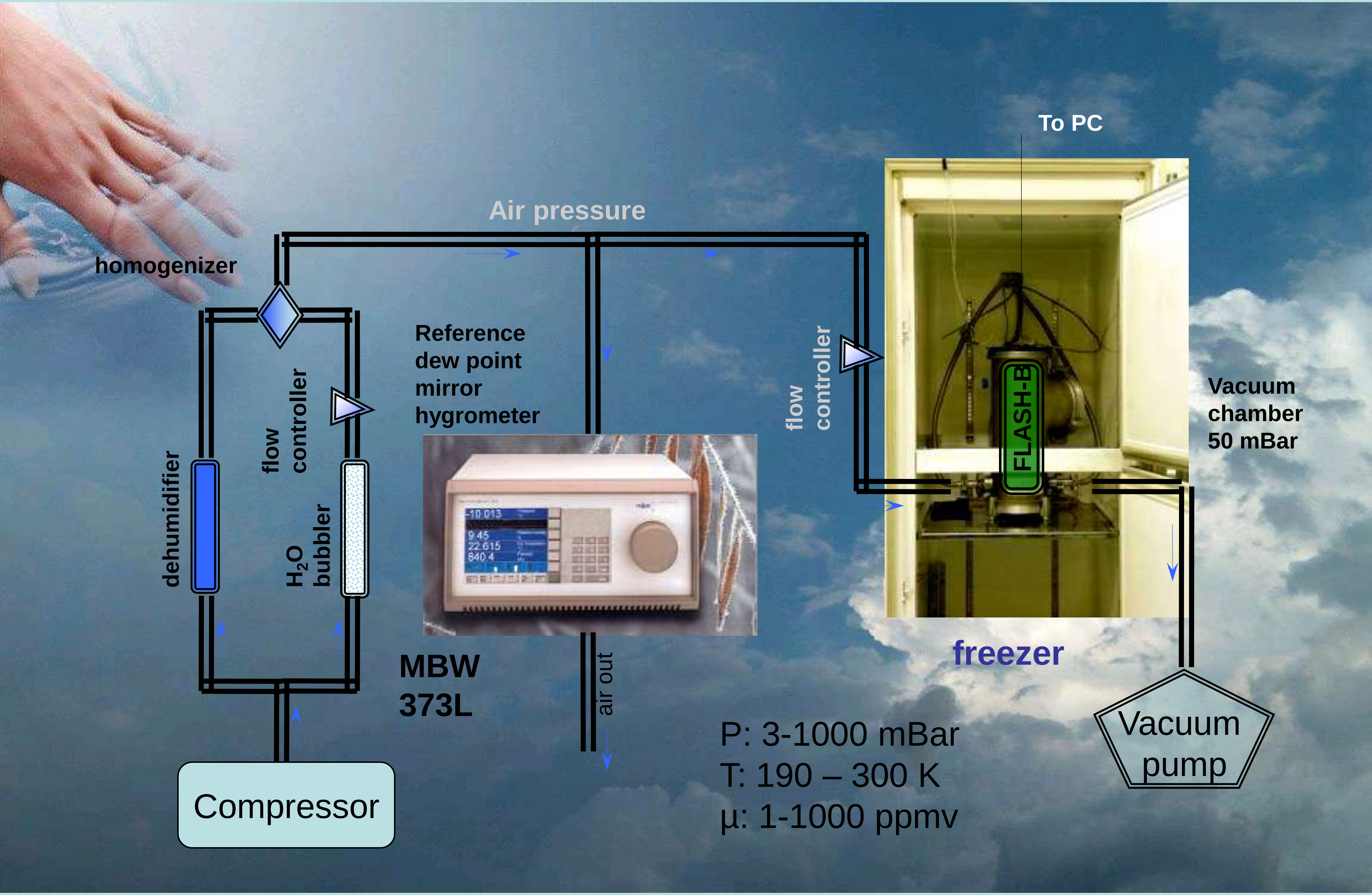
Technical parameters



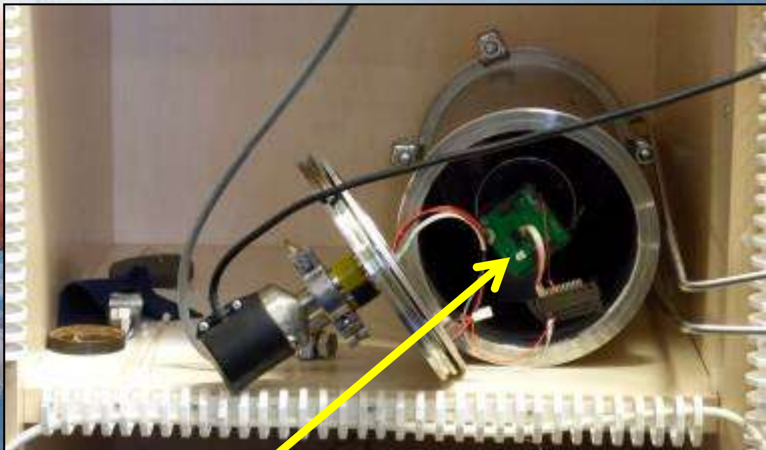
Range of measurements	*0.5...1000 ppmv*
Detection limit	*0.1 ppmv*
Measurement cycle length	*1 sec*
Integration time	*1 - 4 sec*
Vertical resolution	*~ 50 m (descent in UTLS)*
Uncertainty and detection limit	*±(10% + 0.1 ppm) @* *10 hPa<P <30hPa, H2O>3 ppm*
Height range	*7 .. 35 km*
Size, with ins. box	*250mm x 150mm x 70mm*
Weight	*0.4 kg w/out batteries*
Power,max	*12V, 0.6A*



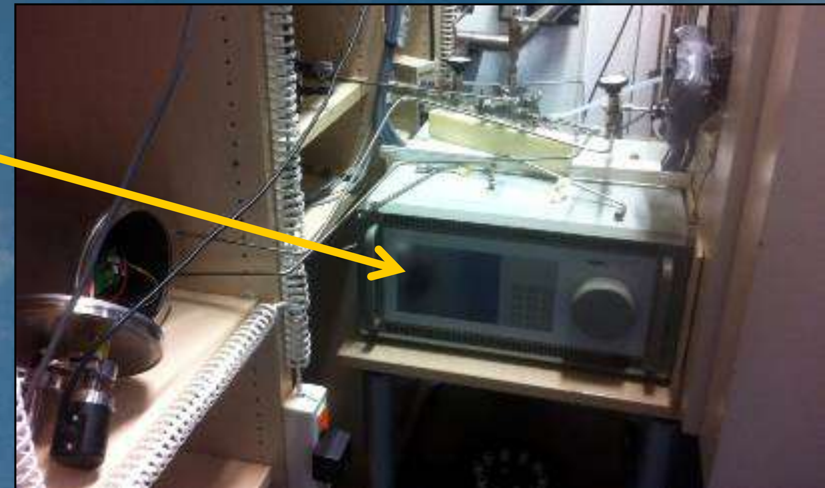
Calibration



Calibration Facility



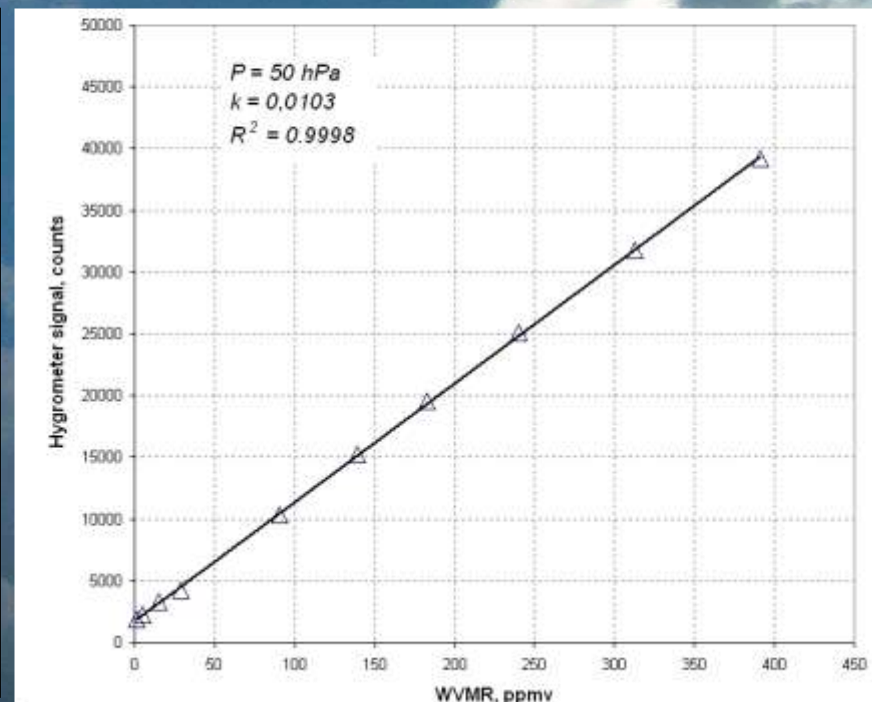
MBW3
73



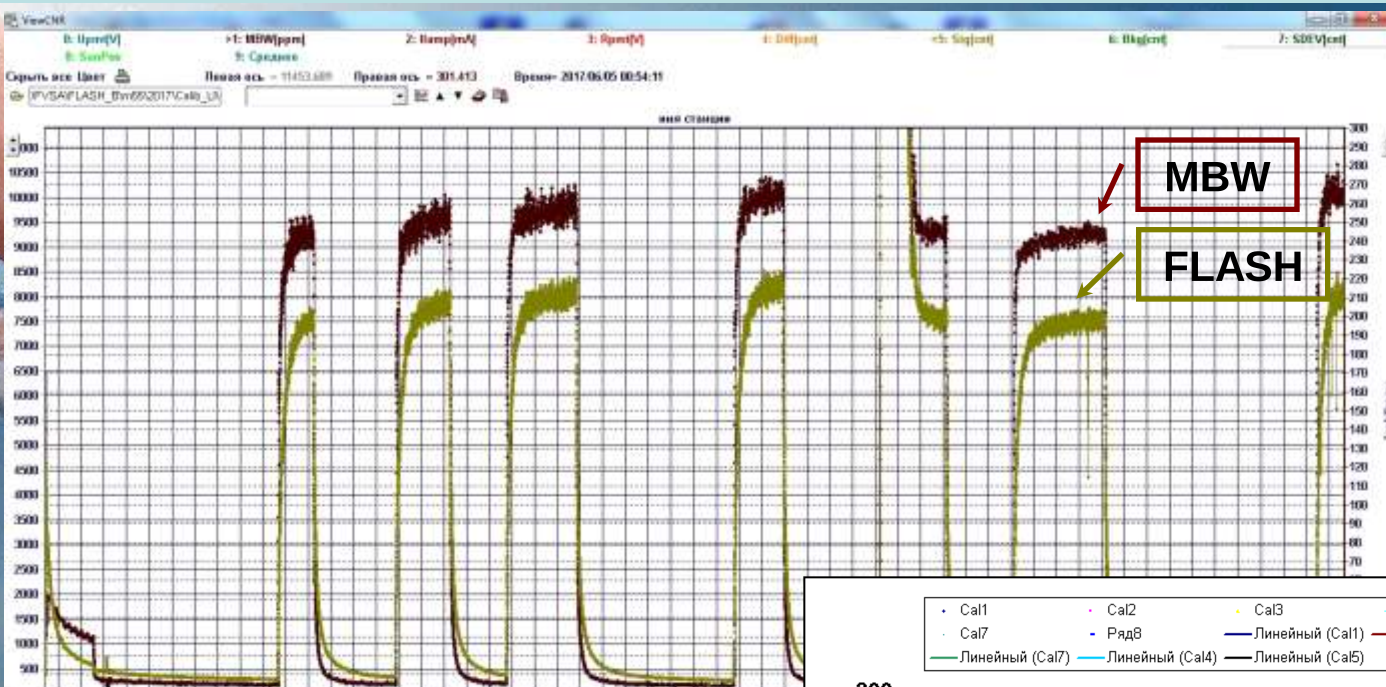
Flash

Calibration facility was created in Lindenberg include the dry air generator, calibration chamber, reference FPH MBW373 and software.

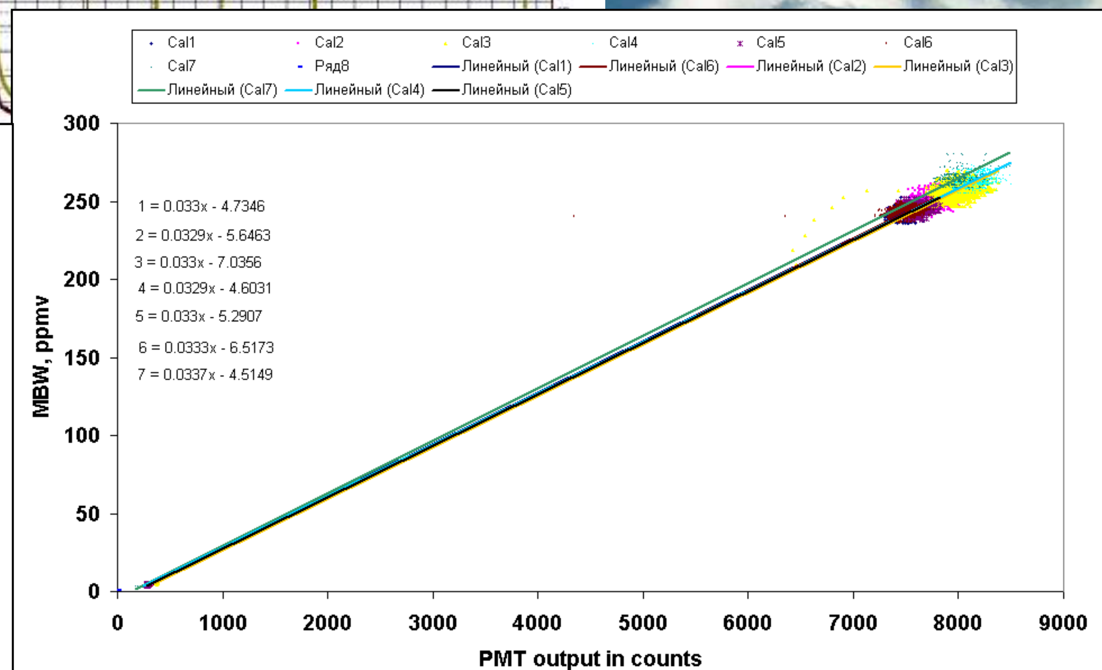
All recovered FLASH-B storing on shelf in LC was renew and recalibrated.



Laboratory calibration results



Repeated calibration give calibration uncertainty



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 lamp emission. The total relative error of the calibration amounts to 4%.

Calculation formula

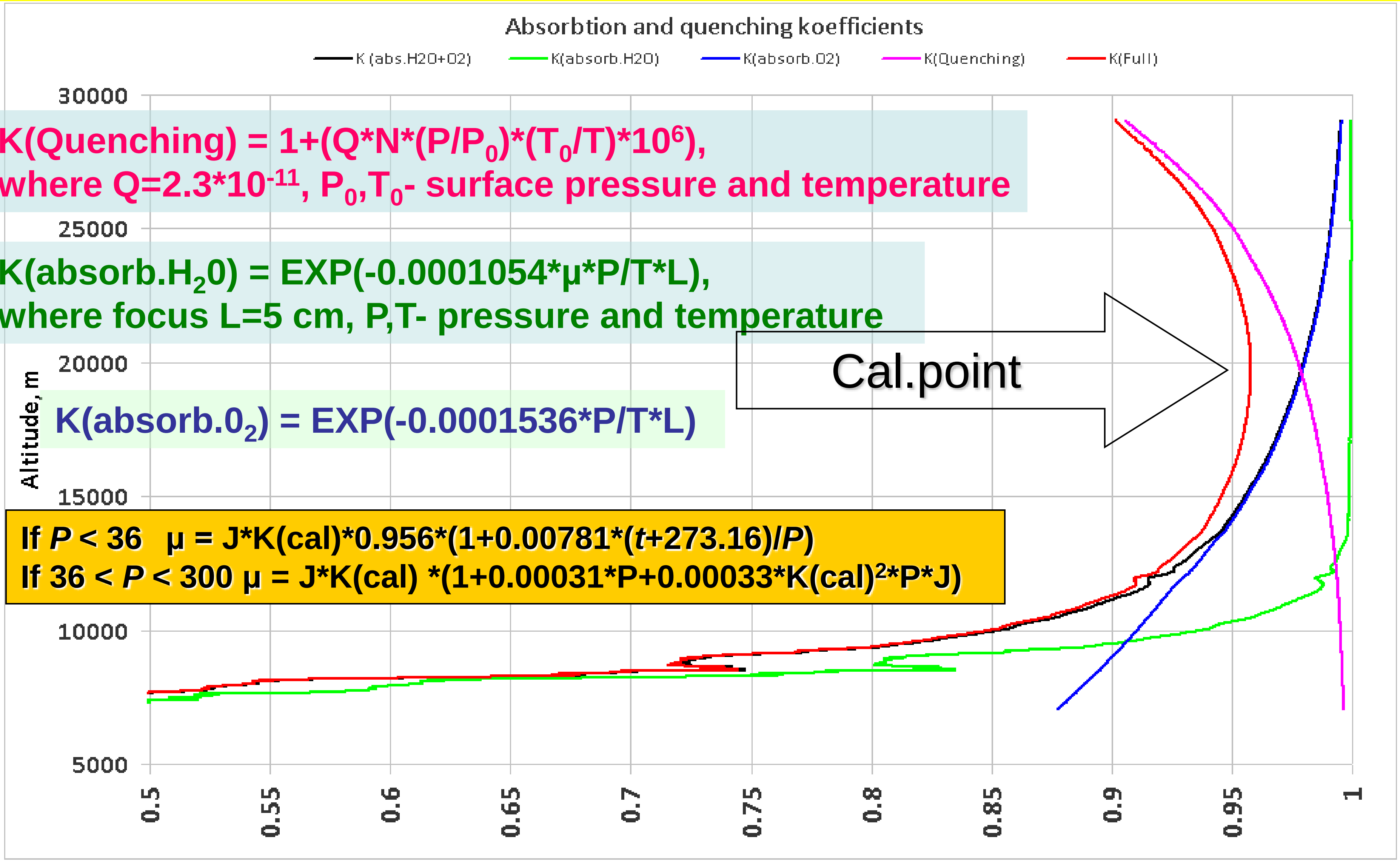
WVMR = J*K(cal) * K(Quenching) * K(absorb.H$_2$0) * K(absorb.O$_2$)

K(Quenching) = 1+(Q*N*(P/P$_0$)*(T$_0$/T)*10^6),
where Q=2.3*10^{-11}, P$_0$,T$_0$- surface pressure and temperature

K(absorb.H$_2$0) = EXP(-0.0001054*μ*P/T*L),
where focus L=5 cm, P,T- pressure and temperature

K(absorb.0$_2$) = EXP(-0.0001536*P/T*L)

If *P* < 36 μ = J*K(cal)*0.956*(1+0.00781*(*t*+273.16)/*P*)
If 36 < *P* < 300 μ = J*K(cal) *(1+0.00031*P+0.00033*K(cal)^2*P*J)



Preparation for flight

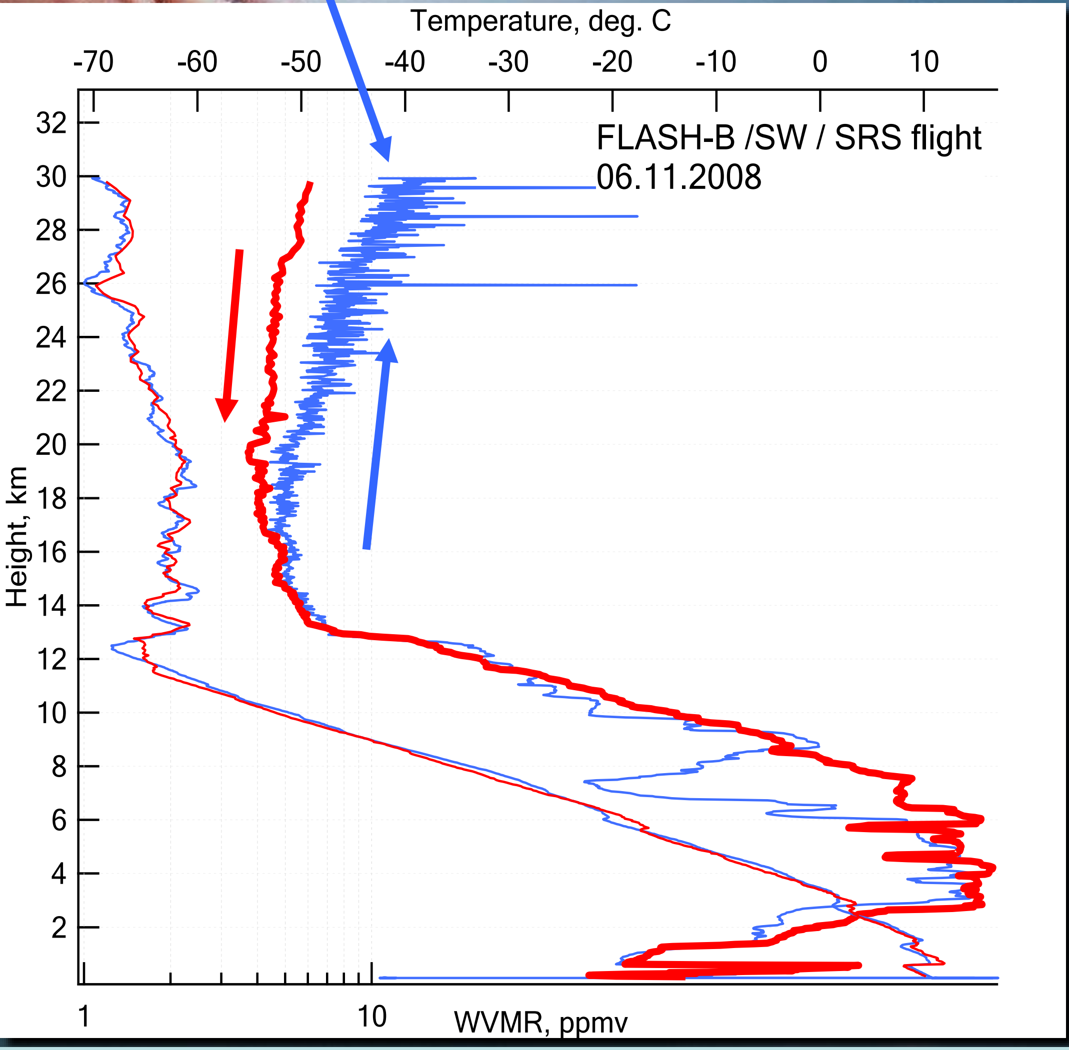
Sealant recommended against contamination in stratosphere

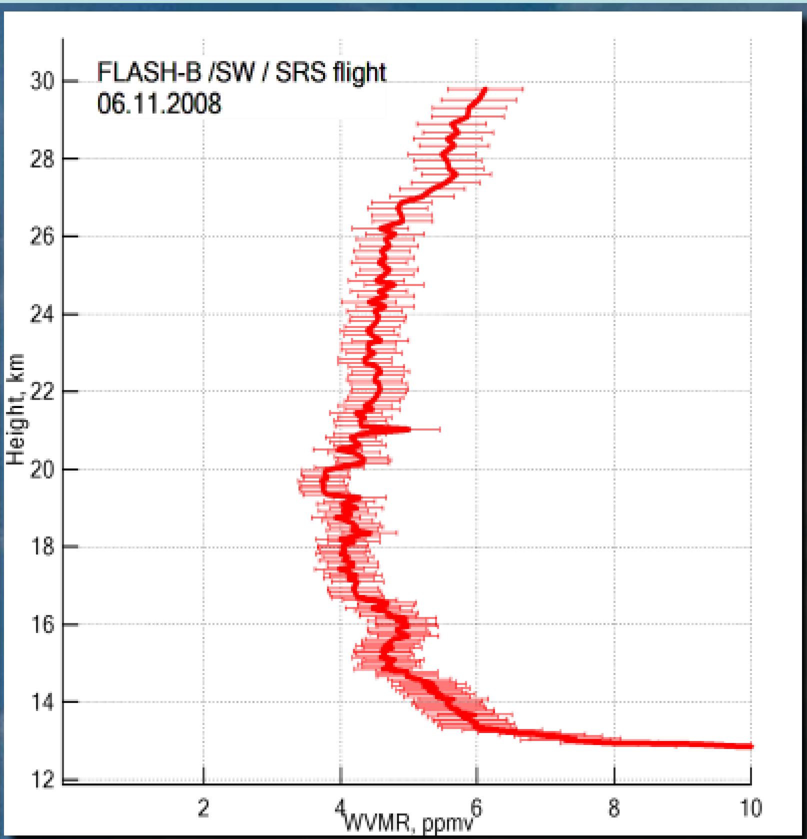
Plug-and-play concept

1. Fixing face down
2. Connect to radiosonde
3. Switch on
4. Check the data incoming
5. Open cap
6. Ready to fly!

Results

Contamination during ascent in downward-looking position of FLASH

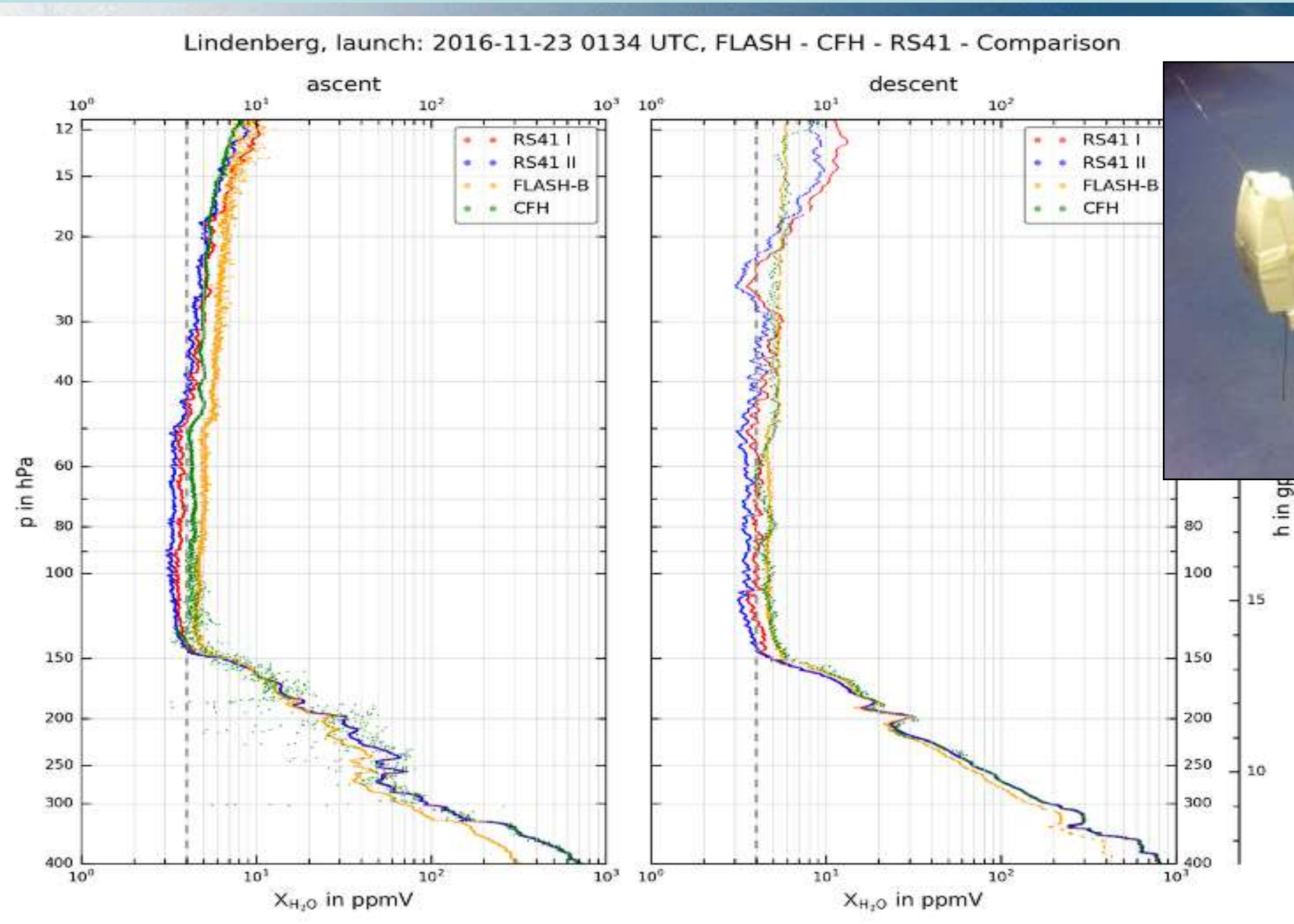




The measurement precision is 5.5% calculated for 4 s integration time at stratospheric conditions.

Total uncertainty (calibration error + 1σ precision) is less than 10% at stratospheric conditions.

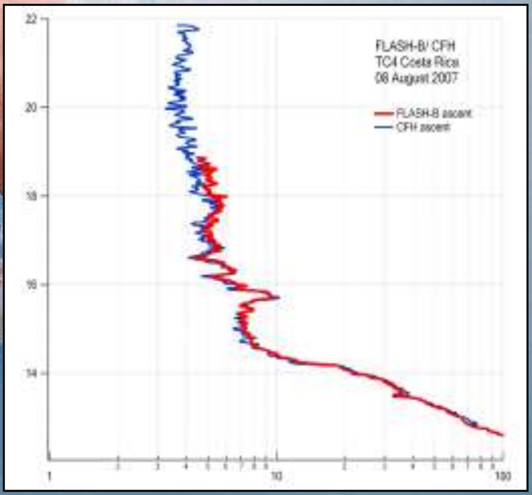
Comparisons vs RS41



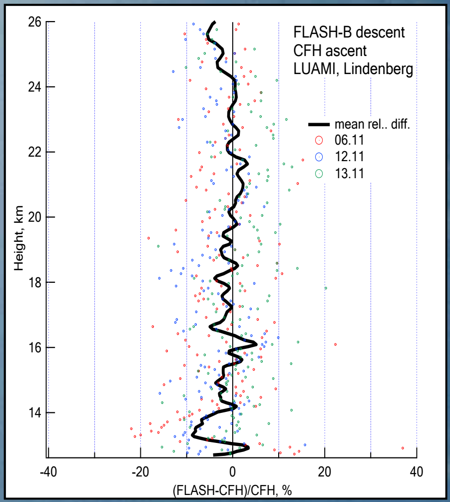
Winter 2017 in Lindenberg 4 FLASH-B was calibrate, have flights, data processed and made comparison by LC staff according with provided technical documentation.

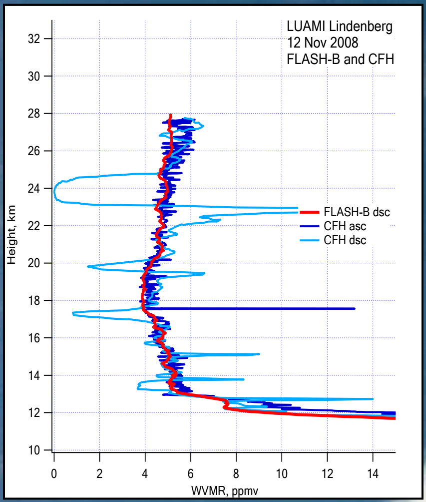
Comparisons vs CFH

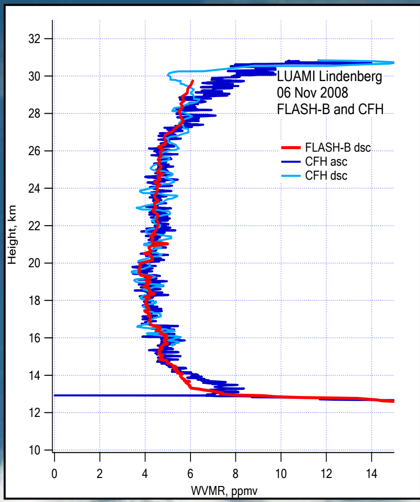
NASA TC4, Costa-Rica



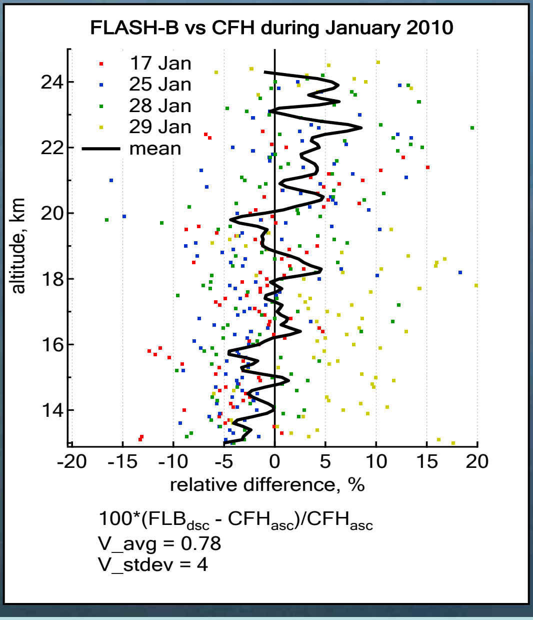
LUAMI UPPER-AIR intercomparison campaign, Lindenberg



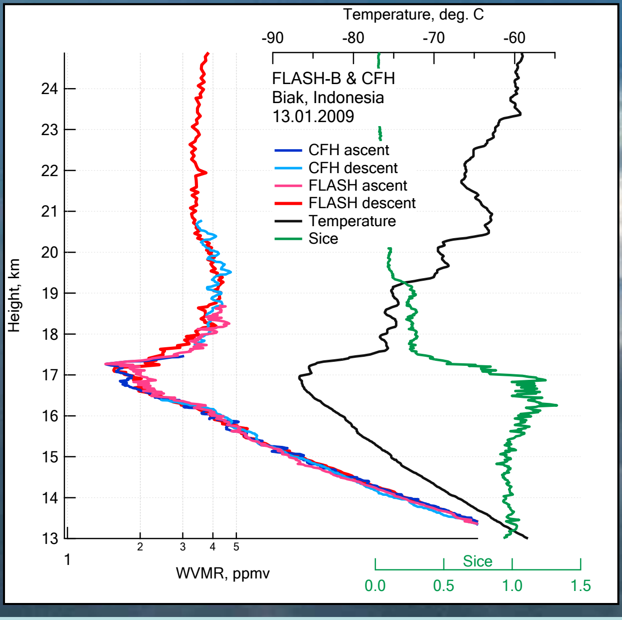


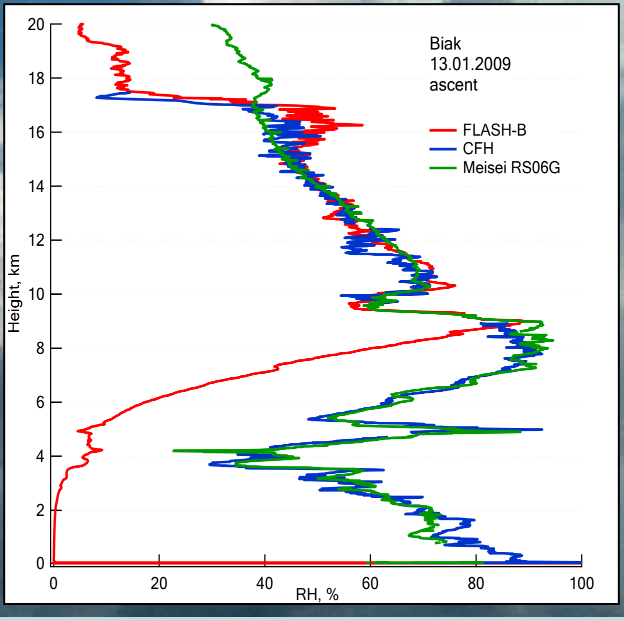


LAPBIAT, Sodankyla

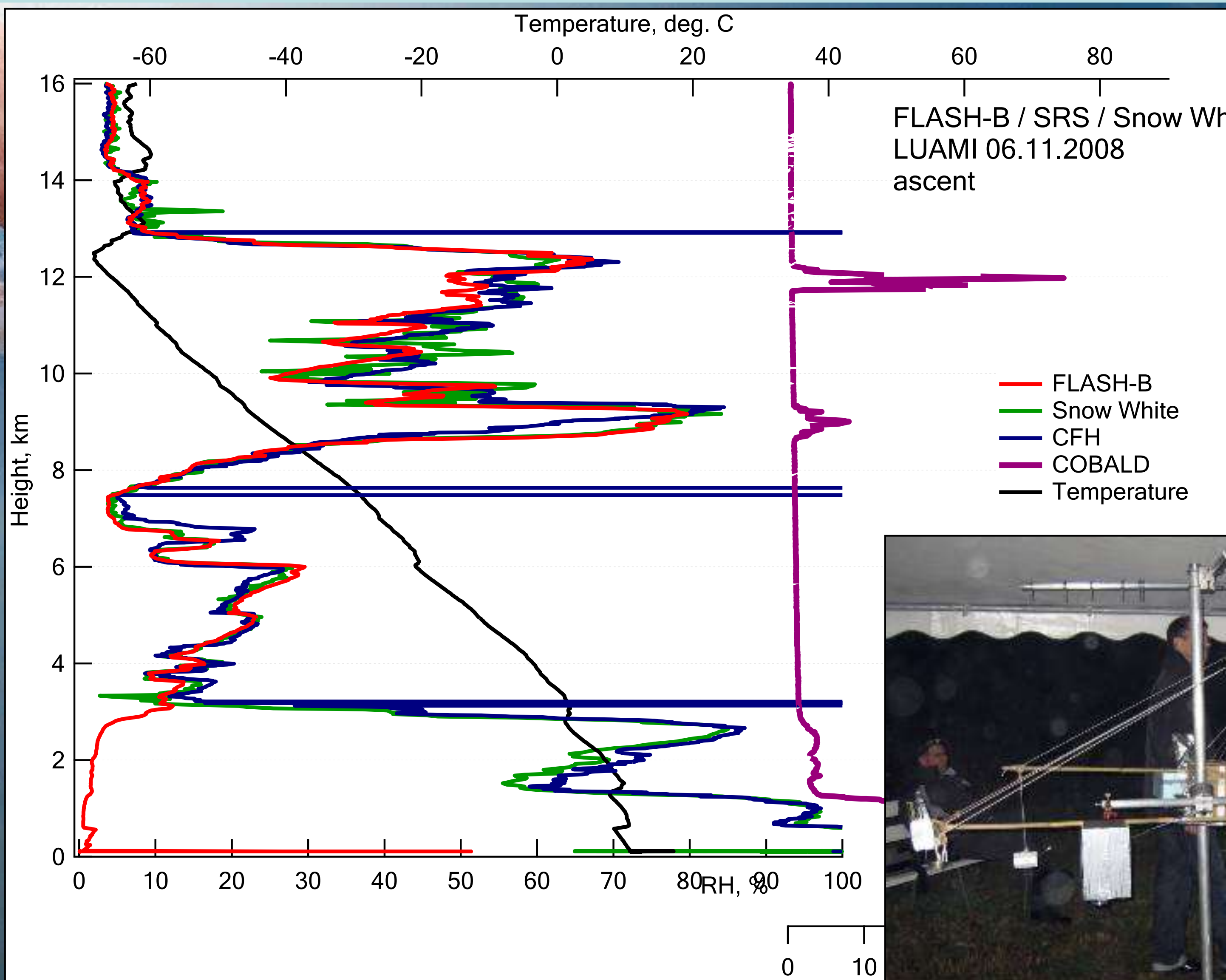


SOWER-2009, Biak, Indonesia





LUAMI campaign



AQUAVit chamber intercomparison campaign

Difference FLASH-B - reference

D. W. Fahey et al.: The AquaVIT-1 water vapor intercompar

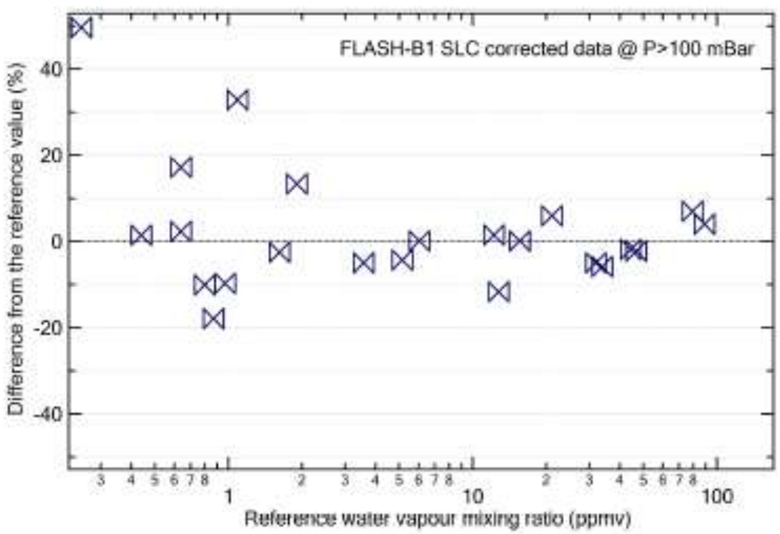


Figure A4. Summary plot of the static experiment results for FLASH-B1 data in the entire range of water vapor mixing ratios, with the data from experiments 3 and 7 recalculated using correct SLC values.

Fahey et al., 2014

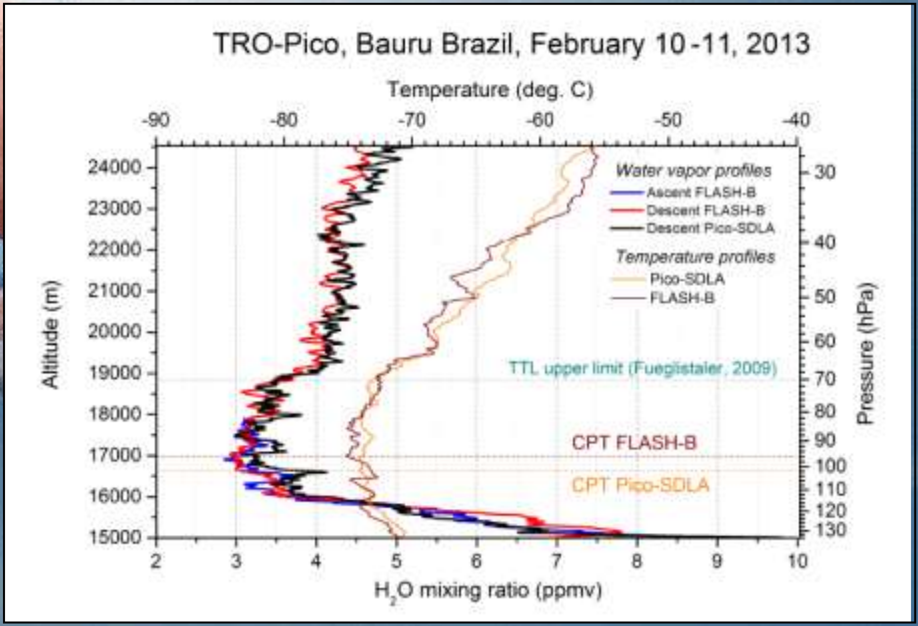
Experimental precision

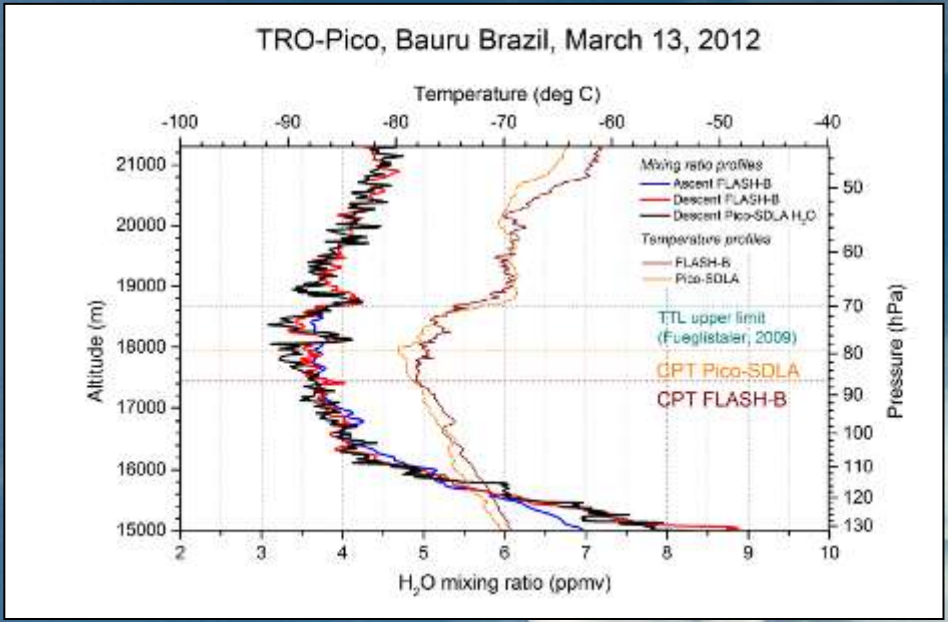
Table 4. Experimental upper limits of instrument precision derived from the AquaVIT-1 intercomparison data for selected segments during the static experiments[a].

Segment	5	22	24	25	Average
Reference H_2O (ppm)	6.1	1.8	1.6	1.0	–
Core instruments					
APicT	0.070 (1 s) 0.062 (5 s)	0.045 0.041	0.12 0.10	0.14 0.12	0.094 0.081
CFH	– –	0.050 0.051	0.072 0.072	0.042 0.041	0.055 0.055
FISH-1	0.24 0.13	– –	– –	0.16 0.11	0.20 0.12
FISH-2	0.077 0.042	0.041 0.025	0.046 0.025	0.039 0.023	0.051 0.029
FLASH-B1	– 0.11	– 0.099	– –	– 0.29	– 0.17
HWV	0.083 –	– –	– –	– –	0.083 –
JLH	0.10 0.082	0.064 0.044	0.069 0.046	0.049 0.034	0.071 0.052
Non-core instruments					
MBW-373LX	0.022 (1 s) 0.020 (5 s)	– –	– –	– –	0.022 0.020
SnowWhite	– –	– –	– –	4.1 4.2	4.1 4.2
ISOWAT	0.15 0.13	– –	– –	– –	0.17 0.13
OJSTER	0.75 0.67	– –	– –	– –	0.75 0.67
PicoSDLA	0.40 0.39	0.087 0.081	– –	0.38 0.38	0.29 0.28

[a] Precision values are in ppm of water vapor. Segments were chosen to meet conditions of (1 < water vapor mixing ratio < 10 ppm) and (70 < AIDA chamber pressure < 150 hPa) in order to represent typical UT–LS values. For each instrument, the top (bottom) row shows precision values for 1 s (5 s) measurement intervals. Segment details are shown in Table 3. Precision is defined as the standard deviation (1σ) of the Gaussian fit, P, to the differences from the reference values ($P = A\exp[-(x-\mu)^2/2\sigma^2]$, where A is a normalization factor, x is the measured value, μ is the reference value, and σ is the standard deviation.)

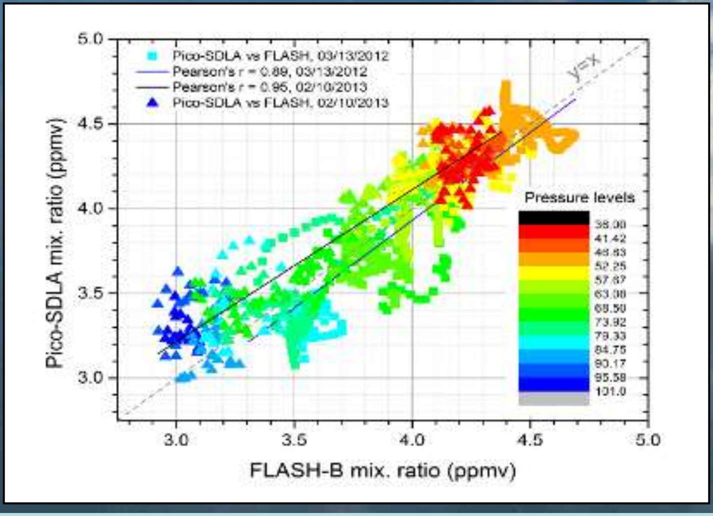
Intercomparison of FLASH-B and Pico-SDLA





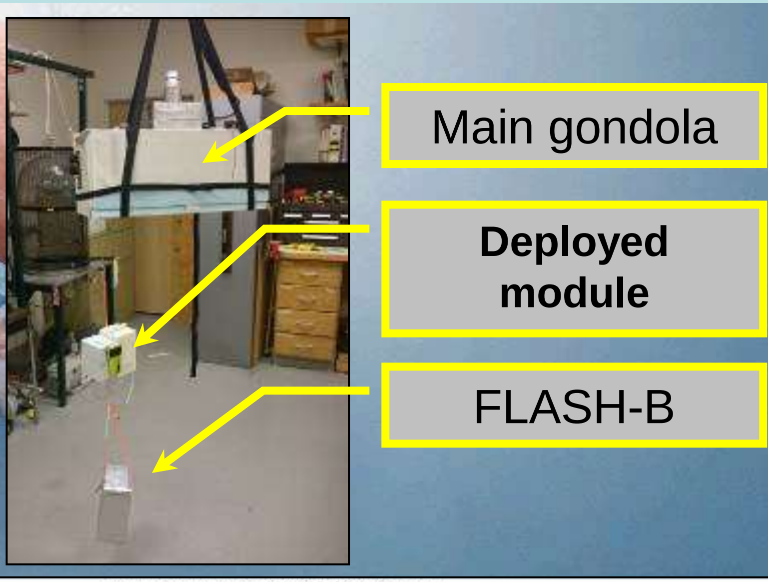
mean difference 0.5 % ((0.02 ± 0.21) ppmv)

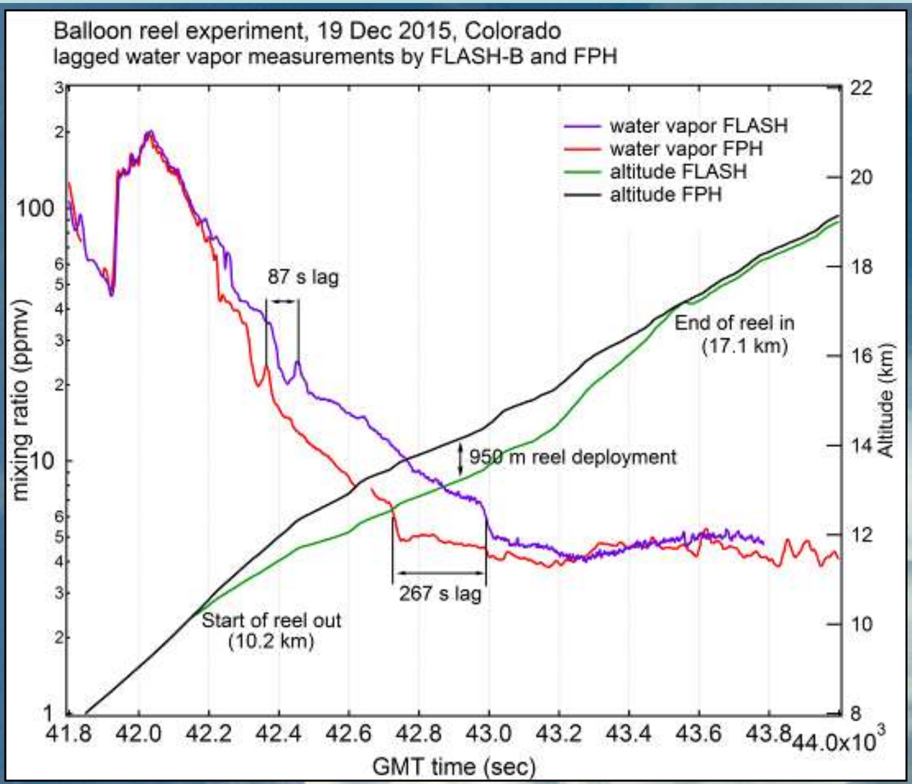
mean difference 1.9 % ((0.08 ± 0.39) ppmv)

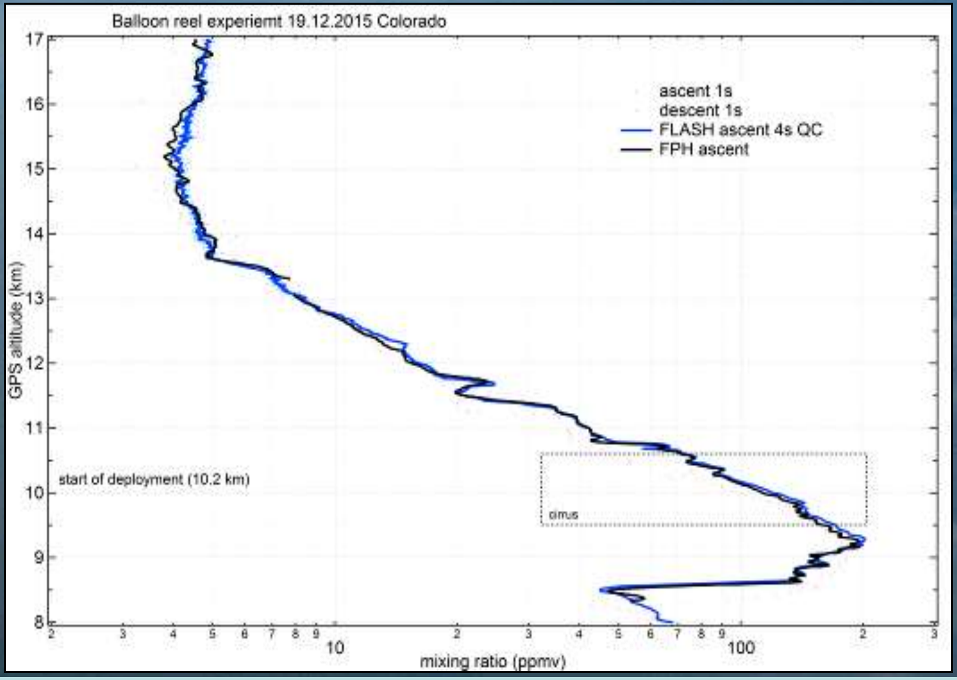


Ghysels et al., 2015, AMT

FLASH vs FPH intercomparison





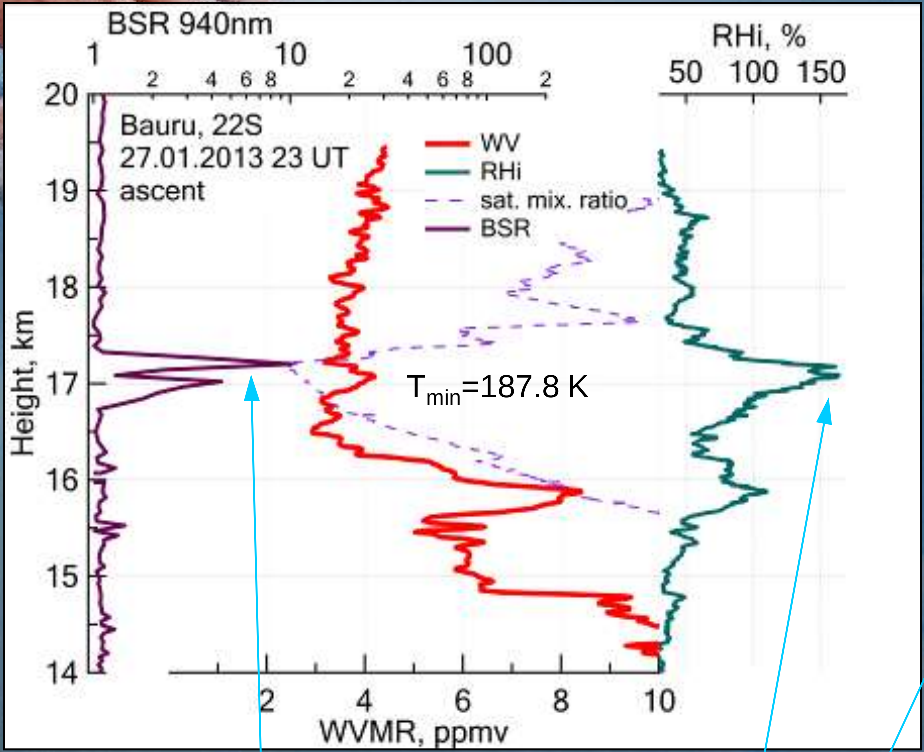


Test of FLASH-B on a reeled device, Wiggins, CO

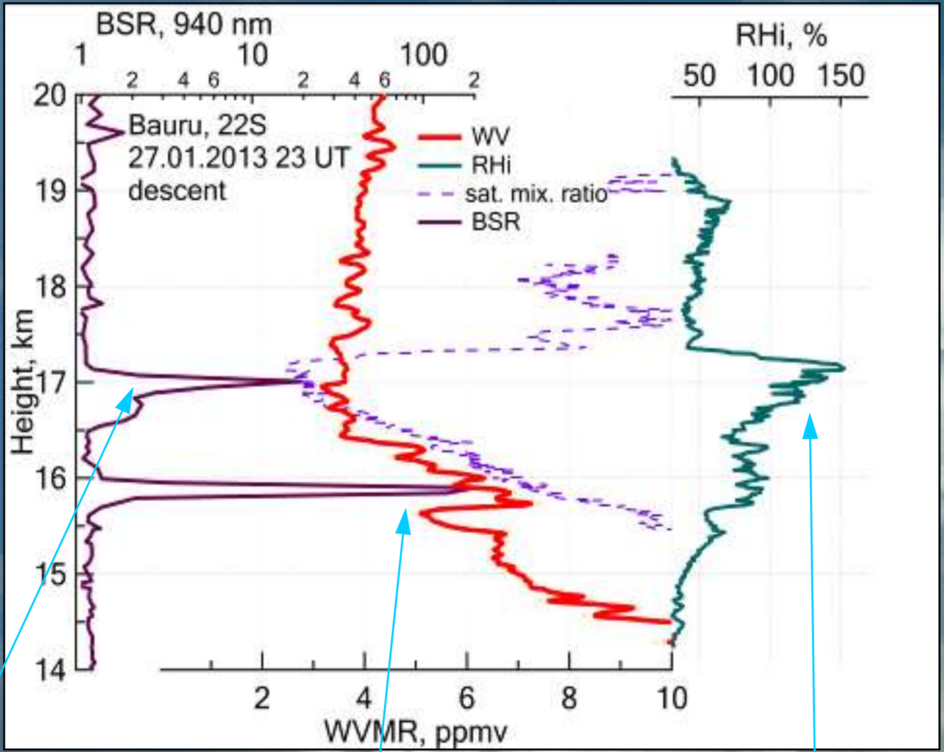
Clouds and dehydration

FLASH and COBALD flight sampling the same air mass at CPT twice

Balloon ascent



Balloon descent



Cirrus with extreme supersaturation (165%) and low backscatter

Subsaturated cirrus with high backscatter

Interface and features

- **integration with:**
  Swiss Meteolabor radiosonde SRS-34
  Vaisala RS-80, RS-92, RS-41
  MESEI RS-6G, RS-11
  Intemet radiosonde by XDATA protocol
  MODEM M10 (in process)
- **Low power electronics (less 6 Watts)**
- **Built-in pressure sensor for safety switch on/off on altitude**
- **1 month capacity data logger**
- **Use 4xC or 8xAA size Litium batteries or 18650 rechargeable LiPol batteries**

- **Reusable**

Publications

1. 1. Khaykin, S. M., Pommereau, J.-P., Riviere, E. D., Held, G., Ploeger, F., Ghysels, M., Amarouche, N., Vernier, J.-P., Wienhold, F. G., and Ionov, D.: Evidence of horizontal and vertical transport of water in the Southern Hemisphere tropical tropopause layer (TTL) from high-resolution balloon observations, Atmos. Chem. Phys., 16, 12273-12286, doi:10.5194/acp-16-12273-2016, 2016.
2. Khaykin, S. M., Engel, I., Vömel, H., Formanyuk, I. M., Kivi, R., Korshunov, L. I., Krämer, M., Lykov, A. D., Meier, S., Naebert, T., Pitts, M. C., Santee, M. L., Spelten, N., Wienhold, F. G., Yushkov, V. A., and Peter, T.: Arctic stratospheric dehydration – Part 1: Unprecedented observation of vertical redistribution of water, Atmos. Chem. Phys., 13, 11503-11517, doi:10.5194/acp-13-11503-2013, 2013.
3. Ghysels, M., Riviere, E. D., Khaykin, S., Stoeffler, C., Amarouche, N., Pommereau, J.-P., Held, G., and Durry, G.: Intercomparison of in situ water vapor balloon-borne measurements from Pico-SDLA H2O and FLASH-B in the tropical UTLS, Atmos. Meas. Tech., 9, 1207-1219, doi:10.5194/amt-9-1207-2016, 2016.
4. Engel, I., Luo, B. P., Khaykin, S. M., Wienhold, F. G., Vömel, H., Kivi, R., Hoyle, C. R., Grooß, J.-U., Pitts, M. C., and Peter, T.: Arctic stratospheric dehydration – Part 2: Microphysical modeling, Atmos. Chem. Phys., 14, 3231-3246, doi:10.5194/acp-14-3231-2014, 2014.
5. Fahey, D. W., Gao, R.-S., Möhler, O., Saathoff, H., Schiller, C., Ebert, V., Krämer, M., Peter, T., Amarouche, N., Avallone, L. M., Bauer, R., Bozóki, Z., Christensen, L. E., Davis, S. M., Durry, G., Dyroff, C., Herman, R. L., Hunsmann, S., Khaykin, S. M., Mackrodt, P., Meyer, J., Smith, J. B., Spelten, N., Troy, R. F., Vömel, H., Wagner, S., and Wienhold, F. G.: The AquaVIT-1 intercomparison of atmospheric water vapor measurement techniques, Atmos. Meas. Tech., 7, 3177-3213, doi:10.5194/amt-7-3177-2014, 2014.
6. Khaykin, S., Pommereau, J.-P., Korshunov, L., Yushkov, V., Nielsen, J., Larsen, N., Christensen, T., Garnier, A., Lukyanov, A., and Williams, E.: Hydration of the lower stratosphere by ice crystal geysers over land convective systems, Atmos. Chem. Phys., 9, 2275-2287, 2009.6. V. A. Yushkov, A. N. Luk'yanov, S. M. Khaykin, L. I. Korshunov, R. Neuber, M. Muller, E. Kuro, R. Kivi, H. Voemel, Y. Sasano, and H. Nakane. Vertical Distribution of Water Vapor in the Arctic Stratosphere in January–February 2004 from Data of the LAUTLOS Field Campaign // Izvestiya RAN, Atmospheric and Oceanic Physics V. 41, No. 5, pp. 622-630, 2005.
7. Deuber, B., A. Haefele, D. G. Feist, L. Martin, N. Kampfer, G. E. Nedoluha, V. Yushkov, S. Khaykin, R. Kivi, and H. Vomel, Middle Atmospheric Water Vapour Radiometer (MIAWARA): Validation and first results of the LAPBIAT Upper Tropospheric Lower Stratospheric Water Vapour Validation Project (LAUTLOS-WAVVAP) campaign, J. Geophys. Res., 110, D13306, doi:10.1029/2004JD005543, 2005.
8. M. Maturilli, F. Fierli, V. Yushkov, A. Lukyanov, S. Khaykin, A. Hauchecorne, Stratospheric water vapour in the vicinity of the Arctic polar vortex, Annales Geophysicae, V. 24, pp. 1511 – 1521, 2006.
9. Vömel, H., V. Yushkov, S. Khaykin, L. Korshunov, E. Kyrö, and R. Kivi: Intercomparisons of Stratospheric Water Vapor Sensors: FLASH-B and NOAA/CMDL Frost-Point Hygrometer, J. Atmos. Oceanic Technol., 24, 6, 941–952, 2007.
10. Karpechko, A., A. Lukyanov, E. Kyrö, S. Khaikin, L. Korshunov, R.Kivi and H. Vömel, The water vapour distribution in the Arctic lowermost stratosphere during the LAUTLOS campaign and related transport processes including stratosphere-troposphere exchange, Atmos. Chem. Phys., V. 7, pp. 107-119, 2007.

Summary

FLASH-B sonde is a well established instrument capable of accurate water vapour measurements in the upper troposphere and stratosphere

Fluorescence method ensures very fast response time and high capacity in resolving fine structures in vertical profile

Calibration of the instruments is performed using MBW frost-point hygrometer, ensuring measurement traceability

FLASH-B performance and metrological characteristics have been validated in a large number of field intercomparisons (NOAA-CMDL, CFH, FPH, Pico-SDLA etc.)

FLASH-B is plug-and-play instrument allowing fast and easy flight preparation

Existing interfaced with most of the existing radiosondes

Possibility of multiple usage of FLASH sondes, provided access to calibration facility

Basic documentation already provided to GRUAN, detailed error budget description in preparation